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Mapping research gaps for sustainable forest management based on the nominal group technique

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Abstract
Managing a complex social-ecological system requires data about the many social and ecological variables characterizing it and about their interactions. While the selection of research topics has its own, mostly unpredictable dynamics and contingencies, there has been a recent surge of interest regarding the involvement of non-academic stakeholders in suggesting research topics and identifying perceived knowledge gaps regarding the management of complex social-ecological systems. Decision-makers will invariably be confronted with limitations regarding resources to be allocated to the study of various systems components, and regarding the processing capacity of scientists and other stakeholders alike. Matang forest is one of the longest-managed mangroves in the world and provides a widely cited example of silvicultural management for charcoal and pole production, while providing a range of other ecosystem services. We applied the nominal group technique (NGT) to identify research priorities for Matang, as it provides a systematic and participatory approach to identify collective priorities while also reducing bias. The method consists of two rounds, during which participants were asked to reflect first individually, and then collectively, about key characteristics of mangrove management and about research priorities in Matang. The results were compared to the recommendations of the scientific literature. NGT provides a rapid, robust and systematic approach to identify research priorities for mangrove management and can hence be a timely method to support decision-makers across South-East Asia in guiding resource allocation toward research needs in times of increasing mangrove degradation. This is the first time that the application of NGT has been documented in a mangrove context. Moreover, NGT is not yet being used frequently in natural resources management, hence in documenting our NGT application, we aim to contribute to the development of a the NGT body of knowledge beyond mere mangrove forest settings. Rapid methods (such as NGT) to identify pressing research priorities are needed to guide resource allocation and investment of time and scientific capacity based on a systematic and pluralistic assessment.

Keywords Mangrove management · Stakeholders · Nominal group technique · NGT · Research needs · Research priorities · Malaysia · Matang

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1 Introduction

Global change processes ranging from anthropogenic climate change to the global impact of trade increase pressure on ecosystems all over the world. As the demand for natural resources increases, human management decisions are increasingly replacing self-regulatory processes (DeFries & Nagendra, 2017). However, making the most adequate decisions to manage ecosystems sustainably is a complex challenge. One cannot foresee all consequences of interventions across different spatial, temporal and governance scales, hence ecosystem management has no clear-cut solution. There is no one-size-fits all approach to ecosystem management (DeFries & Nagendra, 2017; Ostrom et al., 2007). Among other reasons, this is due to the fact that the preferences and perceptions of most resource users are not the same. As most environmental and natural resource management challenges are collective action problems, the inclusion of a diverse range of stakeholders becomes essential to design and apply resilient and sustainable ecosystem management approaches (Bodin, 2017; Tallis & Lubchenco, 2014). Stakeholders are those who are affected by management decisions and who can influence their outcome (Reed et al., 2009). They contribute alternative perspectives on the desirability of various management objectives and their inclusion increases the perceived legitimacy of decisions (Wadsworth et al., 2014). Moreover, stakeholders also help to identify neglected ecosystem services (de Souza Querioz et al., 2017). Ideally, these very same stakeholders should hence be included in research prioritization.

While the selection of research topics has its own, mostly unpredictable dynamics and contingencies, there has been a recent surge of interest regarding the involvement of non-academic stakeholders in suggesting research topics and identifying perceived knowledge gaps regarding the management of complex social-ecological systems. Calls for a transdisciplinary approach to ecosystem management (Angelstam et al., 2017; Sutherland, Butchart, et al., 2018; Sutherland, Dicks, et al., 2018) invariably revolve around the joint identification of challenges and the co-production of action-generating knowledge (Jahn et al., 2012). Making decisions about which knowledge gaps to address is shaped by the same agencies, dynamics and biases that shape any collective decision (Mukherjee et al., 2018). Selecting which knowledge gaps to focus on by conducting scientific research eventually means making decisions about human and financial resource allocations, research priorities and visibility. Both stakeholder values and verifiable facts will shape any research prioritization decision. The management of complex tropical social-ecological systems, in particular, demands a systematic and inclusive approach, as the pressures of global change are impacting these systems strongly and rapidly.

Within the frame of this study, we will focus on mangroves. Mangroves are highly productive intertidal (sub-)tropical forest systems providing ecosystem services to millions of people, yet mangroves are also subject to a continuous degradation (Duke et al., 2007; Mukherjee et al., 2014). The exclusively coastal location exacerbates the pressure on mangroves (*e.g.,* due to increased demographic pressure and vulnerability to sea level rise) and makes their conservation and sustainable management all the more pressing (Duke et al., 2007).

