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ORIGINAL ARTICLE

Climate change mitigation-adaptation relationships in forest management: perspectives from the fire-prone American West

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Abstract
Minimizing negative impacts of climate change on human and natural systems requires mitigation of greenhouse gas emissions and adaptation to new climate conditions. Forestry provides grounds to study the relationship between these two concepts: carbon flux and storage are ecosystem services of forests, while forests are growing increasingly vulnerable to climate-driven disturbances. We examined the practice and interplay of mitigation and adaptation in the American West, which is a testbed for the conceptual balance between carbon cycling and growing climate-related risk given its abundance of dry, fire-prone ecosystems. We sought to understand perceptions of mitigation and adaptation in this region through 38 semi-structured interviews with forest experts in the Rocky Mountains and Pacific Northwest. Our research questions explored (1) perceived mitigation and adaptation action options, (2) conflicts and synergies between mitigation and adaptation in forest management, and (3) factors influencing mitigation and adaptation activities. Our findings revealed the importance of geographic and ecological differences in determining an appropriate balance of mitigation and adaptation options and a need to further integrate intentional climate action in forestry. As the American West confronts the growing threat of intense and extensive wildfires, pest infestation, and other disturbances, many experts in this study called for more support to enable active management for adaptation while balancing multiple objectives, including carbon management. Through an inductive approach, we provide insight into forestry experts' conceptualization of the mitigation-adaptation relationship, revealing implications for integrating climate-informed actions into forest management and the surrounding institutional environment.

Keywords Active forest management · Adaptation and mitigation relationships · Carbon management · Climate change adaptation · Climate change and western wildfires · Climate change mitigation

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Introduction

Many Western US forests, with their dry, fire-prone ecosystems and exposure to climate-driven disturbances like drought and disease, provide a testbed for examining synergies and conflicts between two climate actions: supporting carbon cycling (mitigation) and reducing climate-related risk (adaptation). Mitigation is the intervention to reduce emissions or enhance sinks of greenhouse gases (GHG), while adaptation is the adjustment process to actual or expected climate effects to moderate harm or exploit beneficial opportunities (IPCC 2023a, 2023b). The less effective mitigation is in reducing anthropically generated GHGs and increasing GHG sinks, the more adaptation is needed to avoid negative climate-related impacts (Duguma et al. 2014). Even if GHG emissions are reduced dramatically, mitigation on its own is not sufficient to protect lives and other values under projected warming

(Hoegh-Guldberg et al. 2019); thus, mitigation and adaptation must operate in tandem. Literature studying mitigation-adaptation relationships is often conceptual, and empirical knowledge of their relationship dynamics needs to be improved, as field demonstration of synergy is sparse (Ravindranath 2007).

Forest management serves as a fruitful context for looking at the mitigation-adaptation relationship because forested ecosystems are integral to the global carbon cycle yet are facing increased risk to climate-related impacts, such as wildfire, drought, and disease, and therefore must adjust to future climate scenarios (IPCC 2019). To mend the knowledge gap of limited empirical understanding, we investigated how mitigation and adaptation were being conceptualized and grounded in forestry in the American West, a field crucial for constructing climate-resilient pathways (Pramova et al. 2012). As climate change intensifies, it challenges the natural carbon cycling system. Meanwhile, socio-economic development and human land management practices can either exacerbate or ameliorate these challenges (Metz et al. 2002; IPCC 2019). Our research examined potential synergies and trade-offs between adaptation and mitigation strategies and enabling and constraining conditions for climate activities in a regional, more localized context to help advance considerations of how mitigation and adaptation operate together. Our research questions explored (1) perceived mitigation and adaptation action options, (2) conflicts and synergies between mitigation and adaptation in forest management, and (3) factors influencing mitigation and adaptation activities.

Literature review

Efforts to find synergies between mitigation and adaptation are complicated due to weak conceptual framings of these approaches (Duguma et al. 2014). Older arguments attribute the tension between mitigation and adaptation to differences in competition for economic and cognitive resources and implementation at different spatial and temporal scales, especially with mitigation conceptualized as a global, long-term effort for reducing vulnerability, versus adaptation as local, shorter-term way to reduce vulnerability (Tol 2005; Weber 2006; Locatelli 2011; Urban et al. 2021). Assessing synergies and trade-offs between mitigation and adaptation have been viewed as challenging in part due to a dichotomy created by the global climate change governance system in treating them as separate objectives as well as lack of proper metrics to measure outcomes (Duguma et al. 2014). However, the international governance system has increasingly identified linkages between adaptation and mitigation in recent years (UNFCCC 2022a, 2022b). Exploring how the two concepts interact is important due to growing concern over gaps between the theory, finance, and practice of adaptation, especially as global adaptation progress is reported to be slowing, despite increased attention to adaptation needs (Arteaga et al. 2023; UNEP 2023). There are growing calls for considering mitigation-adaptation dynamics, particularly in forestry and agriculture as these sectors are expected to contribute to mitigation (i.e., natural climate solutions) and reduce vulnerabilities through adaptation (Bakkegaard et al. 2016).

Western US forests, for instance, are home to fire-adapted ecosystems facing other climate-driven disturbances, including drought and disease, which often interact as compounding impacts reducing forest ecosystem resilience (Buma 2015; Stevens-Rumann et al. 2018). Fires are increasing in extent, severity, and frequency due to climate change; changes in fire behavior are also a result of a century of suppressing fire as a critical ecological process (Stephens et al. 2020; North et al. 2022). A primary strategy to address fire hazard is fuel reduction (i.e., tree thinning and controlled burning); done strategically, this can be both a mitigation and adaptation strategy in fire-prone forests (Hurteau et al. 2019; vonHedemann et al. 2020). Exploring mitigation and adaptation in fire-prone forested regions is essential as they face increasingly frequent and intense impacts to carbon flux and storage.

Mitigation and adaptation efforts are ultimately underpinned by governance institutions, including structures and processes, communities of actors, and private organizations (Bowen et al. 2013). Therefore, identifying facilitating or frustrating factors that influence climate-related planning and implementation is needed to visualize a multi-organizational enabling environment. "Enabling conditions" support the feasibility of mitigation and adaptation options (IPCC 2023a, 2023b). The idea of enabling environments is typically held within discussion focused on policy and governance, technology transfer, or private sector and finance (IPCC 2014; UNFCCC 2022a, 2022b). Woroniecki (2019) emphasizes the importance of studying power dynamics, empowerment of actors, and social benefits within visualizing an enabling environment for adaptation. A combination of local factors, such as individual actor knowledge, risk preferences, collaborative history, and partner preferences, affects whether new policies or other innovations take hold in particular places; at the same time, organizational level factors, such as leadership direction, fit with existing processes and performance evaluations, incentives, funding, and capacity affect the uptake of new practices across organizations (Fernandez and Rainey 2006; Moseley and Charnley 2013). Particularly, US land management agencies face ample goal ambiguity; literature indicates actors will prioritize activities familiar and within their professional expertise, and those that yield measurable benefits within 1–4-year timelines align with political and promotion cycles (Schultz et al. 2019). Local ecology can also matter, in addition to perceived salience, legitimacy, and credibility of scientific information and its deliverers for managers and land management contexts (Cash et al. 2006). What is socially and politically acceptable and salient within the broader institutional environment is also relevant (Lemos 2008).

