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Human adaptation to climate change in the context of forests: A systematic review

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A R T I C L E I N F O

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A B S T R A C T

We assessed how people adapt to climate change in the context of forests through a systematic review of the international empirical research literature. We found that drought, precipitation variability, extreme precipitation and flooding, and extreme heat were the climatic stressors to which responses were most frequently documented. Individuals and households received the most research attention, followed by national government, civil society, and local government. Europe and North America were the geographic foci of more research than other regions. Behavioral responses were more reported than technical and infrastructural responses and institutional responses. Within these types of responses, actors used a wide variety of practices such as replanting, altering species composition, and adopting or changing technology. Adaptation efforts in early planning and advanced implementation received some attention, but early implementation and expanding implementation were most reported. While connections between responses and risk reduction were discussed, there is limited evidence of risk reduction. Our review contributes to the scholarly and practical understanding of how people adapt to climate change in the context of forests. The review also identifies opportunities for future research on adaptation to other climatic stressors, such as wildfires and tree pests and pathogens, adaptation in other geographic areas, especially Oceania, and adaptation by actors beyond the individual and household level and through institutional adaptation efforts.

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1. Introduction

Forest ecosystems and the people who depend on them face unprecedented stress because of climate change. Increasing temperatures and alterations in precipitation patterns are expected to expose forests to large-scale droughts, increased insect and disease infestations, and greater risk of wildfires (Bezner Kerr, 2022; Millar & Stephenson, 2015; Oldekop et al., 2020; Parmesan, 2022). As long-lived organisms with relatively slow rates of evolution and migration, trees (and the forests they create) are particularly sensitive to these stressors (Beloiu et al., 2022; Fettig et al., 2013; Zhang et al., 2022). Consequently, forests could see significant changes in their structure and species composition and reduced growth and survival of some forest types and tree species (Parmesan, 2022).

Wildfires, storms, droughts, and pest and disease outbreaks resulting from climate change may damage property, timber, and other values that people derive from forests (Beloiu et al., 2022; Oldekop et al., 2020; Parmesan, 2022). Wildfires may directly threaten human life, as well as human health, by releasing particulates into the atmosphere that are harmful to humans (Liu et al., 2015). Declines in certain tree species, such as some economically important oak and conifer species in temperate forests (Gaisberger et al., 2022; Gómez-Mendoza & Galicia, 2010; Hanewinkel et al., 2013; Jonsson et al., 2009; Keenan, 2015; Peltola et al., 1999), may challenge forestry operations for landowners in some regions (Irland et al., 2001; Lal et al., 2011). In addition, increased cloudiness may reduce productivity, and warmer, wetter conditions may complicate thinning, harvesting, and other forest management activities (Maracchi et al., 2005). As a result, landowners may experience declining profits and land values (Maracchi et al., 2005).

To reduce the risk of adverse impacts, forest users may need to adjust their management practices, shifting emphasis from some activities and practices to others and, in some cases, adopting new strategies (Jandl et al., 2019; Oldekop et al., 2020). Adaptation is a process of behavioral adjustment to actual or expected climate and its effects to moderate or avoid harm or exploit beneficial opportunities (IPCC, 2022). Adaptation in human systems has been the subject of much scholarly and applied research in recent years, including large-scale systematic literature reviews (Berrang-Ford et al., 2021b; Nalau & Verrall, 2021; Vincent & Cundill, 2022). Indeed, an understanding of how people adapt to climate change and what motivates and constrains their behavior is critical for the design of policies and programs to foster adaptation (Thomas et al., 2021).

However, little is known about human adaptation to climate change in the context of forests (Moreau et al., 2022; Zhang et al., 2022). While the nature-based solutions literature is rapidly expanding (Chausson et al., 2020; Key et al., 2022; Turner et al., 2022; Woroniecki et al., 2022), and scholars have addressed forestry-based adaptation in conceptual and review articles (Key et al., 2022), the empirical research literature on human adaptation efforts in the context of forests has not been systematically assessed. Building on a recent inventory of the empirical research literature on human adaptation to climate change published between 2013 and 2019 (Berrang-Ford et al., 2021b), we systematically review the literature regarding how people adapt to climate change in the context of

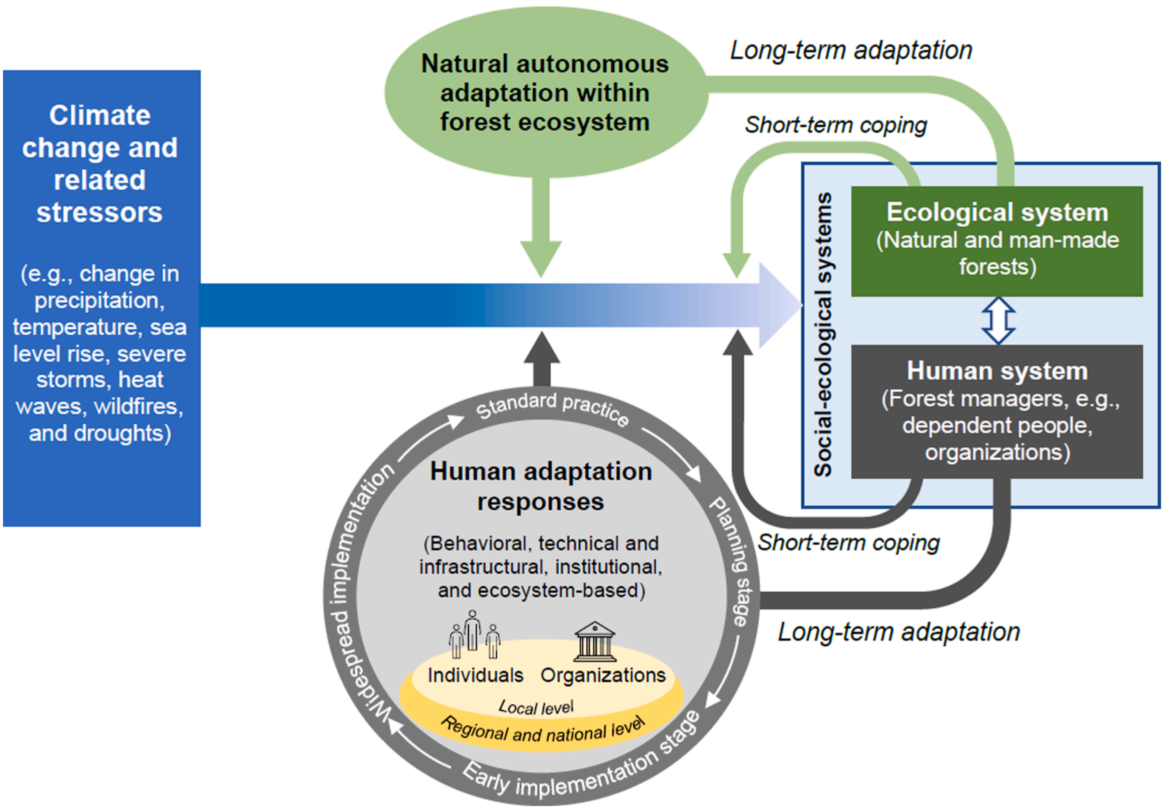

Fig. 1. Conceptual framework for reviewing the nature and characteristics of climate change adaptation in forest contexts.

forests, including the diversity of actor types, climatic stressors, and responses.

