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ORIGINAL PAPER

Climate change impacts and forest adaptation in the Asia–Pacific region: from regional experts' perspectives

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Abstract Expert opinions have been used in a variety of fields to identify relevant issues and courses of action. This study surveys experts in forestry and climate change from the Asia–Pacific region to gauge their perspectives on the impacts of climate change and on the challenges faced by forest adaptation in the region, and explores recommendations and initiatives for adapting forests to climate change. There was consensus regarding the impacts of climate change on forest ecosystems and on economic sectors such as agriculture and forestry. Respondents also indicated a lack of public awareness and policy and legislation as challenges to addressing climate change. However, the results indicate differences in opinion between regions on the negative impacts of climate change and in satisfaction with actions taken to address climate change, highlighting the need for locally specific policies and research. The study presents specific recommendations to address issues of most concern, based on subregion and professional affiliation throughout the Asia–Pacific region. The results can be used to improve policy and forest management throughout the region. This research will also provide valuable suggestions on how to apply research findings and management recommendations outside of the AP region. The conclusions should be communicated relative to the level of the research and the target audience, ensuring that scientific findings and management recommendations are effectively communicated to ensure successful implementation of forest adaptation strategies.

Keywords Adaptation · Asia–Pacific · Climate change · Expert opinion · Forest management · Questionnaire

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Introduction

The Asia–Pacific region is particularly vulnerable to climate change given its large population, high biodiversity, and large number of forest-dependent communities. Effects of climate change have already impacted freshwater resources, coastal systems, food production, and human livelihoods (IPCC 2014). Forest ecosystems are particularly sensitive to changes in temperature and precipitation (FAO 2015), and climate change, therefore, has the potential to alter future composition of forests in the Asia–Pacific region and the nature and extent of the services they provide may become uncertain. Forests also present a major opportunity for climate change adaptation and mitigation, as they have the potential to act either as a carbon source and accelerate climate change (through deforestation and forest degradation), or as a carbon sink and an adaptation strategy (through afforestation and sustainable management) (IPCC 2014). Recognizing the important role of forests as they relate to climate change and wisely managing their potential capacity is crucial for future climate change mitigation and adaptation.

Many forest-related initiatives and strategies have been developed to utilize the potential of forests for climate change mitigation and adaptation. The Kyoto Protocol indicated that forests could contribute to meeting carbon emission reduction targets, and REDD ++ (Reducing emissions from deforestation and forest degradation and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries) has become an important means of achieving these targets (Mollicone et al. 2007). Carbon management has become a standard component of sustainable forest management (SFM), as illustrated by the criteria and indicators developed by the International Tropical Timber Organization (ITTO 2005). Despite many available initiatives and strategies, the extent to which forests contribute to climate change mitigation and adaptation remains limited. Many studies have suggested that this low level of achievement is the result of insufficient institutional effort and a failure to effectively implement policy (Jantarasami et al. 2010; Moser and Ekstrom 2010).

This lack of political structure and guidance has led to the limited success of policies, strategies, and action plans to address climate change in the Asia–Pacific region. Development and implementation of effective forest management plans and policy is hindered by the complexity of social, political, and economic issues, as well as highly diversified local, regional, and national contexts. The capacity for climate change research and understanding of its impacts on forest ecosystems is highly variable across the region, leading to a disparity among countries regarding government and management capacities to adapt to climate change (FAO 2010). As a result, the local context, including specific location and knowledge of the stakeholders, becomes an important factor when making management decisions and communicating forest management recommendations in this region.

As part of the larger research project, *Adaptation of Asia–Pacific Forests to Climate Change*, this study examines current knowledge about climate change in the Asia–Pacific region, including the impacts, tools available for management and decision-making, and opportunities for forest adaptation. The goal of this research is to first identify expert perspectives on the impacts of climate change and on the current challenges faced by forest adaptation in the region, and secondly, to explore recommendations and initiatives for adapting forests to climate change. Experts' opinions have been used successfully in the past to conduct meaningful research (Vaughan and Spouge 2002; Morgan et al. 2006; O'Neill et al. 2008), and a similar approach was therefore adopted for this study in order to gain an understanding of climate change adaptation in forestry from local stakeholders with an educated interest in the topic.

The results of this research will have strong implications for forest management and policy in the Asia–Pacific region, as this study aims to help determine the most important climate change impacts to be addressed and the type of management practices to be applied in different sub-regions. The results will highlight differences in opinions between different professional affiliations and may lead to insightful explanations for the ineffectiveness of current adaptation policies, as well as recommendations for improvement. This research will also provide valuable suggestions for how research findings and management recommendations could be communicated, depending on the location of the research and the professional affiliation of the reader/listener. This will help to ensure that scientific findings and management recommendations are communicated in the most relevant, effective way and lead to successful implementation of forest adaptation strategies.

Methods

Study area

For the purposes of this study, the Asia–Pacific region includes five subregions: North America, East Asia, Oceania, South Asia, and Southeast Asia (Fig. 1).

The climate in North America ranges from the tropics to frozen tundra in the north, and this subregion hosts a variety of forest types, including boreal forest, temperate rainforest, and deciduous forest. The main climate change impacts include decreases in snowpack causing water resource stress, increases in coastal flooding, pest and forest fire outbreaks, and crop damage and yield losses due to increases in extreme weather (Hijioka et al. 2014). East Asia is characterized mainly by a subtropical climate with both winter and summer monsoons. This subregion contains temperate deciduous, subtropical evergreen, and boreal forests, and the main climate change impacts include increased flooding, vulnerability of coastal zones to sea level rise, reduced yields due to drought and water shortages, and increases in intensity of summer monsoons and heat waves (Westphal et al. 2013; Hijioka et al. 2014). Oceania exhibits a range of climates from moist tropical monsoon to arid, moist temperate and is affected by tropical cyclones. This subregion has tropical and subtropical forests, and the main climate change impacts are changes in rainfall intensity, increases in tropical cyclone intensity, sea level rise, and increases in forest fire frequency

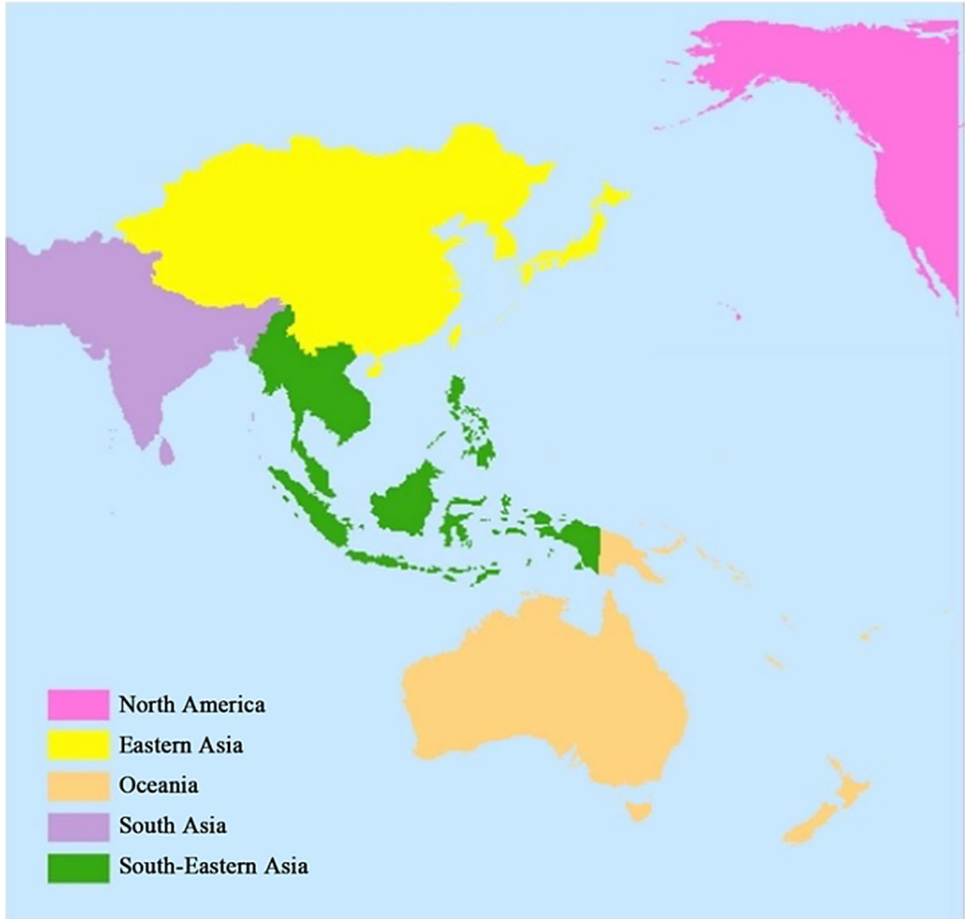

Fig. 1 Study area: the Asia–Pacific region

(Hijioka et al. 2014; IPPC 2014). South Asia ranges from a tropical monsoon climate in the south to temperate in the north, with tropical forests in the south and semi-desert and alpine ecosystems in the north. The main climate change impacts are increases in heavy precipitation and flooding, and extreme temperatures and drought leading to food and water shortages (Hijioka et al. 2014; IPCC 2014). Southeast Asia has a mainly humid tropical climate and this subregion is largely covered in tropical forests. Climate change concerns include increases in events such as fire, landslides, floods, and droughts, as well as sea level rise threatening coastal and marine resources (Asia Development Bank 2009; Hijioka et al. 2014).

