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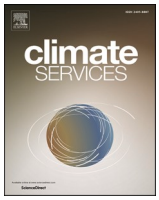

Practitioner needs to adapt to Sea-Level Rise: Distilling information from global workshops

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ABSTRACT

Climate-induced sea-level rise threatens the world's coastal populations, critical infrastructure, and ecosystems. The science of sea-level rise (SLR) has developed to inform understanding of global climate mitigation and adaptation challenges, but there is much less engagement with practitioners to discern their climate services needs and support the development of adaptation planning and action on the ground. In addition, adaptation planning and implementation processes for SLR are relatively new and practitioners developing leading practices are seeking interaction with their peers and the SLR science community. To address these gaps, we co-produced online global workshops with sixty-nine practitioners from twenty-six countries. These workshops aimed to increase understanding of the state of SLR adaptation planning practice worldwide, gather information on practitioners' existing knowledge and service needs to advance their adaptation efforts, and facilitate exchange between practitioners engaged with coastal adaptation and the SLR science community. The workshops uncovered commonalities across contexts and identified consistent needs from scientists and other technical experts amongst the practitioner community. These needs include generating more localized SLR impact data, understanding of compound risk, creating data timelines for decision making, and developing clarity about uncertainties and probabilities. We also observed important differences between urban and rural locations and between places with different economic resources. To meet their needs, practitioners identified three crucial next steps: 1) Develop more online engagement opportunities, 2) Establish a global practitioner community of practice, and 3) Scale and improve the provision of climate services.

Practical implications

Climate-induced sea-level rise (SLR) threatens the world's coastal populations, critical infrastructure, and ecosystems. Governments around the world are working to understand vulnerabilities of their shorelines to SLR and compound threats including storm surge, extreme precipitations, groundwater rise, and more. Adaptation actions, those that intentionally mitigate these identified threats, will require complex choices about who will receive support, what locations will be protected, and what physical strategies should be used. For example, some cities will need to decide if they should use shoreline armoring or nature-based solutions to protect their citizens. Maintaining resilience in this context will be costly, socially disruptive, and politically arduous.

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To maintain resilience, collaborations among practitioners to learn from one another and beteween practitioners and scientists to offer quality climate services is critical. Moreover, maintaining these relationships and the ongoing provision of quality climate services is necessary. Here we share our findings from co-produced workshops that engaged directly with a global practitioner community. These findings bring practitioner voices into the conversation on climate service needs associated with planning for adaptation to SLR.

First, we find a high demand for more online engagement opportunities. Convening online dialogues and workshops help to build regional and global relationships. Through these opportunities practitioners can learn from each other and engage with other groups (e.g. SLR scientists) thus enabling work across disciplinary boundaries. These events can also disseminate knowledge on leading practices and build new knowledge products such as those that can be used to plan considering uncertainty. The virtual workshops analyzed in this paper demonstrated this idea. Specifically, using regenerative design principles (Mang & Haggard, 2016), our workshop engaged the participants throughout the process. Our increased virtual mobility post-pandemic facilitates this type of interaction and removes the barrier of travel for any interested participant to engage.

Second, we observed diverse technical coastal management needs amongst practitioners. These needs go beyond traditional SLR scenarios and include information on extremes, geomorphology, and compound flooding scenarios. These needs can be met by building local adaptive capacity, by supporting improved coastal climate service provision (Le Cozannet et al., 2017), and by expanding the reach of such coastal climate services. These co-produced workshops provide an example of how to structure the dialogue and knowledge exchange that could iteratively meet the diverse needs of communities addressing rising seas apparent across the workshops.

Finally, we found strong support for forming a global community of practice. This community would facilitate these convenings, help with knowledge dissemination, and ensure collaborations with different disciplines. The group could also support the translations and communication of actionable science and promote research into useful planning tools. A direct outcome of the workshops is the formation of one such community under the name "Practitioner Exchange for Effective Response to Sea Level Rise (PEERS)". This organization's early work responded directly to two technical needs indentifited in these workshops: 1) a webinar series about the use of adaptation pathways by practitioners, and 2) a coproductions partnership with NASA leveraging satellite earth observations to provide high quality inundation maps for communities that could use this powerful visulation tool. PEERS currently has 450 members from 55 countires and is planning more work - forming an actionable science working group, diving into science needed to support nature based solutions, and integrating traditional ecological knowledge in adaptation planning. The practitioner-led vision in the workshops has coalesced into a proof of the concept and a promising community that hopes of helping address practitioner needs in meeting future coastal resilience challenges.

Data availability

The data that has been used is confidential.

1. Introduction

There are profound risks for people, infrastructure, and ecosystems from sea-level rise (SLR) (Fox-Kemper et al., 2021; Nicholls & Cazenave, 2010; Oppenheimer et al., 2019). These risks demand action from those within governments tasked with protecting people and natural environments in coastal settings, which we will call practitioners here (sometimes also called "decision makers"). Practitioners operate in highly complex and diverse settings. They need to make decisions in the context of existing management and legal frameworks that operate at different levels of government (e.g., national, regional, local). Many of these legal frameworks were established with an assumption of stationarity (i.e., sea-levels consistent with historic levels) that is no longer applicable (Craig, 2010; Milly et al., 2008; Yamamoto & Esteban, 2014). They also have demands placed on them from different constituent groups that often have competing interests (e.g., landowners, developers, neighborhoods, infrastructure managers) (White, 1996). Further, SLR is just one of many threats and issues that practitioners working in coastal settings need to consider when managing risks and other issues of change (Davies et al., 2020).