2. Conceptual framework

We use a conceptual framework representing the nature and characteristics of adaptation to structure our review (Fig. 1). Adaptation is generally considered a long-term process in which people make enduring changes to their behavior in response to an external stressor to reduce risk and increase well-being (Orlove, 2022). Adaptation is often distinguished from other types of responses based on its time frame and goals. For example, coping behaviors are short-term efforts to mitigate shocks and regain stability (Brown & Westaway, 2011; Fazey et al., 2010). In some cases, responses can be considered maladaptive, such as when adaptation or coping efforts increase vulnerability at other levels, for other actors, or at future points in time (Eriksen et al., 2021; Schipper, 2020; Thomas et al., 2021). While reduced vulnerability and risk and increased adaptive capacity and well-being are considered the ultimate goals of adaptation by many scholars (Singh et al., 2022), not all adaptation efforts achieve these goals. Moreover, reduced risk and increased well-being are difficult to document as outcomes, much less to attribute to a behavioral change (Dupuis & Biesbroek, 2013). Therefore, we use the term “adaptation effort” to refer to responses that people undertake aiming for long-term risk reduction in the context of forests.

Adaptation efforts differ based on who is attempting to adapt (i.e., at which level of social organization), to what (i.e., which type of hazard or stressor), and how (i.e., which behaviors)—therefore, it is important to specify these dimensions of adaptation (Smit et al., 2000; Petzold et al., 2023). Adaptation efforts can be in response to climate change broadly (i.e., the general global pattern of changing precipitation and temperature) or to specific climate change-related stressors such as sea-level rise (Smit et al., 2000). Adaptation efforts can also respond to climate change-induced trends in stressors such as the pattern of increasingly frequent and severe storms, heat waves, wildfires, and droughts (Smit et al., 2000). Adaptation efforts can occur at any level of social organization, from individuals to institutions (Petzold et al., 2023; Smit et al., 2000). At the household level, individuals interpret environmental changes, develop strategies, and implement actions. At the institutional level, many individuals may be involved, but decisions reflect the goals and values of larger groups. Moreover, because institutions have access to more resources than individuals, they can plan and implement adaptation on larger spatial and temporal scales (Berrang-Ford et al., 2021b).

Adaptation efforts can occur in different forms (Berrang-Ford et al., 2021b; Georgeson et al., 2016). Behavioral responses refer to physical actions that people undertake in reaction to stimuli. Technical and infrastructural responses are responses made possible by engineering. Institutional responses are made possible through the creation or administration of policies, programs, regulations, procedures, and organizations. Finally, ecosystem-based responses are responses that shape the structure, composition, and functioning of ecosystem services (Berrang-Ford et al., 2021b). Adaptation efforts can also occur in different stages. In early planning stages, human actors assess their vulnerability to climate change-related stressors and identify possible measures to reduce risk (Berrang-Ford et al., 2021b). In early implementation stages, there is widespread recognition among actors of the need for adaptation, adaptation measures have been identified, and there may be some coordinated implementation, albeit ad-hoc (Berrang-Ford et al., 2021b). In later stages, as implementation expands, adaptation becomes incorporated into decision-making processes (Berrang-Ford et al., 2021b). When implementation is widespread within a unit of social organization (e.g., a household or government body), adaptation measures become standard practice (Berrang-Ford et al., 2021b).

3. Material and methods

3.1. Sampling

We drew our sample from the Global Adaptation Mapping Initiative (GAMI) database of 1682 research articles published between 2013 and 2019 reporting on human climate change adaptation efforts (Berrang-Ford et al., 2021b). The GAMI database is the product of a systematic screening and coding process by a global network of 126 researchers assisted by machine learning. The GAMI team used a set of seven inclusion criteria to identify empirical research articles and reviews of empirical research articles that reported on human responses to hazards or stressors attributable, in some part, to climate change (Berrang-Ford et al., 2021a; Berrang-Ford et al., 2021b; Fischer et al., 2021). Data extraction followed a typology designed for characterizing the respondents, and analyzing their responses, the extent or stage of their adaptation efforts, and whether their responses reduce vulnerability or risk (Berrang-Ford et al., 2021a; Berrang-Ford et al., 2021b; Lesnikowski et al., 2021).

For the present analysis, we sought to identify the subset of research articles within the GAMI database that reported on adaptation efforts in the context of forests and specifically through forestry-related decisions and management practices. We defined adaptation efforts as practices or activities that people undertake (or decide not to undertake) in response to environmental hazards or stressors that are partly attributable to climate change and aimed at reducing risk or increasing well-being. We defined forests as ’ecosystems with relatively dense (at least 10 %) and extensive (at least 0.5 ha) tree cover consisting of multiple stands of trees—varying in size, age, and species—capable of reaching at least five meters in height’, based on Chazdon et al. (2016). This structural definition typically excludes savannah, fruit-tree plantations and orchards, small woodlots, and most agroforests (Chazdon et al., 2016). We relied on a standard definition of forestry, ’the practice of creating, managing, and conserving forests and associated resources’ (Nieuwenhuis, 2000). We included afforestation on historically-forested land in our definition of forestry but not afforestation on land classified as unsuitable for forests. While we focused on articles whose definition of forests likely met the structural definitions above, not all articles provided such detail. We did not investigate adaptation in forested urban contexts, on large-scale, even-aged monoculture tree plantations, or through agroforestry, nor did we assess non-forestry behaviors in forested areas (e.g., farming, habitation).

To identify the articles for this review, we searched the GAMI database for articles with the terms “tree” or “forest” in the title, abstract, or coders’ comments. From the resulting set of 249 articles, we identified 179 articles that reported on human adaptation efforts entailing decisions regarding forestry, agroforestry, and urban forestry. From this set of 179 articles, we eliminated 92 articles that focused exclusively on agroforestry or urban forestry. We reviewed the full text of the remaining 87 articles to confirm that they reported on forestry-related decisions in the context of forests. We eliminated articles that reported exclusively on non-forestry-related decisions in forested areas, e.g., fishing, farming, fruit tree production, animal husbandry, and habitation. We also excluded any articles that reported exclusively on adaptation planning and vulnerability assessments or climate change mitigation, i.e., forestry-based carbon sequestration. This process yielded 35 empirical research articles on forestry-related adaptation efforts, including activities, practices, and strategies that people undertook or decided not to undertake as part of efforts to reduce vulnerability and risks from (or improve adaptive capacity and well-being despite) hazards or stressors that are attributable, at least in part, to climate change. The list of articles can be found in the Appendix.

3.2. Data collection and analysis

For each article, we coded the focal actors, their geographic locations, the climate-related stressors to which they responded, and the nature of their adaptation efforts. We based these characterizations on closed-choice categorical variables in the GAMI database and open-ended comments by the GAMI coding team (Berrang-Ford et al., 2021a; Berrang-Ford et al., 2021b; Lesnikowski et al., 2021) and on full-text review of the articles. We corroborated our coding of the articles with the GAMI variables (Berrang-Ford et al., 2021a; Lesnikowski et al., 2021). In several cases, our coding indicated that fewer or additional categories would be more useful as the GAMI variables.

