Current Forestry Reports (2023) 9:473–489
https://doi.org/10.1007/s40725-023-00205-1

CLIMATE CHANGE AND CARBON SEQUESTRATION (M WATT, SECTION EDITOR)

Forestry in the Face of Global Change: Results of a Global Survey of Professionals

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Accepted: 10 October 2023 / Published online: 13 November 2023

Abstract

Purpose of Review Forests support most global terrestrial biodiversity and contribute to the livelihood of billions of people, but these and other benefits are in jeopardy due to global change. This leads to questions, such as how to address the challenges of global change in forest management, given the lack of knowledge and deep uncertainty about future developments. In addition, many of the impediments to implement adaptation strategies are unknown.

Recent Findings Here, we present an overview of results from a global survey of 754 forestry professionals (370 researchers and educators, 227 practicing foresters, 37 policymakers, 64 administrators, and 56 with other or unspecified roles) from 61 countries across 6 continents who were interested in global change issues. These professionals were asked about their opinion regarding three different adaptation strategies: *resist*, *adapt*, and *transform*. Most respondents agreed that the majority of global change factors will negatively influence the ability of forests to provide desired ecosystem services. Similarly, they agreed about major challenges when implementing adaptation strategies and specifically whether our current knowledge base is sufficient. These concerns were not limited to ecological aspects, but respondents also highlighted the need for a better appreciation of social/political and economic barriers, especially regarding transformation strategies. In addition, the response patterns, including differences due to economic status, highlight the importance of developing and evaluating adaptation strategies in a local social–ecological context.

Summary Our study demonstrates a widespread perception on the part of forestry professionals around the world, especially among researchers and practitioners, that many global change factors will affect sustainable forest management negatively, resulting in the need for active silvicultural adaption. The results also suggest potential barriers to different adaptation strategies, particularly a relative lack of information and social acceptance for *transform* strategies. Further, this study highlights the importance of social and political factors and the need to understand the general public's values regarding adaptation strategies as well as how the influence of public opinion is perceived by forest managers.

Keywords Forest social–ecological system · Adaptive capacity · Transformation strategies · Adaptation barriers · Resilience

Introduction

More than two-thirds of the global terrestrial biodiversity can be found in forests [1]. At the same time, forests contribute more than US$ 600 billion to the global gross domestic product (GDP) from wood-based products alone and are especially important for the livelihood of people in rural regions [2]. These and other benefits such as climate mitigation and other ecosystem services [3••] are at risk, as rapid global change poses unprecedented challenges for managing the world's forests [4–6]. These challenges include the rapid spread of endemic and introduced pests and diseases [7] and increased climate change-related risk of storms, wildfire, and drought [e.g., 8, 9], as well as increasingly globalized trade in forest products and shift of societal demands on land and forests [10]. Such broad and diverse changes in the

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social–ecological environment call for novel adaptive silvicultural strategies to maintain forest ecosystem structure, functions, and sustainable supply of ecosystem services [4, 11, 12]. As the number of different types of disturbance, their interactions, and the dynamics of their relative importance evolve over time and space, numerous strategies and practices might be applied to counter the negative effects of such changes.

Millar et al. [13] categorized adaptive practices into one of the first coherent frameworks for managing forests in anticipation of, and response to, global change. They based their three categories of adaptation strategies on the desired outcomes: *resistance*, *resilience*, and *response*. *Resistance* strategies aim to protect resources and maintain ecosystems in their current or historical condition, for example, treatments that minimize global change impacts or reduce risks to current ecosystem conditions. *Resilience* strategies are intended to increase the ability of ecosystems to cope with disturbance and return to the prior conditions following a disruption. *Response* strategies facilitate adaptive changes in ecosystems, such as management that facilitates the transition of plant community composition toward species more adapted or desirable for future conditions. This includes the transformation of forests to novel forest ecosystems that have no analogue in evolutionary history. Nagel et al. [14] loosely adapted Millar et al.'s [13] three categories to frame different forest treatment responses to climate change but added an additional option of *do nothing*. In terms of adaptation, this may be called a passive adaptation strategy that would typically be applied in strict forest reserves or when conditions hamper the manager's ability to implement any of the three former strategies. The recently proposed RAD (*resist*, *accept*, *direct*) framework [15, 16•, 17] uses the management activity itself as a distinction criterion and draws from other typologies, e.g., *observe change*, *resist change*, and *facilitate change* [18]. Consequently, in contrast to Millar et al.'s [13] framework, "resilience" is not an adaptation category, rather an ecosystem attribute [19]. Divergence on whether resilience is a system property or an adaptation may be guided by the scope of consideration such that it is primarily a property of ecological systems [20] but can also represent an adaptation strategy in linked social–ecological systems [21].

These typologies of strategies explicitly [13, 14, 22, 23] or implicitly [16•] focus on climate change in relation to ecosystem properties and, consequently, may miss strategies that should be considered for adapting to other aspects of global change, such as exotic pests and diseases not necessarily linked to climate change and shifting societal demands on forest ecosystems [5]. Further, the typologies are focused narrowly on the ecological aspects of ecosystem development and forest management. Considering managed forests as complex social–ecological systems, where social and ecological systems are intertwined, illuminates important facets of adaptation strategies. Specifically, changes in worldviews, cultural values, institutional context, markets, and the degree of scientific understanding of social–ecological systems can be factors driving managers' decisions [24•]. Integrating such factors into a mental model suggests that any decisions to pursue an adaptation strategy is context specific, i.e., how specifically the social systems interact with ecological systems [25, 26]. An example of such impact is social barriers to transforming forest ecosystems through assisted migration [27]. But these issues also play out at larger scales. For example, Andersson et al. [28] compared national level forest policy related to climate adaptation in Scotland and Sweden and concluded that forest adaptation strategies are embedded in the specific historical, social, political, and land tenure contexts. However, to date, no studies have explored the perceptions of global change risks and adaptive strategies in forest management, or the multitude of barriers to their implementation, at different scales.

Given the need to develop new silviculture and forest management approaches in a rapidly changing global setting, we conducted a global survey of forestry professionals to provide initial information about perceptions of the relative importance of such social factors on four categories of adaptive strategies for forest management—namely, *resist*, *adapt*, *transform*, and *do nothing* (Table 1)—as drawn from the previous literature.

Resist is consistent with Millar et al. [13] and RAD [23] while *adapt* represents management to shift a system to be better suited for future conditions but remain recognizable within the social, geographical, and ecological context and *transform* means shifting the system to something novel. The *do nothing* strategy is synonymous with *accept* in RAD [23] and can also provide important baseline information for monitoring the success of other adaptation strategies [14]. Table 1 lists the four adaptation strategies proposed in this study and associated management practices we considered in our survey under each category. It is important to note that it is possible for management practices to fit several adaptation strategies, depending on the intensity of the practice and how it relates to natural disturbance and development patterns [29] and the examples are not exhaustive but represent only the management options included in our study. For example, we did not ask questions in our survey about prescribed fires which could be listed under *adapt* or *transform*, depending on the role fires played in the past and the degree of degradation due to past fire exclusion. For our analysis, we have assigned management practices to adaptation strategies we believe are usually most appropriate.