Questionnaire design

The questionnaire consisted of 15 qualitative and quantitative questions derived from four overarching research questions: (1) What are the main impacts of climate change in the Asia–Pacific region?; (2) What climate change-related actions/policies are available in the Asia–Pacific region?; (3) What are the challenges of adapting forestry to climate change in the region?; and, (4) How can current actions to adapt forestry to climate change be improved?

All respondents completed the questionnaire voluntarily and all responses were confidential and anonymous. The first section asked the respondents general information about themselves, including their current country, city, and professional position. The second section examined respondents' perceptions of climate change, including their opinion about possible negative and positive consequences and economic sectors that might be affected. Respondents were then asked whether they were satisfied with adaptation measures taken to address climate change and to indicate their subregion's involvement in international initiatives addressing climate change.

The third section focused on forest adaptation. Respondents were asked if there are initiatives in place to help adapt the forestry sector to climate change, and if so, to rank their satisfaction with these initiatives. This section also examined the impacts of climate change on forestry and challenges in adapting the forestry sector to climate change. Additionally, respondents indicated if and what forest planning tools and climate models were available, if there are policies to promote sustainable forest management, and what areas lack scientific support in their subregion. In the final section, respondents were asked to rank various actions for addressing climate change, from least to most important.

Sampling method

Survey participants consisted of forestry and climate change experts from various disciplines and countries throughout the Asia–Pacific region. Paper-based questionnaires were distributed and collected from attendees at three international conferences, namely the *Workshop of Sustainable Forestry Management in a Changing Climate* in Kunming, China, July 2013; the 25th session of the FAO Asia–Pacific Forestry Commission in New Zealand, November 2013; and the Asia Forestry Summit in Indonesia, May 2014 (Table 1). Paper-based questionnaires were also distributed in September 2015 at a seminar of visiting Chinese scholars at the University of British Columbia in Vancouver, Canada. The remaining participants were contacted through an email containing the link to an online survey that was identical to the paper questionnaire. In total, 1250 questionnaires were distributed starting in July 2013, and 206 questionnaires were collected by October 2015 across 31 countries, giving a response rate of 16.5%. Over 200 questionnaires were valid (had complete answers) and were used for this analysis.

Data analysis

A questionnaire pretest was conducted with 15 individuals prior to its distribution to ensure questions were effective, clearly worded, and accurately reflected the desired information. Questionnaire respondents were grouped into the five subregions based on FAOSTAT guidelines (http://faostat.fao.org/site/371/default.aspx). Respondents were also grouped by profession—government, academic (including professor, student or researcher), and private sector (including community/non-governmental organizations (NGOs) or business person).

Questionnaire responses were input into the software Statistical Package for the Social Science (SPSS), version 23. Data entry was checked for accuracy every five questionnaires to ensure reliability. Responses were analyzed using descriptive and frequency analyses, and the significance of key variables was tested using several nonparametric tests. The methods used here assume independence of observations, meaning that the answers of one respondent do not impact the answers of another. The Chi squared test was used for questions where respondents could select multiple response variables to determine if there were differences among groups in the proportion of people that selected a given variable. When a Chi squared test was significant, we analyzed the adjusted standardized residuals of response proportions to identify the relationship yielding the significant difference. Since this analysis was performed many times, there is a greater risk of false positives (type 1 error). Therefore, statistical significance was determined as follows: for overall analyses, a significance level of $p < 0.05$ was used; for analyses by subregion, an adjusted significance level of $p_{bonf} < 0.05/5 = 0.01$ was used; and for analysis by profession, an adjusted significance level of $p_{bonf} < 0.05/3 = 0.017$ was used.

This type of analysis may generate cases where the initial Chi squared test is significant, indicating group differences, but none of the subsequent adjusted residual statistics are significant. Groups can be significantly different because of one large difference or several smaller differences, and in the latter case, it may not be possible to conclusively identify the source of the difference. This can

Table 1 Summary of distribution and response rate of the questionnaire

Means	Distribution	Date	Location	N distributed	N collected	Response rate (%)
Paper-based	Workshop of Sustainable Forestry Management in a Changing Climate	July 2013	Kunming, China	135	48	35.6
	25th Session of the FAO Asia–Pacific Forestry Commission	Nov. 2013	New Zealand			
	Asia Forestry Summit	May 2014	Jakarta, Indonesia			
	Faculty of Forestry Visiting Chinese Scholar Seminar	Sept. 2015	UBC, Vancouver, Canada			
Electronic	Email & online survey	Nov. 2013-Aug. 2014	N/A	1115	158	14.2
		June 2015-Sept. 2015				
Total				1250	206	16.5

explain the results (provided below) that indicate a significant Chi squared test but a non-significant residual analysis. We used the Kruskal–Wallis test for questions where multiple response variables could be selected. This test was chosen based on its advantages of establishing statistical significance of a sample that does not follow a distribution with unspecified parameters. In one analysis, we followed the Kruskal–Wallis analysis with a Mann–Whitney U-test to investigate if there was a significant difference between pairs of subregions and professions; these pairwise tests used an adjusted p value.

Results

Description of respondents

Responses are summarized in Table 2 by subregion and professional position. The largest proportion of respondents were from Southeast Asia, and when grouped by profession, the largest proportion of respondents were academics.

Climate change in the Asia–Pacific

The survey included several general questions about climate change concerns and policies/initiatives in the region in order to better understand varying regional contexts. Respondents ranked their level of concern from '1—not concerned' to '5—very concerned' for various impacts of climate change. There was variability among subregions in the level of concern for a given impact (Table 3). 'Drought' had the highest mean ranking overall ($M = 4.02$, $SD = 1.12$) and among South Asian ($M = 4.54$, $SD = 0.83$) and Southeast Asian ($M = 4.40$, $SD = 0.89$) respondents, followed closely by 'flooding' ($M = 4.00$, $SD = 1.16$), which was ranked highest in Oceania ($M = 4.15$, $SD = 1.20$) and East Asia ($M = 4.07$, $SD = 1.12$). North American respondents differed in that, on average, they ranked 'forest disturbance' to be their main concern ($M = 3.60$, $SD = 0.94$).

Regarding the positive impacts of climate change, the highest percent of responses overall was for "I don't know" (25.6%) followed by "improving growth of forests" (22.6%) (Fig. 2). There was a significant relationship between subregion and selection of 'improving growth of forests' (Chi squared test; $\chi^2 = 18.28$, df = 4, $p = 0.001$) (Fig. 3a) and 'less need for energy consumption' ($\chi^2 = 15.64$, df = 4, $p = 0.004$) as positive consequences (Fig. 3b). North America had a significantly higher percentage of respondents select 'improving growth of forests' (47.9%; $\chi^2 = 8.41$, $p_{Bonf} = 0.004$) and 'less need for energy consumption' (38.1%; $\chi^2 = 9.06$, $p_{bonf} = 0.003$) compared to other subregions. The average number of positive consequences differed significantly by region (Kruskal–Wallis test; $H = 11.42$, df = 4, $p = 0.022$), with the greatest difference being between North America ($M = 1.48$, $SD = 0.98$) and Oceania ($M = 0.88$, $SD = 0.76$).

