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Exploring Cross-Cultural Barriers and Opportunities to Climate Adaptation Among Tribal-State Forest Stewards in Maine US

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ABSTRACT

Climate change and the effects of non-native plants, insects, and diseases will challenge forest stewards capacity to adapt. Studies show that adaptation does not occur evenly across regions, resulting in adaptation gaps, which have disproportionately greater impacts on populations vulnerable to climate risks. To minimize adaptation gaps, forest stewards must transform adaptive capacity toward action. To explore this phenomenon, we interviewed 22 forest stewards from state agencies (n=12) and Wabanaki Tribal Nations (n=10) in present-day Maine to examine their perceived barriers and opportunities to climate adaptation. We found that barriers and opportunities organized into three distinct themes: i) resource capacity, ii) operational capacity, and iii) decision-making practices. Our results suggest enhancing adaptive forest stewardship by supporting Indigenous self-determination, strengthening government-to-government partnerships, and co-creating flexible institutional arrangements that further climate adaptation. These approaches help ensure that adaptation interventions achieve desired outcomes and avoid reinforcing existing inequities across forest stewards.

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Introduction

The far-reaching effects of climate change and the proliferation of non-native plants, insects, and diseases on forests across the globe are projected to cause unprecedented social, ecological, and cultural impacts (Fischer 2019; Soucy, De Urioste-Stone, Fernandez, et al. 2021). To effectively respond to these rapidly changing conditions, climate adaptation strategies have been widely suggested throughout scientific, policy, and practitioner communities (Jantarasami, Lawler, and Thomas 2010). *Climate adaptation* refers to an adjustment toward resiliency to environmental change through human intervention (IPCC 2022). The increasingly important role of climate adaptation

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is reflected in the growth of peer-reviewed literature on adaptation for forest stewardship (Swanston et al. 2012). In addition, adaptation practices have long been utilized by societies to respond to environmental change, most notably by Indigenous Peoples, over millennia (Abu and Reed 2018).

However, recent reports suggest that climate adaptation is not achieved evenly across regions and often falls short of addressing climate impacts resulting in *adaptation gaps*. Adaptation gaps are projected to widen globally, with disproportionately greater impacts on communities most vulnerable to climatic risk due to growing resource constraints, competing political priorities, and shifting tolerance for a range of climate change impacts (UNEP 2025). Indigenous Peoples are among these vulnerable populations. The intensifying impacts from environmental stressors directly threaten ecological resources, services, and materials that Indigenous Peoples depend on to sustain their cultures, knowledge systems, and economies (Daigle et al. 2019; Voggesser et al. 2013). Despite this vulnerability, Indigenous Peoples also have an inherent capacity to adapt guided by generations of observing and responding to environmental change (Abu and Reed 2018; Tengö et al. 2014). Therefore, adaptative planning and actions benefit from examining the determinants of vulnerability and resiliency specific to Indigenous Peoples to forge more equitable pathways for climate adaptation and to reduce adaptation gaps.

However, common broad level indicators (e.g., national or global) of climate adaptation often fail to capture the regional, cultural, and interjurisdictional contexts unique to forest stewardship, which enable adaptive action (Adger et al. 2007; Burch 2010). To better understand the context whereby climate adaptation is actionable, scholars have explored its related barriers and opportunities. *Barriers* are the challenges that limit adaptation but are surmountable with effort (Eisenack et al. 2014; Moser and Ekstrom 2010). *Opportunities* are the options that enable adaptative planning and implementation (Klein et al. 2014).

The rate and success of adaptative capacity is influenced by how effectively opportunities are leveraged and barriers are overcome. Building an understanding of their context-specific connections will help enrich pathways for forest stewards to transform adaptive capacity into action (Adger et al. 2007; O'Brien et al. 2006). Future research will need to go beyond identifying barriers and opportunities and move toward conceptualizing how and why these conditions emerge in specific contexts to understand vulnerability, resiliency, and adaptative capacity (Biesbroek et al. 2013; Klein et al. 2014).

The scope of qualitative studies examining barriers and opportunities for climate adaptation among forest stewards in the Northeastern United States (U.S.) is diverse, ranging from rural and urban foresters, professional society members, commercial and private land owners, and wider samplings of forestry professionals respectively (Janowiak, Mahaffey, and Riely 2020; McGann et al. 2022; Schattman et al. 2024; Soucy, De Urioste-Stone, Rahimzadeh-Bajgiran, et al. 2021). Within this body of work, perspectives from federally recognized Tribal Nations (also referred to as *Tribes*) are comparatively limited, and a research gap remains in understanding the complex interplay between Indigenous and non-Indigenous perspectives (Baumflek et al. 2021; Daigle et al. 2019; Costanza et al. 2017). Further, there is a need to examine related barriers and opportunities for climate adaptation associated with vulnerability, resilience, and sovereignty. In the Northeastern U.S., there are ongoing challenges between the state

of Maine and the four federally recognized Wabanaki Tribal Nations (i.e., Wabanaki Nations) that impact adaptive capacity in forests. This qualitative study examines forest stewards' perspectives across state agencies and Wabanaki Nations in present-day Maine related to three primary themes i) resource capacity, ii) operational capacity, and iii) decision-making practices. This place-based approach provides real-world context from forestry practitioners and stewards that is critical to enhancing adaptation efforts across distinct governance settings in Maine and beyond.

Background

Understanding Adaptive Capacity: Barriers and Opportunities in the Northeast Region

The rate and success of climate adaptation is influenced by adaptive capacity, or the ability to leverage available opportunities for climate adaptation while overcoming the barriers that constrain these efforts (Adger et al. 2007). Qualitative investigations in the Northeastern U.S. have examined strategies to enhance adaptive capacity in forest management and implementation. For example, interviews with rural and urban foresters found that both manager groups preferred limiting management risk in favor of more familiar practices such as invasive plant control, silvicultural prescriptions, and monitoring environmental change (McGann et al. 2022). Likewise, a related study surveying foresters on the rural-to-urban gradient suggested increasing funding for programs that minimize financial risk for adaptation strategies to increase manager willingness to try experimental approaches (Schattman et al. 2024). Using interviews and the nominal group technique to reach consensus, a study of foresters' perceptions in Maine found that while individuals recognize mounting climate impacts, they also lack a clear understanding of how these changes will affect the forest industry over time (Soucy, De Urioste-Stone, Rahimzadeh-Bajgiran, et al. 2021). Although managers must steward amidst this uncertainty, the complexity and scale of climate change can generate feelings of overwhelm that constrain adaptive action. A needs assessment of forestry professionals across New England suggests that real-world examples of on-the-ground adaptation and related management recommendations can help practitioners gain the confidence needed to continue advancing adaptation (M. Janowiak, Mahaffey, and Riely 2020).