The GAMI variables proved suitable for categorizing the findings of the 35 articles according to actor type (e.g., individual and household, multiple levels of government), geographic location (i.e., all the world’s continents, with Australia and Pacific Islands combined as the region of Oceania), and extent or stage of response (e.g., planning vs. implementation), whether the responses were conceptually linked to risk, and whether the article reported evidence of risk reduction (Berrang-Ford et al., 2021a; Berrang-Ford et al., 2021b; Lesnikowski et al., 2021). Three of the four categories in the GAMI response type variable were suitable for our review: behavioral responses (responses that consist of physical practices or activities that individuals can typically undertake), technical and infrastructural responses (responses that require some level of engineering, and, typically, collective effort), and institutional responses (responses entailing change to policies, procedures, and decision-making processes, usually at the organizational or governance network-level). We did not use the fourth category—ecosystem-based responses—because all forestry responses constitute ecosystem-based responses. We also modified the GAMI hazard variable to accommodate the unique categories of stressors that actors faced in forest contexts. We removed the categories “Rising ocean temperature and ocean acidification” and “Loss of Arctic sea ice.” We added categories that were more salient in the forest-based literature: “Pests and diseases,” “Fire or wildfire,” and “Seasonal variation/ phenological change.”.

4. Results

4.1. Stressors

The articles we reviewed reported forestry adaptation responses to eight broad types of stressors (Fig. 2). However, not all stressors fit into the eight categories, and some articles reported more than one stressor. Drought and variability in precipitation were the most cited stressors to which actors responded. For example, forest landowners in Germany extended their harvest rotations and planted a

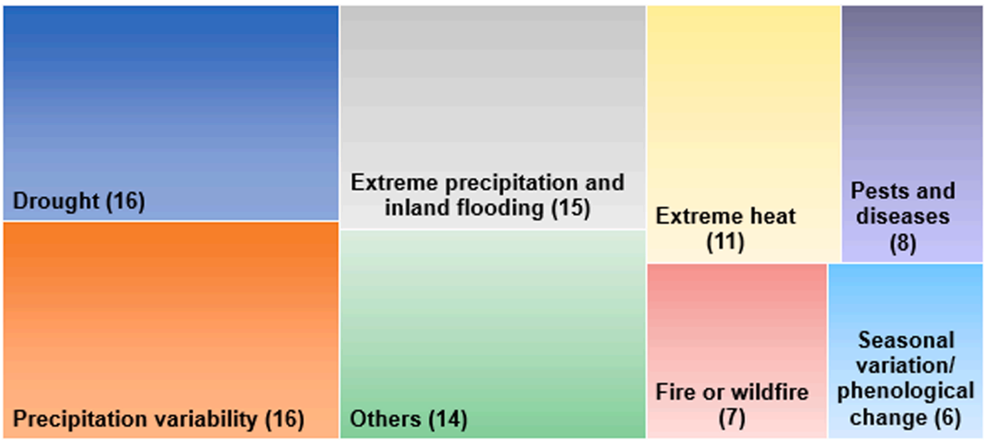

Fig. 2. Categories of climate change-related stressors to which actors responded and count of articles that reported responses to stressors in each category.

more extensive mix of species to reduce potential loss and damage from drought (Milad et al., 2013), and landowners in South Africa shifted the timing of tree planting to coincide with the rainy season to reduce the chance of loss to drought (Ofoegbu et al., 2016). Extreme precipitation and inland flooding events were the next most frequently cited stressors associated with forestry-related responses. In Central America, smallholders who perceived precipitation extremes responded with reforestation practices (de Sousa et al., 2018). In Columbia, smallholder coffee farmers reforested land with exotic tree species to prevent soil erosion and improve soil cover in the face of extreme precipitation events (Barrucand et al., 2017). Extreme heat events were also documented as a trigger of adaptation efforts. In Canada, France, and Belgium, forest landowners replanted stands with heat-hardy species (Sansilvestri et al., 2016; Sousa-Silva et al., 2016). In South Africa, farmers planted more trees near their homes to provide shade (Ofoegbu et al., 2016).

Wildfire risk was another stressor to which actors responded, according to the articles we reviewed, although less frequently compared to drought, heat, and extreme precipitation and inland flooding. Public forest managers in Canada and France used assisted migration to relocate species threatened by climate change-exacerbated fire risk to more suitable habitats (Sansilvestri et al., 2016). Individual and institutional land managers in Mexico and Spain responded to increased fire risk by reforesting individual plots with native species, creating fire lines, and clearing accumulated biomass from forest stands (Campos et al., 2014). In the United States, forest managers with private firms and public agencies conducted fuel treatments to protect forests from fires exacerbated by climate change (Scheller & Parajuli, 2018), and private landowners who believed in climate change conducted prescribed burning and removed flammable vegetation to reduce fire intensity (Boag et al., 2018).

Actors also responded to tree pests and diseases. For example, landowners in the United States undertook management actions to control invasive tree insects and diseases that become established more easily in warmer and wetter conditions (Fischer, 2019a; Snyder et al., 2019). Seasonal variations and phenological change were another set of climate change-related stressors to which actors responded. In Mexico and Spain, the wildfire risks to which forest managers were responding were attributed to a decrease in the seasonal variation in precipitation (Campos et al., 2014). In the United States, public land management agencies responded to phenological changes that made forests vulnerable to diseases and other damage by promoting and maintaining structural complexity and by utilizing climate change projections to select an appropriate tree species for planting (Anhalt-Depies et al., 2016). Private forest landowners increased harvest on dry, sandy soils or slopes and decreased harvest on moist, poorly drained soils or bottomlands during winter warm-ups (Rittenhouse & Rissman, 2015). In Norway, forest landowners adjusted the timing and nature of their forestry practices to reduce damage to soils and roads during winter warm-ups (Heltorp et al., 2018).

Fourteen articles reported on responses to other stressors that did not fit into the primary categories. These included declines in soil moisture and snowpack (Snyder et al., 2019), ice storms (Snyder et al., 2019), wind storms (Anhalt-Depies et al., 2016; Snyder et al., 2019; Sousa-Silva et al., 2016), hail events (Ofoegbu et al., 2016), tree die-off events (Anhalt-Depies et al., 2016; Oakes et al., 2016), soil erosion (Barrucand et al., 2017; Campos et al., 2014), extreme weather in general (de Sousa et al., 2018), landslides and mudslides (Barrucand et al., 2017; Sandholz et al., 2018), and reduced soil fertility (Gross-Camp et al., 2015). Forest managers also responded to sea-level rise. In Indonesia, many types of actors afforested coastal areas and developed and rehabilitated mangrove plantations to protect land from sea level rise (Dalimunthe, 2018). In Mozambique, the City of Beira used mangrove afforestation and restoration to protect against sea level rise (Spekker & Heskamp, 2017).