Top-down SLR science has been extensively developed to support climate mitigation and adaptation as exemplified by the Intergovernmental Panel on Climate Change (IPCC) assessments (e.g., Fox-Kemper et al., 2021; Pörtner et al., 2022). Building on this in recent years there has been a proliferation of climate data portals and tools to provide climate science and SLR information directly to practitioners (Le Cozannet et al., 2017; Steynor et al., 2016; Vinogradova & Hamlington, 2022). There is also a growing field of climate services provided primarily by national governments, non-profit organizations, and UN agencies. However, these services are often developed without reference to bottom-up perspectives and concerns. Hence, they fail to meet users' needs because they often lack quality decision support (Findlater et al., 2021), exhibit a mismatch between the supply of services and the demands for services (Hirschfeld & Hill, 2022; Visscher et al., 2020), and fail to include "trusted relationships" between consumers and producers of services (Jacobs & Street, 2020).

One main reason why the above-mentioned coastal climate services exhibit these limitations is that there has been little systematic and in-depth empirical research on what kind of information practitioners need. Most exploration of practitioner needs is conducted in an ad-hoc manner within single case studies aimed at the co-development of climate services. The results of these studies are rarely published or analyzed to define transferable lessons. For example, analysis of adaptation to sea-level rise in the Thames Estuary has developed high-end SLR scenarios and an adaptive approach which is being applied in practice (Ranger et al., 2013; van de Wal et al., 2022). However, while generic lessons for practitioners were developed, their transferability was not the focus of analysis, and the Thames case is well documented compared to most examples of which we are aware. In recent years, some research on practitioner needs has been conducted across cases in the form of questionnaire surveys. For example, an expert survey to understand the specific SLR science used by national government practitioners in Europe was carried out (McEvoy et al., 2021). Similar projects surveyed practitioners across the globe on their use of SLR information locally (Hirschfeld et al., 2023) and analyzed regional reports used in the United States (Garner et al., 2023). Several other studies used questionnaires to understand practitioner needs for adaptation to SLR in California, USA (Tribbia & Moser, 2008), Denmark (Madsen et al., 2019), and Italy (Geraldini et al., 2021), or among port decision makers (Ng et al., 2018).

While these questionnaire surveys constitute an important step towards understanding practitioner needs across different contexts, questionnaires provide limited in-depth information compared to what is needed to clearly understand practitioner needs. For example, questionnaires cannot capture the social learning context that a practitioner is operating within. As the literature on the co-development of climate services emphasizes, needs generally only become clear through an in-depth interaction between those providing climate information and the user (Hewitt et al., 2017; Vincent et al., 2018). This is because both sides generally do not understand each other sufficiently given the complexity of coastal adaptation situations that practitioners are confronted with (including all the aspects discussed above) on the one hand, and the complexity of climate and SLR information on the other hand,

resulting in frequent misunderstandings and incorrect assumptions (van der Pol & Hinkel, 2019).

This paper addresses this limitation by engaging directly with a global practitioner community through a series of co-produced workshops to bring their voices into the conversation on needs associated with planning for adaptation to SLR. To our knowledge, this was the first attempt at an in-depth empirical inquiry into user needs for SLR information at the global scale. Moreover, the inquiry was not a top-down academic exercise; it was co-designed and co-produced with practitioners to create a space for in-depth interaction which is essential to understanding user needs.

2. Methods - co-produced global workshops

2.1. Workshops context

The workshops were originally motivated by the desire to bring a practitioner perspective to the World Climate Research Programme's (WCRP) Sea Level Rise conference in Singapore in July 2022 titled "Sea Level 2022: Advancing Science, Connecting Society." The conference organizers, striving to achieve the WCRP Strategic Plan's core objective of bridging climate science and society, wanted to hear directly from the practitioner community about their science and adaptation planning needs. Given this purpose, the workshops' aims were to increase our collective understanding of the state of SLR adaptation planning practice at the global scale, gather information on the practitioner needs to advance their adaptation efforts, and facilitate exchange between practitioners working on coastal adaptation and the SLR science community.

2.2. Workshops development & design

These workshops were designed for, and by, practitioners and practitioner partners from other sectors to facilitate communication, exchange, and co-production to develop a set of practical recommendations that can support adaptation responses on the ground. The workshops were designed by an eleven-person international organizing committee (see supplementary material and workshops website for details) with a mix of genders, professional experiences, and geographies. The committee comprised six practitioners and five academics from various disciplines. Professionals in workshop design and facilitation supported the development and hosting of the workshops.