In addition, studies that explore Tribal perspectives in forest management across the Northeastern region, although more limited, help promote the inclusion of cultural values and practices in natural resource management broadly. A case study in Maine, U.S. and New Brunswick, Canada that combined interviews and observations of Indigenous plant gatherers found that while gatherers' values were not readily prioritized in forest management, recommendations such as bolstering Indigenous collaboration, respecting traditional gathering knowledge, and stewarding culturally important species could improve incorporation of biocultural considerations (Baumflek et al. 2021). Similarly, Indigenous and scientific knowledge can complement one another, as demonstrated by a synthesis of discussions from the 2014 Black Ash Symposium in Maine, U.S., which addressed how gaps in black ash stewardship can be filled by enhancing Tribal research partnerships and collaboration among managers and

policymakers (Costanza et al. 2017). Lastly, storytelling is another tool for enhancing climate adaptation approaches. Focus groups among participants from Wabanaki Nations demonstrated that stories can create pathways for facilitating adaptation while strengthening the resilience of traditional lifeways (Daigle et al. 2019). Together, this research helps illuminate the diversity of perspectives and approaches among forest stewards across the Northeastern region. It also points to the importance of including Indigenous and non-Indigenous perspectives together to bridge the ecological, cultural, and social dimensions of adaptive capacity.

Maine's State and Tribal Relations Implications for Forest Stewardship

Affairs between the state of Maine and Wabanaki Nations effect the state's collective capacity for adaption in forest systems. In Maine, the Wabanaki Nations are a confederacy of Tribal Nations that include the Penobscot Nation, Passamaquoddy Tribe-Pleasant Point, Passamaquoddy Tribe-Indian Township, Mi'kmaq Nation, and the Houlton Band of Maliseet Indians (Voggesser et al. 2013). On this landscape, forests are integral to supporting Tribal connections with wildlife, waterways, traditional and commercial harvesting, cultural expressions, and intergenerational knowledge transfer (Daigle et al. 2019).

Federal policy in the United States to support Tribal sovereignty expanded during the Self-Determination Era in the late 1960s. Since this time, the economic, social, and sovereign standing of Tribal Nations has strengthened nationally (Henry 2023). Despite these trends, the status of Tribal relations in Maine remains a relative outlier compared to the other 571 federally recognized Tribal Nations in the United States (Bureau of Indian Affairs 2026). This difference is predominantly the result of a state jurisdictional agreement on Tribal territories made in the Maine Indian Land Claims Settlement Act of 1980 (MICSA). Several "unusual" provisions in MICSA determine that Wabanaki Nations are i) regarded by the state of Maine as municipalities rather than sovereign Nations despite federal recognition and ii) subjected to Maine state law (Friederichs 2023, 333). The Task Force on Changes to the MICSA, established by the Maine Legislature, found that due to "the broad nature of these provisions, any law for the benefit of Indian country that in any way "affects" Maine law may be rendered inapplicable in Maine" (Carpenter et al. 2020, 56). In practice, this has forced the Wabanaki Nations themselves to bear the costly burden of proving the applicability of federal Indian policy meant to benefit Tribes nationally and thus are often unable to pursue these programs due to concerns they may affect state jurisdiction.

Ultimately, the implications of MICSA make it challenging for Wabanaki Nations to pursue federal policies and programs compared to Tribal Nations nationally. For example, Wabanaki Nations were not able to access benefits associated with the Environmental Protection Agency's approval of Tribes for Treatment-as-a-State (TAS). Despite multiple documented attempts, the Penobscot Nation and Passamaquoddy Tribes were unsuccessful in applying for TAS to exercise Tribal authority under the Clean Water Act to strengthen water quality standards that would improve regulatory oversight of pulp and paper mills to enhance forest product supply chains (Manahan and Connors 2016).

The impacts of MICSA are well documented, including that Wabanaki Nations significantly lag behind the national per capita income of Tribal Nations, an indicator used to measure economic and social progress (Kalt, Medford, and Taylor 2022). Economic development is inextricably linked to Tribal governance including in the management of natural resources (i.e., forests) and studies show that enhanced Tribal sovereignty improves the economic and ecological outcomes for Tribes (Kalt, Medford, and Taylor 2022; Krepps and Caves 1994). The resultant consequences of MICSA compound Tribal vulnerability, strain Tribal-state relations, and are projected to have consequences for equitable climate adaptation planning across Maine (Dana-Sacco 2020). All efforts to amend MICSA have been unsuccessful, often citing concerns that changes could further exacerbate tensions between the Wabanaki Nations and state, private, and public sectors (Tomer 2021). However, studies have documented the importance of upholding a government-to-government relationship consistent with the same rights that guide federally recognized Tribes affairs outside of Maine (Dana-Sacco 2020; Tomer 2021).

Methods

Study Area and Participants

This study was conducted in the state of Maine, located in the Northeastern U.S. (Figure 1) to explore primarily stewardship approaches within existing ownership boundaries and to advance discussions of land access, inter-jurisdictional stewardship arrangements, and land return. In Maine, forests are predominantly northern hardwood, consisting mostly of maple (*Acer spp.*), beech (*Fagus grandifolia* (L.)), and birch (*Betula spp.*) species, and spruce-fir forests dominated by spruce species (*Picea spp.*) and balsam fir (*Abies balsamea* L.) (Butler 2018; USDA Forest Service 2022). About 89% of Maine's land area is forested and ~96% of those forests reach productivity levels that allow for timber harvesting. Maine's forestlands are mostly privately (~92%) owned with land holders ranging from large corporate owners to smaller family owned parcels. Public lands are managed by state and federal agencies comprising around 8% of land ownership (USDA Forest Service 2022), leaving a small proportion of lands in Tribal ownership (~1%) (Butler 2018) (Figure 1). Land use across state and Tribal lands varies depending on their designation (i.e., ecological reserves, parks, trust lands), however they broadly include a diverse range of benefits such as recreation, hunting, conservation, timber management, and cultural practices.