Although information on mitigation and adaptation interrelationships at regional and sectoral levels is scarce (Klein et al. 2007), previous work has examined mitigation-adaptation relationships in land management. Table 1 showcases the different conceptualizations of mitigation-adaptation relationships utilized during our analysis of the study's results (Klein et al. 2007; Duguma et al. 2014; Locatelli et al. 2015). The literature studying mitigation-adaptation dynamics has been largely conceptual, and most research uses literature review analysis to frame the relationship, with limited empirical evidence or field demonstration of synergy (Ravindranath 2007; Locatelli et al. 2015). Drawing from the conceptual frameworks explained in Table 1, we explore perceptions and practices of adaptation, mitigation, and mitigation-adaptation relationships through semi-structured interviews with forest experts to understand more concretely what conflicts, synergies, or other relationship types look like in the context of American Western forests. Generating qualitative data from interviews with forest experts reveals valuable insights on how adaptation and mitigation

Table 1 Conceptualizations of mitigation and adaptation dynamics

Mitigation-adaptation relationship		Description
Klein et al. 2007 conceptualization		
Adaptation → mitigation		Adaptation leads to effects on mitigation efforts, positively or negatively.
Mitigation → adaptation		Mitigation leads to effects on adaptation efforts, positively or negatively.
$\int$(Adaptation, mitigation)		Trade-offs or synergies between mitigation and adaptation
Adaptation ∩ mitigation		Processes and consequences for both mitigation and adaptation
Duguma et al. 2014 conceptualization		
Separate measures	↓ Evolution from complementarity to synergy	Mitigation and adaptation are handled separately, without consideration for the other concept.
Complementarity		Mitigation projects, as the main entry point, provide adaptation co-benefits and vice versa.
Synergy		"Super additive synergy," meaning the whole is greater than the sum of parts; there is an enhanced outcome when the components interact with each other. There are no prioritizations of interventions during implementation, but, rather, emphasis on the mix of interventions to optimally achieve simultaneous multiple benefits, while maintaining and enhancing system functionality.
Locatelli et al. 2015 conceptualization		
Joint outcomes		Activities with non-climatic primary objectives deliver positive, joint mitigation and adaptation outcomes
Unintended side effects		Activities aimed at only one climate objective—either adaptation or mitigation—unintentionally deliver a service or a disservice to the other objective.
Joint objectives		Activities with intentional mitigation and adaptation objectives lead to interactions strengthening or weakening outcomes. Sub-categories can include strengthening of adaptation outcomes by adding mitigation objectives (or vice versa), weakening adaptation outcomes by adding mitigation objectives (or vice versa), decreasing adaptation or mitigation outcomes by jointly managing both, and increasing mitigation and adaptation outcomes by jointly managing both.

Table 1 showcases three different conceptualizations of mitigation-adaptation relationships from Klein et al. (2007), Duguma et al. (2014), and Locatelli et al. (2015). The table is to help illustrate some existing frameworks of depicting mitigation-adaptation relationships from previous literature are concretized at the local and regional levels outside of the largely conceptual international climate change discourse and what factors in forest management offer opportunities and challenges to synergize adaptation and mitigation efforts in the field.

Methods

In 2020, we conducted a qualitative study of forest management across different ownership and forest types in the US, organizing our investigation by ecoregions from Bailey (2016). For this paper, we used our data from the Rocky Mountains and Pacific Northwest, regions where mitigation and adaptation forest management activities might be viewed as in tension with each other. In the Pacific Northwest, which includes forests in Washington, Oregon, northern California, and western Montana and Idaho (Fig. 1), addressing climate-related hazards, such as increased dryness, wildfire severity, and extreme rainfall events, is a priority in forest management (Touma et al. 2022). Yet, forests in this region are also managed as carbon stores with heightened wildfire risk (Kaarakka et al. 2023). Across the Rocky Mountains (Fig. 1), concern over vulnerability of critical resources, such as water, fisheries, wildlife, and forest and rangeland vegetation, primarily related to more frequent and intense fire, is contributing to a focus on adaptation strategies, which typically require removal of trees and fine fuels (Halofsky et al. 2018).

As in our 2021 publication, interviewees included federal researchers, silviculturists, ecologists, and managers (US Department of Agriculture, Forest Service [hereafter Forest Service] and Bureau of Land Management); industry experts from forest companies, consulting forestry firms, and forest products associations; university researchers specializing in forest management or policy; forest-related NGO employees; state forest service employees; extension specialists; and Tribal foresters and NGO representatives (vonHedemann