The committee identified three important principles that guided significant parts of the workshops design. First, the workshops committee's **commitment to inclusion** guided the design, development, and facilitation of these international workshops. Integrating multiple perspectives, approaches, and lived realities into the workshops helped broaden our understanding and ability to develop appropriate responses to SLR in a variety of contexts. Second, based on regenerative design principles (Mang & Haggard, 2016), the workshop's primary aim was to **add value** in the lives of individual participants, their immediate working environments, and their professional communities. Third, the workshops needed to be **externally relevant** and produce insights beyond the community of participants. Therefore, the workshops produced a report and recommendations that practitioners can use to support their work, identify new areas of research and collaboration, and leverage opportunities for funding (Boyle et al., 2022).

To further co-develop the workshops, the organizing committee sent a pre-workshop survey to invitees in advance asking them about their desired objectives and outcomes for the workshops. We received 35 responses from practitioners around the world. Their responses reflected a desire to build competencies through shared experiences and work together to produce results relevant for broader audiences.

These goals and desires set the key themes for the workshops: develop capacity, share new knowledge, and facilitate better communication between science and practitioner communities. Specifically, practitioners wanted workshops that would allow them to build professional capacity and acquire knowledge. They also wanted to be part of a larger effort to bring together science and practitioner audiences around shared endeavors. Results from the pre-workshop survey also helped to structure the topics covered during the workshop. Pre-workshop survey respondents highlighted practitioners' need to communicate about SLR with a range of stakeholder groups, which became a core theme.

To welcome participants across all time zones, two virtual, identically structured workshops occurred in consecutive weeks in February 2022. "Workshop A" primarily included participants from North America, South America, Europe, and Africa, while "Workshop B" primarily included participants from Asia, and Oceania.[1] The workshops occurred over three days with each session lasting a total of 2.5 h. Day 1 of the workshops centered on science and its relationship to decision-making and planning. Day 2 centered on planning and implementing SLR adaptation, including consideration of uncertainty. Day 3 focused on communicating the case for action across stakeholder groups as suggested in the pre-workshop survey. Day 3 allowed participants to choose the stakeholder group session they wanted to attend leading to four groups broadly under the categories of: 1) government officials, 2) built environment professionals, 3) impacted communities, and 4) general public.

Each session started with welcoming words and lightning talks (5 min each) to contextualize the conversation (see supplementary material and workshops website for agenda, speakers, and additional details). This was followed by sixty-five minutes of in-depth conversations on the day's topic held in breakout groups with a maximum of seven people. The conversations were guided by trained facilitators, a set of open-ended questions, and pre-designed activities in interactive workspaces on Miro, an online tool that supports collaborative processes (Miro, 2020). Participants provided their initial responses using digital sticky notes within their breakout session's dedicated workspace. Sessions were also supported by volunteer rapporteurs who captured important notes and themes from the sessions. The final 30 min of each day was a reflection or synthesis activity held in the same breakout groups. At the end of the workshops, we conducted a post-workshop survey to gather direct feedback from participants on next steps.

2.3. Workshops participants

To recruit participants, we utilized a global network of relationships from committee members to reach out to practitioners in all global regions. Sixty-nine people from twenty-six countries participated in the workshops (complete list in supplementary material). The continent breakdown for participants was 26 % from North America, 25 % from Oceania, 22 % from Asia, 13 % from Europe, 11 % from Africa, 3 % from South America (Fig. 1). Though the workshop was global in participation, there was an overrepresentation of practitioners from high-income countries with predominantly Western cultural identities. Participants from South America, Africa, the Middle East, and Southeast Asia shared that there were few professional local SLR experts in their regions.

We actively sought participation from multiple disciplines, professions, and levels of career experiences. As a result, 32 % identified as government planners, 18 % as resilience professionals, 18 % as academics, and the others as consultants, engineers, scientists, etc. (see supplementary material and workshops website for details). This variety enriched the conversation and supported an atmosphere of cross-disciplinary sharing. From this, participants relayed that they gained a better understanding and appreciation of other perspectives and were able to see the challenges and opportunities for collaboration more

[1] Here we summarize the information at the continental scale. We had participants from Latin America, the Caribbean that are part of North America. We also had participants from Pacific Islands States that are included in Oceania.

Fig. 1. The distribution of participants by continent.

clearly.

2.4. Coding and analysis of results

The workshops generated more than 30 h of recorded breakout sessions, and 9 online digital whiteboards with more than 2,000 sticky