The overall goal of this study is to get a better understanding of the national, regional [biomes], and global perceptions of forestry experts of the threats and challenges faced by global change in forest management. We placed these

Table 1 Typology of adaptation strategies for forest management in the face of global change with examples of the forest management approaches considered in this study

Type of adaptation strategy	Associated management practices
Resist	Density management, shorten rotations, salvage/sanitize harvests
Adapt	Promote native tree species mixtures, increase structural complexity, establish advance regeneration under existing canopy, leave more legacies and buffers
Transform	Establish new species already on site but not previously used in production, assisted migration, introducing exotic species, developing novel ecosystems
Do nothing	Relying on the assumption that natural recovery and adaptation mechanisms are sufficient to deal with the current and future challenges

opinions in the above framework to synthesize and better understand and interpret responses. We present the results of a first of its kind global survey of people with various roles in the forestry sector to capture professional insights about challenges and opportunities for development and implementation of forest management in a world driven by global change issues. Specifically, we aimed at identifying what professionals view as (1) the greatest risks and potential benefits of global change for forestry, (2) the most important adaptive silviculture strategies, and (3) social, economic, or ecological barriers that prevent adoption of important strategies. Within each of these topics, we were also interested in knowledge gaps and barriers that are potentially important points of emphasis for researchers and policymakers in the immediate future. Here, we provide an overview of the information gained pertaining to the three issues listed above and describe the underlying global database.

Methods

An online survey instrument was developed in Qualtrics (https://www.qualtrics.com) and distributed to forestry professionals globally between December 2020 and March 2021. The survey was written in English and consisted of three sections: (1) demographic questions, (2) questions about desired forest ecosystem services and their importance, and (3) perceived importance, risks, and barriers to implementation of different management activities for adapting to global change. Regarding demographic questions, respondents were asked about their role in the forestry sector, how long they have worked in the sector, basic information about the forests with which they are primarily familiar, and their location. In the second section, respondents rated the relative importance of providing different ecosystem services from their forests on a Likert scale [30]. They further rated the relevance of different value statements (e.g., rating from "not relevant" to "very relevant," the statement "the forest supports the economy and/or development of the region") regarding why landowners and society manage forests. The third section had respondents rate how different aspects of global change are expected to impact the management of their forests in the next twenty years on a five-point Likert scale from "extremely negative" to "extremely positive." Also, in the third section, respondents were asked to rate the importance of different forest management practices for adapting to global change on a five-point Likert scale from "not important at all" to "extremely important" or as "already implemented." Finally, respondents rated the quality of current knowledge for implementing the same forest management practices as well as the likelihood that those practices would be economically feasible and receive social and political support, also using five-point Likert scales. The full list of survey questions can be found in the supplementary materials.

Prior to distributing the questionnaire, the authors, who were selected to represent a wide diversity of countries and experiences, reviewed and edited the survey to ensure questions were relevant and understandable in all regions. The survey was distributed via email by the authors within their professional organizations and networks, including announcements in newsletters, professional email lists, blogs, and by personal invitation. After receiving the initial responses, we assessed the responses in terms of their origin and multiple reminders were sent out to the email lists and networks, with a special effort to encourage participants in countries or regions not yet well represented. The sampling was not random and did not have a similar sampling intensity in the different regions of the world. The non-random sampling issue was not regarded as a limitation per se, as we were not interested in describing the opinions of the whole population of professionals. Instead, our sample was biased toward people with sufficient professional interest in the topic that motivated them to volunteer and respond to the survey. We assume that this interest was often in response to being in a position to influence, to make, or having to implement decisions in response to global change [31]. Thus, our results were biased toward people more likely to have an impact on forest management responses to global change and their actions are likely to be influenced by the perceptions we surveyed [31]. Furthermore, the limitations of sampling intensity were partially offset by the relatively large number of respondents (754) and global spread of representation (Fig. 1).

Global change factors were summarized into five broad categories: atmospheric (nutrient deposition, atmospheric CO_2 concentrations, and acid rain), biotic (insects, diseases, and invasive species), climatic (temperature and precipitation), disturbance (fire, flood, and wind), and social (global trade and land use change) (Table 2). Responses to the five-point Likert scale about the influence of change factors on forest management over the next 20 years compared to today were compressed into three categories: negative (extremely negative and somewhat negative), no effect, and positive (extremely positive and somewhat positive).

Questions about the importance of management practices for adapting to global change were categorized into three types of strategies, *resist*, *adapt*, and *transform*, as defined in Table 1. Five-point Likert scale responses for each question were compressed to three groups: already implemented, average importance or less (included "not important at all," "of little importance," and "of average importance"), and high importance (included "very important" and "extremely important").

Opportunities or barriers for implementing global change adaptation strategies were summarized in three categories: (1) the current state of knowledge to enact different management practices for adaptation, (2) the economic feasibility of different management practices, and (3) the social and political support for management practices.

In-depth exploration of complex contextual drivers is beyond the scope of this paper and best explored at smaller scales, e.g., direct comparisons between a limited number of well-represented countries. We did however explore potential differences between different wealth categories at the country level by using the World Bank's country income groupings which consist of low-, lower-middle-, upper-middle-, and high-income countries. For analysis, we compressed these into two groups, high-income countries (those with gross national income (GNI) per capita greater than $13,205 USD in 2021) and low- and middle-income categories following Ginsburg and Keene [32]. It was prudent to compress to only two groups, hereafter "high-income countries" and "middle- and low-income countries," because only 4.5% of the respondents were from low-income countries, while 40% of the respondents were from low and middle-income countries. While an imperfect metric, GNI does correlate with other indicators of social context such as quality of life, life expectancy, and enrollment rates in school [33].

Table 2 Percentage (%) of respondents indicating negative, positive, or no effects for global change factors, ordered from the highest to the lowest values for the negative category

Global change factor	Category	Negative (Percent)	No effect	Positive
Insects	Biotic	85.3	9.5	5.2
Diseases	Biotic	81.9	13.5	4.6
Windstorm	Disturbance	74.9	20.3	4.8
Precipitation	Climate	72.1	9.8	18.1
Fires	Disturbance	69.3	23.8	6.8
Temperature	Climate	67.6	7.6	24.9
Invasive plants	Biotic	64.5	29.1	6.3
Land use change	Social	54.7	28.5	16.8
Flooding	Disturbance	48.2	45.9	5.9
Acid rain	Atmospheric	42.8	53.7	3.5
Global trade	Social	40.0	25.5	34.5
Nutrient deposition	Atmospheric	37.9	33.6	28.4
CO_2	Atmospheric	33.1	22.0	44.8