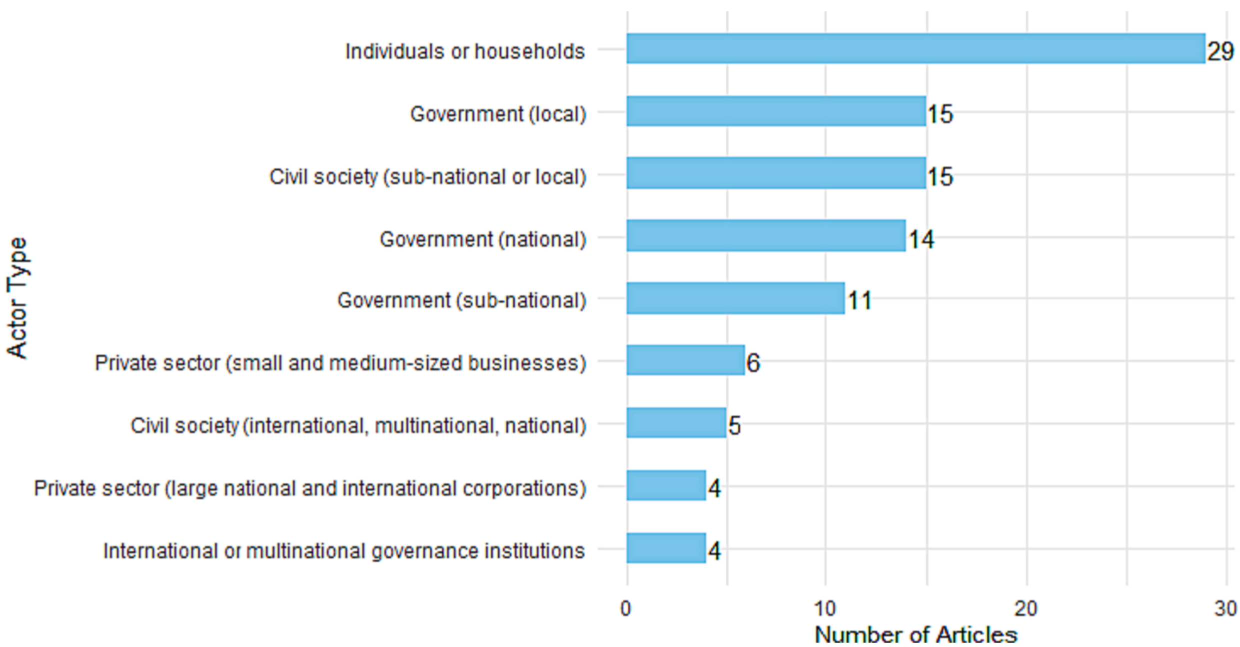

Fig. 3. Categories of actors reported in articles and count of articles that reported actors in each category.

4.2. Actors

Articles reported on adaptation efforts in the context of forests at multiple levels of social organization (Fig. 3). A majority of articles reported responses at the level of individuals and households, mostly among family forest owners, small woodland owners, and smallholder farmers who also managed woodlots. For example, maple sugarbush growers in the United States adopted new technology to enhance sap collection and diversified their products (Snyder et al., 2019) and farmers in Ethiopia developed eucalyptus woodlots on former croplands (Alemayehu & Bewket, 2018).

The next most frequently cited actor group was local government. For example, in Brazil, the City of Rio de Janeiro reforested degraded hills to reduce landslide risk (Sandholz et al., 2018). Efforts by local and regional civil society organizations were also frequently reported. For example, in Colombia, water user associations managed water and watersheds in response to water scarcity caused by climate variability and land-use changes (Murtinho, 2016).

National and subnational governments also received research attention. In Guatemala, the national government established an incentive program that paid smallholders to plant trees for reforestation, watershed management, and soil conservation (Hellin et al., 2018). Along the Bangladesh-India border and in Nepal, public land management agencies fostered climate change adaptation by minimizing forest depletion by local communities (Hassan et al., 2019; Sapkota et al., 2019).

Fewer articles reported on adaptation-oriented efforts by individual private sector entities (i.e., corporations and small to medium-sized businesses or SMEs). One article reported adaptation efforts by individual members of quasi-private sector entities such as the Regional Native Corporation in Alaska (Oakes et al., 2016), and another described the efforts of Maple Syrup Producer Associations in the Upper Midwest, USA (Snyder et al., 2019). Some articles reported on adaptation-oriented efforts at the sector level, for example, the forestry sector in the Southeastern USA, which includes private corporations and SMEs (Dow et al., 2013).

Finally, international organizations also played a role. In Guatemala, the Norwegian Development Fund supported communities in designing and implementing climate change adaptation plans that involved the establishment of forest reserves and reforestation, agroforestry, and soil conservation programs (Hellin et al., 2018).

4.3. Geographies

The articles we reviewed reported on forestry adaptation efforts in all regions except Oceania (Fig. 4). The largest proportions of articles reported on efforts in Europe (Germany, Belgium, Norway, Sweden, Switzerland, and Greece) and North America (Canada, Mexico, and the Western, Upper Midwestern, and Southeastern regions of the US). Slightly smaller proportions of articles reported on adaptation efforts in Asia (Nepal, Bangladesh, and Indonesia), Africa (Ethiopia, Kenya, Mozambique, Cameroon, Equatorial Guinea, Rwanda, and South Africa), and Central and South America (El Salvador, Guatemala, Honduras, Nicaragua, Columbia, Brazil, and Peru).

Fig. 4. Geographic distribution of articles across regions that contain forests.

4.4. Responses

4.4.1. Types of responses

A majority of the articles (30 of 35) documented behavioral adaptation efforts in the context of forests, i.e., physical activities in response to stimuli (Table 1). The most common subtypes of behavioral responses were replanting and restoring forests (i.e., species composition and extent), altering species composition and structure to increase stand robustness and resilience (e.g., to disease, drought), and adjusting the timing of forestry practices to prevent damage from stressors (e.g., winter thaws) or accommodate stressors (e.g., changing phenology). For example, in Sweden, forest owners promoted species diversity and thinned their stands to reduce vulnerability to diseases and wind events (Uggla & Lidskog, 2016). In the USA, forest owners avoided thinning and harvest activities during winter thaws to reduce damage (Fischer, 2019a) and tapped their sugar maple trees for sap earlier in the season (Snyder et al., 2019). In Ethiopia, smallholder farmers planted trees to reduce heat stress (Tessema et al., 2013). In Mozambique, municipal actors planted young mangroves along the riverbanks to afforest coastal areas to protect them against sea-level rise (Spekker & Heskamp, 2017). In South Africa, households planted trees to provide shade to protect themselves against heat (Ofoegbu et al., 2016). In Rio de Janeiro, Brazil, community groups planted trees to reforest degraded hillsides to reduce landslide risk (Sandholz et al., 2018). Purchasing insurance (e.g., to protect homes or land in flood or fire-prone areas) was another behavioral response reported in the articles (Fischer, 2019a; Sousa-Silva et al., 2016).

Table 1
Practices by response type.