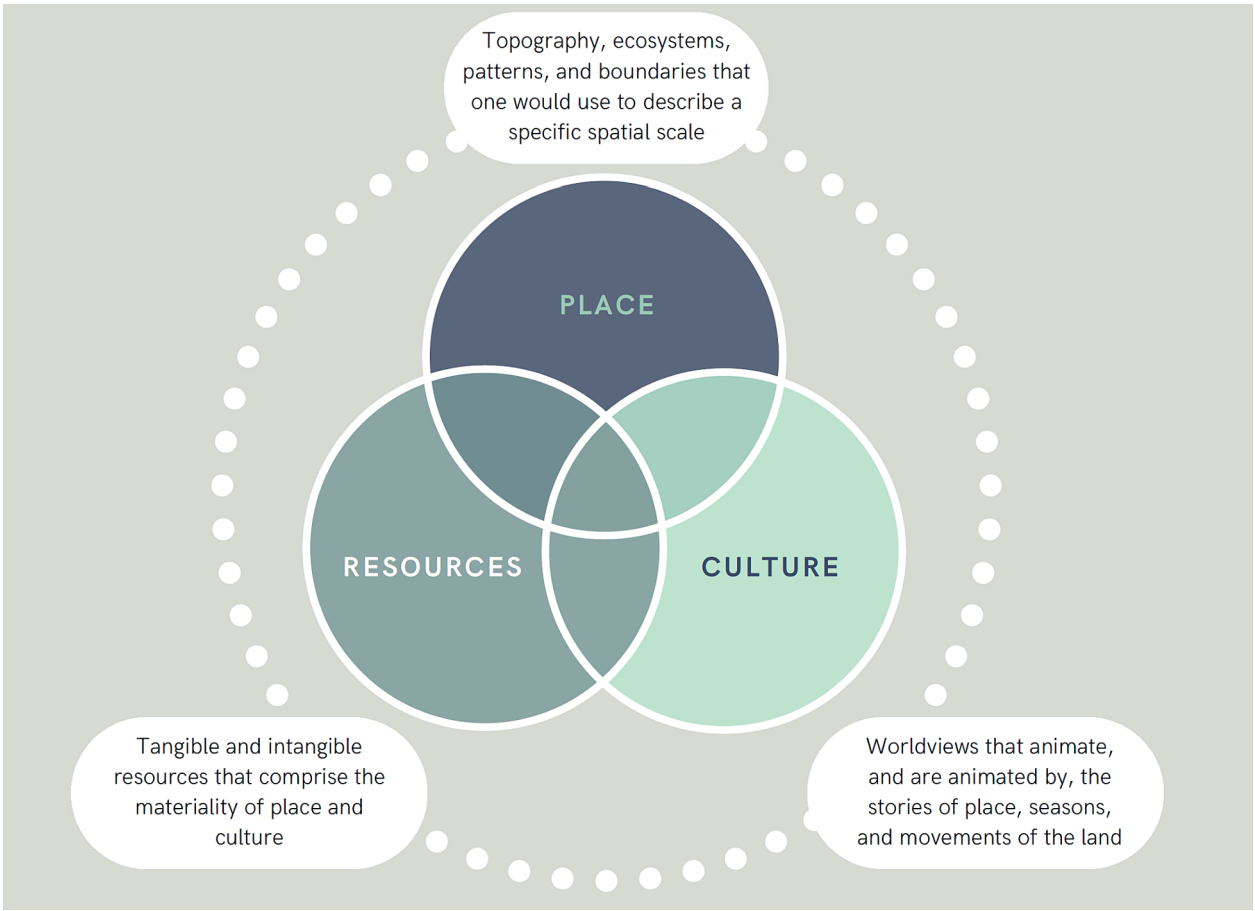

Fig. 2. The three characteristics - place, resources, and culture - that make up our Situating Context framework.

notes captured in a digital archive. Sourcing predominantly from sticky notes and quotes captured by rapporteurs and facilitators, we used an inductive approach to articulate common themes and concepts (Thomas, 2006). When we wanted to verify a concept that was emerging from the analysis, we reviewed specific clips from video recordings. Then, using a deductive approach, we connected specific themes to existing literature on SLR science, adaptation planning, the integration of science into planning, and climate change communication. Through this coding we observed commonalities between different participants in terms of resources, places, and cultures. We report these results in Section 3.1. This coding approach also allowed us to observe commonalities across breakout groups and workshops in terms of science needs (Section 3.2), planning needs (Section 3.3), and communication needs (Section 3.4). We report on results about next steps from the post-workshop survey (Section 3.5).

3. Results

Listening to practitioners and coding the notes from the discussions provided us with important insights. Here we seek to elevate and synthesize the voices of these practitioners and bring forward the lessons from the sessions of these workshops. In section 3.1 we introduce the framework that emerged from our inductive coding process. In section 3.2 we share the greatest needs from science (day 1). In section 3.3 we share the needs specific to planning (day 2). Then in section 3.4 we share our findings related to communications (day 3). Throughout we highlight the important differences based on geographic regions.

3.1. Framework to understand unique geographical settings

To understand the differences and distinct characteristics of places, we developed a framework called "Situating Context" (Fig. 2). By combining existing literature (Davies et al., 2020; Haasnoot et al., 2019; Hinkel et al., 2018) with observations of our participants we identified three specific contextual factors: access and distribution of human, natural, and financial resources (resources), physical attributes of places and the distribution of people (place), and normative orientations to the world (cultural). We used this framework to assist in locating responses within a broader set of conditions. For example, we found that places with fewer resources had different access to and understanding of SLR science data.

In another example we observed that for many (but not all) participants cost-benefit analysis was a challenge to implementing actions. Some participants recognized the difficulty of multi-generational thinking when using a discount rate. Others from predominantly low-income countries articulated frustrations that this analytical approach resulted in circumstances where relocating their communities would be more cost effective than building infrastructure to protect their communities. Similarly, some places noted that cost-benefit analysis excluded nonmonetary relationships to resources such as ancestral legacies. For example, one participant stated "we have legal and moral obligations to restore salmon habitats. This requires more natural shoreline; a fact that puts us at odds with property owners who want bulkheads out of their concern about rising seas.".