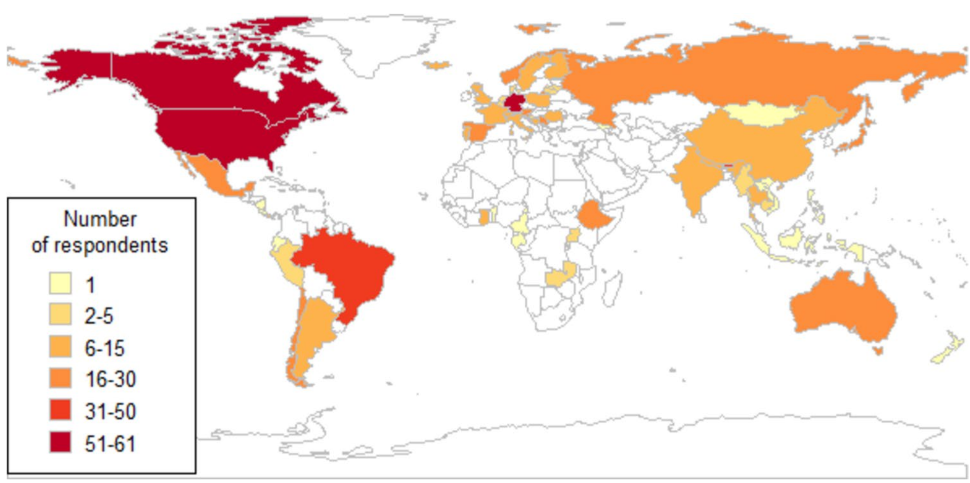

Fig. 1 Number of respondents by country. In total, there were 754 responses from 61 different countries representing all forested continents and a wide range of forest ecosystem types

Results

Makeup of Respondents and the Forests With Which They Are Familiar

A total of 754 completed surveys were used in this study. Respondents were from 61 different countries and all six forested continents and worked in boreal (15%), temperate (60%), subtropical (8%), and tropical (17%) forests of diverse ownerships, size, and species composition. The forest types that respondents worked in were diverse, as well as the management regimes, ranging from intensively cultivated plantations of exotic tree species to extensively managed, semi-natural, and near-primary forests. The respondents themselves were also diverse. Forty-nine percent of the respondents were researchers and/or educators, 30% were practicing foresters, 8% were administrators, 5% were policymakers, 7% had other forestry occupations, and less than 1% declined to list their occupation (see Table 1 in Supplement). When displaying results by professional roles, administrators and policymakers were lumped into one category given their relatively low response numbers and the similar roles as decision-makers. Respondents who did not specify a profession or listed "other forestry occupation" were not included. Respondents represented all career stages: 18% of the respondents had less than 10 years of experience, 30% had 10 to 20 years of experience, 28% had 20 to 30 years of experience, 18% had 30 to 40 years of experience, and 6% had more than 40 years of experience in forestry. Personal information regarding respondents' gender identity, ethnicity, etc. was not gathered for this study.

Global Change Factors

The averages responses for each factor in the five categories of global change factors are presented in Table 2. Figures 2 and 3 indicate how the perception regarding the five categories varied by professional role and job experience, respectively.

Most respondents identified biotic, climatic, and disturbance factors of global change as having a negative impact, with the biotic factors receiving the largest percentage of negative and the smallest percentage of positive responses on average (77% and 5%, respectively). Although trends were fairly similar among groups of respondents, some variation was noticeable. Practitioners were more likely to be optimistic about biotic, climatic, disturbance, and social influences, and larger proportions of those with less job experience were slightly more optimistic regarding the influence of all global change factors.

Just under half the responses indicated that social factors would have negative impacts, but there were also large percentages (more than 25% of all responses and larger percentages of practitioners and researchers and those with less job experience) indicating that social factors and atmospheric factors may have positive impacts. Damage by insects was the single risk factor with the largest percentage of respondents (85%) stating it would have negative effects, while the most frequently identified risk factor having a positive impact was increased atmospheric CO_2 concentrations (45%).

Respondents were also able to list and rate other risk factors not included in the survey. Among global change risks likely to contribute negative impacts, an increase in frequency of extreme weather events like drought and ice storms as well as existing threats like browsing pressures from ungulates was mentioned frequently. Also, regulatory and management restrictions that can limit adaptive actions were listed multiple times as having potential negative impacts on forest management in the next 20 years.

Adaptation Strategies

The percentage of respondents indicating whether the management practices were of average importance or less, of high importance, or already implemented is summarized for the three adaptation strategies in Figs. 3A and 4A sorted by professional role and job experience, respectively. Most respondents (52%) indicated that *adapt* strategies were very important or extremely important and a greater percentage of respondents indicated they were already being implemented in contrast to other strategies (11% compared to 8% and 3% for *resist* and *transform* strategies, respectively). The majority of respondents also indicated that *resist* and *transform* strategies were of average importance or less (57% and 67%, respectively). The respondents were not asked questions about the relative importance of a *do nothing* strategy; however, only three respondents indicated that all prompted management practices were of low or very low importance for adapting to global change, suggesting that the vast majority of respondents think active strategies are important to follow. Respondents were also able to suggest other strategies they deemed important for adapting to global change and there were many diverse suggestions. Among these, strategies to reduce or control wildfire, reduce browsing pressure from ungulates, invest in tree improvement, and manage for biodiversity were frequently mentioned.

Barriers and Opportunities for Adaptation Strategies

Similar percentages of respondents found the current state of knowledge for *resist* and *adapt* strategies (Figs. 3B and 4B,