During this study, twenty-two interviews were conducted with forest stewards from state agencies (n=12) and Wabanaki Nations (n=10). State agency participants were employed by the following agencies: Maine Department of Agriculture, Conservation and Forestry, Department of Environmental Protection, and Department of Inland Fisheries and Wildlife. Tribal participants were associated with one of the four federally recognized Wabanaki Nation either through employment and/or Tribal membership. Eighty percent of Tribal participants were employed by a Tribal Nation's Natural Resource, Forestry, or Recreation department. Thirty percent of Tribal participants held community roles including a traditional harvester, artisan, and community leader. The primary sampling strategies were key informant and snowball sampling. Criteria for participation

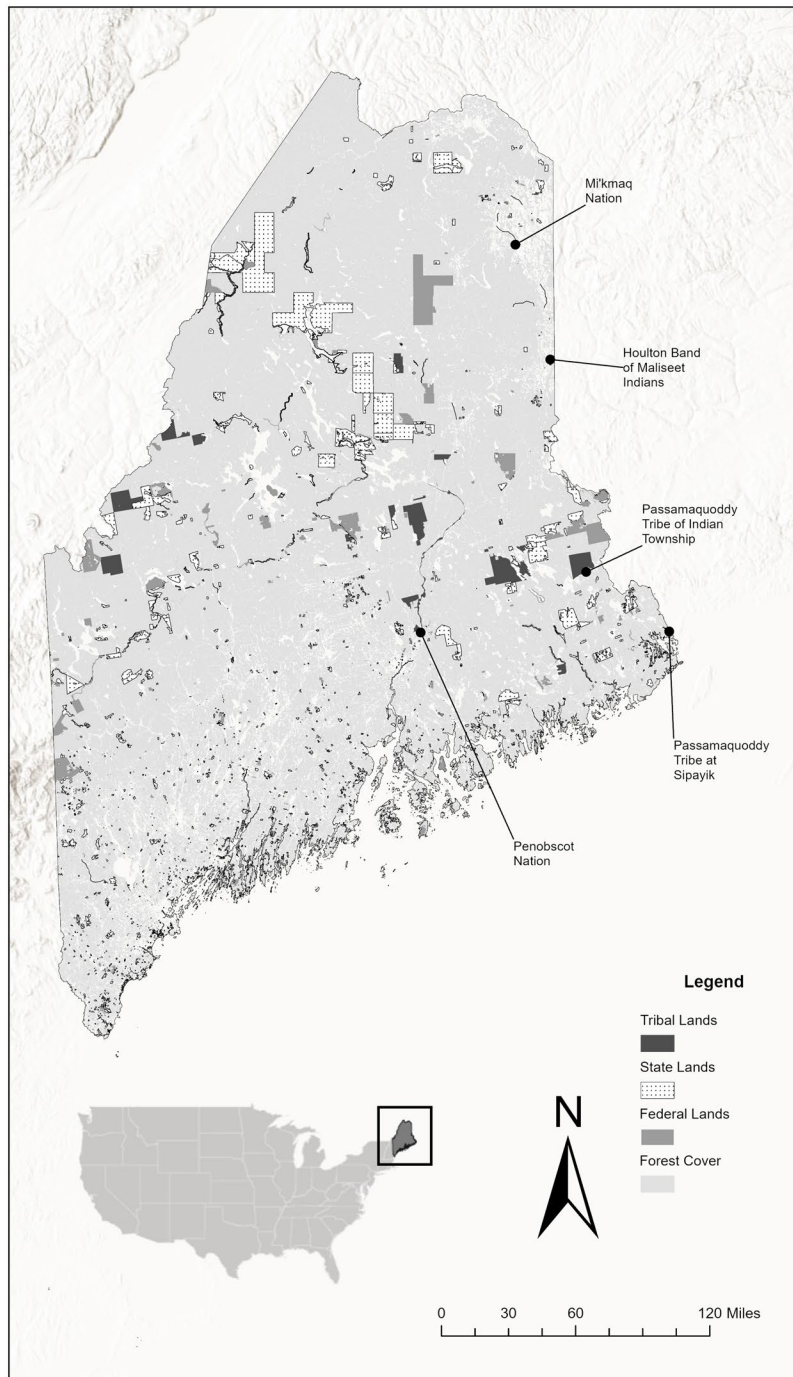


Figure 1. Map of study area (i.e., present-day state of Maine) within the United States inlayed within a map of Maine's land ownership types, lakes, and forest cover. Data sourced from the 2020 US census tract data for tribal lands, Maine conserved lands dataset from the Maine GeoLibrary data catalog for state and federal lands, official government websites for each tribal Nations headquarters, the Maine department of inland fisheries and wildlife for Maine lakes dataset, and USDA forest service forest inventory and analysis program for forest cover. Map created in ArcGIS pro 3.5.4. (U.S. Census bureau 2020; state of Maine 2025).

included formal association with a state agency (i.e., employment) or Tribal Nation (i.e., employment and/or Tribal membership) and an interest in climate adaptation for forest stewardship. The research team suggested key informants ($n=7$) from state agencies ($n=4$) and Tribal Nations ($n=3$) through existing relationships and all subsequent interviews came through key informant recommendations ($n=15$) (i.e., snowball sampling). This sampling strategy allowed for a participatory approach that centers relationships among study participants as foundational to our exploratory analysis while embracing Indigenous research paradigms (Redman-MacLaren and Mills 2015).

The interview guide was pilot tested and reviewed by the research team and colleagues, then revised for clarity prior to interviews. Human subject approval was issued by the University of Vermont's Institutional Review Board (IRB) (STUDY00002132). Additional considerations were included in the IRB to ensure reciprocity between study participants and the research team. First, where participants consented to have their data shared more broadly, these data were provided to the participating Tribal Nations in perpetuity. Second, all participants were offered optional compensation for their participation, which included education credits and Tribal participants could also receive honorarium. Lastly, this study followed the principles of Free Prior and Informed Consent (FPIC), which honors Indigenous rights to self-determination and inclusion of Indigenous peoples throughout project development impacting their homelands (FAO 2016).