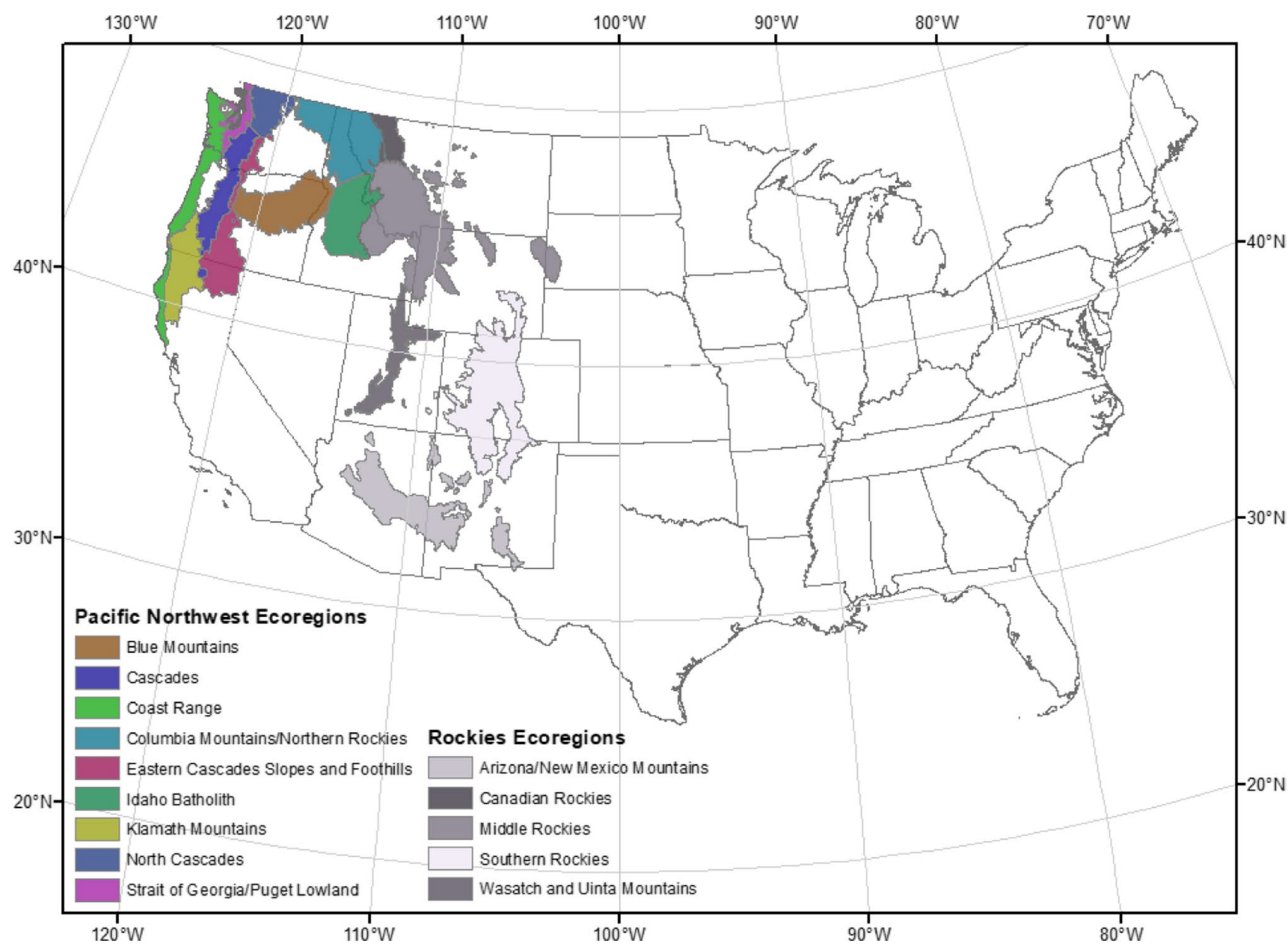

Fig. 1 Regions of focus. Forested US regions where we focused our interviews. Level III Ecoregion boundaries are outlined within the two regions to showcase the diversity of forests in the study areas (https://www.epa.gov/eco-research/ecoregions-north-america). Map shapefiles provided by Chiung-Shiuan Fu and Michael Binford

and Schultz 2021). We began by reaching out to state extension agents and federal land management agency researchers, and then asked interviewees for recommendations, seeking to speak with specialists who understood forest management on all major ownership jurisdictions. Our questions asked about significant drivers and approaches of forest management across different ownerships in their region of expertise (past, present, and future), silvicultural approaches in their region, current climate impacts on forests, climate mitigation and adaptation, barriers to what they see as better forest management, major disagreements about forest management, and what policies would help support desired management (vonHedemann and Schultz 2021). Interviews lasted one to two hours and were recorded with permission and transcribed. Colorado State University's Institutional Review Board reviewed and approved this study, and participants provided verbal informed consent to participate. We completed 38 interviews representing all major ownerships in the two regions. We identified "Parent" and "Child" codes, as outlined in Table 2 in all interview transcripts through a qualitative data analysis program. After coding was complete, we analyzed coded excerpts for patterns, themes, or any emergent concepts from our data that served as relevant in answering the research questions. We tested thematic coding saturation through a method by Guest et al. (2020) consisting of analyzing the application of our codebook, which was developed through an intercoder agreement process with two individuals.

Results

Our results are organized into three sections: (1) activities perceived to be associated with mitigation and adaptation in forestry, (2) relationship dynamics between mitigation and adaptation in forestry, and (3) enabling and constraining conditions influencing mitigation and adaptation activities.

Activities associated with mitigation and adaptation

Table 3 showcases activities perceived by interviewees to be affiliated with mitigation and adaptation. Carbon markets were most often mentioned in response to climate-related prompts, as our interviews directly inquired about this activity. Interviewees indicated that the rise in regulatory and voluntary carbon markets is influencing land management, particularly in the coastal Pacific Northwest. Forestry experts, many of whom focused on industrial, federal, and some state and Tribal lands, discussed their experiences engaging with carbon markets in family forest carbon programs, landowners selling credits through the California market, and insurance programs to protect carbon offsets. Many interviewees, in particular, experts focused on federal lands, perceived soil management, in addition to tree planting, to be a critical component of carbon cycling, sequestration associated with reforestation, and tree protection. Interviewees, primarily those focused on industry and state lands, also highlighted the inclusion of wood and biomass harvesting as elements contributing to long-term carbon storage in wood products.

Interviewees discussed a variety of experienced and anticipated climate-related impacts, linking these to their preferred adaptation activities. For example, interviewees mentioned assisted species migration or seed banks in response to changes in planting zones, protection and retrofitting of infrastructure in response to extreme weather events like flooding, and fuels and fire management as a response to increasingly severe fire seasons. The most mentioned adaptation activity was the composition and placement of species, including species diversification in a stand, assisted migration, and genetic modification to enhance resilience to climatic shifts that will impact species viability in certain locations. Fuels management (i.e., thinning, prescribed burns) was the second most discussed activity for adaptation, followed by restoration and reforestation. Concern over species composition shifts and fuels management was discussed across a wide variety of land ownerships, most often those representing federal, industry, and state. Some experts highlighted strategic organizational models that can address several climate-related hazards, like research and experimental forests as valuable resources to study logistics of and approaches to forest diversification, climate action management plans, and forestry cooperatives that could allow for ease of adaptation implementation.

Relationships between mitigation and adaptation in forest management

This section presents discussed mitigation-adaptation relationship dynamics. Based on interviewee perceptions, relationship dynamics are often not as clean-cut as purely "conflicting" or "synergistic." We found three groups of mitigation-adaptation relationship framings: management style, forest characteristics, and terminology. Table 4 provides a concise detailing of the relationship framings findings, and links to literature to help with translation.

Management: conflict to synergy, passive to active

A dominant theme in the interviews was the perception that passive management, or overstocking trees without active management (i.e., thinning forests and returning fire to the landscape), reveals a conflict between mitigation and adaptation. Active and passive forest management are situated on a continuum in which active management involves planned silvicultural activities designed to achieve landowner objectives, whereas passive ownership largely requires minimal