3.2. Needs from science

For most participants, knowledge, and acceptance of SLR is widespread. Practitioners agree that global SLR data, projections, and models are increasingly consistent, relevant, and accessible. However, they need help translating global-scale information, long (century) timescales, and developing approaches required to incorporate uncertainty into usable science that supports local and shorter-term decision-making in their context. To frame planning challenges such as infrastructure investments, land-use and transportation policy, and development regulations, practitioners' scientific needs have expanded to include detailed information on a variety of local hazards and their interaction over multiple time frames. This need has evolved beyond SLR height alone. Practitioners across contexts requested that science be translated into plain language, tailored to local conditions, communicated on planning-relevant temporal and spatial scales, and framed to inform policy and compel action. In essence, they are asking for appropriate climate services.

SLR is a complex phenomenon that compounds, and is compounded by, other global and local processes. Practitioners would like information, guidance, and tangible models that account for multi-source contributions such as storm surge, fluvial flooding, and vertical land movement alongside climate-induced SLR to explain future local relative sea levels and their potential impacts (Fig. 3). For example, one participant noted that they needed information on the interactions between future sea levels, runoff, shallow groundwater, and the piped water infrastructure network. In other settings, practitioners need to understand the relationship between SLR and coastal erosion, or the flooding threat driven by rising seas combined with extreme precipitation. Participants realize that these physical processes and how they impact local communities are key to both understanding risk and managing future impacts. They noted that models able to characterize the nature of these compound impacts would improve their local decision-making abilities. (Note that the technical challenges of delivering such information was not considered at the Workshops).

According to participants their greatest needs were for near-term information on the implications of SLR (Fig. 3). They noted that this decadal timescale best aligns with the decisions that they make most frequently. They also stated that near-term information matches with election cycles, constituent priorities, and community engagement processes that attempt to coalesce multi-interest stakeholders. Long-term SLR information was also seen as critical with 40 % of responses clustered in this area. Specific examples of information in this category included ice sheet dynamics and improved probabilities on end of century projections to enable regional planners and critical infrastructure engineers to make better long-term decisions and avoid future impacts. Practitioners requested information that could bridge near-term and long-term planning. Specifically, they identified the need to determine thresholds and tipping points that matter regionally such as rate of SLR at a local tide gauge. This information is needed to identify potential impacts on local systems and develop aligned adaptation strategies across contexts and scales.

Three core science needs would improve practitioner's ability to adapt to future SLR. First, they underscored the need for more localized information and in-situ monitoring to better estimate the impacts of SLR on ecosystems, communities, assets, and critical infrastructure. Second, and relatedly, they requested more information on how SLR interacts with geophysical and oceanographic processes to directly impact their coastal zones. Third, the overwhelming majority of responses pointed to the imperative for scientists and practitioners to work together to develop knowledge products more easily used in planning processes.

Participants recognized that access to localized observations and projections is essential for planners worldwide. However, we saw glaring differences in the availability, resolution, and ability to utilize this information in planning for local jurisdictions. Participants from nations and places with greater funds have developed sophisticated data visualization tools and increased in-house capacity for identifying and using localized information. Amidst this proliferation of information, sometimes these locations have difficulty selecting appropriate data sources or future projections for specific planning decisions and the importance of good guidance and training/experience is emphasized.

Participants from small island nations and lower-income regions noted that they have fewer in-situ monitoring resources and local capacity for analysis. They stated that they rely heavily on international organizations and consultants to develop localized information. This third-party support is expensive, and localities are unable to afford ongoing engagements with providers, which leaves critical gaps in the