Data Collection

Prior to participant interviews, all participants were sent a brief online questionnaire (see [supplementary material](#), SM1), designed to collect primarily demographic data. Semi-structured interviews with individual participants lasted between 45 and 150 minutes and were conducted in a single session between fall 2021 and winter 2022. The interview guide consisted of 12 primary questions (see [supplementary material](#), SM2), starting with introductory questions about participants' background and professional roles, and continuing with prompts exploring organizational goals, decision-making processes, and experiences with climate change adaptation in forest management. Follow-up questions encouraged reflection on the use of different knowledge systems, perceived barriers and opportunities to climate adaptation, and participants' visions for improving adaptation efforts. Twenty-one interviews were conducted virtually while one interview took place in-person. The primary data collection method was video and audio recordings, which were transcribed using Otter.ai software, and manually corrected for accuracy. Final transcripts were reviewed for accuracy and then distributed to study participants to validate final transcriptions and allow participants to add or redact content (Hay and Cope 2021). Three state agency participants and 4 Tribal participants elected to edit their own transcripts following the interview to clarify meaning and/or remove content.

Coding and Analysis

All interview transcripts were coded in NVivo 14 software (QSR International Pty Ltd 2022). The primary researcher developed an initial coding scheme based on

line-by-line open coding of five transcripts (Charmaz 2014). Subsequent categories (i.e., themes) and corresponding codes emerged from close reading of interview transcripts. Interviews were coded by a primary researcher and secondary research assistant to determine *inter-coder agreement* (ICA), defined as the ability of two coders to resolve coding disagreements through discussion across interview transcripts (Campbell et al. 2013). Cohen's kappa coefficient (Cohen 1960) was used to assess agreement, following the constant comparison method. Where two coders iteratively met to discuss codes with low kappa scores, then updated codes using the negotiated agreement approach to achieve inter-coder agreement (Emerson, Fretz, and Shaw 2011; Campbell et al. 2013). This method was used for ten of the twenty-two interviews, until the final codebook was refined (see [supplementary material](#), SM3) and the primary researcher coded the remaining transcripts. Coders initially achieved an average kappa score of 47%. Through the negotiated agreement approach, inter-coder agreement increased to over 90% across all ten transcripts, with an average final kappa score of 98%. Thematic saturation was assessed using Guest, Namey, and Chen (2020) method, which determines the saturation point at which the number of new themes identified in the interview coding process, is proportionally less than 5% of the themes already used. Using a base size of 4 interviews, saturation of new information was reached at 5^{+2} (Guest, Namey, and Chen 2020). Although saturation was reached at 5^{+2} interviews, additional interviews were conducted ($n=22$) to capture variability across participant groups (i.e., state and Tribal), deepen understanding of themes, and enhance broader applicability of findings in the context of complex state-Tribal relations.

Results

Participants

The majority of state agency participants were male (75%), all identified as white, and 58% worked in forest management for >10 years. All state participants' representative agencies managed >4,000 hectares of forested land and were asked to share perspectives on state land management only. 3/10 participants from Tribal Nations did not respond to the questionnaire and their responses are not included in the following demographic descriptions. The majority (57%) of Tribal participants were male, 57% identified as American Indian/Alaska Native, and 57% identified as white (participants could select more than one race). Seventy-one percent of Tribal participants worked in forest management for >10 years. A higher proportion of Tribal respondents (57%) indicated that their Tribal Nation managed >4,000 hectares and 29% reported that they managed <4,000 hectares (Table 1).

Barriers and Opportunities to Transform Adaptive Capacity into Action

We found that participant perceptions of barriers and opportunities were organized into three distinct themes: i) *resource capacity*; ii) *operational capacity*; and iii) *decision-making practices*. Each theme served as an organizing framework for a set of distinct codes applied across the interview transcripts, to identify recurring patterns and assess the relative importance of particular barriers and opportunities, such as funding, staffing, and the chain of command (Table 2).

Table 1. Interview participants and organizational level data across participants from state agencies (n = 12) and Tribal Nations (n = 7).

	State, n = 12 (% of valid responses)	Tribal, n = 7 (% of valid responses)
Gender		
Male	9 (75%)	4 (57%)
Female	3 (25%)	2 (29%)
No response	N/A	1 (14%)
Race		
White	12 (100%)	4 (57%)
American Indian/Alaskan Native	0 (0%)	4 (57%)
Years in profession		
<10 years	5 (42%)	2 (29%)
10–19 years	3 (25%)	2 (29%)
20–29 years	2 (17%)	1 (14%)
30+ years	1 (8%)	1 (14%)
No response	1 (8%)	1 (14%)
Land base size		
400–4,000 hectares	0 (0%)	2 (29%)
>4,000 hectares	8 (67%)	4 (57%)
No response	4 (33%)	1 (14%)

*Three Tribal participants did not provide demographic data and therefore those responses are not included in this table.

Table 2. Codes and frequency counts organized by primary coding themes across participants from state agencies (n = 12) and Tribal Nations (n = 7).

Coding theme	Code	Frequency count
Resource capacity	Funding	92 (S = 48, T = 44)
	Markets	16 (S = 7, T = 9)
	Staffing	82 (S = 52, T = 30)
	Workforce pipeline	24 (S = 3, T = 21)
Operational capacity	Acquiring lands	24 (S = 13, T = 11)
	Equipment stipulations	44 (S = 22, T = 22)
	Land access	17 (S = 4, T = 13)
Decision-making practices	Administrative burden	27 (S = 15, T = 12)
	Chain of command	33 (S = 18, T = 15)
	Federal nexus	42 (S = 8, T = 34)
	Rules and regulations	36 (S = 23, T = 13)
	Sovereignty	23 (S = 2, T = 21)
	State agency and maine	31 (S = 31)
	Status quo needs improvement	26 (S = 13, T = 13)

*The frequency count refers to the number of times a particular code was applied across all interview transcripts. State agency references are represented by “S” and Tribal Nation references are represented by “T.”