Agriculture (92.5%) and forestry (79.1%) were considered the two economic sectors most directly affected by climate change overall (Fig. 4), as well as regionally and professionally (Table 4). Regionally, there were significant differences in the percent of respondents who indicated that 'agriculture' (OC = 100%, SA = 95.8%, SEA = 95.3%, NA = 95.2%, EA = 79.5%) ($\chi^2 = 14.47$, df = 4, $p = 0.006$) and 'fisheries' (NA = 66.7%, SEA = 63.5%, OC = 59.3%, SA = 54.2%, EA = 31.8%) ($\chi^2 = 13.42$, df = 4, $p = 0.009$) would be directly affected by climate change (Fig. 4), with East Asia having a significantly lower level of concern for both economic sectors ($\chi^2 = 13.77$, $p_{bonf} = 0.0002$; $\chi^2 = 12.48$, $p_{bonf} = 0.0004$, respectively) (Table 4). There was also a significant difference in the average number of affected sectors selected among regions ($H = 15.565$, $p = 0.004$) and among professions ($H = 9.95$, $p = 0.007$). The greatest average number selected were for North America ($M = 3.90$, $SD = 1.41$) and private sectors ($M = 4.16$, $SD = 1.36$), with the lowest occurring for East Asia ($M = 2.82$, $SD = 1.43$) and academics ($M = 3.26$, $SD = 1.47$).

The Kyoto Protocol was the international initiative indicated to have the most involvement across all responses (81.2%). Involvement in the Protocol ranked highest

Table 2 Percentage of respondents by region and professional position

Region	Respondents (%)
South Asia (SA)	11.9
Southeast Asia (SEA)	42.3
Eastern Asia (EA)	21.9
Oceania (OC)	13.4
North America (NA)	10.4
Professional position	
Government	22.4
Academic	62.2
Professor	29.9
Researcher	29.9
Student	2.5
Private sector	15.4
NGO	7.0
Business person	3.0
Other	5.4

Table 3 Ranking for various climate change impacts based on average level of concern—overall and by subregion

Impact	Overall	NA*	EA	OC	SA	SEA
Drought	1	6	1	1	3	2
Flooding	2	4	5	2	1	1
Freshwater shortage	3	10	2	5	2	3
Forest disturbance	4	1	3	6	4	4
Fire hazard	5	2	6	3	8	5
Spread of insects	6	3	4	8	6	8
Spread of disease	7	5	7	9	5	7
Rising sea level	8	8	10	4	10	6
Storms and tornadoes	9	7	8	7	9	9
Melting of ice, snow and avalanches	10	9	9	10	7	10

*Subregion abbreviations are the same as in Table 2. Units are ranked from 1 (of most concern) to 10 (of least concern), based on sub-regionally organized responses

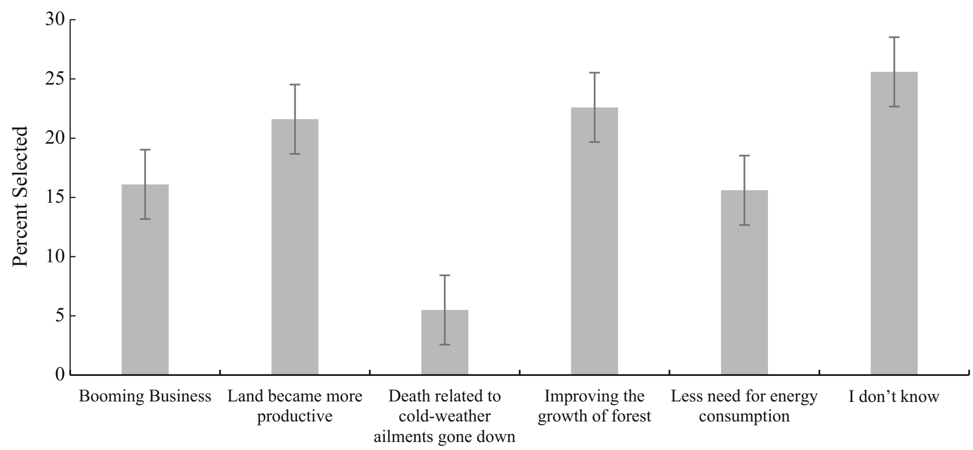

Fig. 2 Overall percent of responses for each option associated with the question 'Any positive consequences of climate change in your region? (Check all that apply)'

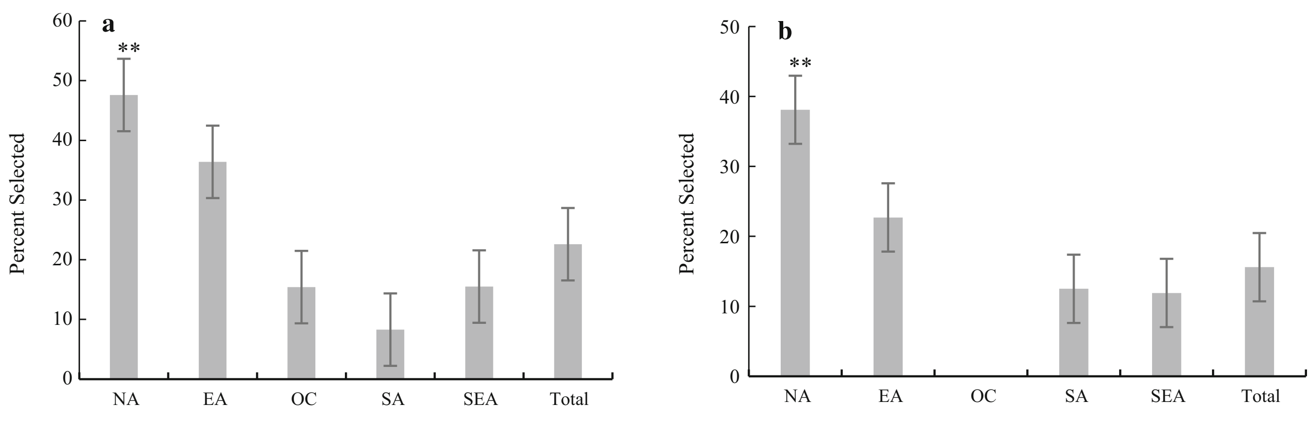

Fig. 3 Percent of responses by subregion associated with the selection of the variables (**a**) 'improving growth of forests' and (**b**) 'less need for energy consumption' for the question 'Any positive consequences of climate change in your region?'. A significant ($p < 0.005$**) relationship was found between subregion and selection of 'improving growth of forests' and 'less energy consumption' as positive consequences of climate change. In the case of both variables, North America contributed most significantly ($p_{Bonf} < 0.01$*) to the relationship, implying that North American respondents indicated these variables as positive consequences more often than other subregions. Subregion abbreviations are the same as in Table 2

among all subregions except East Asia (63.6%), which had significantly less involvement ($\chi^2 = 16.72$, df = 4, $p = 0.002$) ($\chi^2 = 13.05$, $p_{bonf} = 0.0003$). Subregions also differed significantly in their involvement in International Strategies for Disaster Reduction (UNISDR) ($\chi^2 = 20.90$, df = 4, $p < 0.001$). No North American respondents

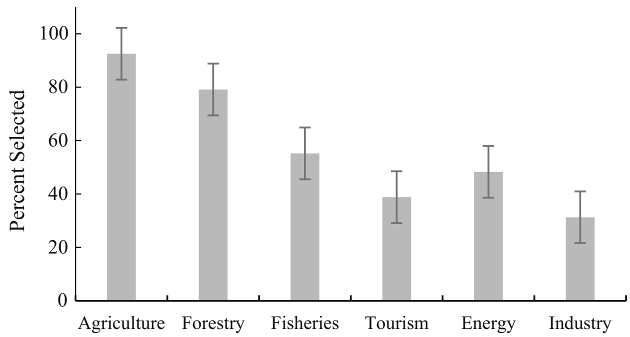

Fig. 4 Overall percent of responses for each option associated with the question 'Which economic sectors do you think would be directly affected most by climate change? (Check all that apply)'

Table 4 Ranking of economic sectors most directly affected by climate change according to the average percent of responses—overall and by subregion

Economic sectors	Overall	NA	EA	OC	SA	SEA
Agriculture*	1	1	1	1	1	1
Forestry	2	2	2	2	2	2
Fisheries*	3	3	4	3	4	3
Energy	4	5	3	4	5	4
Tourism	5	4α	6	5	3	5
Industry	6	4α	5	6	6	6

There is a significant ($p < 0.05$*) relationship between subregion and respondents selecting 'agriculture' and 'fisheries' as the sectors affected most by climate change. East Asia is the subregion contributing most significantly ($p_{bonf} < 0.001$**) to this relationship, implying that respondents from this subregion are less likely to indicate these two sectors as being affected by climate change

Note: Subregion abbreviations are the same as in Table 2

α indicates a tie in the percent of respondents that selected the sector

selected UNISDR (0.0%; $\chi^2 = 9.98$, $p_{bonf} = 0.0016$), while South Asia had significantly higher selection than the other subregions (54.2%; $\chi^2 = 7.70$, $p_{bonf} = 0.0055$). The subregions differed significantly in the average number of selected initiatives that they were involved in ($H = 15.68$, $p = 0.003$), with North America averaging the least ($M = 1.85$, $SD = 0.85$) and South Asia the most ($M = 2.79$, $SD = 0.83$).