Mangroves are conceptualized here as social-ecological systems: Mangroves provide a wide range of ecosystem services (Mukherjee et al., 2014), and this provision of humanly used resources is embedded in a complex ecosystem. A social-ecological system consists of multiple subsystems and internal variables, which are in constant interaction with each other (Ostrom, 2009; Stojanovic et al., 2016). A social-ecological system hence consists of

a resource system (e.g., a forest), resource units (e.g., individual trees), users (e.g., timber harvesters, charcoal industry workers, etc.) and a governance system (organizations and rules that govern the management of the forest). These sub-systems are relatively separable but are also in constant interaction with each other. Ignoring parts of the system can lead to incomplete understanding and mismanagement of mangrove forests (as shown for instance by Thompson (2018) when reporting false successes in mangrove reforestation hampered learning effects and created 'cycles of failure' due to a lack of acknowledgement of ecological realities and due to weak linkages between various actors). The social-ecological system's framework allows to identify and structure the ecological (resource system and resource units) and the social (user and governance system) components of scientific and management efforts needed to maintain the sustainability of such systems. Within the frame of this study, we aim at identifying knowledge gaps regarding the management of a complex social-ecological system, Matang mangrove forest reserve in Malaysia. The social-ecological system's framework will contribute to identify key stakeholders (i.e., users in SES terms), who will in turn be asked to identify and prioritize knowledge gaps following a structured collective judgement elicitation approach (the nominal group technique). The identified knowledge gaps will reflect under-studied and/or neglected topics of interest, which can in turn be situated within the social-ecological system's framework. Conceptualizing Matang as a social-ecological system (Ostrom, 2007), in which resource systems and their constitutive units interact with users and their governance systems allow to link the ecological and social dynamics shaping the area (Hugé et al., 2016).

Mangroves are subject to a range of management approaches (the 'governance' subsystem of SES), which can be categorized based for example on their land use purpose (van Oudenhoven et al., 2015). The management of low-intensity use mangroves is focused on forest products, while high-intensity use mangroves are plantations or high-intensity-use sylvo-fisheries systems. Other mangroves remain in a natural state or are converted to aquaculture with varying degrees of intensification (van Oudenhoven et al., 2015). Mangrove management regimes can also be categorized based on the degree of involvement of different categories of stakeholders in the setup and the enforcement of management rules (Datta et al., 2012).

Mangroves as social-ecological systems can hence be managed under different regimes, and multiple stakeholders can and do have different expectations and roles in managing these mangroves. Mangrove managers (formal and informal) face challenges, and this is particularly the case in Southeast Asia. While southeast Asia still holds the world's largest mangrove area, mangrove area is declining in this region too (e.g., in southern peninsular Malaysia as studied Sarmin et al., 2016) and mangroves remain comparatively neglected by decision-makers (Thomas et al., 2017), which is not reflecting a cautious tendency to convergent standards in sustainable forest management in Malaysia's terrestrial productive forests (Abdul-Rahim & Mohd-Shahwahid, 2012).

Matang Mangrove Forest Reserve in Malaysia can be termed a high-intensity-use mangrove and is often presented as an exemplary forest in the literature, a forest in which a sustainable management model is implemented (Ahmad, 2009; Ammar et al., 2014). However, recent studies on silvicultural rejuvenation (Goessens et al., 2014) and on the plurality of perspectives on the current management regime (Hugé et al., 2016) add nuance to this picture.

Matang mangrove forest reserve (hereafter Matang) covers an area of approximately 40,000 hectares (ha) along a 52 km long coastal stretch located in the state of Perak on the west coast of peninsular Malaysia (4_150-5_10 N; 100_20-100_450 E) (Ibharim et al., 2015). The management regime in the productive sections of the forest is based on

a 30-year rotation with first and second thinning for pole production (when the trees reach 15 and 20 years, respectively), and clear-felling (when the trees reach 30 years) for charcoal production. Part of the clear-felled areas are replanted with *Rhizophora spp*. after two years. The management of Matang is designed, carried out and supervised by the Forestry Department of the state of Perak, which drafts a comprehensive management plan once every ten years (Ariffin & Mustafa, 2013) and allocates permissible (productive) forest land areas to pole and charcoal contractors. Studies on the implementation and relationships between the different actors of the management system in Matang indicate a generally consensual approach, in which the Forestry Department grants permission to charcoal and timber contractors using a rotation system. While Ammar et al. (2014) have analyzed opportunities for a further diversification of the mangrove-based economics and income-flows by linking it to the international REDD+ System (reducing emissions from deforestation & forest degradation), controlled access to and exploitation of timber- and charcoal-producing plots is the main forest-related activity so far. A study on the different stakeholders' perspectives on possible management change reflects a mostly cautious, reformist approach to diversify the management to focus increasingly on eco-tourism (Ahmad, 2009; Hugé et al., 2016), without jeopardizing the main existing economic activities. Open conflict regarding the forest's management appears rare to non-existent (Ammar et al., 2014; Goessens et al., 2014; Hugé et al., 2016).

Matang has been the subject of a range of—mostly uncoordinated—scientific studies in the last few decades, covering a wide range of topics including silviculture and management (Aziz Thomas, et al., 2015; Aziz Phinn, et al., 2015; Aziz et al., 2016; Goessens et al., 2014; Hamdam et al., 2014; Ibharim et al., 2015), natural regeneration (Amir, 2012), pollution (Auta et al., 2017; Ghaderpour et al., 2014; Rahman et al., 2017), invertebrate ecology (Chew et al., 2015), fish larvae assemblages (Ooi & Chong, 2011); and building on a variety of disciplines and methods (including remote sensing (Aziz Phinn, & Dargusch, 2015; Aziz Thomas, et al., 2015; Ibharim et al., 2015), tree density measurement (Goessens et al., 2014), stakeholder perception studies using *Q* methodology (Hugé et al., 2016), and bird census (Khaleghizadeh et al., 2014) among others. Still, important knowledge gap probably remains, and this realization triggered the present study.