State Agency Participants

Across the three primary themes, *resource capacity* related to funding and staff capacity were the most frequently cited barriers, within their distinct category, by state agency participants. Although agency funding varied, all participants indicated that a lack of clarity around funding for climate adaptation was a barrier to implementing treatments with a net cost given competing management priorities. State participants identified various climate adaptative measures that would benefit from investment including pre-commercial thinning (PCT), adaptive plantings, and technological advancement (e.g., modeling software, drone imagery). One state participant noted when asked about why adaptation strategies are not more readily utilized,

[There’s a] lack of cohesion in terms of administrative processes and prioritization for decisions like PCT, often they can be one-off decisions. So, I believe that there needs to be a

system in place to prioritize these things [agency] wide and better clarify where that funding line is. (S2)

Compounding challenges identified by state managers were the limited time and resources available for staff to plan and implement climate adaptive measures stated above. Given broad agency responsibilities, 67% (8/12) of state agency participants shared that resource constraints left them feeling stuck in a business-as-usual cycle, with limited capacity to move beyond their day-to-day obligations. A state participant explained,

Really the biggest obstacle are resources, we don't have enough manpower to do the work that needs to be done and sometimes we don't have the money that would be required to take the next step. So we're constantly having to prioritize our improvements based on the resources that we have. (S8)

Participants explained that tradeoffs between management goals affected the time available to attend and/or develop climate adaptation trainings, apply for external funding, and build new partnerships. These resource limitations made it extremely hard for participants to transition from building understanding about climate change through training, to planning, and ultimately implementation of adaptation actions and strategies.

Operational capacity, which is the ability of forest stewards to successfully and efficiently operate across their land base, was a crucial part of maximizing adaptation efforts. Four contributing barriers to operational capacity were identified and include: i) contractor availability and value discrepancies, ii) climate change impacts (e.g. frequency of freeze-thaw cycles and a shortened harvesting window), iii) endangered and threatened species listings, and iv) inefficient external and internal operating procedures. These challenges create operational uncertainty as a state participant described,

We don't have a steady reliable seasonal weather window any longer for wildlife habitat and forest management activities...narrowing the window in the wintertime would push us into the open ground part of the season, which because of our funding sources creates a management challenge. (S10)

State agency participants described another integral part of leveraging operational capacity was securing forested lands for management, either through direct acquisition or access agreements. State agency participants discussed Maine's goal of conserving 30% of Maine's lands by 2030 outlined in Maine's Climate Action Plan enacted by Governor Janet Mills' administration (*Maine Won't Wait* 2020). However, participants noted that land acquisition processes are lengthy and 25% (3/12) of participants indicated that the current rate of land acquisition outpaced staff capacity for management.

A further related challenge is a lack of flexibility in *decision-making practices* embedded in state agency's institutional frameworks. Fifty-eight percent (7/12) of participants explained that shifts in state administrations and agency leadership halted progress on long term projects and disrupted relationships between agency directors and staff. A slightly smaller proportion of state agency participants (42%, 5/12) also explained that under administrations where issues of climate change were politicized, such as during the LePage governorship (2011–2019), management actions explicitly referencing climate adaptation were not supported. This contrasts with the Mills governorship (2019–present),

where climate change has been more readily prioritized. When asked how state agency goals and priorities have changed over time, a state participant described,

It creates a bit of whiplash, sometimes when you can shift from an administration very strongly oriented in one direction to one very strongly oriented and totally the opposite direction in a matter of weeks. That can be challenging to adapt to...the wheels of state government don't easily shift overnight. (S5)

Although not discussed as a primary barrier, 67% (8 out of 12) of state agency participants referenced the influence of public perceptions on forest management. Participants explained that while decisions were based on best management practices, they also acknowledged that the public-facing nature of their work added pressure to ensure the highest possible management standard. Participants expressed a desire to improve public outreach on issues such as herbicide application and timber harvesting where they most often experienced public opposition.

State participants simultaneously suggested opportunities for adaptive capacity to overcome perceived barriers. For example, despite budgetary limitations, 83% (10 out of 12) of state participants indicated that they did not feel pressured to generate revenue from timber sales due to a multiplicity of state funding sources. One state participant described, *"We can afford to fail, we can afford to experiment and there's not going to be major financial implications for us...It just puts us in a different place in terms of the pressures that we're under."* (S4)

In regard to *operational capacity*, ongoing land acquisition efforts were recognized as a tool for conservation and adaptation. Specifically, the state-wide 30×30 Initiative that targets Maine's natural and working lands allocates resources (i.e., funding and staff) to land acquisition efforts (*Maine Won't Wait* 2020). Participants noted that these conservation initiatives furthered a state-wide dialogue around achieving climate goals.

Lastly, all state agency participants described that *decisions-making practices* for management were often made collectively. Partnerships with external organizations (i.e., federal agencies, scientific advisory boards, universities) were important sources of collaboration. Internally, state participants across all hierarchical levels shared that they contributed to forest management. Two state agency participants representing different state agencies in supervisory positions described avoiding command decisions in favor of incorporating staff perspectives to make operationally sound and efficient management choices. This decision-making "up and down the chain of command" (S3) was perceived to greatly benefit management outcomes that inform climate adaptation for forest systems.

Tribal Nation Participants

Similar to state agency participants, Tribal participants affiliated with Wabanaki Nations commonly cited (90%, 9/10 participants) barriers related to *resource capacity*. Three out of four Tribal Nations in Maine rely on timber revenue for income. Eighty-three percent (5/6) of Tribal participants associated with those timber dependent Tribal Nations expressed feeling a pressure to harvest for revenue to support their Tribal Nations' economic development. One Tribal participant explained, *"There's a lot of pressure. It's not in your face pressure. It's more we as foresters, understand the accounting, we understand what funds what...And so, we see that pressure is on our shoulders."* (T8)

The interrelated nature of funding and staffing constraints was also a barrier to adaptation actions. All participants wanted to expand employment opportunities within Tribal government and hire Tribal youth to invest in their community, sustain adaptive capacity, and preserve Indigenous knowledge over generations. However, participants noted a series of interconnected barriers that obstruct workforce pathways including a lack of positions in Tribal government, a decline in apprenticeship opportunities, and broader socio-political constraints on economic development related to MICSAs. The distances between Tribe's reservations and noncontiguous land holdings were noted to impact the feasibility of offering training opportunities and ensuring the economic viability of employing Tribal members, as one participant shared,

For a four day week, two of your days are travel...it's four hours from where most of the forestry staff live...a lot of forest management companies make it more attractive by paying employees more because you're away but we don't have the luxury of being able to do that because we don't harvest as much and we're already underfunded...so if we have TSI [timber stand improvement] work or thinning that we can utilize Tribal staff it's really hard to get the capacity out there, because it's so far away. (T5)