Table 2 Themes and sub-themes utilized to code transcripts

Parent codes	Child codes	Detailed description of child codes
"**Forest Management Types**" were coded for background information to understand interviewee's objectives when it comes to forest management in their work. The four types, "ecological, passive, preservation, and production," were identified as management classes to prompt interviewees to describe major forest management practices in their region and to facilitate the adaptation of management prescriptions from interviewees for input into an ecosystem dynamic model (Becknell et al. 2015). "Cultural" and "Recreational" were management objectives added during the coding process.	Ecological	Ecological management aims to enhance/maintain the structural complexity of the forest by mimicking or allowing for natural disturbance regimes. This management type balances ecosystem services, such as habitat provision or carbon storage, while harvesting wood products in perpetuity.
	Passive	Passive use of land demonstrates minimal activity on land, such as occasional opportunistic harvest driven by economic need, or no objective management interventions at all.
	Preservation	Preservation maintains ecosystems in states based on historical or natural range of variation for conservation with minimal intervention (as might be found in ecological forestry).
	Production	Production management indicates that areas of land are primarily used for timber harvesting and extraction of wood products for economic gain.
	Cultural	Cultural uses of land translate to maintaining identity and traditional forest-related activities, most commonly relating to Tribal lands.
	Recreational	Recreational-oriented forest management pursues activities to maintain hobbies or exercise of mass populations (e.g., skiing).
"**Land Ownership Types**" were coded to understand the conditions (e.g. funding, policy, resources) that come with their legal land ownership and to understand the conditions and practices directly related to the land ownership types.	Industrial, Non-Industrial Private Forest Owners, NGO, Federal, State, Tribes	
"**Enabling-Constraining Conditions**" were coded across four different categories to identify conditions that either foster desired forest management (enabling) or act as a barrier to the desired forest management (constraining), as outlined by the interviewee.	Finance & Economy	"Finance & Economy" entailed discussions related to funding projects, or limitations surrounding jobs or production efforts. The code was used when discussions centered around finances and supply chains.
	Information, Research, & Technology	"Information, Research & Technology" was used when discussions covered the topics of resources, innovation, or technology to carry out management activities. Discussions of knowledge gaps and lack of technology were also included.
	Policy & Planning	"Policy & Planning" entailed discussions related to federal, state, or local law, plans and administrative matters regarding carrying out forest management practices. If there was a discussion around tax, funding, and finance that heavily involves policy and planning in the discussion, the code was marked "Policy & Planning" instead of "Finance & Economy," since policy dictates funding.
	Social Aspects & Politics	"Social Aspects & Politics" was used when the interviewee described social factors that sway actions, such as strong social opposition, barriers related to identity, or internal politics within the policy/management system.
"**Forest Impacts**" was applied when the interviewee described disturbances like fire, drought, or species decline.	Driven by Climate Change	"Driven by Climate Change" was utilized when these disturbances were explicitly linked to climate change.
"**Management Actions/Strategies**" For the purpose of this analysis, "Adaptation" and "Mitigation" were the codes of focus. **Emergent activities connected to "Adaptation" and "Mitigation" are found in** Table 3.	Adaptation	"Adaptation" was used when the term was explicitly mentioned, or when the interviewee discussed ecological, social or economic system adjustments in response to actual/expected climate impacts.
	Mitigation	"Mitigation" was used when climate change mitigation, greenhouse gas mitigation, carbon credits, sequestration, carbon stocks, and cap-and-trade were mentioned.

Table 2 (continued)

Parent codes	Child codes	Detailed description of child codes
"**Relationships among Adaptation, Mitigation, and Forestry**" was coded when there were conflicts or synergies between adaptation and mitigation, or if there was a relationship described between climate change discourse and forestry. **Themes and relationship framings of these codes are found in** Table 4.	*Not applicable as this theme had no child code during the coding phase. Only the parent code was utilized.	

Table 2 showcases the parent, or primary, and child, or secondary, codes used to conduct the coding and analysis phase of the research. More information on the emergent themes related to "Management Actions/Strategies" or "Relationships among Adaptation, Mitigation, and Forestry" can be found in Table 3 and Table 4, respectively

activity with no objective management interventions, at most monitoring or opportunistic harvest for economic purposes with little planning for future forest conditions (Becknell et al. 2015; Bailey 2023). The framing of passive management being a tension between mitigation and adaptation was in response to increasing interest in tree planting and protection of existing trees to offset carbon emissions, which can come with an increased disturbance risk due to overstocking trees in fire-prone forests. Multiple interviewees argued that, while seemingly counterintuitive, fire-adapted forests in the West must have trees removed to increase their carbon sequestration capacity because doing so reduces their vulnerability to increasingly catastrophic wildfires that could burn at such a high severity in overstocked forests that all tree cover is lost, and forests do not readily regenerate (Hurteau et al. 2019). "It's difficult to sequester carbon … you need lots of trees. But if you're not managing that forest appropriately and building fire resiliency, all those efforts can go up in smoke" (#25, industry representative). Mirroring this conflicting framing, interviewees highlighted enrolling in a carbon project and primarily managing forests for sequestration and storage requires active management to protect carbon stocks and decrease risk of disturbance: "We want to manage for carbon sequestration… You got to do the thinning work; you've got to make healthy productive forests. It's going to take more than chainsaws, and you're going to have to burn it … [It] takes money and resources … Fire's going to dictate how we approach forest management." (#23, Tribal government employee).

Increased concern over fuel and fire risk in the West was a common driver behind this framing. An industry representative (#16) explained, "I'm an advocate for active management of landscapes that have been actively managed. Not old growth forests … Landscapes that have been managed and should be managed… It doesn't have to be aggressive… They're at risk from fire… disease… roads failing… How do you protect your carbon project from sudden oak death? … It is not that you leave it, let it sit, grow, and sequester carbon, and job done … How do you make sure you're protecting that investment?" Many interviewees brought up a history of overstocking, fire suppression, and passive management in fire-prone forests. Another industry representative (#15) asserted the need to actively manage forests while allowing trees to survive and sequester carbon, "It just pains me as a forester in the state to keep watching … trees burn up, be replaced by brush, and not be replanted. Talk about a loss of sequestration potential … Let's try and put an end to that by thinning out our forests and not getting them there in the first place."

Forest characteristics: local conditions and holistic ecosystem perspective

Forest managers across the Rockies and Pacific Northwest described differing needs between drier and wetter forests. These differences translated into identifying some forests as significant carbon sinks (i.e., Pacific Coast old growth), versus others, mostly dryland ecosystems, which require active management to maintain carbon storage and sequestration potential. An NGO representative focused on federal lands (#13) exemplified Oregon, "On the [wetter] west side, we need to stop cutting old trees on all ownerships. On the [drier] east side, we need to do more logging and reduce the number of stems per acre … If we're going to be serious about climate policy, we're going to have to lock up some forests that are carbon sinks, like the west. In our other forests, we are going to have to do a lot more active management to keep them as forests."

Interviewees often noted geographic considerations and local forest characteristics as foundational in finding a balance between mitigation and adaptation activities. Some said changes in fire behavior and severity are increasing pressure for forest managers to be more focused on fuel management, although some argued fuel management did lead to carbon

Table 3 Described activities considering climate change in forest management

Perceived action	Description	Number of mentions	Region most prevalent in discussions?	Land ownership type most prevalent in discussions?
Commonly mentioned mitigation activities (most to least commonly mentioned)				
Carbon valuation, market, and taxes	Excerpts on the regulatory, voluntary, or potential carbon market system, and the tools that come with it such as carbon trading/offsets, carbon taxes, and the valuation of carbon	38	Both regions, more often in Pacific Northwest	Mostly industry and federal, some state and Tribal
Carbon sequestration and storage protection	Excerpts on tree planting and protecting old growth forests or older trees with an explicit focus on doing so for carbon sequestration or storage	7	Both regions	Mostly federal, some industry
Soils management	Excerpts on the role soil plays within the carbon cycle	6	The Rocky Mountains	Mostly federal
Wood products, biomass harvesting	Excerpts on the role wood products and biomass can play within the carbon cycle	6	Both regions	Mostly industry and state
Commonly mentioned adaptation activities (most to least commonly mentioned)				
Perceived action	**Description**	**Number of mentions**	**Region most prevalent in discussions?**	**Land ownership type most prevalent in discussions?**
Species composition and placement	Excerpts on the desire or various ways to diversify, physically move, or increase protection of forests to climate-related hazards, including assisted species migration, seed source movement trials, nurseries/seed banks, and genetic modification	34	Both regions, more often in Pacific Northwest	Mostly federal, industry, and state, some Tribal
Fuels management	Excerpts on all forestry activities related to fuel and fire management, including thinning, prescribed burns, or creating fuel breaks to reduce fire hazard	11	Pacific Northwest	Mostly industry, some state and federal
Restoration and reforestation	Excerpts on how restoration or reforestation of land, or the rehabilitation of forest conditions before degradation (e.g., post-fire, conditions before settler colonialism), consider a changing climate	8	The Rocky Mountains	Mostly Tribal, some state
Research and experimental infrastructure	Excerpts on experiment stations, forests, and active research activities that influence decisions related to adaptation	7	Both regions	Mostly federal, some state