The identification of research priorities is often based on surveys of experts and practitioners—mostly scientists—and often has a broad (often global) scope, e.g., focusing on research priorities for marine ecosystem services (Rivero & Villasante, 2016) or on emerging issues for global conservation and biodiversity (Sutherland Butchart et al., 2018; Sutherland Dicks et al., 2018). While the diversity of ecological thinking among scientists seems to be increasingly acknowledged (e.g., through global Delphi studies (Mukjerhee et al., 2014)), the diversity of perspectives outside the scientific world is still insufficiently translated into the selection of research priorities. In the present study, we focus on the identification of research priorities for a specific social-ecological system: Matang mangroves, for which we involved a wider range of participants, going beyond the prevailing '-scientific- experts only'-approach. This inclusion of non-scientists has a good potential to yield community- and society-relevant research and to avoid feelings of dissatisfaction regarding research lines and hence funding agencies and researchers present in the area (e.g., da Silva et al., 2014). Hence, dialog between scientific and other stakeholder knowledge is essential in the joint search for effective solutions to social and environmental problems (Silva Abreu et al., 2017) and in the development of future-proof scenarios for management and research (Carlsson et al., 2015). Following up on the mapping of the plurality of perspectives regarding the management of Matang (Hugé et al., 2016), this study aims at gathering information on stakeholder preferences regarding research prioritization in one

of the world's longest-managed mangroves. Furthermore, this study aims to explore the applicability of the nominal group technique (NGT) to identify knowledge gaps and to suggest future research priorities.

2 Materials and methods

2.1 The nominal group technique (NGT)

Although the importance of including the knowledge and perspectives of a variety of stakeholders in support of the management of complex social-ecological systems is now increasingly recognized, selecting which method to use in a particular case is not straightforward. Based on the review of judgement elicitation techniques of Mukherjee et al. (2018), we opted for the nominal group technique (NGT) to elicit the judgements of a group of stakeholders and to come up with a list of knowledge gaps to be addressed in priority regarding Matang mangrove forest reserve. Given the fact that NGT explicitly focuses on eliciting judgements, includes both individual and collective reflection, and can be organized with a relatively low logistical and facilitation loads, the method was considered appropriate for the present study's objectives. A Delphi method (iterative survey among resource persons (Mukherjee et al., 2018)) was initially considered as another possible method, but the possibility for live group interaction and the output of prioritized options were considered a key advantage of NGT. Delphi has the advantage of maintaining anonymity among participants but lacks the option of live interaction and hence typically reduces opportunities for social learning.

The nominal group technique (NGT) is a structured group-based technique in which participants are first asked to individually reflect and to generate ideas based on pre-determined, structured questions asked by a facilitator (e.g., what are research priorities in this specific area?). Subsequently, participants are asked to collectively prioritize the ideas and suggestions issued by the group members (Hugé & Mukherjee, 2018; de Ven & Delbecq, 1971). NGT is based on a combination of individual and collective reflection and eventually generates a list of ranked priorities. The technique is used in a variety of fields ranging from spatial planning (Hugé, 2017) to business, and increasingly –yet still relatively infrequently—in conservation and natural resources management (Hugé & Mukherjee, 2018). NGT outputs range from lists of management needs and indicators to top five (Colton & Bissix, 2005) or top ten (Mountjoy et al., 2014) priority issues. NGT results are sometimes used as an input to multi-criteria exercises (e.g., to assign weightings to different criteria).

Two subsequent NGT applications (during one workshop session) were conducted in the present study, involving the same group of participants. All participants were informed about the objectives and the use of the study results, and their anonymity has been guaranteed. Each NGT application centered on a different question:

Questions asked during the NGT 1:

- According to you, which part of the current mangrove management in Matang could be a source of inspiration for other mangrove areas in the region? Please list three good characteristics of mangrove management in Matang that could also be applied in other areas.

Question asked during NGT 2:

- According to you, what would be useful to know about Matang mangroves? Please list three topics of interest for which additional research could be useful.

Both questions were open-ended, and each question required a separate NGT application. Before the start of the NGT, the facilitators gave a brief introduction on the context of mangrove management in Matang, and on the purpose of the exercise. The facilitator team consisted of four researchers (two Malaysian researchers with extensive field experience and an extensive network in Matang, and two Belgian researchers, who were also knowledgeable of the Matang area, and who were experienced NGT facilitators). The facilitators did not provide any hints at the content of the answers that would be expected—the participants were free to respond as they wished. The facilitators only provided the starting questions (these are the structured questions that are asked at the start of an NGT). Before the start of the NGT, participants were asked to provide information regarding their professional background. Each NGT application (both NGT question 1 and NGT question 2) consisted of four steps (following the outline proposed in Hugé & Mukherjee, 2018):

2.1.1 Step 1: Generation of ideas

The participants were asked to reflect individually about the question asked and to write down a range of ideas in bullet points. At this stage, there was no interaction among participants.

2.1.2 Step 2: Sharing and recording ideas

The ideas are subsequently shared in the group by way of a round robin feedback session (one response per person each time) to record each idea concisely. Each participant can contribute one idea at a time until all ideas are exhausted and has the opportunity to voice his/her opinion freely, without rejection or modification of their view before the group discussion starts. The ideas were recorded by the facilitators on a PC and projected on a screen in real time by the facilitators.