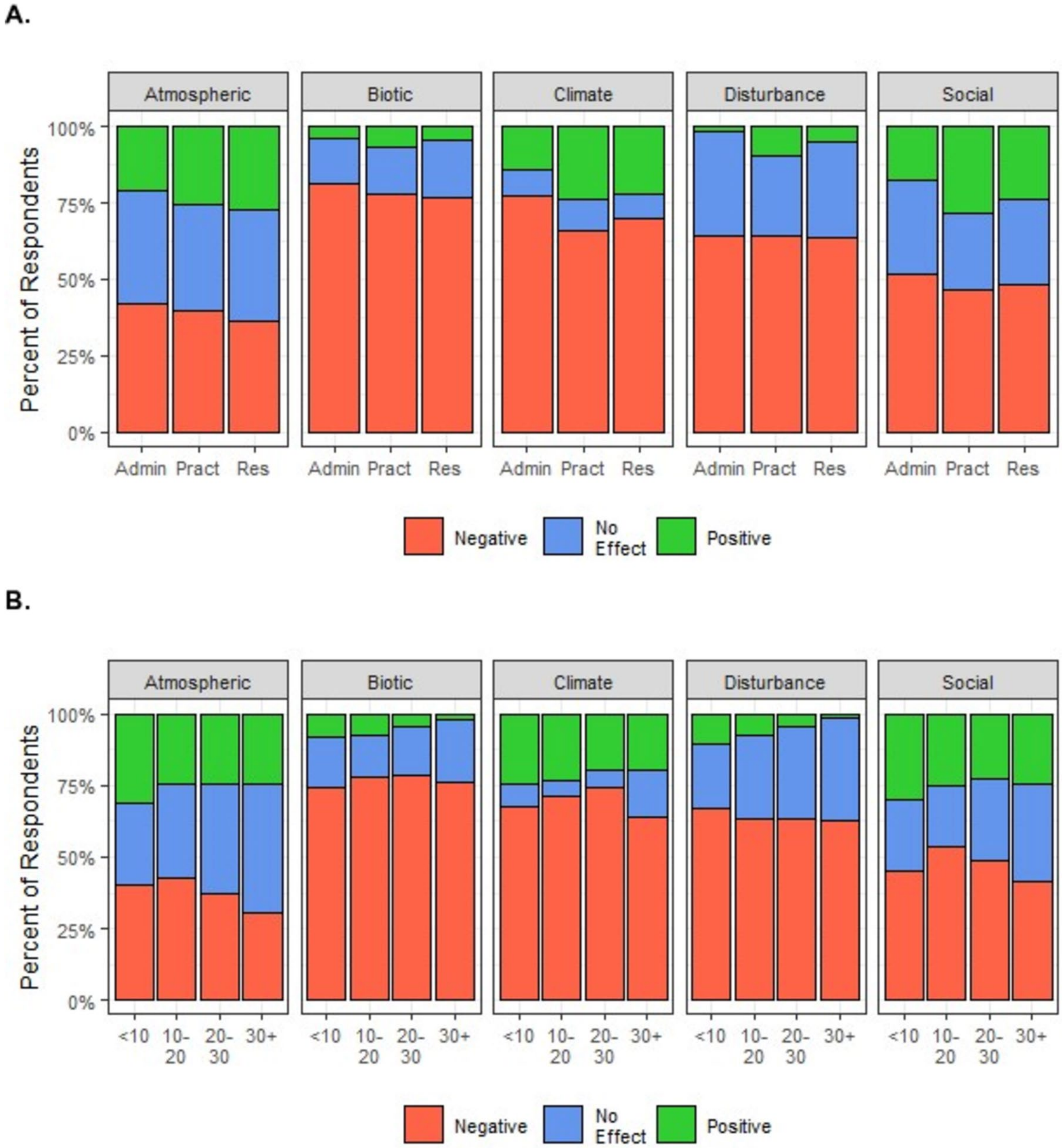

Fig. 2 Percentage of respondents sorted by **A** professional roles (*X*-axis: Admin = administrator, Pract = practicing forester, Res = researcher or educator) and **B** job experience (*X*-axis: years in the profession) rating different global change factors as having a negative impact, no effect, or a positive impact on their forests

sorted by professional role and job experience, respectively) were good/very good (38% and 37%, respectively), adequate (35% and 34%, respectively), or poor/very poor (26% and 29%, respectively). A higher percentage of respondents identified current knowledge for strategies characterized as the *transform* strategy as poor/very poor (44%) and a correspondingly lower percentage identified knowledge of strategies under the *transform* strategy as good/very good (23%) (Fig. 3B).

A majority of respondents indicated that it was likely or very likely that *resist* and *adapt* strategies would both be economically feasible (56% and 55%, respectively) and roughly half as many respondents thought either strategy was unlikely or very unlikely to be economically feasible (27% and 24%, respectively). On the other hand, approximately equal percentages of respondents indicated that the *transform* strategy would be likely or very likely to be economically feasible as unlikely or very unlikely (~40% each) (Figs. 3C and 4C).

A large majority (65%) of respondents thought it likely or very likely that there would be social and political support for the *adapt* strategy. Only the *transform* strategy category had more respondents indicating it was unlikely or very unlikely than those who thought it was likely or very likely (42% compared to 32%). Similar numbers of respondents thought social and political support would be neutral for all three types of strategies: 24%, 24%, and 26% for *resist*, *adapt*, and *transform*, respectively (Figs. 3D and 4D).

There were few discernable patterns based on profession type or job experience. A larger proportion of researchers indicated the current state of knowledge is poor for all adaptation strategies. Respondents with the most work experience were more pessimistic about the importance of adapt and resist strategies and a larger proportion of them thought it unlikely that resist strategies would be economically feasible or socially and politically supported.

Comparing Results of High-Income Countries to Middle- and Low-Income Countries

Respondents based in high-income and middle- and low-income countries differed in their views of the greatest global change factors likely to affect forest management in the next 20 years (Fig. 5). A substantially larger percentage of respondents based in middle- and low-income countries (see Table 1 in Supplement) indicated that atmospheric change factors were likely to have a negative impact (48%) compared to respondents based in high-income countries (mostly temperate and boreal regions; 32%). In contrast, in high-income countries, a larger percentage indicated atmospheric change factors were likely to have no effect on their forest management (42% from high-income vs. 26% from low- and middle-income countries). The opposite was found for biotic risk factors, where a substantially larger percentage of respondents representing high-income countries indicated biotic factors would have a negative effect (82%) compared to respondents representing low- and middle-income countries (69%). Only 22% of the respondents based in low- and middle- income countries thought disturbance factors would have no impact, compared to 35% of the respondents from high-income countries. Also, a smaller percentage of respondents from high-income countries indicated disturbance factors would have a positive impact (2% compared to 11% of the respondents from middle- and low-income countries). More respondents from middle- and low-income countries indicated social factors of global change will have negative impacts on forest management. Only 15% of the respondents from middle- and low-income countries thought social change factors would have no effect, compared to 36% of the respondents from high-income countries, while a correspondingly greater percentage of respondents representing middle- and low-income countries indicated social factors would have a negative impact (55% compared to 43%). It should be noted that 90% of the respondents working in tropical and subtropical forests were from low- and middle-income countries; thus, country income and forest biome may be confounded in some cases.

Differences between the percentage of respondents representing high-income and middle- and low-income countries in the importance, current quality of knowledge, economic feasibility, and social and political support for different adaptation strategies are summarized in Fig. 6. The majority of respondents (61%) from middle- and low-income countries indicated that management actions under the *adapt* strategy were of high importance, compared to 46% representing high-income countries. The results were similar for strategies under the *resist* strategy, with 43% of the respondents for middle- and low-income countries indicating they were important, compared to 30% responding for high-income countries. The percentage of respondents from middle- and low-income countries who considered strategies of the *transform* strategy to be average or unimportant was greater than that of high-income countries (71% and 60%, respectively). Compared to high-income countries, a smaller percentage of respondents from middle- and low-income countries thought the current quality of knowledge for approaches supporting the *resist* strategy was good or very good and more believed it was poor; 34% of the respondents indicated knowledge was poor and only 31% indicated it was good compared to only 22% of the respondents from high-income countries rating it poor and 43% indicating it was good. A higher percentage of respondents from middle- and low-income countries indicated that an *adapt* strategy was likely to be economically feasible (61%) compared to high-income countries (51%), while the reverse pattern was true for social and political support, where 69% of the respondents from high-income countries thought support was likely compared to 57% representing middle- and low-income countries.