Climate change and forest adaptation in the Asia–Pacific

'Changes in forest fire/drought' was most frequently indicated as the major impact of climate change on forest ecosystems overall and by respondents in Oceania, Southeast Asia, and East Asia (Table 5). This was followed closely by 'biodiversity changes', which differed significantly between subregions ($\chi^2 = 12.94$, df = 4, $p = 0.012$) (Fig. 5a), with the significance being due to a higher response by respondents from South Asia ($\chi^2 = 8.33$, $p_{bonf} = 0.0039$). Subregions differed significantly in their opinion of pest outbreaks ($\chi^2 = 27.88$, df = 4, $p < 0.001$), with North American respondents selecting this as an impact significantly more frequently ($\chi^2 = 17.56$, $p_{bonf} = 0.00003$) and Southeast Asian respondents significantly less frequently ($\chi^2 = 16.43$, $p_{bonf} = 0.00005$) (Fig. 5b). Although 'disease spread' had the lowest frequency overall, there was a significant difference between subregions in the percent of responses indicating it as a major impact ($\chi^2 = 13.75$, df = 4, $p = 0.008$), with the highest percent of responses from East Asia ($\chi^2 = 8.27$, $p_{bonf} = 0.0040$) and lowest from Southeast Asia ($\chi^2 = 7.26$, $p_{bonf} = 0.0071$) (Fig. 5c).

When analyzed by profession, there was a significant relationship between respondents' profession and their view that 'forest productivity changes' ($\chi^2 = 7.055$, df = 2, $p = 0.029$), 'changes in forest fires/droughts' ($\chi^2 = 8.98$, df = 2, $p = 0.011$), and 'biodiversity changes' ($\chi^2 = 6.94$, df = 2, $p = 0.031$) are the major impacts of climate change in forest ecosystems (Table 6). The significance of 'changes in forest fires/droughts' was associated with a lower percent of responses from the government group than from other professions ($\chi^2 = 8.96$, $p_{bonf} = 0.0028$), while the significance of 'forest productivity changes' and 'biodiversity changes' was due to the higher percent of responses by private sector respondents ($\chi^2 = 7.00$, $p_{bonf} = 0.0082$; $\chi^2 = 6.84$, $p_{bonf} = 0.0089$, respectively).

The majority of respondents indicated that 'yes' actions or initiatives have been taken to address climate change in their subregion (Fig. 6a), and 'yes' there are specific policies or regulations available in their subregion that promote sustainable forest management (SFM) (Fig. 6b). Satisfaction with actions to address climate change were gauged among those who selected 'yes' from "1—very satisfied" to "5—not satisfied at all", yielding an overall mean satisfaction of $M = 2.70$ ($SD = 0.937$), between '2—somewhat satisfied' and '3—neither satisfied nor unsatisfied'. The indication that 'yes', policies and regulations that promote SFM are present was highest in North American and Southeast Asian respondents and among government respondents (Fig. 7). Although the majority indicated that policies specific to SFM exist in their subregion, 6% who specified a policy indicated that it exists only on paper and not in practice.

Satisfaction with actions to address climate change adaptation in respondents' countries as well as in the forestry sector was gauged from '1—very satisfied' to '5—not satisfied at all'. With regards to overall satisfaction with action to address climate change, there was a significant difference in the level of satisfaction among subregions

Table 5 Average ranking of responses by subregion for options to the question 'What are the major impacts of climate change on forest ecosystems in your region? (Check all that apply)'

Impacts	Overall	NA	EA	OC	SA	SEA
Changes in forest fires/droughts	1	2	1	1	4	1
Biodiversity changes*	2	3	2α	2α	1	2
Forest productivity changes	3	4	5α	5	3	3
Land suitability changes	4	6	5α	2α	2	4
Changes in pest outbreak**	5	1	4	4	5	5
Disease spread*	6	5	2α	6	6	6
Other	7	7	7	7	7	7

There is a significant relationship between 'biodiversity change' ($p < 0.05$*), 'pest outbreaks' ($p < 0.005$**) and 'disease spread' ($p < 0.05$*) with subregion

Note: Subregion abbreviations are the same as in Table 2

Units are rankings of responses, organized from 1 (of most concern) to 7 (of least concern), based on subregionally organized responses

* indicates a significant relationship ($p < 0.05$*) when evaluated by subregion

α indicates a tie in the percent of respondents that selected the impact

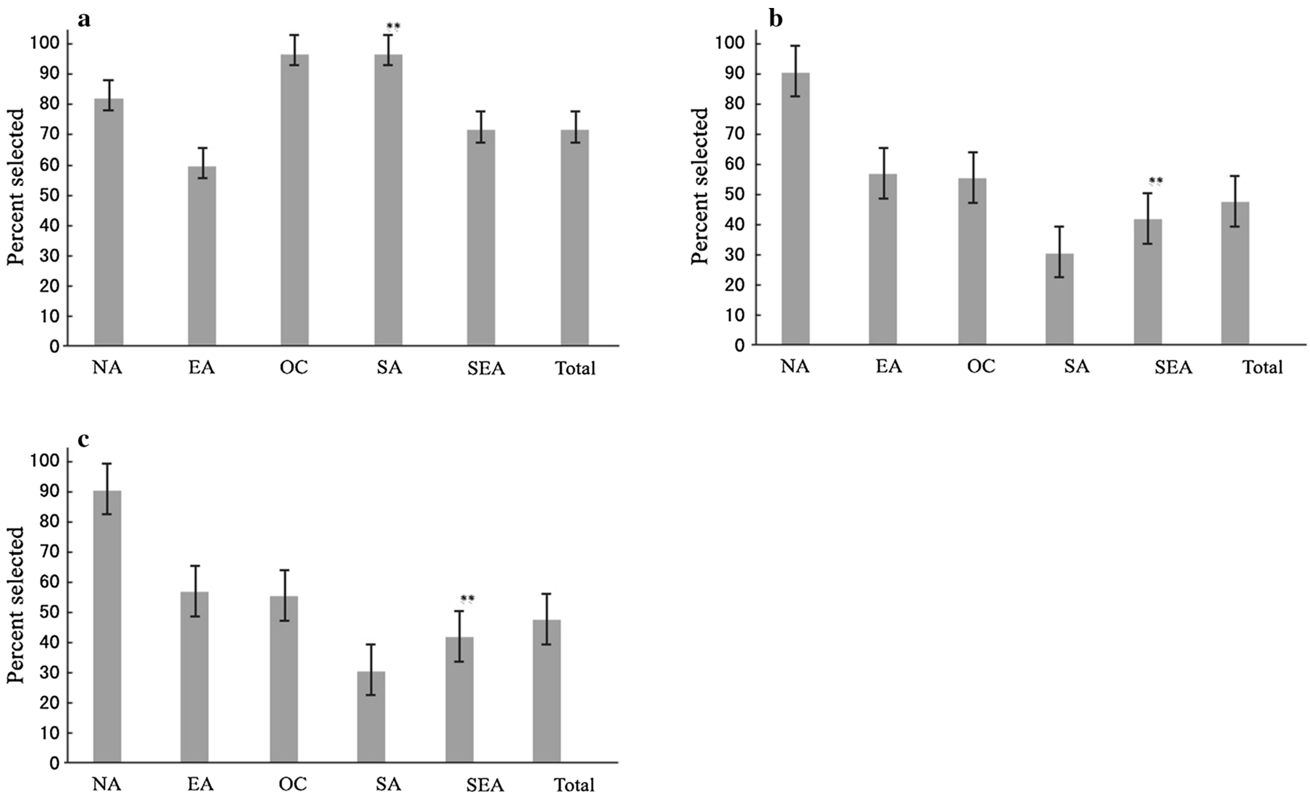

Fig. 5 Percent of responses by subregion associated with the selection of the variables (**a**) biodiversity change, (**b**) changes in pest outbreak, and (**c**) disease spread for the question 'What are the major impacts of climate change on forest ecosystems in your region? (Check all that apply)'. The subregion contributing most significantly ($p_{bonf} < 0.001$**) to the relationship with the variable is indicated above. This implies that South Asian respondents are more likely than other subregions to select 'biodiversity change', North American respondents are more likely to select 'pest outbreaks', and Southeast Asian respondents are less likely to select 'pest outbreaks' and 'disease spread' as a major impact of climate change. Subregion abbreviations are the same as in Table 2