2.1.3 Step 3: Group discussion

During the third strep, the participants are invited to clarify and elaborate on the ideas proposed by all in Step 2. This step ensures that every listed idea is clearly understood, so as to facilitate the ranking exercise in Step 4. The facilitators ensured that everyone can contribute to the discussion, which was held in English and in Bahasa Malaysia (Malay), in simultaneous translation. Similar ideas are grouped based on an open discussion, while there is no value judgement or ranking of ideas yet at this stage.

2.1.4 Step 4: Voting & ranking

In Step 4, participants were asked to publicly vote and rank each of the listed ideas. Participants were asked to vote openly, and hence non-anonymously, allowing to judge the popularity of the proposed ideas. Public voting was preferred in this case, as it generates interaction and group dynamics (Boddy, 2012), and can help the research team to gather additional insights on participants' motivations and preferences. Each participant was assigned three votes in the first NGT application, meaning that everyone could select three 'inspirational' characteristics

of mangrove management in Matang. In the second vote, each participant was assigned one vote, which had to be cast in favor of only one research priority. Step 4 resulted in 63 votes in the first NGT application (i.e., three votes per participant), and 21 votes in the second NGT application (i.e., one vote per participant). Individual participants were not allowed to cast more than one vote per idea. The results of the votes were compiled in real time by the facilitators and projected in a tally sheet (in Microsoft Excel) showing the number of votes for each idea. The most highly rated ideas were considered the group's most favored actions.

2.2 Selection of participants

All NGT participants were attending a mangrove management workshop in Kuala Sepetang, State of Perak, Malaysian July 2017. The workshop was organized jointly by the Malaysian university UMT (*Universiti Malaysia Terengganu*), the Belgian university ULB (*Université Libre de Bruxelles*) and the Perak Forestry Department (*Jabatan Perhutanan Negeri Perak*) and was part of the MAMAFOREST project, funded by the Belgian Science Policy. All participants were invited, and the sample included people with a direct link with Matang (Forestry department officials, charcoal contractors, ecotourism actors, scientists). While the diversity of stakeholders' perspectives on the management of Matang mangroves has been studied before (Hugé et al., 2016), there has been no specific study on collectively identifying research priorities for Matang. As identified by *Q* methodology in previous research (Hugé et al., 2016), participants representing a diversity of perspectives on the management of Matang forest were invited. This ensured that a diverse range of opinions was represented within the participants of the NGT exercise.

The NGT participants also represent a relatively heterogeneous group in terms of background (See Sect. 3.1), meaning that the NGT would yield a diversity of perspectives on topics of research interest. In a future study, different successive NGTs involving participants with a more homogenous professional background could be envisaged and their results could be compared. Most NGT applications in ecology and conservation involve between 4 and 20 participants (Hugé & Mukherjee, 2018). This study was conducted with 21 participants, which is in line with international practice (as found by Hugé and Mukherjee (2018) in a review of NGT applications in ecology & conservation).

2.3 NGT: data analysis

After an NGT, the facilitators already had an overview of the ideas of the group (the main ideas having been synthesized collectively by the group in Steps 2 and 3), after which the scores had been expressed in the ranking and voting stages (Step 4). These steps are done during the actual NGT process. This allowed for an immediate reporting of the key results (that are co-produced by the participants and outlined live by the facilitators) to the participants. In the discussion section, the research priorities as listed and ranked by the NGT participants are compared to the research recommendations from published scientific literature on Matang.

2.4 Exploratory literature review to compare with NGT results

An exploratory literature search was conducted on scientific search engines Google Scholar and scienecedirect.com on January 28th, 2018, using the keywords 'Matang and mangrove.' Abstracts were read and non-relevant references were left out (these include

references to the homonymous Matang mangroves in Borneo). A selection of 14 scientific sources was analyzed in detail with regard to their inclusion of future research needs and research recommendations. Table 3 provides an overview of the research needs identified by the stakeholders in the NGT exercise and the research need identified in the scientific literature.

3 Case study findings

3.1 Case study findings: profile of participants

Participants were asked to report on their own professional background (no prior categories were given) before starting the exercise (demographic questions were asked at the start of NGT 1). Similar descriptions (e.g., scientists, researcher, academic) were clustered in agreement with the participants. Figure 1 shows the absolute number of participants per background (total number of participants = 21). Figure 2 shows the years of experience participants reported to have working in or on mangrove systems.

3.2 Case study findings: results of the voting and ranking exercise

The results of the NGT are presented as tally sheets, showing the ranked list of ideas, respectively, the characteristics of mangrove management in Matang that the participants deem inspirational and/or exemplary for other areas (Table 1), and the research priorities (Table 2). Absolute number of votes and share with regard to the total number of votes cast is presented (Fig. 3).