Discussion

Global change provides a variety of novel challenges for natural resource management. This study provides a global overview of the perspectives of professionals involved in practical forest management, research and education, administration, and policy setting with an interest in global change trends. Specifically, survey respondents provided their perspective on the perceived impacts of global change on forests, the importance of different adaptation options, and the challenges involved to implement them. The range of responses to the survey supports the need to place the discussion about managing forests in the face of global change in the societal

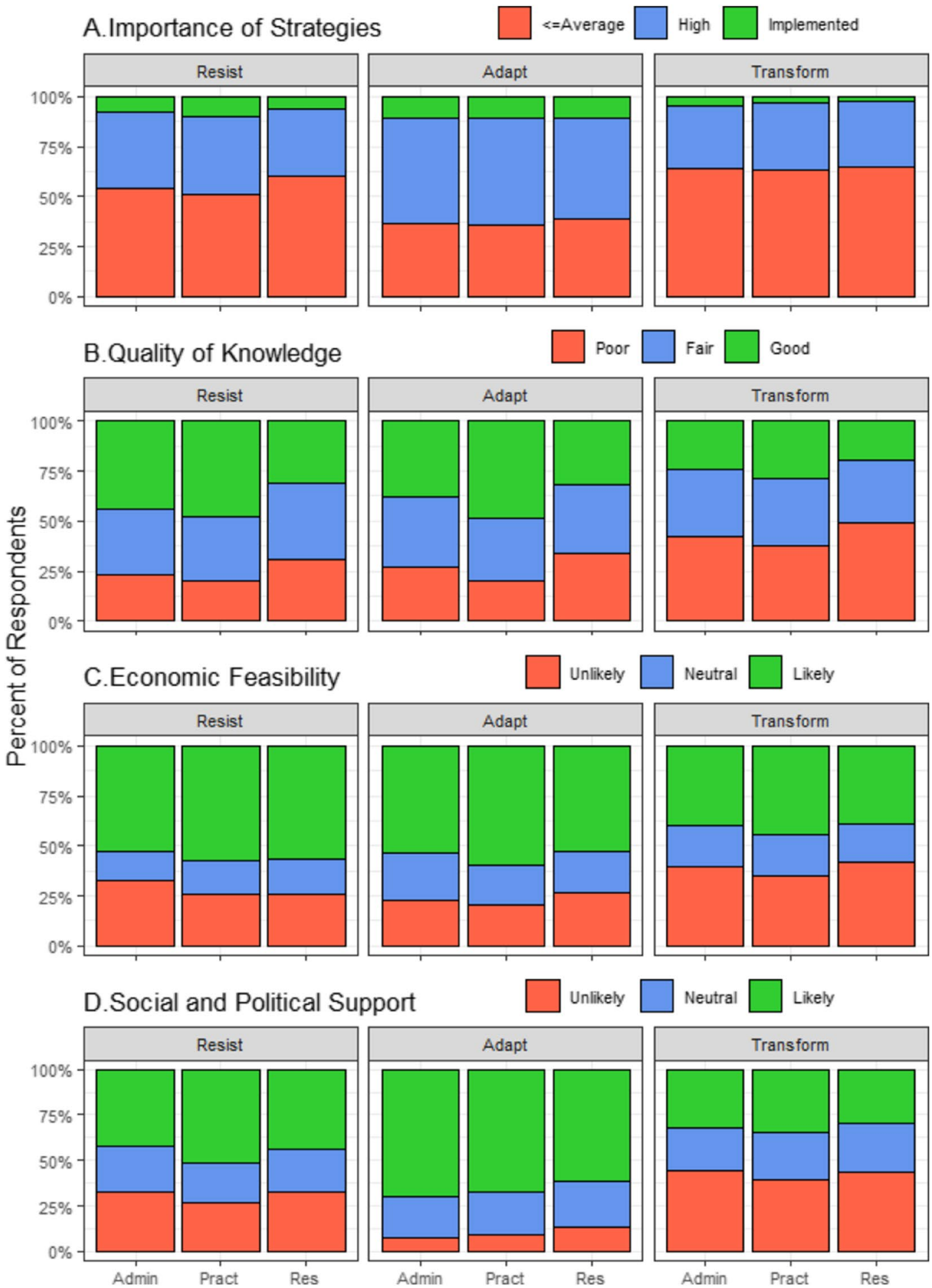

Fig. 3 Percentage of responses sorted by professional role of respondents (*X*-axis: Admin = administrator, Pract = practicing forester, Res = researcher or educator) indicating **A** the importance of different strategies for adapting to global change and averaged by *resist*, *adapt*, and *transform* strategies. Average or less includes responses "of average importance," "of little importance," and "not important at all." High importance includes the responses "very important" and "extremely important," **B** the state of knowledge for executing different strategies for adapting to global change, averaged by adaptive strategy categories. Good indicates responses that the current state of knowledge was "good" or "very good." Poor indicates responses that the current state of knowledge was "poor" or "very poor," **C** the economic feasibility for executing different strategies for adapting to global change, averaged by adaptive strategy categories. "Unlikely" indicates responses that practices were "very unlikely" or "somewhat unlikely" to be economically feasible. "Likely" indicates responses that practices were "somewhat likely" or "very likely" to be economically feasible, and **D** how likely social and political support is for different management practices for adapting to global change, averaged by adaptive strategy categories. Feasibility categories in the legends are as described for **C**

and institutional context [26, 34], supporting findings about the role of values, worldviews, and psychological barriers as an indicator of management actions [35, 36].

The acceptability of forest adaptation strategies in the face of global change hinges on embedded and specific historical, political, and social contexts. These contextual drivers can make generalizing results from global studies like this one difficult. Teasing out contextual similarities and their impact on responses often requires intimate knowledge of local conditions that are not feasible to capture for many countries from different continents in a single survey. For instance, two countries with relatively similar demographics, climate, and forest types can have widely different strategies to adaptation that are driven by divergent governance, history, and land tenure [28]. For example, *Pseudotsuga menziesii* forests managed primarily for timber production in the Pacific Northwest of the USA may face different barriers to adaptation strategies than very similar forests across the border in Canada because of the large extent of privately owned forests in the USA and predominantly publicly owned land in Canada. Similarly, adaptation strategies will differ greatly in forest landscapes dominated by small landowners between regions. For example, the capacity and interest to adapt will differ in regions of Europe, where the proportion of owners with little need to generate income is relatively high among non-resident or urban forest owners [e.g., 37], compared to tropical landscapes, where forests are more likely to contribute to local community subsistence, e.g., smallholder plantations in Vietnam [38].