($H = 18.49$, $p = 0.001$) (Fig. 8); no respondents from North America, Southeast Asia, government, or the private sector selected '1—very satisfied' for this question. However, mean satisfaction with actions to address climate change specific to the forestry sector was fairly similar among subregions (Fig. 8a) and among professions (Fig. 8b). There was a slightly more positive mean satisfaction with regards to initiatives in the forestry sector

Table 6 Percent of responses by profession to the question 'What are the major impacts of climate change on forest ecosystems in your region? (Check all that apply)'

Challenges	Overall (%)	Government (%)	Academic (%)	Private sector (%)
Changes in forest fires/droughts*	71.1	53.3	76.0	77.4
Biodiversity changes*	70.6	68.9	66.4	90.3
Forest productivity changes*	55.7	53.3	51.2	76.4
Land suitability changes	55.2	60	52.8	58.1
Changes in pest outbreak	47.3	35.6	48.0	61.3
Disease spread	40.3	33.3	38.4	58.1

Three of the impacts show a significant ($p < 0.05$*) relationship with profession. In the case of 'forest fires/drought', government respondents contributed most significantly ($p_{bonf} < 0.017$*) to the relationship, implying that they are less likely to indicate this as an impact of climate change. For 'forest productivity changes' and 'biodiversity changes', private sector respondents contributed most significantly ($p_{bonf} < 0.017$*)

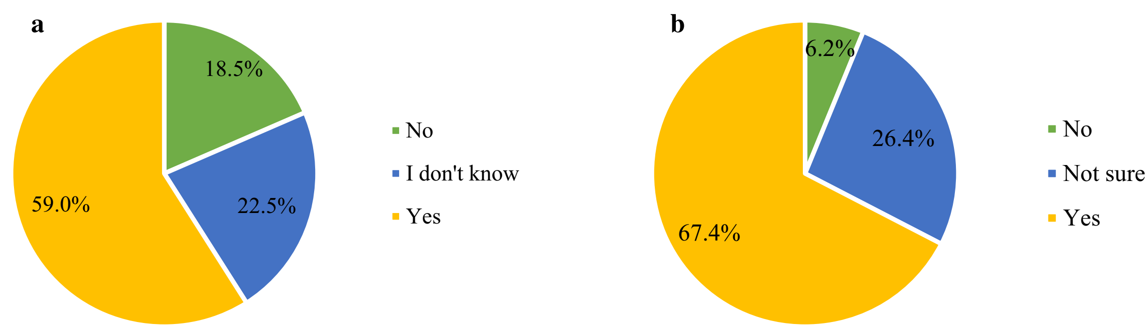

Fig. 6 Distribution of responses to the questions, **a** Are there any actions or initiatives that have been taken to adapt to climate change in the forestry sector in your subregion?, and **b** Are there any specific policies or regulations in your subregion that promote sustainable forest management?

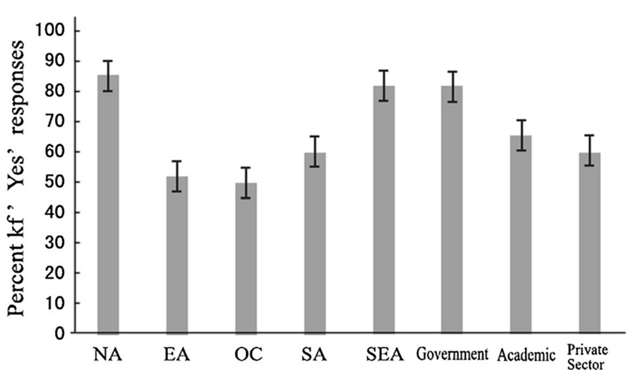

Fig. 7 Percent of respondents from each subregion and profession that indicated 'yes' there are specific policies or regulations in their subregion that promote sustainable forest management. Subregion abbreviations are the same as in Table 2

($M = 2.70$, $SD = 0.937$), with the mean lying between '2 – somewhat satisfied' and '3—neither satisfied nor unsatisfied', as compared to climate adaptation action at the country level ($M = 3.28$, $SD = 1.8$), with the mean lying between '3—neither satisfied nor unsatisfied' and '4—somewhat unsatisfied'.

The most frequently selected challenge for the forestry sector to adapt to climate change was 'public awareness' (63.7%), followed by a 'lack of scientific guidance' (59.2%) (Table 7). Among subregions, 'public awareness' was the most frequently selected challenge, except for North America and Oceania where 'actions plans' (76.2%) and 'legislation' (63.0%) were the most frequent, whereas all professions differed in the most frequently selected challenge for the sector to adapt to climate change (Table 7). There was a significant difference among subregions in the percent of responses for 'public awareness' ($\chi^2 = 14.50$, df = 4, $p = 0.006$), with the significance being due to a low selection of this variable among Oceania respondents ($\chi^2 = 9.57$, $p_{bonf} = 0.002$) (Fig. 9a). The challenge of 'stakeholders' participation' differed significantly among professions ($\chi^2 = 6.76$, df = 2, $p = 0.034$) (Fig. 9b). Although the profession associated with this difference was not discernable based on adjusted residual analysis, the concern tended to be higher for the private sector (71.0%) and lower for academics (48.8%). Furthermore, there was a significant difference in the number of challenges selected by each subregion ($H = 12.42$, $p = 0.014$), with North America on average selecting the most ($M = 3.43$, $SD = 1.12$) and Oceania on average selecting the least ($M = 2.37$, $SD = 1.08$).

Respondents were asked to select areas that lack scientific support that could help address climate change

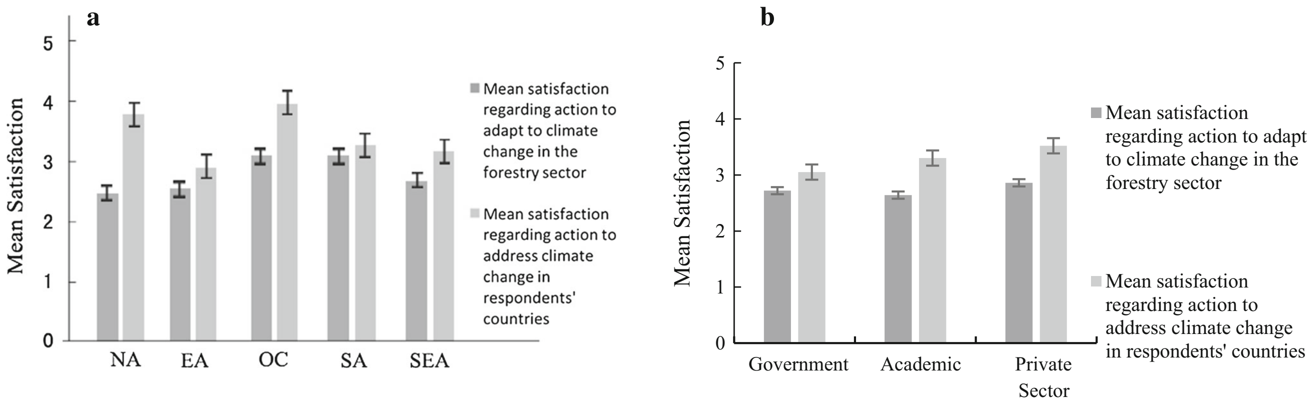

Fig. 8 Mean satisfaction by **a** subregion and **b** profession regarding action taken to adapt to climate change in the forestry sector (dark grey), and in the respondents' countries (light grey). Subregion abbreviations are the same as in Table 2

Table 7 Challenges for the forestry sector to adapt to climate change ranked according to percent of responses—overall, by subregion, and by profession

Challenges	Overall	NA	EA	OC	SA	SEA	Government	Academic	Private sector
Public awareness*	1	2α	1	4	1	1	1	2	3
Lack of scientific guidance	2	3	2	3α	2	2	3	3	1
Legislation	3	2α	3α	1	4	5	5	1	5
Action plans	4α	1	3α	2	5	4	4	4	4
Stakeholders participation*	4α	3	4	3α	3	3	2	5	2

There is a significant ($p < 0.05$*) relationship between selection of public awareness and subregion, and a significant relationship ($p < 0.017$*) between selection of stakeholders' participation and profession

Note: Subregion abbreviations are the same as in Table 2

Units are rankings of responses, organized from 1 (of most concern) to 5 (of least concern) based on sub-regionally organized responses