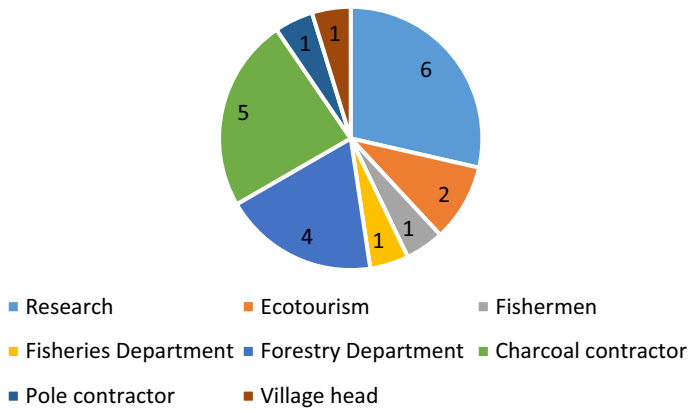

Fig. 1 Background of the NGT participants

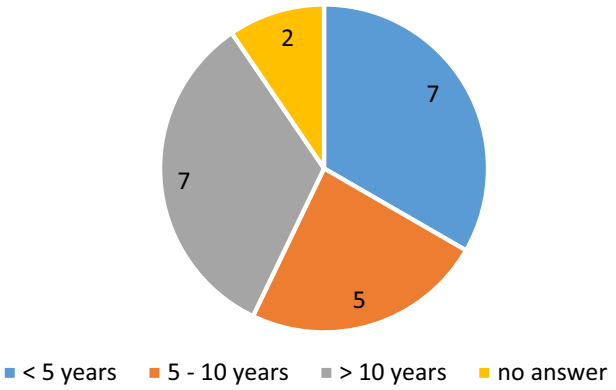

Fig. 2 NGT participants' self-reported experience on working in/on mangrove systems

4 Discussion

4.1 Key management issues & research priorities as expressed by the NGT participants

The NGT participants expressed a shared understanding of what makes Matang stand out as one of the longest continuously formally managed production mangroves in the world, by mentioning its overall silvicultural management scheme and associated sustainable wood extraction, and its use as an educational, research and eco-tourism site. While the unicity of the century-long management has been regularly highlighted (Jusoff & Taha, 2008), recommendations for improved management have been made in recent years (Aziz, Phinn, et al., 2015; Goessens et al., 2014; Hugé et al., 2016). The provision of direct economic benefits to local communities was cited by the participants, but was not mentioned as the key characteristic—probably because the provision of jobs along the charcoal and pole production chains (Quispe-Zuniga et al. unpublished data 2014) is inherently intertwined with the overall management approach as outlined in the management plans which are updated every ten years (Arifin & Mustafa, 2013). Fourteen percent of the participants cast a vote for the long-term vision, including climatic resilience, which is slightly more surprising, as, e.g., Goessens et al. (2014) explicitly mention the lack of acknowledgements of climate-related uncertainties in the management of Matang mangrove. However, this does not alter the overall conclusion of a considerable alignment of the stakeholders' opinions on what management aspects in Matang can inspire other mangrove management regimes.

The second NGT application allowed to identify and rank research priorities according to the participants. The need for a—quantitative—assessment of the sustainability of mangrove management in Matang is widely acknowledged and cited as the key research priority by one-third of the participants. This reflects the collective need to understand, share and fine-tune/improve the sustainability of the current management regime, based on scientific data and stakeholder inputs. The use of supporting remote sensing technologies is linked to this need for data in support of sustainable mangrove management (Dahdouh-Guebas, 2002). Water pollution emerges as another key research area for the participants, possibly at least in part influenced by the visible (macro-) plastic pollution in the rivers

Table 1 Results of the first NGT application, scoring the inspirational characteristics of mangrove management in Matang

Inspirational characteristic of mangrove management in Matang	Number of votes ($n=63$ votes, i.e., 3 votes/participant)	Share of votes (in %, as share of total number of votes ($n=63$)	Share of participants who included the idea in their top-3 (in %, as share of total number of participants ($n=21$))
Eco-tourism & eco-education	16	25.3	76.2
Sustainable wood extraction	14	22.2	66.7
Overall silvicultural management	10	15.9	47.6
Provision of jobs	5	7.9	14.3
Long-term vision in management incl. focus on (climatic) resilience	3	4.8	14.3
Economic viability of pole and charcoal production	2	3.2	9.5
Community engagement	2	3.2	9.5
Biodiversity and habitat conservation	1	1.6	4.8
Carbon sink	1	1.6	4.8
Surveillance and enforcement	1	1.6	4.8
Disaster prevention	1	1.6	4.8
Research (role of Matang as research site)	1	1.6	4.8
Prevention of damaging land use such as aquaculture	1	1.6	4.8

Table 2 Results of the second NGT application, ranking the research priorities

Research priority	Number of votes ($n=21$ votes, i.e., 1 votes/participant)	Share of votes (in %, as share of total of participants ($n=21$)
(Socio-)economic studies (quantifiable impacts, e.g., with vs. without logging), as part of integrated assessments	7	33.3
Water pollution (focus on plastics)	6	28.6
Mapping (remote sensing & GIS)	6	28.6
Effects of erosion (impact of boat waves on mangroves)	4	19.0
Effects of climate change	4	19.0
Soil accretion (vs. sea level rise)	3	14.3
Effects of ecotourism	3	14.3
Salt water seepage into drinking water resource	3	14.3
Mangrove phenology	2	9.5
Pathogens (in water)	2	9.5
Monitoring of work/jobs	2	9.5
Forestry (replanting, restoration ecology, self-thinning, clear-felling)	2	9.5
Yield/Productivity improvement	1	4.8
Width of the buffer zone (between rivers and productive forest zones)	1	4.8
Resource values of protective zones (economic value and livelihood)	1	4.8
Carbon sequestration	1	4.8
Biodiversity	1	4.8
Mangrove fisheries (role of mangroves for fisheries)	1	4.8
Variety of wood/diversification of trees	1	4.8
Propagule growth rate	1	4.8
Research infrastructure	1	4.8