Several perceptions were fairly consistent among the diversity of respondents. For example, all three strategies (*resist*, *adapt*, *transform*), which represent different levels of acceptable changes in ecosystem structure and composition, were considered of average or high importance, and most respondents recognized that economic factors limit the implementation of such strategies. In contrast, there was more variation regarding the perspectives of respondents on other issues, such as the quality of current knowledge and the degree of political and social support for these strategies. Such variability in the global responses likely reflects differences in ecological impacts of global change, in institutional and socio-cultural contexts, and in capacities to address them [39]. Our overview of survey responses set the stage for future in-depth analysis of the economic, political, and social barriers to adaptation strategies within specific forest types and jurisdictions. Further, our survey, while broad in scope, cannot facilitate detailed comparisons of contrasting opinions about forest management within a given context. It does, however, point to areas where inconsistencies or controversies exist and are worth exploring in future studies. For example, almost equal proportions of respondents thought *transform* strategies were likely and unlikely to be socially acceptable and economically feasible.

Forest management professionals are in broad agreement that, over the next two decades, global change will generally have a negative effect on the forests' ability to provide the suite of ecosystem services that societies depend on. With the exception of atmospheric impacts, the proportion of respondents who felt global change will have negative impacts was approximately two (in the case of social factors) to fifteen (in the case of biotic impacts) times higher than those who considered global change would have a positive impact. The higher percentage of respondents expecting positive impacts from atmospheric CO_2 concentration probably reflects anticipation of the CO_2 fertilization effect increasing tree growth [40]. According to most forestry experts who completed our survey, biotic, climate change, and disturbance factors are expected to negatively impact forests and their management in the next 20 years. Practitioners seemed to be more optimistic, than other groups, in terms of the positive impacts of climate, disturbance, and social impacts. This unexpected result suggests the need for further investigations. These results are not likely caused by lack of information as these professionals were most confident in the quality of knowledge about global change factors. Similarly, early career professionals (those with less than 10 years of experience) were more likely to think global change factors would have a positive impact. Maybe early-career professionals are in certain positions more open to accept different management outcomes including those that benefit from disturbances, such as early successional habitat [41]. A substantially larger percentage of respondents from high-income countries compared to low- and middle-income countries expected that biotic risk factors would have negative effects on forests. This likely reflects the geographic concentration of high-income countries in temperate and boreal regions and recent experiences with pest and disease impacts in these regions, such as *Dendroctonus ponderosae*. There are many examples of accidentally introduced pests and diseases through global trade which had devastating impacts in countries of the northern hemisphere which transcended forest management and impacted society broadly, e.g., the demise of the genera *Ulmus* and *Fraxinus* in North America and Europe. It is also quite well known that the frequency and impact of such introductions are still increasing [e.g., 42].

There were stark differences in the expected impact of social factors based on country incomes. Most respondents representing middle- and low-income countries expect social factors of global change to have negative impacts on forest management (55%), which was 12 percentage points more than respondents from high-income countries. However, respondents from middle- and low-income countries also had a much larger percentage of respondents indicate social factors would have a positive impact, 31% compared to 22%, and only 15% thought social factors would have no effect compared to 36% in high-income countries. Altogether,

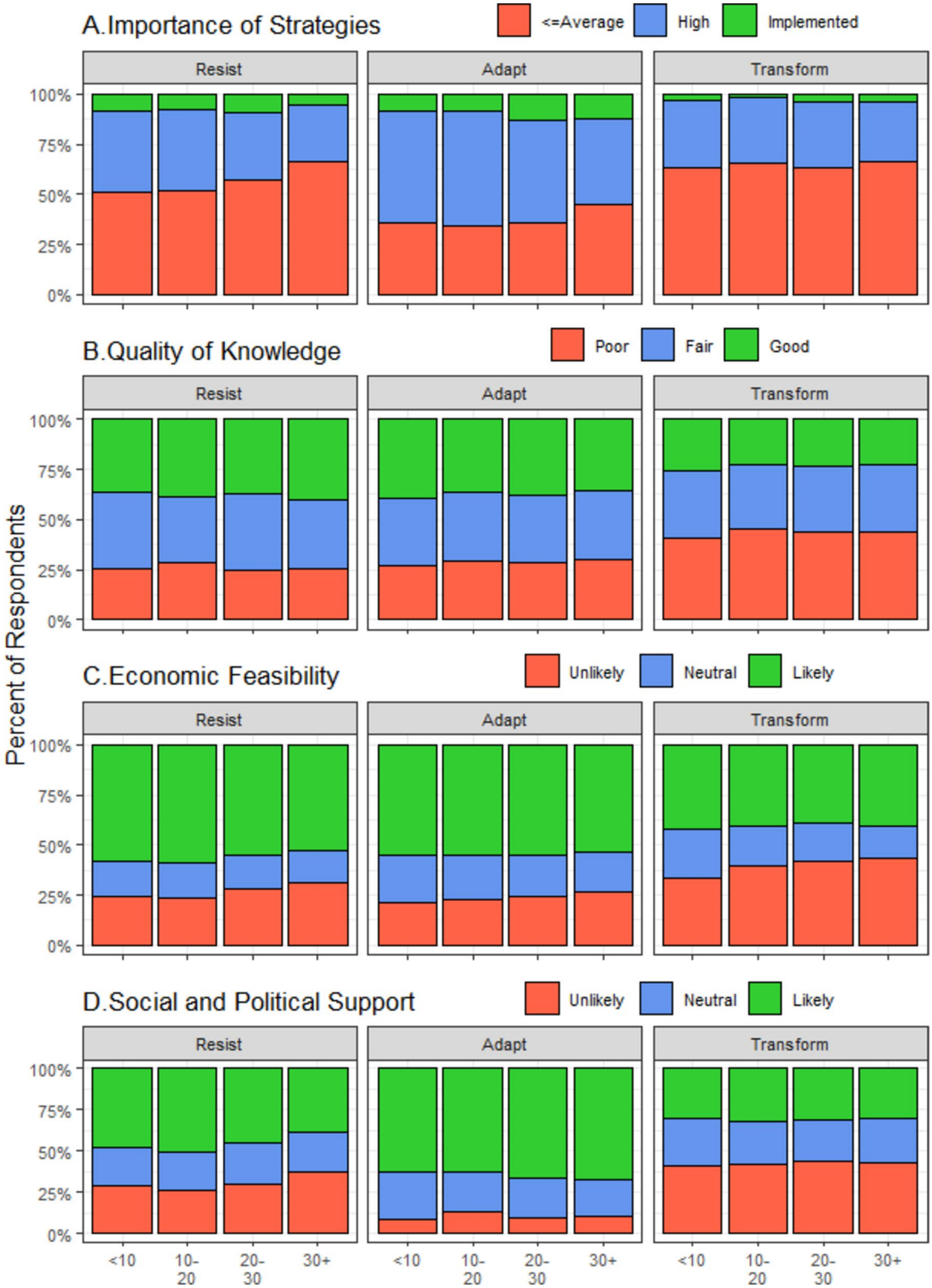

Fig. 4 Percentage of responses sorted by length of job experience (*X*-axis: years in the profession) of respondents indicating how respondents perceive different strategies for adapting to global change with respect to **A** the importance, **B** the state of knowledge for executing the strategies, **C** the economic feasibility, and **D** how likely social and political support is for different management practices. The definition of legend ratings follows those described for Fig. 3