Table 3 (continued)

Management plans	Excerpts on the development and implementation of action or adaptation plans relevant to climate change and forestry	6	The Rocky Mountains	Mostly Tribal and state
Cooperatives	Excerpts on the role of cooperatives in enhancing forest productivity and resilience by shared resources and exchanges in membership	4	Pacific Northwest	Mostly industry
Enhanced infrastructure	Excerpts on need for infrastructure to be considerate of climate-related risks (e.g., roads and flooding)	2	Pacific Northwest	State and industry

Table 3 showcases activities perceived by interviewees to be affiliated with mitigation and adaptation and reflects how we grouped perceived actions associated with climate change. The table includes mentions per perceived action to showcase the level of popularity throughout the interviews. Regions and land ownership types offering substantial insight to the discussion are noted

management when considering longer time scales. A state-level forester focused on non-industrial private lands (#5), explained local conditions are important to consider, "[Colorado] is not a carbon sink, nor should it be. I would dare say dry forests in the context of climate change … need to go toward not planting trees … Take care of places that do [carbon mitigation] well … There's an incentive to plant trees to achieve these global outcomes that in turn are going to create [local] problems. When you're planting windbreaks, you're busting sod … [and] you've instantly liberated soil carbon … We're not viewing the problem holistically."

The above quote highlights another dynamic between mitigation and adaptation in the interviews: knowledge of other aspects of forestry (ex. soil, grass, wood production) was often perceived as sidelined in the carbon cycling and adaptation discourse. Forest experts not only discussed trees as critical to carbon cycling, but some also emphasized soil and wood products' role in sequestration and storage. A federal research forester (#3) explained, "If we're talking about carbon storage, then we want more organic matter in soil … we want older trees to store the carbon … we want those trees sold so they become buildings so they can store carbon … If we lose the soils, we lose everything."

Terminology: compatibility of climate action and forestry

A common perception was preparing for a future climate is already a central component in silviculture and forestry; many interviewees were trained in these fields. As an interviewee (#3) stated, "We've always considered climate … 'Are we taking a proactive approach to adapting to an uncertain climate?'… Yes, to a certain extent, we are because we've always had seed zone transfer guidelines … The context of silviculture is to always think about long-term situations." The utilization of the term "adaptation," however, was not consistently incorporated across all interviewees' diction. A few respondents said they do not use the word "adaptation" and prefer other terms or phrases, such as "resilience," "sustainability," "forest health," or "managing disturbance." This may be due to the nascence of adaptation science, or the term being viewed as a trend or a "buzzword" (#21, industrial representative). One extension forester specialized in non-industrial private lands (#20) noted adaptation "may not be in our translation … because the audience in the room at any given time might have a lot have mixed opinions [about climate change]." Another industry interviewee (#19) stated, "Climate change has elevated everybody's awareness of the fact that … competition in our forested landscape is going to increase. We're going to have an increase in insects, disease, and fire over time. What that has done is to help clarify for landowners and the public is the need for more active forest management. Has it changed prescriptions out there? No."

Public discourse can influence how forests are managed and what that management is called, yet influence can be limited because incorporating resilience is something managers perceive themselves to already be doing. Some interviewees found it difficult to distinguish mitigation and adaptation activities from common forestry practices. A state agency interviewee (#14) explained, "I consider it forestry and silviculture. It's being aware of what's happening and adapting as necessary. You could call it climate adaptation, but to some extent I think that's almost giving them more credit than what it is." This debate over how climate change influences forestry may be because, as many interviewees mentioned, mitigation and adaptation are not single, primary objectives in forestry, but rather entwined with other, sometimes multiple,

Table 4 Common relationship dynamic descriptions between mitigation and adaptation

Relationship Dynamic Description	Relationship Framing from Literature in Table 1	Number of Mentions	Region most prevalent in discussions?	Land ownership type most prevalent in discussions?	Notes
Framing focused on management style					
Passive management, or often minimal activity with no objective management interventions, alongside overstocking trees in forested lands can serve as a locus of conflict between adaptation and mitigation, as it can increase forest disturbance risk. Active management, or planned silvicultural activities designed to achieve landowner objectives, of forested lands can serve as a locus of synergy between adaptation and mitigation, especially if activities involve reducing fuel loads of forests and improving overall forest health. Although these are two relationship framings, in interviews they were mentioned mostly interchangeably or in tandem, as active opposes passive management.	• Mitigation activities lead to effects on adaptation activities, negatively (Klein et al. 2007) • Unintended side effects, a disservice to adaptation through mitigation objective (Locatelli et al. 2015) • Processes and consequences for both mitigation and adaptation (Klein et al. 2007) • Synergy (Duguma et al. 2014) • Joint objectives- synergy (Locatelli et al. 2015)	18	Both regions	Mostly NIPF and industry, some federal and Tribal	These two framings are not incompatible. They showcase two points on a continuum that emphasizes the role of active management within forests in the West. One showcases the consequences of passive management on disturbance regimes, the other perceives synergy between mitigation and adaptation within active management.
Framing focused on forest characteristics					
Risk management is a priority over carbon management, or vice versa, depending on location and risk.	• Separate measures or complementarity (Duguma et al. 2014) • Joint objectives- competition (Locatelli et al. 2015)	6	Both regions, more often in the Rocky Mountains	Mostly state	The framings do not act as foils to one another, but rather showcase how important location and characteristics of forests are in influencing an appropriate suite of climate activities.
Knowledge of how other aspects of forestry, such as wood production or soil, can play in carbon cycling warrants more attention.	• Processes and consequences for both mitigation and adaptation (Klein et al. 2007)	4	Both regions	Industry and state	
Framing focused on terminology					
Mitigation and adaptation are already embedded within forestry and silviculture.	• Processes and consequences for both mitigation and adaptation (Klein et al. 2007)	4	The Rocky Mountains	Mostly federal	These framings oppose each other; one touts that mitigation and adaptation are natural to the forestry sphere, and the other questions the placement and influence of climate action in forestry. This reveals a debate around definition, intention, and adoption of climate considerations in forestry.
It is unclear how influential climate action is within forest management.	• Processes and consequences for both mitigation and adaptation (Klein et al. 2007)	3	Pacific Northwest	Mostly NGO	

Table 4 displays perceived relationships between mitigation and adaptation concepts and practices. The relationship framings have three main groups, with two relationship dynamics for each group: management approach, forest characteristics, and terminology. The most similar framings from literature are offered to help with translation (Klein et al. 2007; Locatelli et al. 2015; Duguma et al. 2014). The table includes mentions per perceived relationship dynamic to showcase the level of popularity throughout the interviews. Regions and land ownership types offering substantial insight to the discussion are noted. NIPF stands for "Non-Industrial Private Forest Owners"

objectives. "Do you look at a stand and say, 'am I going to mitigate climate change or am I going to adapt to it?' That's not the starting point… 'My objective for this stand is to adapt to climate change' is almost nonsensical. What's the actual core objective for that piece of land? Then we can consider climate change in the equation and decide if we need to mitigate or adapt or a mix of the two" (#8, federal employee).