Response type (# of articles)	Response sub-type(# of incidences)	Examples
Behavioral (30)	Replant or restore forests (28)	Reforestation Soil restoration Restore native species Promote natural regeneration Protect forests on hillsides Afforestation Managing for riparian health Wildlife protection Reduce forest depletion and degradationRemoving invasive species
	Alter species composition and structure (25)	Planting climate-resilient species Diversify forest composition Diversify forest structure Plant exotic species Alter stand structure to provide storm protection Manage for healthier trees Manage for more productive treesRemove competing species
	Adjust timing of forestry practices (15)	Change the timing of planting Change timing of tree harvestChange timing of harvest of other forest products (e.g., sap) Prioritize stand treatments according to season and accessibility
	Reduce wildfire risk (8)	Remove or reduce flammable vegetation Thin to prevent spread of fire Purchase or maintain fire-fighting equipment Install or maintain water-intake taps and tanks Install or maintain fire observatoriesConduct prescribed burning
	Alter economic model (5)	Product diversification (e.g., to include non-timber forest products) Shift livelihood away from forest dependenceIncrease focus on tourism
	Participate in programs (2)	Seek out information on climate or forest managementPurchase insurance
Technical and infrastructural (19)	Adopt or change technology (10)	Adopt new harvest or thinning technology Implement low-impact harvesting Assisted migration Develop new uses for diseased, dead, and damaged treesProduct simplificationTap new species for syrup production (e.g., non-sugar maples)
Institutional (15)	Create or administer programs (30)	Increase education/info-sharing on climate impacts/adaptation Monitor climate impacts Improve communication with public Cooperate with those outside agency/intra-sector network Watershed management Reduce community-induced forest depletion Incorporate climate change into planning Involve local communities Monitoring and sanctioning of rutting Old growth management Carbon storage through forest management in carbon trading market Financial incentives for sustainable forest management Increase *trans*-national cooperation Establish forest reservesSupport communities to reduce forest dependency

Fewer articles (19 of 35) reported on technical and infrastructural efforts, i.e., responses that require some level of engineering. Some of these responses were undertaken at an individual or household level, while organizations on larger scales conducted others. Terracing, altering slopes to control drainage and erosion, installing irrigation systems, and assisted migration were examples of technical and infrastructural responses (Reichel & Frömming, 2014; Sandholz et al., 2018; Sansilvestri et al., 2016). In the USA, owners of sugar maple forests utilized newer technologies such as vacuum tubing and reverse osmosis to improve the efficiency of sap collection and processing as the length of the season became shorter and less predictable (Snyder et al., 2019). In Ethiopia, smallholders developed irrigation systems and terraced slopes to help newly planted trees survive (Tessema et al., 2013). In Canada and France, government forestry and natural resources agencies used assisted migration to save tree species and create forests better adapted to future climate conditions (Sansilvestri et al., 2016). In Greece, forestry and fire protection agencies used satellite data, computational models of forest fire management, sophisticated fire-fighting vehicles, water-intake taps and tanks, and fire observatories to improve firefighting capabilities (Tsiolis & Efthimiou, 2016).

Less than half of the articles (15 of 35) reported on institutional efforts, i.e., responses that entail a change to policies, procedures, and decision-making processes, usually at the organizational or governance network level. Creating and administering programs to control illegal harvesting, facilitate income generation in poor households, and afforest coastal areas were examples of institutional responses (Dalimunthe, 2018; Pandey et al., 2016). Participatory risk mapping was used to identify areas for hazard mitigation in Switzerland (Reichel & Frömming, 2014). In the southeastern US, the forestry sector mobilized networks to facilitate information sharing, encourage collaborative monitoring, data collection, and research, and enhance public education and outreach (Dow et al., 2013).

4.4.2. Stages of responses

The articles reported on adaptation efforts at multiple stages from early planning to successful implementation (Table 2). One example of early planning efforts was mobilizing networks in the forestry sector to facilitate information sharing, encourage collaborative monitoring and research, and enhance public education and outreach in the Southeastern US (Dow et al., 2013). In another example, government forest managers concerned about the survival of tree species under future climatic conditions experimented with mixing tree species to spread the risk of loss, reducing the rotation periods to decrease the risk of abiotic damages, and planting exotic species where natural regeneration was not successful (Milad et al., 2013). A greater number of articles provided evidence of early implementation. For example, in Ethiopia, farmers adopted tree planting to respond to climate change, which they widely perceived they were experiencing (Tessema et al., 2013).

Some articles reported on cases of expanding implementation, i.e., where adaptation had been incorporated into broader decision-making processes. For example, in Rwanda, agricultural communities diversified revenue streams by planting woodlots for charcoal to protect livelihoods threatened by climate change (Clay & King, 2019). Finally, some articles reported on cases where adaptation was widespread and had become standard practice. In Indonesia, mangrove reforestation and rehabilitation to adapt to climate change had become institutionalized as part of a formal disaster risk reduction program (Dalimunthe, 2018). Also, in Indonesia, people converted forests to rubber plantations, reforested less productive croplands, protected forests on hillsides, and planted trees in gardens extensively at the landscape scale (Fedele et al., 2018).

4.4.3. Link to risk reduction

Given that risk reduction is often considered the goal of climate change adaptation, research on adaptation should arguably describe conceptual links between adaptation efforts and risk. Fifteen articles implied a link between the responses and risk reduction but did not explain the rationale for how the responses would reduce risk (Table 2). Some articles implied that increasing access to forest resources would improve actors' capacity for adaptation but did not explain how the two conditions were causally connected. Other articles suggested that adopting new practices such as tree planting, terracing, and irrigation would increase household income, thereby improving welfare. However, again, the link between high income and reduced risk was unclear.

Twenty articles explicitly stated at least one link to risk (Table 2). For example, in the US, changing the selection, number, and placement of sap taps and managing productive trees were described as strategies to address declining maple syrup production due to climate change (Snyder et al., 2019). In Belgium, landowners shifted the planting season and replaced vulnerable species with species more tolerant of drought, flooding, heat, and precipitation variability to make forests more resilient to climate change (van Gameren & Zaccai, 2015). In Mozambique, cities restored mangrove forests with the expectation that more tree cover would reduce coastal flooding (Spekker & Heskamp, 2017).

Four of the 35 articles provided evidence that actors' responses had reduced risk (Table 2); that is, the articles provided moderate to

Table 2
Response stages and links to risk.

Response Stage	Number of articles implying conceptual link to risk	Number of articles describing explicit conceptual link to risk	Number of articles reporting evidence of reduced risk
Early planning	4	2	NA
Early implementation	13	7	0
Expanding implementation	14	8	1
Widespread implementation	4	3	3
Total	35	20	4

substantial evidence (attribution-based or based on robust narratives and theories of change) that key indicators of risk declined because of the reported adaptation efforts. For example, in Peru, communities worked with a local non-profit organization to address drought and precipitation variability through reforestation projects that increased water availability (Doughty, 2016). In Indonesia, reforestation and afforestation efforts contributed positively to villagers' livelihoods by diversifying their income sources and improving water quality (Fedele et al., 2018). In Nepal, community forestry enhanced access to and sharing of food and other forest products, which reduced stress and improved the well-being of forest users (Pandey et al., 2016). In Kenya, pastoralists' efforts to plant fodder trees rehabilitated degraded lands and improved farm productivity, thereby reducing food insecurity in the face of drought and variable precipitation (Muricho et al., 2019).

5. Discussion

5.1. Summary

We assessed how people adapt to climate change in the context of forests through a systematic review of the international empirical research literature. We found that drought and variability in precipitation were the climate change-related stressors to which responses were most frequently documented, followed by extreme precipitation and flooding, and extreme heat. Individuals and households featured most prominently in the empirical research literature on adaptation in the context of forests, followed by national government, civil society, and local government. Europe and North America received more research attention than other regions, and no research from Oceania had been published during the timeframe of our review. Behavioral responses featured more prominently in the research literature than technical and infrastructural responses and institutional responses. Within these types of responses, actors used a variety of practices such as replanting, altering species composition, and adopting or changing technology. Adaptation-oriented responses in early implementation and expanding implementation stages were most frequently reported, although early planning and widespread implementation stages also received attention. Twenty articles made explicit connections between the responses they were reporting on and risk reduction, the ultimate goal of adaptation. However, only four articles provided evidence that responses had resulted in reduced risk.