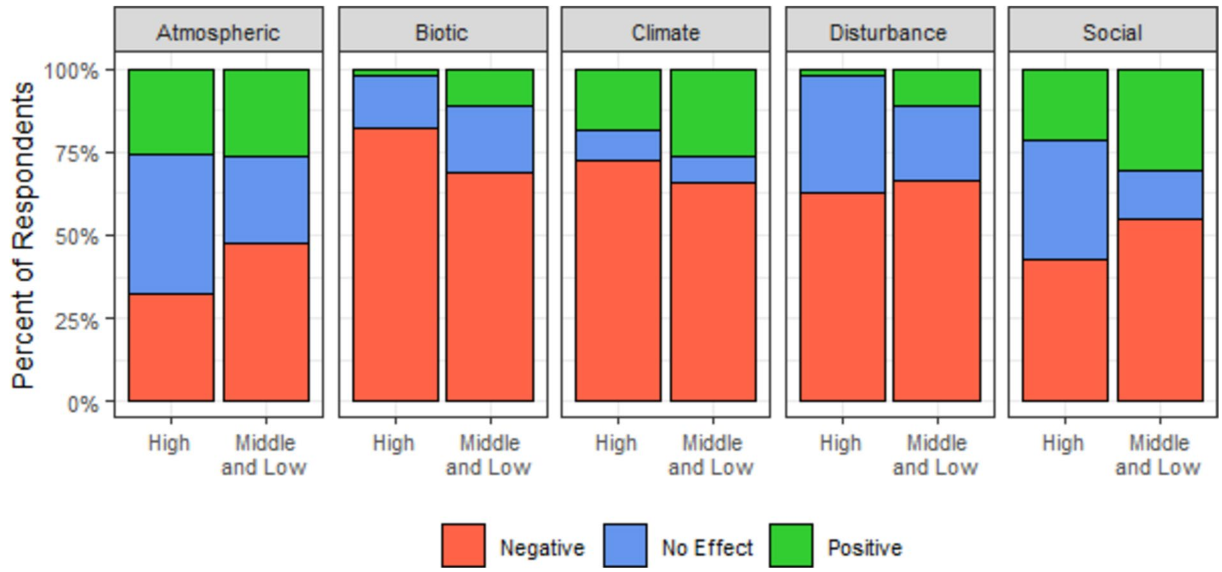

Fig. 5 Comparison of the percentage of respondents indicating whether major global change factors were likely to be negative, have no effect, or be positive separated by high-income countries versus middle- and low-income countries

this suggests that social factors are much more important in middle- and low-income countries compared to high-income countries. This is likely to be due to the expanding populations in these countries placing increased demands on forests, with those countries having limited resources and capacity to manage these impacts [43]. It may also reflect greater community participation in forest management in middle- and low-income countries where it is much more common for forest land to be owned by indigenous people and local communities and be managed as a common resource [31].

The expectation by forestry professionals that global change is going to negatively impact forest management in the next two decades highlights the need for silvicultural systems to change to anticipate and mitigate these negative impacts. *Adapt* strategies which include strategies such as more mixed-species stands, heterogeneous stand structures, establishing advance regeneration under an existing canopy, variable tree spacing, and leaving (more) legacies and buffers [4] were considered highly important, economically feasible, and socially acceptable by the majority of respondents, even though not all of these strategies are fully appreciated by the general public, e.g., leaving legacies [44]. These strategies have been recommended under the umbrella of "ecological forest management" to accommodate a wider array of social interests and encourage more resilience in the face of climate change [45]. They largely align with close-to-nature silviculture which has been suggested to provide suitable strategies to adapt forests to climate change [46, 47]. However, respondents also pointed out challenges implementing practices aimed at adapting forests to global change [48]. More than a quarter of respondents believe that the current knowledge base for implementing practices related to the *adapt* strategy is less than adequate, indicating there are still knowledge gaps that warrant further research. However, this also means that more than 70% of the respondents believe the current knowledge about *adapt* strategies is at least adequate. Despite most respondents indicating these strategies are of high importance, barely more than a tenth of all respondents indicated that they are being implemented. Future studies may benefit from investigating how well the current knowledge is being disseminated to practitioners. Since most respondents believe *adapt* strategies are likely to be economically feasible and socially acceptable, it suggests that other barriers to implementation exist, e.g., communication problems between researchers, managers, and other stakeholders [49]. Further research is warranted to determine what those barriers are and how to overcome them.

Less than a third of respondents indicated a need to implement a *transform* strategy. This low importance attributed to transformation may be driven by lack of knowledge to support this type of strategy and that transform approaches may be less socially acceptable and economically feasible. These results echo findings that the general public and forestry experts think that moving tree species outside their current range is very risky [27, 50, 51], which echoes a larger debate in the literature over assisted migration, a type of transformation strategy [52–54]. Further research into the economic and social barriers to *transform* strategies may be warranted as such strategies could prove increasingly important to mitigate severe adverse effects and maintain functional diversity