Enabling and constraining factors influencing climate action

Relationships between mitigation and adaptation were coupled with factors influencing forestry decision-making, including information gaps, funding, capacity, policy, and social understandings of forestry.

Financial and economic factors

Through carbon markets, landowners have the incentive to manage carbon storage in forest ecosystems and products; increased interest in carbon also has led to more money for tree planting. A federal interviewee (#12) said, “We have a lot of partners interested in helping us… Support is largely in the form of post-fire reforestation efforts through tree planting to accelerate carbon sequestration.” Many interviewees were critical of logistics affiliated with market participation, inaccuracies of carbon valuation, and geographical appropriateness of carbon projects in the American West. Perceived problems included longer rotations that do not fit within typical harvesting timelines, near-century-long participant agreements that “take decision-making and opportunities away from the next generation” (#1, industry representative), and moral complexity behind “getting paid for somebody else’s right to pollute” (#2, forest manager for Tribal land). Many interviewees emphasized that carbon storage projects need active management to prevent major disturbance and large-scale loss, while also noting the large costs associated with thinning and burning. “One of the big issues is the overstocking… There are too many trees. That’s one of the costs. There’s not enough funding to do thinning and prescribed fires with Tribal forests.” (#26, NGO representative focused on Tribal lands). A federal interviewee (#10) said, “When you talk about trying to maintain high density forest, we know it’s not sustainable … We could do better if we had the funding and the capacity to ramp up a lot more reforestation … and we are doing that but not anywhere near the scale that needs to be done.” Forest management activities are crucial for minimizing risk in fire-prone landscapes, but as one interviewee stated, values associated with treatments are not fully reflected in economic carbon accounting models: “In California, it’s just a bear to get the avoided emissions stuff to pencil out. You don’t see a lot of thinning work done in the name of carbon offsets. You do see reforestation in the name of carbon offsets” (#17, NGO representative).

Interviewees also said life cycle considerations of wood production warrant more attention and noted the challenges of maintaining the wood products industry in parts of these regions. An industry representative (#22) explained, “Renewable resources and benefits of using wood with respect to climate and carbon … that discussion is taking place. It just hasn’t manifested itself in any kind of economic market yet.” Several interviewees also noted that a robust infrastructure for producing these wood products was lacking. A Tribal government employee (#23) recounted the impact on milling after the 1990s Northwest Forest crisis (a rapid reduction in timber harvest on federal lands in part due to northern spotted owl protections), saying “It is hard for us to find a mill that can handle our logs … because everybody switched over to the smaller stuff. There are fewer mills. They're farther away. We're already remote. The haul costs are high … The profit margins aren't huge.” Some interviewees called for investment in and incorporation of localized, sustainable wood production to contribute to carbon storage, as opposed to “concrete, steel, plastic, none of which are renewable and have a much higher footprint” (#4, trade association representative). Other interviewees described the need to remove fuel to reduce risk and develop a market for biomass to financially support fuels reduction work; yet limited infrastructure and labor are common barriers. One federal interviewee (#8) said, “I think a lot of people feel like the infrastructure in the Rocky Mountain region is getting about as low as we could go and still maintain those supply chains that can help us conduct forest management activities.”

Information, research, and technology factors

Composition and placement of species within forestry were the most mentioned adaptation activity, revealing conditions related to research, technology, and information as the crux of this conversation. Some described logistical uncertainty in implementing these adaptation activities because of unknowns with regard to what changes in climate locations will experience and how tree varieties will respond to these changes. One federal interviewee (#10) said, “The trees that you plant today have to survive the current climate. That’s not feasible to go into sites and plant things that are not going to survive the next five years just because you think the climate there in 50 years will be suitable for them.” One respondent (#11, industry representative) described a cultural shift in the forestry community related to climate-informed seed transfers, explaining “We’re starting … to think [where] seeds can be deployed based on climate rather than geography … Losing seedlings during the early reforestation stages is a huge financial hit. That’s one of the reasons people are more focused on [climate] aspects because they have experienced those losses in the last few years with drought.” Interviewees expressed excitement around methods to shift species placement and composition while considering climate projections. Despite ecological and economic uncertainty in achieving successful implementation, some experts highlighted research and experimental forests as valuable resources to ease difficulties in diversifying forests with species situated for a future climate. For instance, a federal interviewee (#12) said, the seed lot selection tool “is a different way of looking at seed zones … Now, we can look at climate data for growing days, moisture, and temperature … when we're doing reforestation work.”

Interviewees also perceived a need for more monitoring and evaluation of mitigation and adaptation actions, yet also mentioned the challenges in implementing widescale monitoring. Some noted monitoring and evaluation within forestry takes many years and is expensive. This also affects market participation; a trade association representative (#4) explained, “One of the things about not really participating in the carbon markets has been the high costs of monitoring required with it. You must go out there and take plots … it is not worth [a few dollars a ton] that the markets have been giving.” Surveying, experimentation, and research affiliated with mitigation and adaptation activities require robust and well-funded infrastructure; some noted use of LiDAR may make monitoring and reporting much easier and cheaper. Finally, some experts emphasized cooperatives and research extension services in sharing findings across forest-oriented communities. “There’s been a huge shift in thinking [within tree improvement cooperatives] … it’s not all about just finding the fastest growing tree in a certain geographic area … It is about a lot of different things now, and drought hardiness is a big one.” (#11, industry representative).

Social and political factors

Limiting or enabling conditions related to social and political factors were not as well discussed compared to the roles of research and economy. Respondents outlined standard forest management may pay “lip-service” to climate-informed activities without a shift in management priorities or new actions. As one NGO representative (#13) stated, “[Climate-informed forestry] has not truly entered the groundwork … We are doing the same things that we’ve been doing for 20 years. And now we’re calling it fire risk reduction … or climate resiliency, but we’re not really doing anything different. If we really want to set up our forests to deal with climate change, we're going to have to change policy and not just do the same thing with a different name.”

Some interviewees saw potential in public lands and entities monetizing carbon at a larger scale. One federal employee (#6) said, “If the government were to establish a network of carbon reserves, that could be utilized in developing international markets for carbon storage… These models exist, but I don’t think the Forest Service has moved into that arena… The Forest Service has an opportunity to become an international player in that arena because of the vast carbon reserves that exist on public lands.” Another perceived benefit of allowing federal lands to participate in carbon markets was creating cohesion with other land ownerships participating in carbon sequestration. “Only private lands are eligible to participate in the [carbon] program. Most of the forest lands in California are National Forest… If we could structure it so more lands, National Forest lands, could participate in the program, then you'd have real scale” (#23, Tribal government employee). Others offered their reservations about scale of government lands in carbon markets. “If the federal government can produce carbon credits cheaply because … [there’s] 95 million acres of standing forest, that becomes the gorilla in the room and small private landowners, family forest owners may not be able to compete in that environment in terms of producing carbon credits at a price that can match the U.S. government” (#8, federal employee).