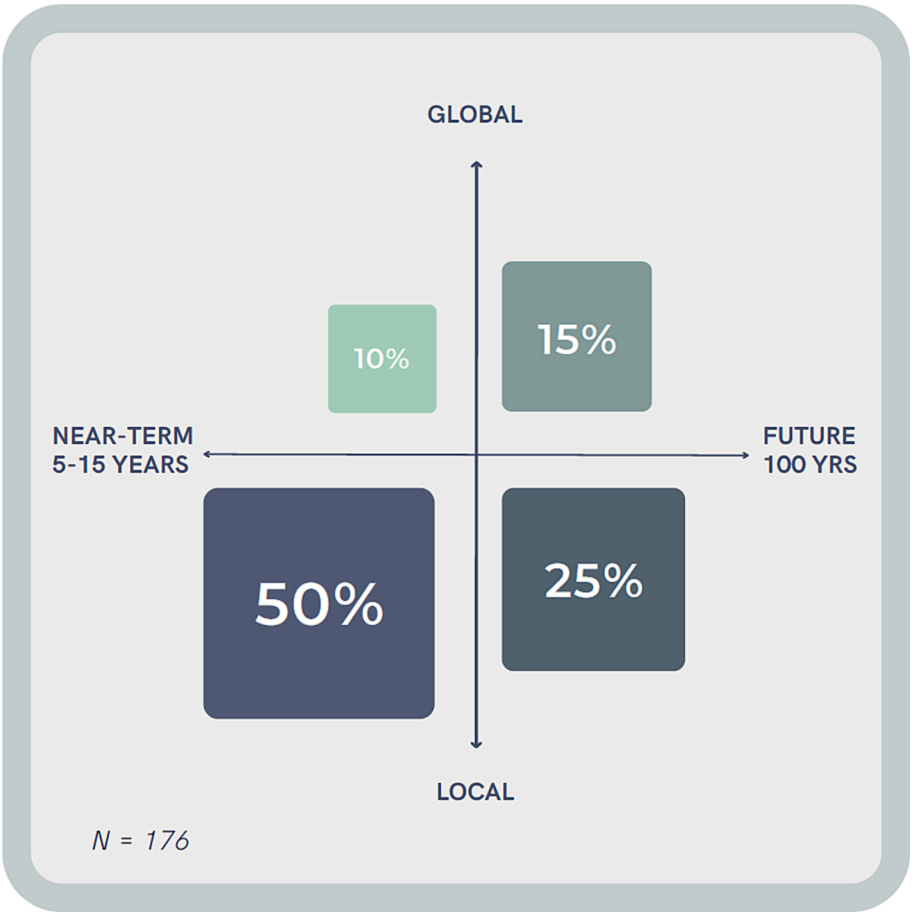

Fig. 3. Placement of answers to the question "What is the most important information about SLR you need to make decisions?" 75% of responses clustered in "local," and 60% clustered in "near-term." 50% of all responses clustered in "near-term and local.".

data and assessments. The information gaps and lack of local capacity can lead to detrimental impacts on the ground. Planners who work under these constraints reported being under-prepared and under-resourced when attempting to plan for and implement measures that could reduce risk, save lives, and protect local economies.

3.3. *Enabling planning*

Day 2 of the workshops centered on planning and implementing SLR adaptation in the context of uncertainty. We learned from practitioners about a number of conditions that were simultaneously enabling and disenabling, depending on the situating context of the practitioner. For example, engaging the resident communities was seen as both an enabling and disabling condition by many participants. For some planning processes, increased community support engendered a sense of ownership over projects while in others, weak or poorly run community engagement led to resistance and, in some cases, maladaptation.

The first set of conditions pertain to people and those living in the coastal zone: these include building trust through community engagement, developing communication tools and techniques, and the degree of acceptance and understanding of SLR. Another cluster of conditions fit into the umbrella of capacity and include: access to funding, and government siloes. Two conditions related specifically to the implementation of SLR adaptation actions. They include the regulatory environment that practitioners are operating within and the design of infrastructure.

Practitioners agreed that community engagement, citizen trust, and an acceptance of the reality of SLR are necessary ingredients for forward progress. Specifically, participants acknowledged difficulties associated with meeting the demands of their daily work on near-term problems with the need to also consider long-term threats like SLR. Many participants also brought up the relationship between the frequency of exposure to hazards and the level of urgency this created amongst citizens to take, or not take, action. Workshop participants recognized the importance of clear communication, acknowledging uncertainty upfront, and the critical role that tools such as inundation maps and plain language translations of science play in securing buy-in and funding. Participants identified two planning approaches - adaptation pathways and scenario planning - that can help move planning forward conceptually given existing uncertainties.

The theme of capacity was woven into many layers of day 2 and was iteratively brought up by workshop participants. The largest capacity challenge that came up repeatedly was access to funding for planning and implementation. Additional challenges included having sufficient capabilities to integrate science into the planning process, to implement complex planning processes, and to break down the silos between different sectors and levels of government. Ultimately, it was clear that building local capacity is crucial to support ongoing efforts to adapt to SLR.

The funding needs associated with SLR adaptation are enormous, and thus it is no surprise that securing financial assistance is an issue for all participants, regardless of their country's GDP. However, capital distribution, access to funding mechanisms, and economic vulnerability vary across contexts. Practitioners acknowledged that wealthier jurisdictions get better access to funding because they have the staff and expertise to apply for grants, or impose fees and taxes on their populations. Representatives in lower-income countries with limited country-level staff, let alone city-level staff, are concerned about

wealthier countries having disproportionate access to capital, when it is the lower-income countries that are more immediately vulnerable to the impacts of SLR and financially incapable of meeting the demand. Moreover, some practitioners from low-income countries reported that they are unwilling or unable to seek financing for adaptation and question the environmental and social justice implications of allocating scarce resources to a problem perpetuated by countries with much higher carbon emissions.

Underpinning the differences in capacity and capabilities is access to relationships and networks that can help fill the gaps in knowledge and expertise. Participants from under-resourced contexts emphasized the need for international collaboration and institutional knowledge sharing more than those with access to more resources. They suggested that, in the absence of local capacity, there is an opportunity for workshops and conferences to help build connections between practitioners from different contexts so that they can learn from each other rather than continuously relying on expensive consultants or international organizations. Conversely, it was evident that practitioners from better resourced contexts have robust relationships with academic institutions, topic experts, and in-house colleagues with technical expertise.