Tribal participants also illustrated how these distances affected *operational capacity* and necessitated Indigenous contractors to hire non-Indigenous sub-contractors to conduct most timber harvests at economically viable rates. Forty percent (4/10) of participants indicated that these barriers made communication with contractors, scheduling, and oversight of operations challenging, which ultimately constrained their adaptive capacity. Adding to this complexity, non-Indigenous subcontractors were not always aware of Tribal priorities. When prompted on how Tribal Nation's define knowledge for stewardship, a Tribal participant described,

We reserve certain canoe birch trees and contractors are confused, because a lot of times those trees do end up dying, but there is the opportunity to harvest them...it's always a hard conversation to have with the contractor. When you're also explaining well you cut this brown ash stand, and this is bad because we use it, explaining that part of it, the cultural side of it. Sometimes you feel like you're in a weird position if that happens. (T5)

All Tribal participants discussed the related importance of stewarding forests for culturally-important materials such as black or brown ash (*Fraxinus nigra Marsh.*), paper birch (*Betula papyrifera*), medicinal and rare plants. However, participants employed in Tribal government perceived challenges to i) enhance knowledge exchange with Indigenous knowledge holders (i.e., basket makers, harvesters, medicine people) and all participants identified barriers to ii) access culturally significant sites for gathering and harvesting cultural materials beyond Tribal property boundaries (i.e., public, private).

In regards to Tribal participants ability to leverage effective *decision-making practices* for adaptive capacity, many Tribal participants indicated that working with state and federal agencies caused planning delays, bureaucratic complexity, and diminished decision-making ease. For example, 60% (6/10) of Tribal participants referred to the temporal scale of stewardship across multiple generations. Two participants mentioned a "seven generations" (T4/T7) philosophy to convey the Indigenous responsibility for planning in life cycles. These participants described the mismatch between western paradigms that commonly constructed timelines on rotation ages (i.e., ~60-100 years

depending on tree species), political appointments, and grant funding cycles with generational stewardship goals. This was explained by one Tribal participant,

As a people adaptation was what we did. We just adapted, that's how we survived constantly. But there's a lot of folks who will get very set in their ways and they like to have things the same way every year. They want it to be consistent across the board. And that's never really been the way that we've adapted traditionally... I think that [bureaucracy] has a lot to do with it, it insists upon itself. It really needs to have this order, every year has got to be the same...Whereas nature it changes. (T2)

Tribal participants whose associated Tribal Nation did not harvest timber commercially experienced additional hurdles navigating the federal nexus. These participants explained that stewarding forests for cultural values and forest health fell outside of their regional Bureau of Indian Affairs (BIA) management scope, which focuses primarily on timber harvesting. This resulted in planning delays, confusion, and strain on Tribal and BIA staff capacity and resources. As one Tribal participant noted,

We're doing a prescribed cut for forest health as opposed to a commercial cut for timber sales, which is problematic. The BIA doesn't really know what to do with us and our custodial plan. They only seem to want to deal with commercial forest operations. (T7)

Overall, the majority of Tribal participants felt disconnected from federal and state oversight. They pointed to the challenge of working within a government-to-government relationship when a proportion of their decision-making authority was held by external powers removed from day-to-day operations, values, and knowledge systems. Despite this, many Tribal participants explained that allyship in support of Tribal values from external governance systems was important and highly regarded. Therefore, participants suggested that building relationships for greater adaptive potential required an examination of ongoing power asymmetries to overcome barriers to lasting partnership.

In regard to opportunities for adaptive capacity, Tribal participants explained that they aimed to diversify income streams beyond timber revenue to improve financial resilience, self-determination, and community development. Participants described expanding into ventures such as carbon credits, maple sugaring operations, and forestry drone contracting services to strengthen pathways for economic development.

All Tribal participants also noted the role of Tribal community engagement in forest stewardship. Tribal participants explained that in certain cases it was not economically feasible to hire contractors for adaptive treatments with limited economic value (e.g., pre-commercial thinning, forest health treatments). Therefore, opportunities to employ Tribal youth improved *operational capacity*, ensured economic viability of adaptation, and allowed for community workforce development.

Lastly, participants also explained that management priorities for Tribal lands are set by the Tribal community. This communal approach is key to *decision-making practices* guided by Indigenous worldviews and collaborative stewardship. A Tribal participant explained, "I've always, in my practice, followed the lead of the community I work for. If they want to do something in a certain way, that's how we're going to do [it]...I find it inspiring and valuable, and just a way better way to frame what we're trying to do." (T6)

Tribal participants explained that the opportunity to invest in Tribal lands and their community is a pathway to sustain Tribal sovereignty for future generations. Eighty

percent (8/10) of participants spoke about the relationship between suppression of sovereignty and their ability to adapt to climate change. The vision that all Tribal participants shared for their communities was to increase self-reliance to overcome barriers to climate adaptation and meet their diverse goals.

Discussion

Through this study, we identified nuance in the perceptions of barriers and opportunities to climate adaptation summarized in Figure 2. For both state and Tribal participants, lack of available resources was the most frequently perceived barrier to climate adaptation. This finding is consistent with related work, showing that