5.2. Responses to wildfires, tree pests and diseases, seasonal variation, and phenological change need attention

Our finding that drought, precipitation variability, and extreme precipitation and inland flooding were the most frequently cited stressors that people responded to in forest contexts is consistent with the broader literature on human adaptation to climate change (Berrang-Ford et al., 2021b). However, it is notable that a relatively small proportion of articles reported on adaptation responses to wildfires, a rapidly growing problem in all forest types worldwide (Duane et al., 2021; Ellis et al., 2022). Given that human behavior can moderate wildfire risk via ignitions and vegetation conditions, it is surprising that there were few empirical research articles documenting efforts to adapt to climate change through wildfire risk reduction. It is also notable that few articles reported on adaptation responses to seasonal variation and phenological change and pests and diseases since it is well-recognized that climate change is exacerbating these stressors. Active forest management can moderate the spread and severity of these agents (Simler-Williamson et al., 2019). Relying solely on natural mechanisms or passive approaches to adapt to climate change-exacerbated pests and diseases is recognized as risky (Jandl et al., 2019). It is important to note that while the forest stressors to which actors respond are at least partially attributable to climate change, many other biotic and abiotic drivers may be at play, such as land use change, population growth, introduced pests and pathogens, and pollution (Teshome et al., 2020). In other words, actors are trying to adapt to climate change in the broader context of global change.

5.3. Oceania is under-researched

Our finding that most of the published literature on adaptation in forest contexts focused on Europe and North America is not surprising, given that another recent large-scale review reported a disproportionately large focus on the United States (Nalau & Verrall, 2021). The relative abundance of forestry-oriented adaptation research in Europe and North America may be due to the strong tradition of silviculture in these regions (Achim et al., 2021). However, our finding of no articles on Oceania, which contains Australia and New Zealand, where European forestry traditions run strong, is notable. Oceania is home to extensive forest ecosystems of substantial economic and ecological value, and climate risks to these forests, such as wildfire, have received significant attention in the research literature (Abram et al., 2021; Boer et al., 2020). Berrang-Ford et al. (2021b) also found much less empirical research in Oceania than in other regions. Nalau and Verrall (2021), on the other hand, found that Australia has been the geographic focus of a large proportion of climate change adaptation science. A possible explanation for this discrepancy could be that the focus of Nalau and Verrall (2021) was broader and included vulnerability assessment and adaptation planning literature). Nevertheless, our finding that Oceania has received little attention in human adaptation research in the context of forests reveals a significant research gap, given the importance of forests and the significant threats to forests in parts of the region.

5.4. More research is needed beyond the household and individual level

While our finding that most articles on human adaptation in forest contexts focused on individuals and households is consistent with other systematic reviews (Berrang-Ford et al., 2011; Petzold et al., 2023; Vincent & Cundill, 2022), it still reveals a research gap.

Although many individuals and households rely on forests for their lifestyles and livelihoods and, therefore, would benefit from climate change adaptation, most ecosystem services from forests, even in private property rights regimes, are public goods. Moreover, in many countries, forests are common pool resources. While public goods and common pool resources can be produced and managed at the property level, their benefits and costs are experienced at higher levels as well (e.g., watershed, region, globe) (Mayer, 2019; Raudsepp-Hearne & Peterson, 2016). Therefore, governments and governance networks should arguably play a prominent role in climate change adaptation through the management of ecosystem services such as biodiversity, water, habitat, air quality, and carbon emissions (e.g., from wildfire and other agents of mortality) (Raudsepp-Hearne & Peterson, 2016). Another reason that more research is needed on actors beyond individuals and households is that higher-level actors control more forestland than individuals. As of 2010, the vast majority of forestland globally was in public ownership (Whiteman et al., 2015). This tenure pattern is especially strong in tropical and boreal forest countries (Whiteman et al., 2015). To better understand adaptation efforts that could be affecting large areas of forest land and populations of people reliant on forests and forest ecosystem services, it is vital to increase attention to governmental actors. More research is also needed on communal landholders. Communal land ownership is a growing tenure pattern. Globally, the extent of land owned by community landholders (not individuals and households, private companies, or governments) is estimated at more than six billion hectares, and in many countries in Africa and areas of Australia, more than 80 % of forestland is held by communally (Alden Wily, 2018). Again, to better understand how people adapt to climate change in forest contexts, it is crucial to investigate the phenomenon across all ownership types.

5.5. *Institutional adaptation efforts may be overlooked*

Our finding that behavioral responses were the most frequently documented type of response follows from our finding that most research on climate change adaptation in the context of forests focuses on individuals and households whose adaptations tend to be behavioral. This finding is consistent with broader climate change adaptation reviews such as Berrang-Ford et al. (2021b) and Petzold et al. (2023). The fact that technical and infrastructural responses were the second most frequently documented type of response is also consistent with Berrang-Ford et al. (2021b). It is also unsurprising given the substantial emphasis on traditional grey infrastructure in typical climate risk reduction strategies (Powell et al., 2019).

However, the low level of reporting on institutional responses is disconcerting because institutional strategies (i.e., those entailing change to policies, procedures, and decision-making processes, usually at the organizational or governance network level) are needed for the governance of common pool resources with many users such as forests, and public goods with many consumers such as air and water purification, habitat, and other ecosystem services that forests provide (Ostrom, 2003). A better understanding of institutional adaptation would inform efforts to reduce climatic risk to people dependent on common pool and public forest resources. Another reason why research on institutional responses is essential is that the most extensive and rapidly growing forestland ownership types are types that must be managed, in part, by institutions: government-owned forestland is the largest land tenure pattern (Whiteman et al., 2015), and communally-owned land is expanding (Alden Wily, 2018). The livelihoods of many people are dependent on managing these lands as part of human climate change adaptation strategies, and management of these types of lands requires institutional efforts. Furthermore, because many of the most pressing threats to forests (e.g., wildfire and tree pests and diseases) do not adhere to property boundaries, institutions must facilitate adaptation across multiple tenure groups. Therefore, to better understand adaptation in the context of forests, more research is greatly needed on institutional efforts entailing change to policies, procedures, and decision-making processes, usually at the organizational or governance network level.

5.6. *Little research had documented widespread implementation of adaptation efforts*

We sought articles that reported on behaviors that people had undertaken in response to climate change, not intentions or plans; therefore, the paucity of early planning stage articles is likely an artifact of our sampling approach. On the other hand, the fact that most forestry adaptation articles reported early and expanding implementation and very few reported widespread implementation is likely a reflection of the developing state of adaptation worldwide (Berrang-Ford et al., 2011; Berrang-Ford et al., 2015; Ford et al., 2011; Lesnikowski et al., 2015; Scheelbeek et al., 2021). However, to better understand human adaptation in the context of forests, more research is needed on advanced stages of widespread adaptation. What factors enable such a process, and with what outcomes for risk? —answers to these questions could inform the design of adaptation efforts in more nascent stages.