α indicates a tie in the percent of respondents that selected the challenge

* indicates a significant relationship ($p < 0.05$*) when evaluated by subregion

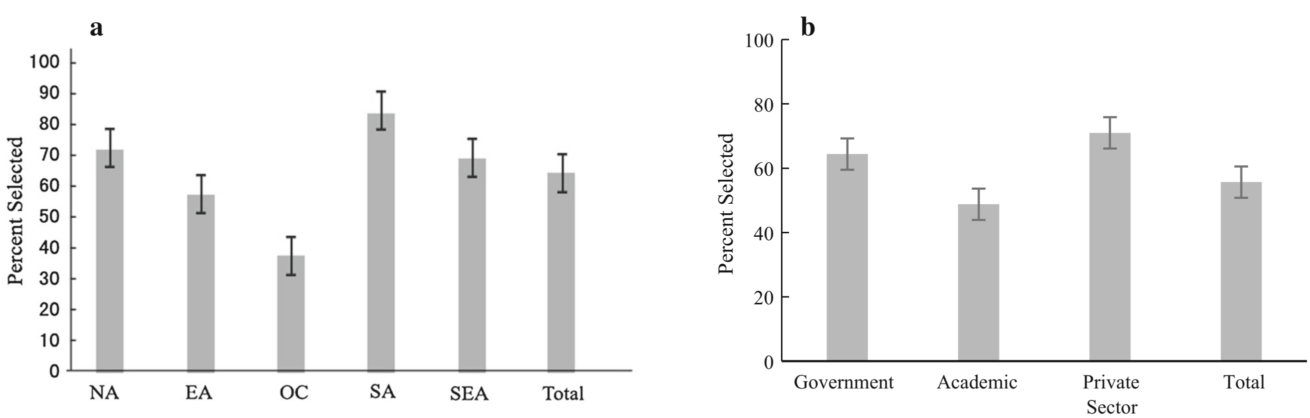

Fig. 9 Percent of respondents from: **a** each subregion that selected 'public awareness' and from **b** each profession that selected 'stakeholders' participation' in response to the question 'What are the most important challenges for the forestry sector to adapt to climate change in your subregion (check all that apply)?'. In the case of 'public awareness', Oceania contributed most significantly ($p_{bonf} < 0.017$*) to the relationship, implying that these subregional respondents were less likely to select 'public awareness' as a challenge for forest adaptation. In the case of 'stakeholders' participation', no single profession was responsible for the relationship. Subregion abbreviations are the same as in Table 2

adaption. ‘Understanding of local predicted climate change scenarios’ received the highest response percent (69.2%) (Table 8) among all professions (government = 71.1%, academic = 63.2%, private sector = 83.9%), and subregions, with the exception of Oceania (South Asia = 87.5%, North America = 71.4%, Southeast Asia = 69.4%, East Asia = 63.6%, Oceania = 51.9%). ‘Understanding ecosystem dynamics’ was the most frequently selected response among Oceania respondents (63.0%). There was a significant difference in the average number of responses selected among subregions ($H = 17.27$, $p = 0.002$) and professions ($H = 10.24$, $p = 0.006$); SA ($M = 3.58$, $SD = 1.25$) [on average selected significantly more variables] compared to Oceania ($M = 2.15$, $SD = 1.32$), and the private sector selected on average ($M = 3.34$, $SD = 1.38$) significantly more variables than academics ($M = 2.49$, $SD = 1.43$). There was a significant relationship between subregion and selection of ‘knowledge on climate change’ ($\chi^2 = 14.36$, df = 4, $p = 0.006$). South Asia (58.3%) had the highest response percent while Oceania (22.2%) had the lowest; however, the specific subregion or subregions contributing to the significant relationship is unclear as the adjusted residual analysis was inconclusive.

When inquiring if climate change models and planning tools for developing forest management plans that address climate change were available in the subregion, ‘I don’t know’ was the most common overall response (41.2% and 45.7%, respectively) (Fig. 10). This was also true subregionally, with two exceptions regarding model development; the majority of Oceania respondents indicated ‘Yes’ (65.4%), and there were equal responses between ‘I don’t know’ and ‘Yes’ (47.6%) for North America. Regarding the availability of climate change models, 65.7% of respondents indicated that only ‘some’ or ‘no’ models were publically available; 41.2% of respondents did not know the suitability of these models for forest management planning. With regards to forest management planning tool availability, no respondents from North America indicated that ‘high resolution climate models of the region’ were available.

Suggestions for addressing climate change

Respondents were asked to rank the importance of 5 different actions for addressing climate change on a scale from ‘1—least important’ to ‘5—most important’. Out of 201 responses, 178 respondents answered this question completely. When analyzed by subregion, there were significant differences regarding the rankings for ‘governance and institutions’ ($H = 17.34$, $p = 0.002$, df = 4) and ‘climate change expert networks and cooperation’ ($H = 14.57$, $p = 0.006$, df = 4), which had overall means of $M = 4.19$ ($SD = 1.08$) and $M = 3.58$ ($SD = 1.23$), respectively. Southeast Asian respondents showed significantly higher concern for ‘governance and institutions’ than East Asian respondents (Mann–Whitney U-test; $U = 35.33$, $p = 0.001$) (Fig. 11a). North American respondents had a significantly higher average concern regarding ‘climate change expert networks’ than South Asia ($U = 52.54$, $p = 0.012$), Southeast Asia ($U = 49.56$, $p = 0.003$), and East Asia ($U = 44.15$, $p = 0.026$) (Fig. 11b).

There was a significant difference in overall mean ranking by action ($H = 40.68$, df = 4, $p < 0.001$) (Fig. 12), as ‘climate change expert networks and cooperation’ was ranked significantly lower than all other variables: ‘scientific support’ ($U = 94.26$, $p = 0.006$), ‘management guidance’ ($U = 117.02$, $p < 0.001$), ‘legislation and policies’ ($U = 144.04$, $p < 0.001$), and ‘governance and institutions’ ($U = 151.23$, $p < 0.001$).

Table 8 Ranking of areas lacking scientific support to address climate change adaptation based on average response percent—overall and by subregion

Scientific area	Overall	NA	EA	OC	SA	SEA
Understanding of local predicted climate change scenarios	1	1	1	2α	1	1
Forest adaptation and/or rehabilitation techniques	2	2	2	2α	3	2
Understanding of ecosystem dynamics	3	3	3	1	2	3
Knowledge on climate change*	4	4	5	4	4α	4
Sophisticated climate models	5	5	4	3	4α	4

There is a significant ($p < 0.05$*) relationship between subregion and selection of ‘knowledge on climate change’ as an area lacking scientific support

Units are rankings of responses to question from 1 (of most concern) to 5 (of least concern), based on subregionally organized responses

Note: Subregion abbreviations are the same as in Table 2

α indicates a tie in the percent of responses

* indicates a significant relationship ($p < 0.05$*) when evaluated by subregion

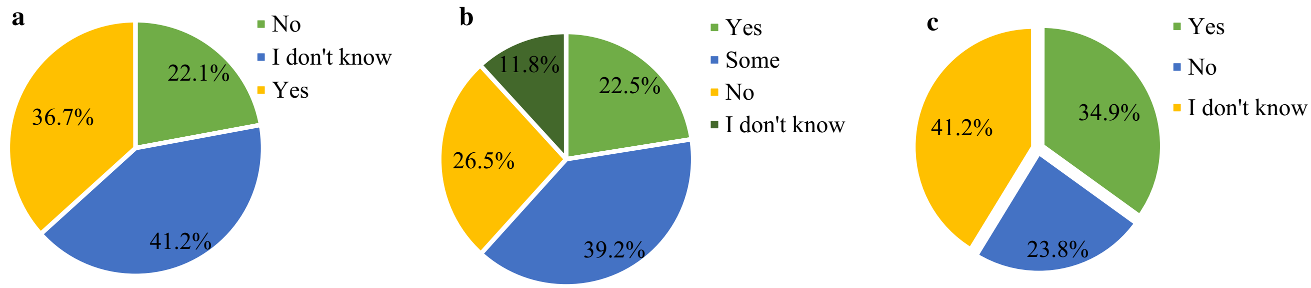

Fig. 10 Distribution of responses to the questions **a** Have any climate change models been developed in your region? **b** If yes to the previous question, does the public have access to the climate change models? and **c** If yes to the first question, are the models suitable for forest management planning?