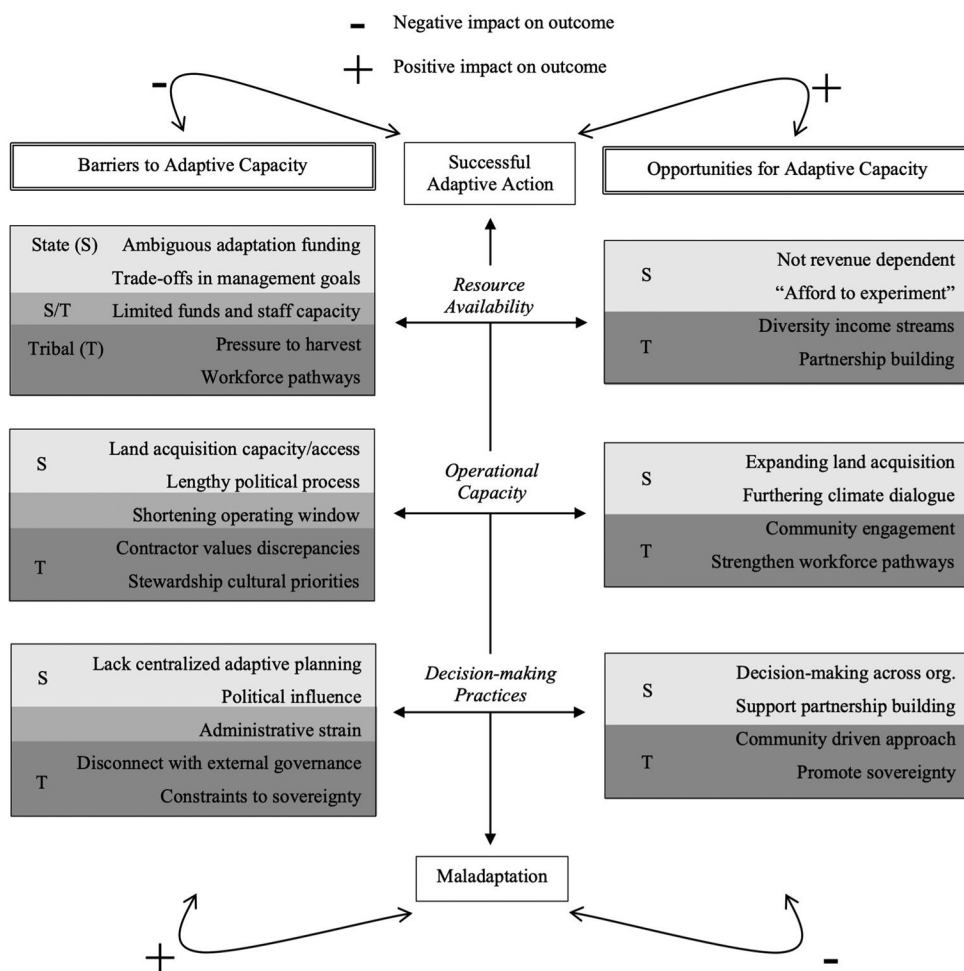


Figure 2. The relationship between barriers and opportunities can lead toward maladaptive responses or adaptive actions. The framework of this figure is adapted from Biesbroek et al. (2013) conceptual diagram on the process continuum of barriers and opportunities toward adaptive outcomes. It has been adapted using results from our study where participant responses are shown according to their affiliation with a state agency (S, n=12), Tribal Nation (T, n=10), and relevant overlapping responses (S/T).

perceptions of climate adaptation costs constrain adaptation and underscore an information gap regarding the cost-effectiveness of different adaptation approaches (McGann et al. 2022; Scheller and Parajuli 2018; Williamson and Nelson 2017). Several studies suggest integrating climate adaptation throughout management, as a more cost-efficient way to plan for future silvicultural treatments (D'Amato et al. 2023; Duguma, Minang, and van Noordwijk 2014; Ontl et al. 2018). Our study found that among Tribal participants, integrating youth workforce development opportunities into forest stewardship offered a two-pronged solution to improve the economic and operational efficiency of climate adaptive strategies. This finding supports a connection between cost effectiveness, community development, and adaptive action that is applicable across different jurisdictional contexts.

Both state and Tribal interviewees are greatly impacted by resource limitations. Participants from Tribal Nations that prioritize timber revenue felt pressured to harvest forest products for income, compounded by development restrictions enacted through the Maine Indian Land Claims Settlement Act. A study on Wabanaki Nations' economies and governance cited an underlying determinant of economic development for Tribal Nations is self-determination (Kalt, Medford, and Taylor 2022). This suggests an important relationship between forest management, funding, and sovereignty- to support adaptive capacity and reduce singular reliance on timber revenue. It also points to the critical role of interjurisdictional approaches to minimize the reinforcement of existing inequities and promote sustained adaptive actions across the landscape. Collaborative governance arrangements such as co-management (i.e., formal) and co-stewardship (i.e., informal), are examples of inter-jurisdictional agreements that have demonstrated value in facilitating collaborative problem solving for climate adaptation (Berkes and Armitage 2011; Rathwell, Armitage, and Berkes 2015). We suggest additional research explore these collaborative approaches for forest systems within specific regional contexts to identify how they may lead to positive outcomes for forest stewardship.

An unexpected finding from Tribal participants were the various barriers to workforce pathways for Tribal youth. Sharik et al. (2015) found a possible contributing barrier, that Indigenous Peoples are the most underrepresented minority in natural resource and forestry programs across U.S. universities. They suggest that distances between reservations and universities may be one factor inhibiting enrollment. Further compounding these constraints, Maine has no Tribal colleges or Universities (TCUs) governed by Wabanaki Nations to specifically focus on recruiting and retaining Tribal youth (USDA 2025).

Our study found that distances between Tribes' reservations and noncontiguous land holdings also limit natural resource employment and training for Tribal members in Maine. This suggests that a dispersed mosaic of land holdings, resulting from colonization, is impacting the economic feasibility of scaling workforce opportunities among Tribal youth. Future research would benefit from examining perceptions of Tribal youth along with forest management professionals to better understand the full scope of workforce development pathways. Similarly, Dockry et al. (2023) surveyed fifty-nine Tribal natural resource professionals and identified workforce development as one of the most highly cited categories for future research needs.

We further recommend land acquiring organizations, including the State of Maine through the 30×30 conservation initiative, pursue co-management agreements or land

return for parcels close to Tribal headquarters. This approach has already proven successful in California's 30×30 initiative, where "strengthening Tribal partnerships" is one of its three key objectives and the 30×30 framework is explicitly used to advance Tribal land access, co-management, and ancestral land return (California Natural Resources Agency 2025). These strategies are poised to strengthen state-wide management capacity while addressing the stewardship challenges Tribal Nations face as a result of fragmented, noncontiguous land holdings.

A commonly cited barrier for state and Tribal participants are differences in values between forest stewards and contractors that inhibit collaboration to meet adaptive goals. This echoes findings from a study on barriers to climate action in British Columbia, Canada, which found that "conflicting cultures" between outside workers responsible for operations was a barrier to climate adaptation (Burch 2010). Therefore, we suggest that it is important to strengthen engagement and education pathways for forestry contractors. While training and certification programs are common for foresters, to our knowledge, no efforts to educate contractors on diverse management values, knowledge systems, and culturally inclusive consultation mechanisms exist. We suggest that knowledge exchange and collaboration should be part of contractor education, to go beyond standard operational arrangements and move toward a collective approach to achieve ecologically focused adaptive outcomes.