Practitioners from different situating contexts have distinct orientations to relationship building, stakeholder engagement, and integrating alternative perspectives and worldviews as part of their planning processes. To successfully engage communities and move toward action, practitioners from Canada, New Zealand, Australia, South Africa, and the Philippines stressed the importance of starting with indigenous perspectives as the value-system underpinning how climate change and SLR impacts are conceptualized. Relating to historical narratives and proverbs connect the threat of SLR to lived experience and cultural legacies. Participants noted that these framings often contest hard infrastructure and engineering approaches in favor of nature-based solutions that restore ecologies and relationships.

On the other hand, there were very few mentions of traditional ecological knowledge from Western European countries and the United States. In these places, practitioners referred to the rarity and difficulty of integrating this knowledge into planning processes. Still, they pointed to the value it provides when it is present. For example, one participant admitted that, to the detriment of their planning processes, the inclusion of indigenous communities was often tokenized rather than fully participatory. More technocratic, rational planning processes justified by cost-benefit analysis or risk reduction were met with community resistance that practitioners indicated may result in increased community vulnerability.

When it came to implementing adaptation strategies, the regulatory context and its reflection of values played a role for participants. Private-interest at the expense of collective protection was an important disabling condition shared by many participants. Cost-benefit analysis came up repeatedly as a challenge to implementing actions. On the other hand, participants noted that incorporating SLR into land-use regulations and local laws were potentially successful approaches. For example, one participant shared that because of political will and support for integrating vertical allowances and setbacks into land-use bylaws their community was able to make these risk reducing changes.

3.4. Communicating about sea-level rise

We found that participants across both workshops identified six common messaging strategies that worked in the past for them to communicate about SLR. The first five messaging strategies were effective for all four audiences the participants considered in the breakout rooms - government officials, built environment professionals, impacted communities, and the general public. Participants identified the sixth strategy as effective when communicating with government officials and other stakeholders noted to have fiduciary responsibility over budgets and projects. The effective messaging strategies are:

1) **Make it relevant** - Connecting SLR to memories about loved places, cultural identities, and impacts on daily life in quantifiable terms helps stakeholder communities relate the risks associated with SLR to their lived experiences.

2) **Generate a sense of immediacy** - Relating the impacts of SLR to today's public health, livelihoods, and property values to overcome the temporally distant nature of the threat of SLR for many communities.

3) **Expand awareness of compound hazards** - Sharing SLR's relationship to other hazards that people experience more regularly, like precipitation-based flooding, rising groundwater tables, and increased storminess, helps people connect long-term threats to today's conditions.

4) **Engage ancestral legacy values** - Framing near-term actions on climate change as a dimension of ancestral legacy has the potential to attract people's attention to climate change and motivate people to respond.

5) **Empower decisions about the future** - Acknowledging the current reality and framing actions as agency over what is to come helps people relate to the topic.

6) **Provide financial justification** - For those responsible for budgets knowing that investment today saves money tomorrow provides a quantitative case for action.

Through coding participant responses to the question "what approaches have you used/seen that resonate and achieve buy-in from important audiences" we identified four approaches to deliver messages across all stakeholder groups. The first is to engage stakeholders through meetings and public presentations. The second is to use visual storytelling techniques including maps, works of art, and interactive online tools. The third is communicating benefits and consequences such as justifying a new zoning code by articulating the number of deaths that it could avoid in 50 years. Fourth is using scientific, technical, and financial rationale to make the case for action. An example of this approach is providing centennial time scale charts. Within each category participants provided examples of specific steps that were more or less successful. In Fig. 4 we show some of the examples provided during the workshop and cluster them as more or less successful.

3.5. Participants recommendations for next steps

We gathered data from participants of both workshops through an internal post-workshop survey. We learned that all respondents (N = 42) were interested in follow-up online activities including workshops, training, science practitioner dialogues, and conversations with practitioners on lessons learned. We found that 81 % of post-workshop survey respondents selected "yes" when asked whether they would be interested in joining and participating in a global community of practice[2] (Fig. 5). Another 17 % responded "maybe" to the same question, while only 2 % responded "no".

4. Discussion

The challenge for coastal communities to adapt to rising sea-levels is tremendous and requires exchange between practitioners and the SLR science community to meet specific local needs. However, to our knowledge there have been limited attempts at global systematic and in-depth empirical research gathering evidence from practitioners on their SLR science needs. To address this issue, we conducted co-designed workshops that brought together practitioners and SLR scientists from around the world in the first attempt at an in-depth global empirical inquiry of these issues. Our findings provide insights to inform processes that can be used to better support adaptation efforts by local practitioners. Using an inductive coding method (Thomas, 2006) we found

[2] A community of practice is a group of people who share a common concern, a set of problems, or an interest in a topic and who come together to fulfill both individual and group goals.