5.7. *Links to risk are underdeveloped*

Our finding that only four articles provided empirical evidence of reduced risk is consistent with the broader human adaptation literature beyond the context of forests (Berrang-Ford et al., 2011; Berrang-Ford et al., 2021b; Scheelbeek et al., 2021). It is challenging to study adaptation in the strict sense since risk reduction and improved adaptive capacity are born out over time periods that are generally longer than the time frame of a typical research study. Moreover, many scholars focus on the process of adaptation rather than outcomes (Singh et al., 2022). Nevertheless, the dearth of articles that connect adaptation efforts, even theoretically, to outcomes for risk, well-being, and vulnerability reflects a lack of rigor in adaptation research, and more specifically, a lack of consistency in definitions of adaptation (Dupuis & Biesbroek, 2013; Ford & Berrang-Ford, 2016; Orlove, 2022). As many scholars have argued, adaptation research would benefit from greater rigor and more consistent use of a more coherent definition of adaptation (Dupuis & Biesbroek, 2013; Ford & Berrang-Ford, 2016; Orlove, 2022).

5.8. Research opportunities

Forests provide a unique opportunity for rigorous study of adaptation because the lifespan of trees is often many times that of humans, presenting adaptation actors with the opportunity to undertake long-term behavioral adjustments in addition to short-term measures (Fischer, 2019b). Moreover, because forests function and provide ecosystem goods and services on many scales (individual trees, stands of trees, landscapes, and ecosystems), actors on many levels can be involved in decision-making and on-the-ground activities (individuals and households, small and medium-sized enterprises and corporations, local, national, and international governments and civil society groups). Furthermore, forests are threatened by a variety of climatic stressors. Therefore, forests offer a rich array of contexts for the study of adaptation.

The uneven attention researchers have paid to the diversity of stressors, geographic regions, actor types, and response types could reflect that adaptation efforts are unevenly distributed. It also could indicate a pattern in research preferences. We propose that researchers could take greater advantage of the potential that forests offer the study of human adaptation to climate change. Specifically, researchers should consider investigating adaptation to other pressing stressors such as wildfires, tree pests and diseases, seasonal variation, and phenological change. We suggest that researchers expand their focus to overlooked regions where forests are notably threatened by these stressors, such as Oceania, home to Australia, which is suffering from increasingly frequent and damaging fires. More research on adaptation efforts by actors beyond the household and individual level is needed, as is research on institutional adaptation efforts, which typically entail change to policies, procedures, and decision-making processes, usually at the organizational or governance network level. As with adaptation research in general, links between adaptation efforts and risk are underdeveloped in the forestry adaptation literature. Therefore, we propose that there is a critical need for researchers to consider, if not document, risk outcomes.

5.9. Limitations

One limitation of this review is the time period of data collection, 2013–19, the time frame for the IPCC Sixth Assessment Report (AR6), and, consequently, the GAMI inventory. For a review to be considered a systematic review, the sampling, data collection, and analysis methods must be consistent across observations. This timeframe excluded several papers that reported on management responses by family forest owners in Sweden to climate change-associated stressors (e.g. Blennow, 2012; Blennow & Persson, 2009; Blennow et al., 2012). The timeframe also excluded five articles published more recently. Three of these recent articles reported on households' efforts to manage forests that were stressed by invasive plant species, insect and pest species outbreaks, extreme weather events, landslides, and floods (Denny & Fischer, 2023; Dhungana et al., 2020; Gurung et al., 2021). The fourth recent article reviewed the research literature on behavioral, institutional, and technical and infrastructural adaptation efforts in Mexico's coastal zones, including efforts to manage and restore mangroves (Escudero & Mendoza, 2021). The fifth article reported on adaptation efforts by forest managers in France (Fouqueray et al., 2020). Another limitation of our study is using machine learning for sampling (Berrang-Ford et al., 2021a). While machine learning is very efficient compared to manual literature searches, we found that some relevant empirical research articles were missing from the GAMI database (e.g., Eriksson, 2014). Finally, although the GAMI database includes articles written in other languages, the sampling approach focused on articles indexed in English. This may have led to some potentially relevant articles not being included in the GAMI database. We provide a list of relevant articles published outside the window for or missed by the GAMI inventory in Appendix II.

6. Conclusion

We assessed what is known about adaptation to climate change in the context of forests through a systematic review of the empirical literature. Drought and variability in precipitation are the climatic stressors that were most frequently documented as stressors to which people responded, followed by extreme precipitation and flooding, and extreme heat. Individuals and households featured most prominently in the empirical research literature on adaptation in the context of forests, followed by national government, civil society, and local government. Europe and North America received more research attention than other regions. Behavioral responses were more commonly reported than technical and infrastructural responses or institutional responses. There was limited evidence for adaptation efforts in early planning and advanced implementation. Early implementation and expanding implementation were more common. Finally, clear connections to risk reduction, the commonly accepted goal of adaptation, was lacking. The uneven attention researchers paid to the diversity of stressors, geographic regions, actor types, and response types could reflect that adaptation efforts are unevenly distributed. It also could indicate a pattern in research preferences. This systematic review suggests researchers could take greater advantage of the potential that forests offer the study of human adaptation to climate change. Specifically, we identify opportunities for future research on adaptation to other climatic stressors, such as wildfires and tree pests and pathogens, adaptation in other geographic areas, especially Oceania, and adaptation by actors beyond the individual and household level and through institutional adaptation efforts. We also identify opportunities for greater research attention to advanced stages of adaptation and more disciplined conceptualizations of links between adaptation and outcomes for risk.

Declaration of Competing Interest

The authors declare no financial interests/personal relationships which may be considered as potential competing interests.

Data availability

Data will be made available on request.

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Appendix 1. List of articles included in systematic review