Among state agency participants, short-term political horizons and shifting political priorities associated with administration changes were commonly described as a constraint on climate adaptation planning and implementation. Participants pointed to a dilution in their decision-making capacity, consistent with the literature, resulting from a pressure to respond to politically motivated agendas (Kemp et al. 2015; Williamson and Nelson 2017). Our findings help underscore an important constraint to adaptive capacity, a need to shift climate change from the realm of 'standard' political issue to an existential threat that requires urgent action. Rhinard et al. (2024) suggest using a risk management approach, modeled by the Norwegian national government, to improve the adoption of climate adaptation in the public governance sphere. We recommend building on existing organizational procedures for emergency threats (e.g., flooding and severe drought) to implement climate adaptive practices, thereby minimizing the politicization of adaptation efforts. Further research on how the politicization of climate change affects adaptive capacity will be essential for closing the adaptation gap.

Tribal participants also experienced decision-making barriers connected to external governing institutions. They often cited the importance of equitable government-to-government partnerships, to uphold Tribal sovereignty. However the complex values and needs of Tribal Nations, coupled with financial, institutional, and cultural barriers experienced by government agencies, can strain this relationship (Adger et al. 2007; Whyte 2013). Differing interpretations of Tribal sovereignty and jurisdiction also impact Tribal self-determination across state and federal spheres (Armstrong 2015; Banai 2016; Dana-Sacco 2020). Yet, ongoing examples of federal, state, and Tribal partnerships demonstrate the importance of collaboration; to ensure federal trust responsibilities are met, Tribal priorities are reflected in forest stewardship, and trust is built to achieve equitable adaptive action broadly (Case-Scott and Lynn 2021; Chief et al. 2014; Tomer 2021).

Throughout interviews, state and Tribal participants referenced the relationship between barriers and opportunities. By incorporating opportunities alongside barriers, this study captured a more holistic view of adaptive capacity as perceived by participants. Collaborative approaches to climate adaptation were described by all participants and in the associated literature as critical to maximizing the effectiveness of proposed adaptive strategies and ensuring that measures are grounded in the experiences, values, and priorities of diverse forest stewards (McGann et al. 2022; Soucy, De Urioste-Stone, Fernandez, et al. 2021). Both state and Tribal participants perceived internal and external collaboration as integral to their adaptive responses. Results from participant interviews reveal that a strong culture of collaboration exists among forest stewards in Maine, far beyond state agencies and Tribal Nations. Related studies have found that collaborative practices must be reinforced through institutions, leadership, and funding opportunities (Burch 2010; Tribal Climate Adaptation Menu Team 2019). Therefore, the continued investment by environmental organizations (e.g., government agencies, Tribal Nations, nonprofits, and community groups) in strengthening these pathways and finding engagement synergies, specifically across cultures, is essential to supporting equitable adaptive capacity (Tengö et al. 2014; Whyte 2013).

Lastly, it is important to acknowledge the limitations of this study. The key informant sampling strategy began with an initial round of participants ($n=7$) who had preexisting relationships with members of the research team. This may have biased sampling toward individuals already engaged in research collaboration and more likely to hold perspectives relevant to our study. However, the majority of interviews ($n=15$) were conducted through snowball sampling, which helped reduce selection bias and incorporated community perspectives beyond existing research networks. In addition, fire management regimes are of increasing importance throughout the Northeastern U.S., including prescribed burning, cultural burning, and fuel reduction treatments. Although fire was not widely discussed by our study participants, this is an important area for future research that offers additional pathways for cross-boundary coordination among diverse forest stewards. Finally, comparisons of perspectives across participants from different states, Tribal Nations, and countries with complex Indigenous relations were beyond the scope of this study. We recommend that future research on collaborative environmental governance, workforce development, and cross-cultural knowledge exchange include participants from broader regional, national, and international contexts.

Conclusion and Future Directions

The perceptions of participants from state agencies and Wabanaki Nations offer insights to transform adaptive capacity into action, overcome adaptation gaps, and enable cross-cultural collaborate across Maine, the region, and worldwide. Our findings are consistent with related literature highlighting the importance of Indigenous self-determination and knowledge exchange to strengthen adaptive capacity (Colombi 2012; Reo et al. 2017). These dimensions of adaption, specifically, recognizing the central role of culture and power will allow us to better identify climate risks, understand adaptive responses, and strengthen inclusive decision-making.

In addition, the widespread nature of collaboration in forest stewardship characterized in our study speaks to the potential of strengthening sovereign government-to-government partnerships to improve equitable climate adaptive responses. There is great interest among our study participants to build relationships and develop collaborative pathways between state agencies and Wabanaki Nations. Stewards may benefit from seeking shared funding opportunities, establishing informal and formal communication networks, and reimagining relationships to better accommodate a long-term vision of stewardship and reciprocity. Frameworks such as biocultural approaches, a justice forward framework, and Two-Eyed Seeing provide ways for forest stewards to bridge western and Indigenous priorities in an ethical and community driven way (Bartlett, Marshall, and Marshall 2012; Baumflek et al. 2021; Eisenberg et al. 2024). These approaches are critical to implementing effective climate adaptation strategies that prioritize resilience, connected landscapes, and diversity of knowledge systems.

Our study also demonstrated that both state agencies and Wabanaki Nations are actively adapting to environmental changes. However, the articulation of these adaptive responses in their day-to-day duties, institutional structures, and longer-term horizons are inconsistent across participant groups. Therefore, further institutionalization of climate adaptation (Biesbroek et al. 2013; Whyte 2013), may improve centralized planning for climate adaptation, allocation of funding, streamlining of processes, and knowledge exchange.

Lastly, there are comparatively fewer studies examining the experiences and perceptions of climate adaptation among Tribal Nations, as compared to western organizations (e.g., state and federal agencies). We suggest that future research explore climate adaptation across diverse cultural paradigms along with inter-jurisdictional agreements such as co-management and co-stewardship to strengthen a collective place-based climate adaptive response. These approaches will create pathways for a range of forest stewards (e.g., state, federal, Tribal, nonprofit, non-governmental, and private family/corporate landowners) to equitably forge partnerships, which is paramount to our collective capacity to adapt to a highly uncertain climatic future.

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Data Availability statement

The authors do not have permission to share data.

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