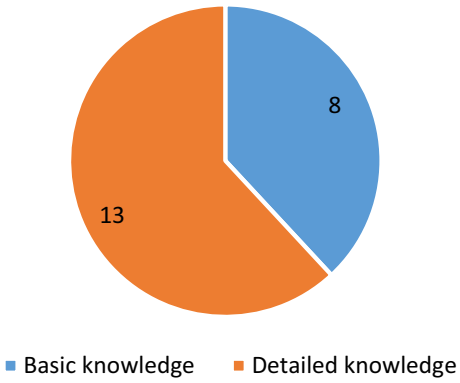

Fig. 3 Level of prior knowledge about Matang (before the workshop). Basic knowledge was defined as based on occasional visits, news, reports, friends. Detailed knowledge was defined as based on long-term work and/or study experience, multiple visits to the area)

and creeks surrounding the places with the highest population densities in Matang (such as the villages of Kuala Sepetang and Kuala Gula). The remainder of the identified research priorities consists of a mix of very specific questions driven mainly by local pressures and activities (e.g., regarding impacts of boat waves on erosion; the width of the buffer zones between productive forest zones and water channels; the diversification of productive mangrove wood species (Matang is now heavily dominated by *Rhizophora apiculata*)); and issues related to drivers at a non-local or even global level (e.g., climate change and its implications at the local scale (such as the rates of soil accretion vs. erosion)). The range of listed research priorities emerged as a result of the NGT, and some research topics seem generic compared to others (e.g., biodiversity and carbon sequestration are broad terms), or are mere specifications of general topics (e.g., monitoring of job provision and forest productivity would be part of the integrated socioeconomic assessment). We chose to stick to the terms and formulations proposed by the participants to give a clear picture of their preferences. While the management of Matang Mangrove Forest Reserve's actual forests is run by the forestry department and focuses mainly on silvicultural issues (e.g., see Ariffin & Mustafa, 2013), the knowledge gaps and research priorities also focus on non-strictly silvicultural topics, emphasizing the respondents' shared perspective that Matang is more than a forest—it is a complex network of forests, creeks, villages, that requires a multi-dimensional management framework.

4.2 Matang research priorities as expressed in the scientific literature

While the NGT application provided lots of relevant information on possible future research topics in Matang, Matang is not a virgin territory which has not been studied before. Therefore, a literature search was conducted to identify other possible future research topics in Matang. This approach, while not typically done as a complementary source of information after an NGT, can provide additional information and contributes to a better contextualization of the NGT results. Mukherjee et al. (2014) similarly compared the findings of a Delphi study (another stakeholder knowledge elicitation method) with the findings of the published literature in order to make practical suggestions at the level of mangrove management.

Table 3 provides an overview of the research needs identified by the stakeholders in the NGT exercise and the research need identified in the scientific literature.

Table 3 Comparison between research needs identified by the stakeholders in the NGT exercise and research need identified in the existing literature (N.A. refers to the non-availability of scientific sources pinpointing these specific research needs for Matang)

Research priorities as identified by NGT participants (in order of decreasing priority, as presented in Table 2)	Scientific sources suggesting/fine-tuning similar research priorities
(Socio-)economic studies (quantifiable impacts, e.g., with vs. without logging), as part of integrated assessments	Aziz, Phinn, et al. (2015): focus on trade-offs between production of different ecosystem services in Matang; include effects of areas outside Matang on the mangroves; Aziz, Thomas, et al. (2015): focus on research on avoiding logging in slowly regenerating areas & focus on mechanisms to make end users (of charcoal) pay for better ecosystem health; Goessens et al. (2014) call for monitoring of wood extraction by surveying wood-cutters; Ibharim et al. (2015): equilibrium between productive forest & biodiversity; integration of all stakeholders is needed, incl. for socioeconomic assessments; Abdullah et al. (2014): research on local governing and community institutions and community-based mangrove management capacity;
Water pollution (focus on plastics)	Auta et al. (2017): focus on assessment of the suitability of mangrove bacteria for the bio-degradation of micro-plastics; Rahman et al. (2017): metal pollution (lead & cadmium) & aquaculture & boat transport activities;
Mapping (remote sensing & GIS)	Aziz, Phinn et al. (2015): focus on use of remote sensing images & linkages with forest management; Hamdan et al. (2014): use of L-band SAR data to assist forest management; Ibharim et al. (2015: continuous monitoring of deforestation using moderate resolution remote sensing; and higher spatial resolution to increase the potential of discriminating different land use categories; texture analysis to classify neighboring pixel change more accurately;
Effects of erosion (impact of boat waves on mangroves)	Aziz, Phinn et al. (2015): erosion; Khaleghizadeh et al. (2014): impact of motor boat traffic on birds;
Effects of climate change	Goessens et al. (2014) points at the lack of climate-uncertainty acknowledging management;
Soil accretion (vs. sea level rise)	N.A
Effects of ecotourism	N.A
Salt water seepage into drinking water resource	N.A
Mangrove phenology	N.A
Pathogens (in water)	Ghaderpour et al. (2014): public health risks associated with bacteria in the water (and possible contamination of aquaculture products);
Monitoring of work/jobs	N.A