A few interviewees perceived a changing public perception shifting from a “hands-off” passive approach towards supporting more active forest management. One federal employee interviewee said, “People had in their mind … that doing nothing on the landscape always has less impact than doing something … What I see a driver of is the understanding you see in public meetings… a lot of different people with different hierarchies of needs associated with the forest land are coming together and saying active management is going to be better than doing nothing” (#8). Yet, some emphasized that active management is still limited by funding and political will. An NGO representative (#13) stated, “I don’t see the Forest Service getting a huge infusion of cash over the next 30 years, which is what it would take to address the forest health issue in frequent fire forests … People aren’t voting on the environment, they may vote on climate, but people aren’t voting on forests.” Since then, and noted in the discussion, the 2021 US Congress appropriated major funding for federal forest management. Despite perceived public misunderstandings, some interviewees noted collaborations and organizations that engage in cross-boundary or multi-sectoral collaboration enhance political buy-in and public understanding of forest management objectives.

Discussion

Our results describe forest experts’ perspectives on mitigation and adaptation actions, dynamics between these two concepts, and factors that can facilitate or frustrate desirable climate actions in forestry. Our findings add to expanding literature that explores synergies and conflicts between mitigation and adaptation, drawing from land managers’ conceptualization of and experience with climate-related activities.

Reflection on relationship dynamics

Results for our second research aim offered a spectrum of relationship mitigation-adaptation dynamics, making it difficult to assign “conflicting” or “synergistic” to relationship descriptions. Interviewee framings on management do not conflict but speak to one another: overstocking trees with passive management can increase disturbance risk (a mitigation activity influencing loss to adaptation), and active management of forests can improve overall forest health and resilience to disturbance (mitigation and adaptation synergy). These two framings clearly advocate for a more active approach to forestry, in the shape of intentionally planning and implementing adaptation and risk management as a synergic way to stabilize carbon management. Adaptation decisions need to reflect local contexts, and some interviewees repeatedly expressed concern over a one size fits all approach that does not cater to characteristics held by mostly dry, fire-prone, and fire-adapted forests in the US West. Local forest climates need to be considered, particularly as macroclimate warming and land-use changes can significantly alter biodiversity and ecosystem function (De Frenne et al. 2021). Ontl et al. (2018) noted ecoregion and ownership characteristics influence climate adaptation decisions, reinforcing the idea of a "one size fits all" approach to adaptation is insufficient for land managers. Our findings show management goals central to the operation of each land ownership type can potentially influence the recognition of mitigation and adaptation activities; for example, industry representatives mostly noted the potential of wood products as a viable mitigation activity while interviewees working on Tribal lands discussed adaptation through ecological restoration to conditions before settler colonialism and fire suppression. In addition, the interviews emphasize how important location and characteristics of forests are in influencing a suite of geographically appropriate climate activities. Our findings reveal complementarity, even competition, between mitigation and adaptation in some cases. For drier, fire-prone forests, adaptation seems to be a priority over mitigation in the short term (while they can be synergistic at larger time scales), while old growth, coastal forests could emphasize carbon management. This framing reveals neither synergy nor direct conflict but demonstrates adaptation as an entry point for mitigation co-benefits.

The next framing focuses on placement of other aspects of forestry that are often sidelined in understanding carbon cycling. Wood production and soil management are key examples (Smith 2012), and some interviewees highlighted their need to be more incorporated in present-day discourse. These aspects have links to adaptation and climate impact framings as well: wood production can serve as a by-product of fuel management activities, and soil organic matter is proven to positively affect long-term forest productivity (Cabiyo et al. 2021; Laganière et al. 2022). It is important to note present research continues to examine expanding wood and biomass use in various markets to contribute to mitigation, revealing substitution assumptions remain oversimplified (Hurmekoski et al. 2023; Peng et al. 2023). Wood production substituting other materials as a benefit to both mitigation and adaptation needs to be investigated to assess its effectiveness in offsetting emissions, benefitting energy and material flows, supporting adaptation activities, and enhancing sustainable institutional and economic support for local economies (Malmsheimer et al. 2011).

The group of terminological framings reveals conflicting stories about how forest experts perceive mitigation and adaptation in their field. One framing declares mitigation and adaptation are naturally placed within forest management activities, and the other questions the placement, role, and influence of climate action in forestry. The variety of answers indicate adaptation and mitigation are not yet widely utilized or intentionally incorporated into forest management. These conflicting answers could indicate a variety of reasons why communication of mitigation and adaptation is not consistently integrated (Moser 2010). Climate action within forestry is nascent but growing. There are existing tools and resources explaining mitigation and adaptation in forestry (Ontl et al. 2020). Based on our findings, there is a need to further explore perceptions around mitigation and adaptation, and the barriers and opportunities related to social and political adoption of climate-related conceptualizations in forestry. As Shannon et al. (2019) noted, intentional climate adaptation planning for an ecosystem is necessary for natural resource managers and professionals. The effort to intentionally incorporate mitigation and adaptation within a multi-use objective is accompanied by significant challenges of translating broad climate action concepts into concrete actions, emphasizing the need to enhance climate communications and training for forestry professionals.

Reflection on enabling and constraining factors

Synergies and conflicts between mitigation and adaptation are products of an enabling environment, or a group of conditions (finance, politics, technology, etc.) that allow for the ability to plan and implement climate-related action. The literature suggests addressing barriers to climate change perceptions can promote widespread and coordinated adaptation actions (van Valkengoed et al. 2022). Within the research, we found calls for more knowledge to support climate-informed decision-making in both mitigation and adaptation, as well as funding and political support to carry out activities that are climate-related, mostly as it relates to fuel management.

As forests prove integral to the global carbon cycle, through a variety of mitigation activities (e.g., avoiding deforestation, protecting existing forests, reforestation, and afforestation), more accurate and holistic estimation of the complex forest carbon system, including disturbance events, soil, biomass, and wood production, is a key research need for decision-making to protect forest health and carbon stability (Birdsey et al. 2000; Anderegg et al. 2020). Interviewees' remarks on logistics and valuation issues are consistent with research on participation barriers within American carbon market systems, such as early withdrawal penalties, contract length, and high entry costs concerning private landowners (Markowski-Lindsay et al. 2011; vonHedemann and Schultz 2021). There is also systemic criticism of the reliance on forests to offset carbon emissions generated from the combustion of fossil fuels (Nong et al. 2021). Critics reveal social consequences from carbon trading, concerns about allowing too much onus to fall on forests to offset emissions, and over-valuing carbon sequestration in contrast to undervalued activities associated with forests (Lindenmayer et al. 2012; Lejano et al. 2020; vonHedemann et al. 2020; vonHedemann and Schultz 2021). Despite carbon accounting as being an uneven technical and political process, there are ongoing efforts that aim to support private landowner carbon management through for-profit and nonprofit entities, as well as more holistic assessments and descriptions of measuring carbon that should be noted (Goetz et al 2012; Littlefield and D'Amato 2022).