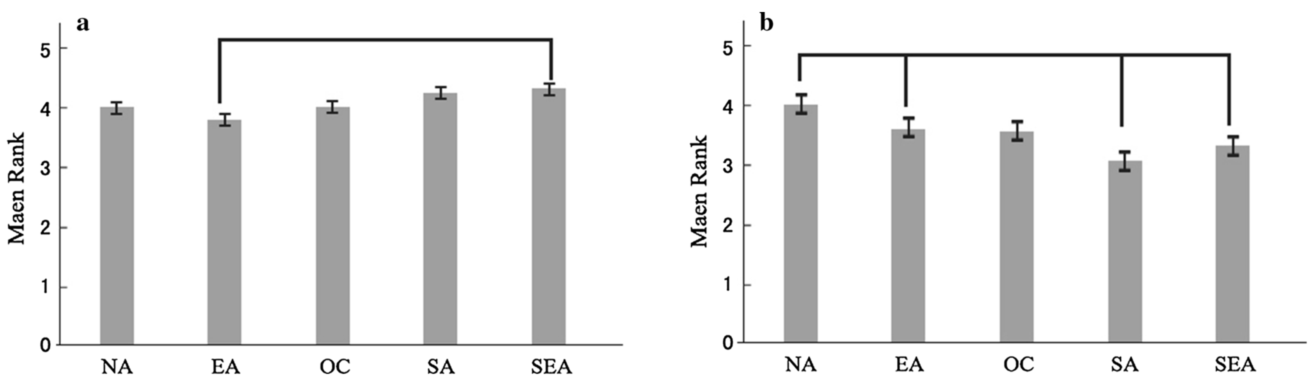

Fig. 11 Mean rank of importance by subregion for (**a**) 'governance and institutions' to address climate change, and (**b**) 'climate change expert networks and cooperation' to address climate change. SEA respondents ranked governance and institutions significantly ($p < 0.005$**) higher than EA, and NA ranked expert networks significantly ($p < 0.05$*) higher than SA, SEA, and EA. Subregion abbreviations are the same as in Table 2

Discussion

Main impacts of climate change

The objective of this survey was to identify expert perspectives on the impacts of climate change in the Asia–Pacific region, and to explore current challenges, recommendations and initiatives for adapting regional forests to climate change. As expected, there are subregional and professional differences in opinion regarding the impacts of climate change related to economic and forestry activities, as well as different challenges faced by groups regarding the availability of research and technology and their ability to move forward with adaptation and mitigation activities. However, there are also similarities present among subregions and professions, indicating that similar steps can be taken to resolve these issues across regional and professional sectors.

Although specific concerns about climate change varied by subregion, there was a common concern regarding hydrological related issues such as drought, flooding, and freshwater shortages. The Asia–Pacific is a region adapted to, and reliant on, seasonal rainfall patterns driven by monsoons, with cyclic variability driven primarily by the El-Nino-Southern Oscillation (ENSO) and the Indian Ocean Dipole (IOD) (IFAD 2009; Christensen et al. 2013). Climate change is expected to alter these climate systems, causing shifts in their arrival times and intensities, leading to variable impacts in the region such as flooding, drought, and greater intensity and frequency of extreme weather events such as tropical cyclones (FAO 2010; Ahmed and Suphachalasai 2014). Although flooding was of highest concern in South Asia and Southeast Asia, the literature suggests that these subregions are also vulnerable to drought and water-stress as a result of climate change (IFAD 2009; Loo et al. 2015). The selection of 'flooding' as more of a concern than 'drought' by these subregions highlights that broad-scale projections and patterns may not match local circumstances and concerns. The respondents may be located in areas within the region more prone to flooding, while other areas will experience drought. Variability within subregions is expected, as the impacts of climate change will differ seasonally and among river basins (Westphal et al. 2013; Hijioka et al. 2014), and shifting rainfall patterns may leave some areas inundated with water and some in extreme drought (The World Bank 2013). As such, forest management efforts across the

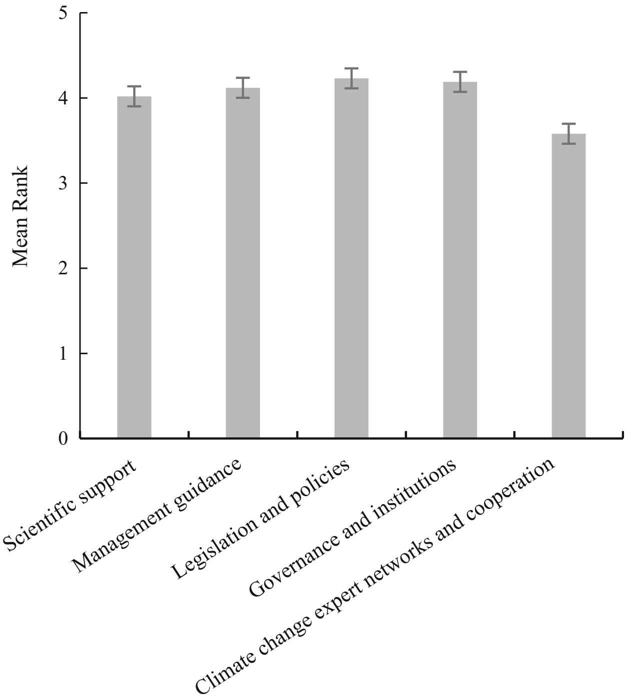

Fig. 12 Mean rank of importance of actions to address climate change. 'Climate change expert networks and cooperation' was ranked significantly lower than 'scientific support' ($p < 0.05$*), 'management guidance' ($p < 0.005$**), 'legislation and policies' ($p < 0.005$**), and 'government and institutions' ($p < 0.005$**)

region may benefit from research into locally specific climate change impacts such as changes in rainfall patterns. The application of locally specific, high accuracy climate and ecological models (e.g., those used by Wang et al. 2016a, b) are essential to generate accurate predictions that can be used to tailor future management strategies to address ecosystem vulnerability.

The generally positive impact of climate change on forest productivity (Boisvenue and Running 2006) was recognized by respondents. Acknowledgement of this potential benefit creates an opportunity for forest managers and researchers to explore ways to maximize it. For instance, niche modelling in China has shown how the niches of ecologically and economically important tree species will shift spatially and temporally with climate change (Wang et al. 2016a, b). The use of ecological models, such as FORECAST Climate (Seely et al. 2015), can be used to evaluate the long-term impacts of climate change and forest management strategies on forest productivity (Kang et al. 2016), and trade-offs between economic and ecosystem-related factors [e.g., using the Landscape Summary Tool (LST)] can be analyzed to determine the best possible management strategies under climate change (Kang et al. 2016). This type of locally specific analysis can be used to develop long-term management strategies such as plantation development and reforestation projects in accordance with habitat suitability for species that capitalize on changes in climate to maximize productivity and maintain ecosystem vitality.

Agricultural production and forest ecosystem stability are particularly vulnerable to changes in climate (FAO 2012b; Hijioka et al. 2014), and this was reflected in the respondents' comments that these sectors will be most affected by climate change. Although some crops in certain locations may be expected to see an increase in productivity [e.g., winter wheat in China (Hijioka et al. 2014)], increases in temperature and changes in precipitation patterns are expected to have an overall negative impact on agriculture and forestry in the Asia–Pacific region, resulting in lower crop yields, increased pest outbreaks, crop damage, changes in the length of the growing season, increased frequency of fires, and greater soil erosion (Asia Development Bank 2009; Hijioka et al. 2014). This in turn will impact the economic stability of these sectors which currently play a key role in sustaining the Asia–Pacific economy (Asia Development Bank 2009; FAO 2010). The populations of several subregions rely heavily on agriculture and forestry for their livelihoods; for instance, approximately 200 million people depend on non-timber forest products for income and subsistence needs (FAO 2010), and SEA's agriculture industry employed 52.78% of the population and contributed to 12.57% of GDP in 2015 (OCED/FAO 2017). Agriculture and forestry are key areas of concern and importance across the Asia–Pacific region, and effort should be made to better understand the consequences of climate change on these sectors. Research regarding ecological, social, and economic impacts, as well as the interaction between these sectors under climate change, is necessary, particularly regarding the potential of agroforestry in maintaining more resilient and sustainable land-use systems (Verchot et al. 2007; Ong et al. 2015).