Table 3 (continued)

Research priorities as identified by NGT participants (in order of decreasing priority, as presented in Table 2)	Scientific sources suggesting/fine-tuning similar research priorities
Forestry (replanting, restoration ecology, self-thinning, clear-felling)	Amir (2012): compare forest growth under natural conditions vs. managed conditions; Aziz, Phinn et al. (2015): refine estimates of forest areas using remote sensing, to inform forest management; Goessens et al. (2014) call for a renewed validation of silvicultural field data vs. ground observations;
Yield/Productivity improvement	Aziz, Phinn et al. (2015): research on trade-offs between wood yield and other ecosystem services;
Width of the buffer zone (between rivers and productive forest zones)	N.A
Resource values of protective zones (economic value & livelihood)	N.A
Carbon sequestration	Aziz, Thomas et al. (2015): focus on management & transaction cost estimated associated with REDD + implementation;
Biodiversity	Aziz, Phinn et al. (2015): linkages between declines in shorebird populations (especially Milky Stork *Mycteria cinerea*), management and ecological variables (such as cockle production); and linkages between bird health and—heavy metal- pollution (Rahman et al. 2017) Chew et al. (2012): fine-scale dynamics of copepod migration in Matang estuaries; Ibharim et al. (2015): equilibrium between productive forest and biodiversity; Khaleghizadeh et al. (2014): impact of motorboat traffic on birds; study of anthropogenic activities on wildlife in Matang, with a focus of present threatened birds (Milky Stork *Mycteria cinerea*, Lesser Adjudant *Leptoptilos javanicus*, Chestnut-bellied Malkoha *Phaenicophaenus sumatranus*)
Mangrove fisheries (role of mangroves for fisheries)	Ooi and Chong (2011): species-specific response of fish larvae to environmental variables;
Variety of wood/diversification of trees	N.A
Propagule growth rate	Goessens et al. (2014) highlight the unknowns regarding propaguls dispersion and colonization in Matang
Research infrastructure	N.A

Additional future research topics that were not mentioned by the NGT participants include the study of the amounts of biomass and nutrient exports under the current management system in Matang (Gong & Ong, 1990). The umbrella terms listed by the participants (such as biodiversity in particular) are elaborated upon in a range of scientific studies, which contain much more specific information (e.g., on fish larvae assemblages indicating the value of Matang as a fish nursery; and on research needs regarding particular threatened bird species). The expressed need regarding socioeconomic integrated assessments and the assessment of management trade-offs are mirrored in more specific

research questions in the scientific literature, where the concept of ecosystem services is used to frame and assess the multi-purpose management regime in Matang. Interestingly, some issues that are listed by the NGT participants are absent from the future research tracks found in the literature. These include issues such as salt water intrusion, the balance between soil accretion and sea level rise—which are linked to climate change which seems to be granted almost no attention in the literature on Matang so far (at least when it comes to climate impacts and risks in Matang). Other issues such as the diversification of the productive tree species and the width of the buffer zone between productive forest and water channels are very specific and have a direct relevance to forest management. This may reflect the heavy presence of Forestry Department officials in the NGT participants' pool.

Combining the academic scientists' lens (which can sometimes be blind for the bigger picture) and the stakeholders' lens (which can be blind for the invisible or long-term consequences or which can fail in determining specific research questions) provides a useful and strong input for the actual managers of Matang, for researchers and for other stakeholders. The combination of the participatory NGT and the exploratory and targeted literature review of this study is in line with the call of Nguyen et al. (2017), who identify science-based and local knowledge-based approaches to mangrove management in muddy coastal areas and call for '*mechanisms for integrating different knowledge systems for effectively managing mangroves.*' These mechanisms should promote a high level of integration of local and scientific knowledge, local ownership, and sustainability (Nguyen et al., 2017).

4.3 Reflections on methodology

While NGT has proven useful to explore and rank the characteristics and research priorities in this study, other methods are available to identify research priorities and knowledge gaps. These methods include comprehensive literature searches (as done by Nguyen et al., 2017 regarding muddy mangrove dominated coasts) and systematic- reviews (Cvitanovic et al., 2015; Sciberras et al., 2013), yet if one aims at gathering site-specific information: (i) the available literature will inevitably be more limited; and (ii) local stakeholders are expected to have strong, site- and context-specific opinions about conservation, development and hence research needs (Dharmawan et al., 2016).