The need for fuels management to accompany elevated carbon stocks is a growing discussion within western forests (Earles et al 2014; Herbert et al. 2022). Wu et al. (2023) reflect geographically driven carbon storage suitability; while forests have considerable potential to mitigate climate change, climate-related risks in the US West may fundamentally compromise the permanence of forest carbon storage. Many forest experts in our study discussed the role of thinning and prescribed burning needed to manage fuel loads in fire-prone forests. Prichard et al. (2021) emphasize the need for restoring open, fire-tolerant canopy structure and composition, favoring larger trees, and reducing surface fuels to avoid fuel accumulation in seasonally dry forests. As carbon markets become more influential in land-use decision-making, western, dry forests operating under higher fire and mortality risk under climate change need to be protected through fuels management to prevent major disturbance and large-scale loss (Prichard et al. 2010; Hood et al. 2016). Interviewees noted constraints related to promoting active management in terms of cost and personnel to carry out thinning and prescribed burns on a variety of land ownerships, proving consistent with the literature (Timberlake and Schultz 2017). Finding a balance between mitigation and adaptation, and offering political and financial support are crucial for the longevity of carbon sequestration and storage to help offset carbon emissions (Hurteau et al. 2019).

Since 2021, the US Congress appropriated major, additional funding for federal forest management and directed federal agencies to focus on climate-informed forestry. The Bipartisan Infrastructure Law (BIL, or Infrastructure Investment and Jobs Act 2021) and the Inflation Reduction Act (IRA 2022) included unprecedented investments in federal forestry programs over a five-year period from 2022 to 2026 (Office of the Federal Register 2021; Congress.gov 2022). The BIL focuses primarily on funding through the Forest Service's Wildfire Crisis Strategy, allocating $5.447 billion to the Forest Service for reducing wildland fire risk, investing in training, retention, and preparedness of wildland firefighters, restoring ecosystems and watersheds, and repairing federal forest infrastructure (Charnley et al. 2023). The IRA directs funding to climate mitigation and forest resilience efforts through the Forest Service's State, Private, and Tribal Forestry branch (Congress.gov 2022). The law allocates funds to programs that support access to "emerging private markets for climate mitigation or forest resilience" for private forest landowners and encourages landowners to adopt practices that measurably increase carbon sequestration and storage in forestland. In addition to legislation, the Biden presidential administration has also issued executive orders and memos directing attention and funding to enhancing the role forests play in carbon storage and sequestration. The Executive Order *Tackling the Climate Crisis at Home and Abroad* (2021) notes the importance of forest landowners in combatting climate change and calls for the creation of the Civilian Climate Corps to "address the changing climate" (EO No. 14008). Another Executive Order, *Strengthening the Nation's Forests, Communities, and Local Economies* (2022), describes the value of conserving old growth and mature forests to maximize carbon sequestration and storage on federal forestland (EO No. 14072). Additionally, the Secretary of Agriculture issued Memorandum 1077–004, directing the Chief of the Forest Service to draft recommendations for developing carbon optimization projects on National Forest System lands that leverage partnerships and private-sector capital, exploring if and how the federal government should enter private carbon markets (USDA 2022). These initiatives illustrate national-level interest in ramping up the scale of active forest management and considering both climate mitigation and adaptation in forest management decisions and have the potential to shift the broader institutional environment where many of these interviewees engage.

Collaborative mechanisms and multi-stakeholder cooperation are useful in ironing out disagreements and improving understanding of the latest science. Science-management-public partnerships can strengthen dialogue and transparency among different groups (stakeholders, industry, experts, public and private), with the potential to enhance climate change considerations across political boundaries and spatial and temporal scales (Golladay et al. 2016; Peterson St-Laurent et al. 2019). Interviewees highlighted the role cooperatives and research extension play in sharing latest research and innovation across forest-focused communities. As collaborative mechanisms move toward encapsulating the latest science to carry out mitigation and adaptation activities, Anderegg et al. (2020) encourage the fortification of the science-policy link through tools that are openly accessible, transparent, modular, applicable across scales, and usable by a wide range of stakeholders.

Conclusion

At the heart of understanding mitigation-adaptation relationships is a terminological debate around climate change's influence and incorporation into discourse and practice within forest management. Conflicting framings around the definition, intention, and adoption of climate considerations in forestry reveal the need for more studies on how on-the-ground practitioners of climate-vulnerable fields view climate change, its impacts, mitigation, and adaptation. Our findings support the continued integration of intentional climate action, particularly adaptation, in forestry. Although a growing set of tools and resources exists to embed climate-related resilience and adaptation in forestry, this integration also calls for enhancing communication and engagement, especially as adaptation activities resonate with different audiences, depending on perspective, location, and other factors (Moser 2014).

Our findings emphasize the importance of geographic and ecological differences in determining an appropriate balance of mitigation and adaptation options. As the US West confronts the growing threat of intense and extensive wildfires, pest infestation, and other disturbances, many experts in this study called for more support to enable active management for adaptation while balancing multiple objectives, including carbon management. Further knowledge and research infrastructure are required to achieve a geographically appropriate balance between mitigation and adaptation actions. Investigating these balances can address a crucial gap in visualizing mitigation-adaptation relationships related to scientific uncertainty regarding the mix of practices to achieve benefits out of synergy.

Our research offers an opportunity to dive deeper into understanding climate-related perceptions between concept and practice and how that can vary among application contexts and end-users or professional groups. Studying how climate-related concepts are perceived and practiced can transfer the discussion around synergies and conflicts from the conceptual to “on-the-ground,” including enabling or constraining mechanisms that either help or harm desired management goals. More empirical research on understanding the trade-offs and synergizing elements of mitigation and adaptation is needed, as relationship dynamics can be geographically dependent and institutionally influenced.

Limitations and reflections on methods

The purpose of this research was to investigate how mitigation and adaptation are considered in management decisions. As such, the study offers a unique perspective in understanding the Pacific Northwest and Rocky Mountains regions, which have extensive public lands, but the broad geographic scope across different ecosystems, political jurisdictions, and human populations limit the ability to understand management more precisely for mitigation and adaptation across every jurisdiction type in each state in the regions. Tribal perspectives could be included to a greater degree, and the largest corporate landowners were not able to be interviewed directly. Additionally, these interviews touched on many themes beyond mitigation and adaptation and thus had limited capacity to probe into more details on these topics. The strength of this sampling method, however, is to compare across regions that have several differences but are also facing similar climate challenges.

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Author contribution EC analyzed data and wrote the manuscript. NvH co-designed data collection, collected data, and edited manuscript. CS solicited and received funding, co-designed data collection, and edited manuscript.

Data availability The datasets presented in this article are not readily available because the data (interviews) are not available to the public. Requests to access the datasets should be directed to eliisa.carter@colostate.edu.

Declarations

Research involving human participants and informed consent The study involved human participants and was reviewed and approved by Colorado State University Institutional Review Board. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements. Participants provided verbal informed consent to participate in this study.

Conflict of interest The authors declare no competing interests.

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