Results of this analysis show some consistency between subregions regarding the major impacts of climate change, with the most frequent responses concerning forest fires, drought, flooding, and biodiversity changes. The main disparity among subregions is a higher concern for pest outbreaks among North American respondents, which may be due to the Mountain Pine Beetle outbreak in western North America over the past two decades, making this a prominent concern. The outbreak has impacted over 18 million ha of Canadian pine forest (Natural Resources Canada 2016), while other Asia–Pacific subregions have not experienced the same recent, large-scale pest outbreaks. The high concern for biodiversity changes as an impact of climate change is expected, as the Asia–Pacific region contains some of the world's most diverse ecosystems (CEPF 2016), including 13 of 34 biodiversity hotspots (UNEP 2010). However, the perceived severity of changes in biodiversity differed between regions, with South Asia indicating the greatest concern. Although more biodiversity conservation research is conducted in South Asia than in Southeast Asia, there is substantially less literature on the subject from South Asia compared to East Asia, Oceania, and North America (Wilson et al. 2016). Given the high degree of concern for biodiversity, effort should be made to increase research focused on biodiversity conservation in South Asia. This, in conjunction with improved knowledge of the expected changes in climate in the subregion, will enable better understanding of the impacts of climate change on biodiversity, which may improve implementation of mitigation measures.

Tools for climate change adaptation and mitigation

High public awareness of the impacts of climate change is related positively to risk perception (Schulte and Miller 2010), which is critical for climate change adaptation and successful implementation of adaption and mitigation strategies. Insufficient awareness about ecological requirements and sustainable management practices among forest- dependent communities may constrain their adaptive capacity for future climate change (FAO 2012a). In South Asia, education and awareness were great concerns, as 'public awareness' was the most frequently selected challenge and 'knowledge on climate change' was selected as most lacking scientific support. Research suggests that awareness of the existence of climate change in South Asian countries occurs in 30–39% of the population, while in Australia (the country having the majority of OC respondents), 97% of the population is aware of climate change (Lee et al. 2015). However, of the people who are aware of climate change in South Asia, the percentage of people who view climate change as a serious threat is between 80 and 89% (Lee et al. 2015). This is consistent with our findings that the challenge of public awareness related to climate change adaptation was lowest for Oceania and greatest for South Asia; although public awareness is low in South Asia, people who are aware of the issue such as this survey's respondents elicit high levels of concern regarding the economic and environmental implications of climate change. Programs to educate the public, employees of vulnerable economic sectors, and government officials are needed to reduce the challenges posed by uninformed (or misinformed) people. One such program was developed by the Climate and Development Knowledge Network in partnership with Panos South Asia (Panos South Asia 2014). It focuses on increasing climate change awareness in South Asian media through increased capacity and knowledge of the reporters themselves, ultimately leading to improved coverage of climate change issues and increased public awareness. The priority respondents placed on the lack of public awareness overall in the Asia–Pacific region suggests gaps in knowledge and understanding of the role of forests in climate change. More initiatives are needed across the region to reduce the hindrance that an uninformed public places on forest adaptation to climate change, particularly in South Asia where public awareness is of greatest concern.

Another important challenge for the forestry sector is to respond to a lack of scientific support, particularly a lack of understanding of locally predicted climate change scenarios. Variable adaptive capacities across the Asia–Pacific region (Wang et al. 2015) are highlighted by the differences in the number of areas lacking scientific support by subregions. However, a lack of scientific knowledge is a constraint on climate change adaptation for developed countries (Ford et al. 2011; Milfont 2012) and for developing countries (Begum and Pereira 2013). A lack of accessibility and understanding of the tools available for climate change adaptation may also contribute to a perceived lack of scientific support. From a professional standpoint, academics may be better able to access scientific tools due to resources provided by their employers as compared to respondents working in the private sector. This may account for the greater average number of selections for areas that lack scientific support by private sector respondents. Additionally, nearly half of the respondents indicated that they did not know what forest planning tools were available in their subregion. For instance, no respondents from North America indicated that high-resolution climate models were available, when these specific tools do exist for their subregion, e.g., ClimateWNA (Wang et al. 2012) and Climate Wizard (Girvetz et al. 2009). Improvements in the accessibility and dissemination of research findings, models, and management tools are necessary to enable researchers and resource managers to address areas where true knowledge gaps exist (Sterrett 2011).

Recent development of the climate model, ClimateAP, can address this lack of scientific support and help increase understanding of locally predicted climate change scenarios, as it is a locally specific, high-resolution model that is freely available and can be applied to any location in the Asia–Pacific region (Wang et al. 2016a, b). Furthermore, models such as ClimateAP (Wang et al. 2016a, b), FORECAST Climate (Seely et al. 2015), and LST (Kang et al. 2016), can address this gap in knowledge and scientific support, as they are applicable to species, ecosystems, and management plans in any location. These tools have been applied to several areas in the Asia–Pacific region (Kang 2015; Wang et al. 2015; Kang et al. 2017). However, further work using these tools and similar resources is needed to increase the support available in this region and to provide decision-makers and resource managers with better information to make well-informed decisions regarding policy implementation and the development of management strategies to cope with climate change (IPCC 2014).

Knowledge and strategies to adapt forests to climate change are not enough if there are insufficient quality action plans and legislation to transform this knowledge into action. Legislation and actions plans were identified as the most important issues for addressing climate change; however, they pose the greatest challenge to adaptation in North America and Oceania. This is reflected in the low levels of satisfaction regarding actions and initiatives taken to address climate change in these subregions. The indication that legislation is the main challenge in addressing climate change adaption may be a result of the low representation of government officials in Oceania and North America, as academics were the most highly represented group in these subregions. As a result, academic respondents may have less knowledge about the state and process of implementing legislation compared to other challenges such as scientific guidance. However, particular attention should be paid in these regions to developing effective and practical legislation for adaptation to climate change.

The results indicate an overall low level of satisfaction regarding actions taken to address climate change. Diverse goals, objectives, and scope of the available actions or initiatives often make it difficult for decision-makers to choose the appropriate strategy (Preston et al. 2011), potentially leading to outcomes that do not meet desired expectations. Action plans are often fragmented, lacking comprehensive solutions, focus on specified sectors, and fail to address long-term mitigation and adaptation to climate change (Preston et al. 2011; Dannevig et al. 2012; Runhaar et al. 2012). However, satisfaction does appear to be higher across all subregions when the focus shifts to actions and initiatives specific to climate change adaptation in forestry. This may reflect the importance of the forestry sector in the Asia–Pacific economy as forest-based industries are rapidly growing and make significant economic contributions in much of the region (Lebedys 2004; Agrawal et al. 2013). This may lead to more adaptation strategies focused on maintaining this important and lucrative industry, and may also be due to the bias of respondents, as respondents were forestry experts more likely to be aware of legislation and action plans focused on their particular area of expertise. This leads to a false sense of awareness that more action is being taken to address forestry adaption than on other climate issues.

Limitations

Although the questionnaire was distributed to residents of several countries, there was not an equal representation of experts from each country within the subregions. Since the effects of climate change are expected to vary within each subregion and since each country is unique in its vulnerability and adaptive capacity, the analysis for each subregion may not represent the views and conditions of each country within that subregion. Future research may benefit from analysis at the country level or lower, as this might generate more targeted and specific information to account for the nuances in climate change impacts and ecological, social, and economic conditions across the Asia–Pacific region.

It is evident that experts' opinions do not always agree with information in the published literature. It is difficult to determine whether this is due to the respondent associating their answers with an ecosystem or a situation that differs from the regional pattern, or whether it is simply due to the bias of a person's perception of a situation not always reflecting reality. To address this concern, future surveys could include questions designed to gauge the respondents' expertise on the subject, and respondents should be asked to provide further context so that information about their background and reasoning can be obtained from the survey.

Conclusion

Overall, this study identified consensus regarding the major impacts of climate change on forests, and the potential for increased forest productivity to be a positive outcome of a changing climate. This potential benefit should be capitalized on by developing management strategies that account for climate change and the responses of local ecosystems to environmental changes. It is also evident from this study that there are unique risks and challenges related to climate change adaption between subregions. As such, the same policies and management strategies cannot be applied to all locations, even within the same subregion, and locally based research is important to facilitate the development of strategies and policies specific to local needs and objectives. Furthermore, effort should be made by all levels of government, education institutions, and relevant organizations to increase public awareness of climate change impacts on forests, as knowledge is essential for developing socio-economic and ecological resilience to climate change. Greater understanding of climate change impacts may improve policy and legislation through an increased public demand for action. It is evident that actions, policies, and technologies have low accessibility and suitability in the Asia–Pacific region. Limited accessibility in some countries constrains the ability to generate coping strategies for specific problems, to implement national or local policies, and to further adaptive capacity. Without accessible information, assessments about climate change may be biased, limiting the suitability of policies or technologies. To address this, the research community should increase development and accessibility of climate and ecosystem models, and support research to reduce this knowledge gap and increase adaptive capacity across the region. This will enable better informed policy and management decisions and may help address the lack of action taken towards climate change adaption and the dissatisfaction with current policies and legislation in this region.

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