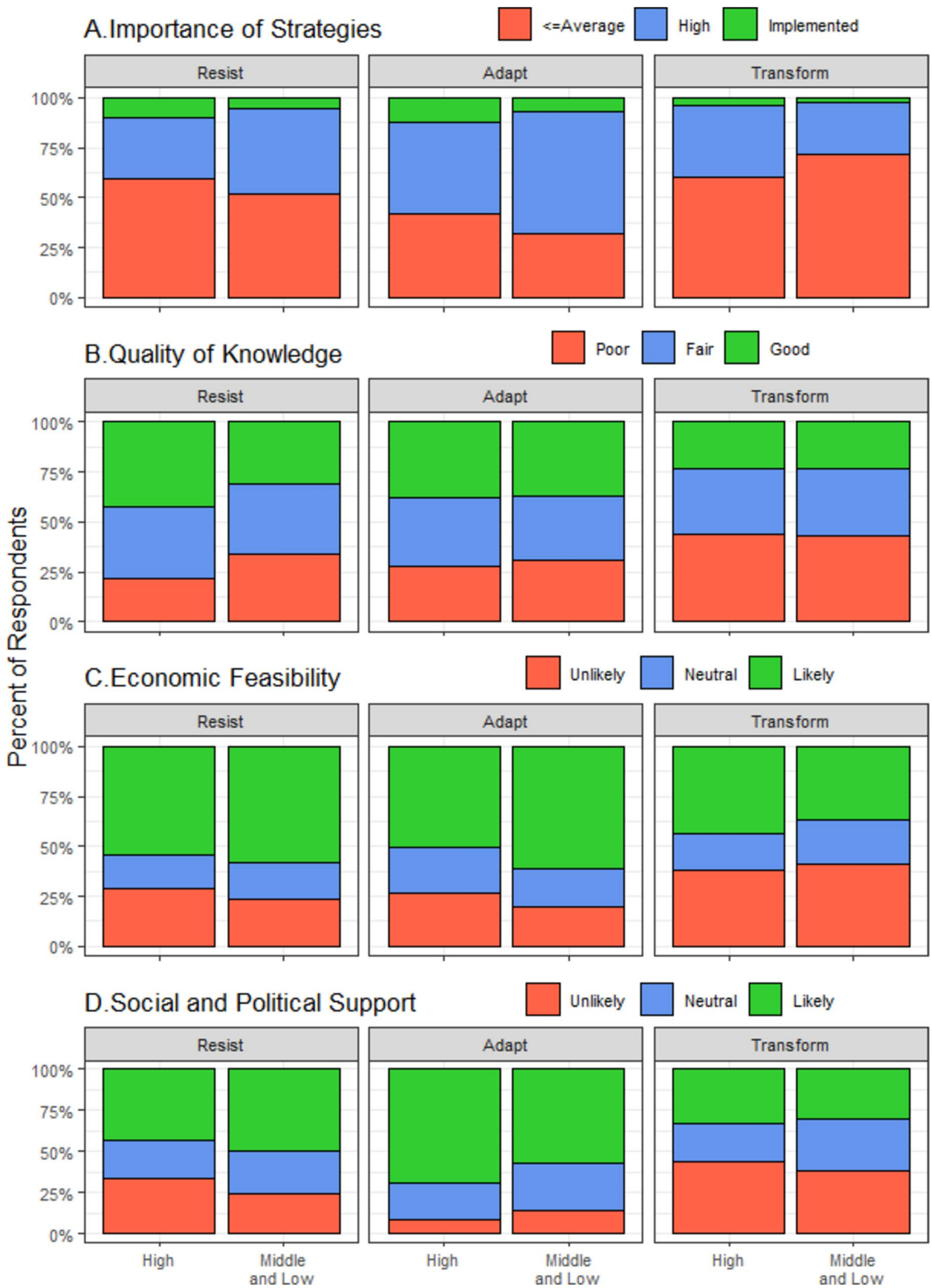

Fig. 6 Comparing the percentage of responses separated for high-income versus middle- and low-income countries about the perception of the different adaptation strategies with respect to their **A** importance, **B** quality of current knowledge, **C** economic feasibility, and **D** social and political support. Legends are as described for Fig. 3

of forest landscapes [14, 55, 56]. However, implementation of *transform* strategies may be hampered by concerns about the economic feasibility and social resistance, regardless of their potential benefits to the forests.

Resist strategies were reported as most likely to be economically feasible (although only slightly more so than *adapt* strategies). However, such management practices comprising spacing and thinning to lower stand densities and creating even spacing, shorter rotations, and sanitation/salvage harvests were perceived to be less socially acceptable compared with *adapt* strategies. Surprisingly, only 38% of the respondents believed that the current level of knowledge to support the *resist* strategy was good or very good, despite several systematic reviews and meta-analyses on silvicultural practices for this strategy. For example, we have a high degree of evidence for the influence of thinning on forest hydrology and drought tolerance of trees [e.g., 57, 58]. This relatively low opinion about the current quality of knowledge for the *resist* strategy was particularly evident in middle- and low-income countries (Fig. 6), which may reflect that recent information about silvicultural research is less well disseminated and integrated in curricula in those countries [59].

Even though more respondents indicated that the *adapt* strategy was highly important compared with other adaptation strategies, more than 30% indicated *resist* and *transform* strategies were also of high importance. This suggests that, at least in some contexts, experts in the field of forestry believe that it is important to pursue all three adaptation strategies. Further, there is no reason that these adaptation strategies must be implemented in isolation as “either/or” options for facing global change challenges. Strategies that intentionally incorporate all three strategies and thus diversify landscapes [60] may be more effective than pursuing any single strategy uniformly, e.g., functional zoning strategies like TRIAD [61].

While results indicate that no adaptation practice was already commonly implemented, those adaptation strategies that were seen as highly important, such as *adapt* strategies, were most likely to already be implemented. This trend, although tenuous, may suggest that adaptive strategies are being implemented in general accordance with expert opinion. However, adaptation is slow or restricted to low levels of adoption, since 11% or less of the respondents indicated that practices to increase the adaptive capacity are already implemented.

Conclusion

Foresters and thus the environment and society will likely benefit from having a portfolio of adaptation options representing *adapt*, *transform*, and *resist* strategies, but respondents considered those options that align with an *adapt* strategy most important. Our study demonstrates widespread perception of forestry professionals interested in global change issues that many global change factors are going to negatively affect sustainable forest management, resulting in the need for adaptive silviculture. Selected trends, such as a more positive perception of global change agents by early-career professionals, highlight the need for further more detailed investigations. The results of our global survey also suggest potential barriers to different adaptation strategies, including a relative lack of information and social acceptance for *transform* strategies compared to *adapt* and *resist* options. But it may be just as important to explore and understand specific barriers, beyond social acceptability and ecological feasibility, to implementation of strategies to adapt forests and forest management to global change. The management options in high-income countries may diverge from those of middle- and low-income countries, highlighting the importance of context when considering adaptations to global change in silviculture [26]. For example, in lower income countries, the focus needs to be expanded to include social in addition to technical issues due to the higher population growth and increased demands on forests (including demands from higher income countries who are increasingly protecting their forest from any harvesting). More detailed investigations are needed that include various other aspects of the management contexts. For example, future studies may benefit from including information about documented positive and negative impacts of global change factors in a random subset of questionnaires to see if the additional information affects forestry professionals' opinions. It may also be fruitful to include more questions about the backgrounds of respondents in order to more deeply investigate how experience with specific management practices, such as the introduction of exotic tree species, affects their opinions about adaptation strategies. The importance of social and political factors also highlights the need to understand the general public's values when exploring strategies to adapt forests to future conditions [62] and how the influence of the public is perceived by forest managers [64]. Both of these factors appear to be crucial when designing educational efforts [63]. Our results provide a strong “jumping-off” point for more detailed surveys and studies to overcome challenges inherent in implementing practices and policies toward achieving forests that are resilient and well adapted to global change.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s40725-023-00205-1.

Author Contributions KJP, AH, and JB conceived the idea for the study and designed the survey. All authors reviewed the draft survey and disseminated the final survey within their networks. AH analysed the survey data and prepared the figures and tables. AH, KJP and JB drafted the manuscript. All authors helped interpreting the results and reviewed the manuscript.

Funding Open Access funding enabled and organized by Projekt DEAL. The work was supported by the Edmund Hayes Professorship in Silviculture Alternatives at Oregon State University, then US Department of Agriculture National Institute of Food and Agriculture, McIntire Stennis project 1023932, and by the authors' respective institutions. Jürgen Bauhus received a Fulbright Scholarship to work at the Oregon State University. The research leading to these results has received funding from the Deutsche Forschungsgemeinschaft (DFG), project ID 422010107, reference number UP 14/1, through the Freiburg Research Collaboration Programme.

Data Availability Data can be made available on request.

Declarations

Competing Interests The authors declare no competing interests.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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- •• Of major importance

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