	Author(s)	Year	Title	Journal	Volume and Issue
1	Alemayehu, A., & Bewket, W.	2018	Trees and rural households' adaptation to local environmental change in the central highlands of Ethiopia	Journal of Land Use Science	13(1–2)
2	Anhalt-Depies, C. M., Knoot, T. G., Rissman, A. R., Sharp, A. K., & Martin, K. J.	2016	Understanding climate adaptation on public lands in the Upper Midwest: Implications for monitoring and tracking progress	Environmental Management	57(5)
3	Barrucand, M. G., Giraldo Vieira, C., & Canziani, P. O.	2017	Climate change and its impacts: Perception and adaptation in rural areas of Manizales, Colombia	Climate and Development	9(5)
4	Boag, A. E., Hartter, J., Hamilton, L. C., Christoffersen, N. D., Stevens, F. R., Palace, M. W., & Ducey, M. J.	2018	Climate change beliefs and forest management in eastern Oregon: Implications for individual adaptive capacity	Ecology and Society	23(4)
5	Campos, M., McCall, M. K., & González-Puente, M.	2014	Land-users' perceptions and adaptations to climate change in Mexico and Spain: Commonalities across cultural and geographical contexts	Regional Environmental Change	14(2)
6	Clay, N., & King, B.	2019	Smallholders' uneven capacities to adapt to climate change amid Africa's 'green revolution': Case study of Rwanda's crop intensification program	World Development	116
7	Dalimunthe, S. A.	2018	Who manages space? Eco-DRR and the local community	Sustainability (Switzerland)	10(6)
8	de Sousa, K., Casanoves, F., Sellare, J., Ospina, A., Suchini, J. G., Aguilar, A., & Mercado, L.	2018	How climate awareness influences farmers' adaptation decisions in Central America?	Journal of Rural Studies	64
9	Doughty, C. A.	2016	Building climate change resilience through local cooperation: A Peruvian Andes case study	Regional Environmental Change	16(8)
10	Dow, K., Haywood, B. K., Kettle, N. P., & Lackstrom, K.	2013	The role of ad hoc networks in supporting climate change adaptation: A case study from the Southeastern United States	Regional Environmental Change	13(6)
11	Fedele, G., Locatelli, B., Djoudi, H., & Colloff, M. J.	2018	Reducing risks by transforming landscapes: Cross-scale effects of land-use changes on ecosystem services	PLoS ONE	13(4)
12	Fischer, A. P.	2019	Adapting and coping with climate change in temperate forests	Global Environmental Change	54
13	Gross-Camp, N. D., Few, R., & Martin, A.	2015	Perceptions of and adaptation to environmental change in forest-adjacent communities in three African nations	International Forestry Review	17(2)
14	Hassan, K., Higham, J., Wooliscroft, B., & Hopkins, D.	2019	Climate change and world heritage: A cross-border analysis of the Sundarbans (Bangladesh–India)	Journal of Policy Research in Tourism, Leisure and Events	11(2)
15	Hellin, J., Ratner, B. D., Meinzen-Dick, R., & Lopez-Ridaura, S.	2018	Increasing social-ecological resilience within small-scale agriculture in conflict-affected Guatemala	Ecology and Society	23(3)
16	Heltorp, K. M. A., Kangas, A., & Hoen, H. F.	2018	Do forest decision-makers in southeastern Norway adapt forest management to climate change?	Scandinavian Journal of Forest Research	33(3)
17	Milad, M., Schaich, H., & Konold, W.	2013	How is adaptation to climate change reflected in current practice of forest management and conservation? A case study from Germany	Biodiversity and Conservation	22(5)
18	Muricho, D. N., Otieno, D. J., Oluoch-Kosura, W., & Jirström, M.	2019	Building pastoralists' resilience to shocks for sustainable disaster risk mitigation: Lessons from West Pokot County, Kenya	International Journal of Disaster Risk Reduction	34
19	Murtinho, F.	2016	What facilitates adaptation? An analysis of community-based adaptation to environmental change in the Andes	International Journal of the Commons	10(1)
20	Oakes, L. E., Ardoin, N. M., & Lambin, E. F.	2016	"I know, therefore I adapt?" Complexities of individual adaptation to climate-induced forest dieback in Alaska	Ecology and Society	21(2)
21	Ofoegbu, C., Chirwa, P. W., Francis, J., & Babalola, F. D.	2016	Assessing forest-based rural communities' adaptive capacity and coping strategies for climate variability and change: The case of Vhembe District in South Africa	Environmental Development	18

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	Author(s)	Year	Title	Journal	Volume and Issue
22	Pandey, S. S., Cockfield, G., & Maraseni, T. N.	2016	Assessing the roles of community forestry in climate change mitigation and adaptation: A case study from Nepal	Forest Ecology and Management	360
23	Reichel, C., & Frömming, U. U.	2014	Participatory mapping of local disaster risk reduction knowledge: An example from Switzerland	International Journal of Disaster Risk Science	5(1)
24	Rittenhouse, C. D., & Rissman, A. R.	2015	Changes in winter conditions impact forest management in north-temperate forests	Journal of Environmental Management	149
25	Sandholz, S., Lange, W., & Nehren, U.	2018	Governing green change: Ecosystem-based measures for reducing landslide risk in Rio de Janeiro	International Journal of Disaster Risk Reduction	32
26	Sansilvestri, R., Frascaria-Lacoste, N., & Fernández-Manjarrés, J.	2016	One option, two countries, several strategies: Subjacent mechanisms of assisted migration implementation in Canada and France	Restoration Ecology	24(4)
27	Sapkota, P., Keenan, R. J., & Ojha, H. R.	2019	Co-evolving dynamics in the social-ecological system of community forestry—prospects for ecosystem-based adaptation in the middle hills of Nepal	Regional Environmental Change	19(1)
28	Scheller, R. M., & Parajuli, R.	2018	Forest management for climate change in New England and the Klamath ecoregions: Motivations, practices, and barriers	Forests	9(10)
29	Snyder, S. A., Kilgore, M. A., Emery, M. R., & Schmitz, M.	2019	Maple syrup producers of the Lake States, USA: Attitudes towards and adaptation to social, ecological, and climate conditions	Environmental Management	63(2)
30	Sousa-Silva, R., Ponette, Q., Verheyen, K., Van Herzele, A., & Muys, B.	2016	Adaptation of forest management to climate change as perceived by forest owners and managers in Belgium	Forest Ecosystems	3(1)
31	Spekker, H., & Heskamp, J.	2017	Hochwasserschutz für Hafenstadt Beira	Bautechnik	94(12)
32	Tessema, Y. A., Aweke, C. S., & Endris, G. S.	2013	Understanding the process of adaptation to climate change by small-holder farmers: The case of East Hararghe Zone, Ethiopia	Agricultural and Food Economics	1(1)
33	Tsiolis, K. S., & Efthimiou, G. S.	2016	Forest-fire protection infrastructures in natural protected areas with management bodies in Greece	Forestry Ideas	22(2)
34	Uggla, Y., & Lidskog, R.	2016	Climate risks and forest practices: Forest owners' acceptance of advice concerning climate change	Scandinavian Journal of Forest Research	31(6)
35	van Gameren, V., & Zaccai, E.	2015	Private forest owners facing climate change in Wallonia: Adaptive capacity and practices	Environmental Science & Policy	52

Appendix II. Relevant articles published outside the window for or missed by the Global Adaptation Mapping Initiative inventory

	Author(s)	Year	Title	Journal	Volume and Issue
1	Blennow, K.	2012	Adaptation of forest management to climate change among private individual forest owners in Sweden	Forest Policy and Economics	24
2	Blennow, K., & Persson, J.	2009	Climate change: Motivation for taking measure to adapt	Global Environmental Change	19(1)
3	Blennow, K., Persson, J., Tomé, M., & Hanewinkel, M.	2012	Climate change: Believing and seeing implies adapting	PLoS ONE	7(11)
4	Denny, R. C. H., & Fischer, A. P.	2023	The effects of climate change event characteristics on experiences and response behaviors: A study of small woodland owners in the Upper Midwest, USA	Frontiers in Climate	5
5	Dhungana, N., Silwal, N., Upadhaya, S., Khadka, C., Regmi, S. K., Joshi, D., & Adhikari, S.	2020	Rural coping and adaptation strategies for climate change by Himalayan communities in Nepal	Journal of Mountain Science	17(6)
6	Eriksson, L.	2014	Risk perception and responses among private forest owners in Sweden	Small-scale Forest Economics, Management and Policy	13(4)
7	Escudero, M., & Mendoza, E.	2021	Community perception and adaptation to climate change in coastal areas of Mexico	Water	13(18)
8	Fouqueray, T., Charpentier, A., Trommetter, M., & Frascaria-Lacoste, N.	2020	The calm before the storm: How climate change drives forestry evolutions	Forest Ecology and Management	460
9	Gurung, L. J., Miller, K. K., Venn, S., & Bryan, B. A.	2021	Climate change adaptation for managing non-timber forest products in the Nepalese Himalaya	Science of The Total Environment	796

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