Questionnaire-facilitated workshops (exhibiting the characteristics of focus group discussions (Nyumba et al., 2018)) are also used to identify research needs (York et al., 2017), yet the combination of the individual and collective steps of the NGT makes it especially relevant to collect original and yet consensual stakeholder input on research priorities, as done in this study and in a similar way in Robinson and Shepard (2011) and Colton and Bissix (2005). The application of the NGT allowed us to avoid production blocking, which refers to the loss of efficiency in generating ideas in a group during verbal brainstorming (as only one individual can speak while the others are listening, during which their own thoughts can effectively be 'blocked' (Hugé & Mukherjee, 2018)). Moreover, the output of an NGT is a ranked list of ideas, which is suited for the identification of research priorities. Although there is considerable consensus on how to conduct NGT, there are many variants, e.g., regarding the group's homogeneity, regarding the public versus private voting, and regarding the provision of supporting information (such as criteria that could facilitate (yet possibly also –unduly- influence) the ranking step). While we consider NGT an adequate method to identify key characteristics of mangrove management and research priorities, the technique is not fit for all purposes. It is not suited to deal with multidimensional questions and cannot replace specific recommendations for future research which are based on

current or past studies regarding specific topics, but NGT does provide the opportunity to gather stakeholders' preferences regarding research priorities in a transparent and systematic way by capitalizing on the fruitful combination of individual and collective reflections. When interpreting NGT results, one should also be careful about the representativity of the NGT participants: Are these participants an actual reflection of the numerical strength of different stakeholder categories in the overall population at one site? NGT findings cannot just be extrapolated to the wider population.

In the future, gathering additional information on NGT participants' demographics (beyond mere professional background) would allow to perform a more in-depth interpretation of possible differences in perspectives among different stakeholders. This would also allow to have a series of NGTs, targeting different stakeholder groups, who would complement the findings of the present study.

4.4 Policy and managerial implications

The participatory elicitation of stakeholder opinions, regarding research priorities in support of the sustainable management of Matang Mangrove forest, has direct implications for the short- and long-term management of the forest. As recent literature has highlighted the need for some modifications to the current management regime in order to ensure the sustainability of the forest as a diverse and dynamic social-ecological system, the insights of this study are timely. Moreover, the implication of the Perak State forestry departments (who manages the forest) in the current study and the regular updating of the forest management plans in Matang together create a window of opportunity to feed the findings of this study directly into the decision-making process underpinning potential adjustments to the current forest management regime. The current study highlights the following issues: On the short-to-medium term, additional attention needs to be granted to (i) systematic (and when possible, quantitative) assessment of the sustainability of current management activities; (ii) the use of remote sensing technology in support of forest management; (iii) the study of the effects of water pollution on human and ecosystem health (reflecting a One Health perspective (as defined in Moussiaux et al., 2019)); (iv) The diversification of tree species to maintain a sustainable forestry production. On the longer term, attention needs to be devoted to the impact of climate change on the long-term sustainability of Matang Mangrove Forest as a multifunctional social-ecological system under a multiple-use management regime. The approach followed in this study—a combination of participatory judgement elicitation by way of NGT, and a compilation of existing prior scientific knowledge—is of direct use for managers and other stakeholders—hence this case study provides an illustration and a possible source of inspiration for forest managers in other locations.

5 Conclusion

Managing a mangrove system requires data about the many social and ecological variables characterizing it and about their interactions. The task can seem daunting to decision-makers as they will invariably be confronted with limitations regarding resources to be allocated to the study of various systems components, and regarding the processing capacity of scientists and other stakeholders alike. In complex social-ecological systems, such as mangrove forests, inevitably many stakeholders make claims about resource use and have—possibly divergent—preferences regarding forest management options. Systematic,

stakeholder-inclusive methods are needed to identify pressing research priorities, to guide resource allocation and the investment of time and scientific capacity. The nominal group technique (NGT) provides an adaptable, systematic and robust method to harness individual and collective insights on a given topic. Designed to minimize potential group bias, NGT allows to gather and analyze stakeholder preferences regarding future research needs. This is the first time that the application of NGT has been documented in a mangrove context. Moreover, NGT is not yet being used frequently in natural resources management, hence in documenting our NGT application, we aim to contribute to the development of a the NGT body of knowledge beyond mere mangrove forest settings. As we applied NGT in Matang Mangrove forest reserve in Malaysia, the need for integrated sustainability assessment surfaced, as the exemplary function of the century-long management of this multipurpose forest system, is expected to trigger the interest of decision-makers across the region, struggling as they are to design and apply sustainable natural resources management. This study may provide input for the upcoming 2020–2029 'Working Plan,' which is to outline the management of Matang forest for the coming decade. The method also highlighted some neglected issues (when compared to hitherto identified research needs in the scientific literature on Matang), such as the impacts of climate change on the area and its management, and a range of technical questions regarding silvicultural management. While research needs regarding biodiversity are voiced by the NGT participants, the demand for research on water pollution is under-represented in the literature. The combination of the participatory identification of research needs and the needs identified in existing scientific studies on Matang provides a shortlist of research priorities which is useful to both scientists and decision-makers. The diverse range of topics offers opportunities for in-depth, multi-year research programs and more concise pilot projects. In the future, it is advised to involve an even more diverse range of stakeholders in selecting research priorities, by conducting multiple NGTs with different categories of stakeholders. The list of priorities may also inspire research initiatives in other mangrove areas in the region, most of which are facing increasing pressures from urban development, climate change and/or encroachment by other land uses ranging from aquaculture ponds to oil palm plantations. Furthermore, the de-polarizing approach of NGT provides opportunities for stakeholders with initially diverging opinions and values, to bridge these disagreements and to identify collectively generated priorities for research and management.

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