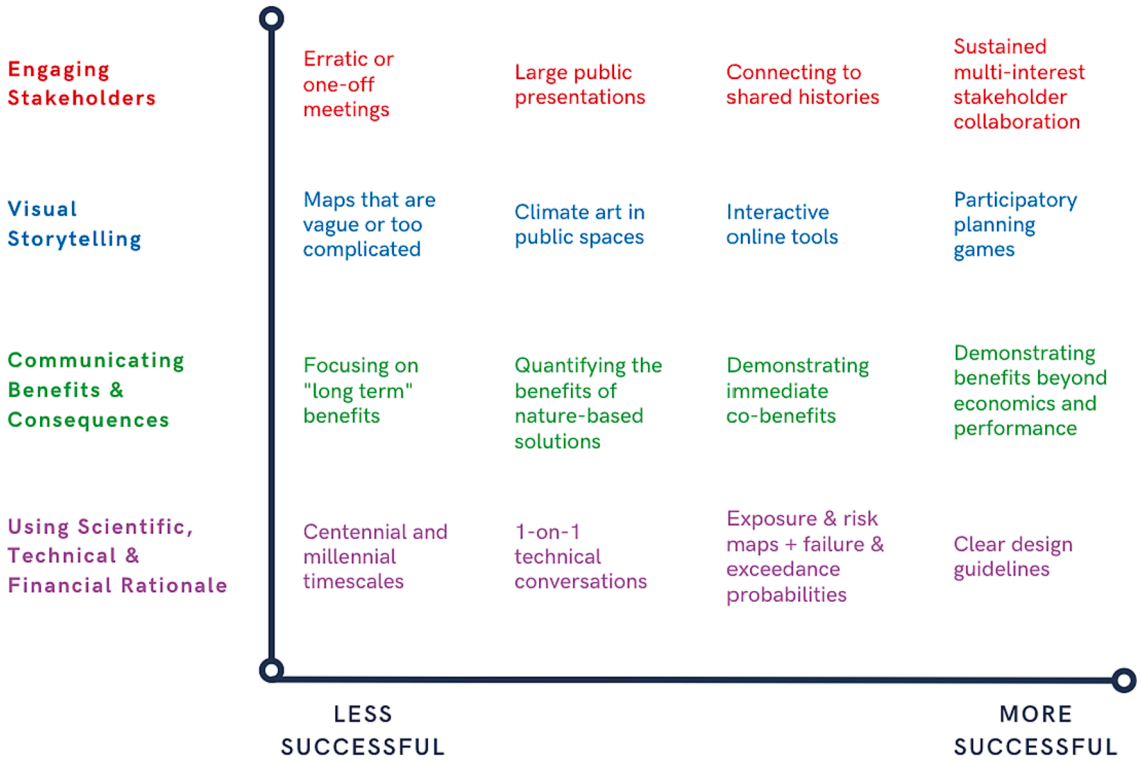

Fig. 4. The four approaches that resonate and achieve buy-in from important audiences that we identified through coding and examples of specific techniques that were more (right) or less (left) successful.

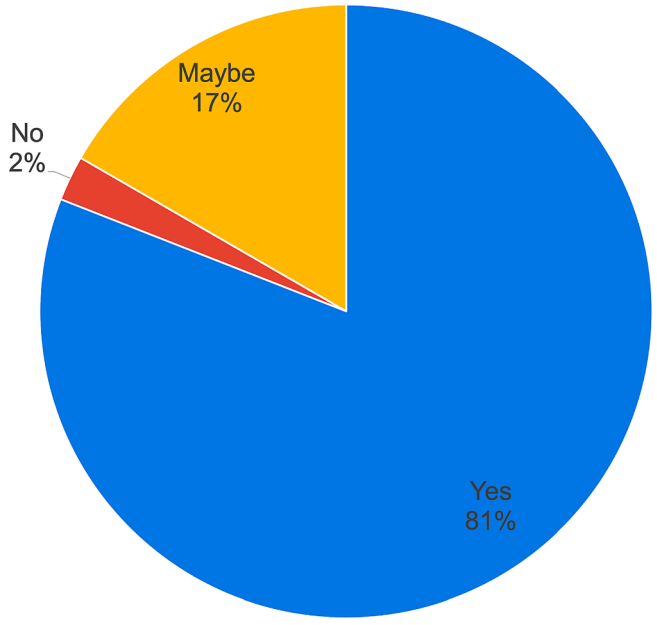

Fig. 5. Percentage of respondents (N = 42) that would be interested in joining and participating in a global community of practice.

that practitioners' unique Situating Context based on our framework (Fig. 2) played a key role in their needs from SLR science and what enables or disables adaptation actions. We also found common themes shared across contexts that provide important insights for the ongoing conversation around improving adaptation to SLR and reducing future risks. In the following subsections, we discuss insights from the workshops that pertain to the different situating contexts of our participants (Section 4.1), practitioners' shared needs related to SLR science, planning, and communications (Section 4.2), and building sustained institutional capacity (Section 4.3).

4.1. *Unique situational contexts*

The results highlight the potential to develop archetypes of communities based on our Situating Context framework (Fig. 2). We observed critical distinctions based on practitioners' geographic contexts (place), access to tangible and intangible contributors to capacity (resources), and relevant local narratives, values, and worldviews (culture). In one example, we found that participants from small island nations and lower-income regions have fewer in-situ monitoring resources. It is well known that this lack of localized monitoring makes it difficult to build a case for action (Tribbia & Moser, 2008) and to translate global projections to the local context (Thompson et al., 2016). Others have found similar challenges pertaining to localized measurements. For example, while there is strong interest in nature-based solutions for risk reduction it is very difficult to obtain the data necessary to assess and design these measures (Ruckelshaus et al., 2020).

In another example we observed different perspectives on cost-benefit analysis between participants. Many practitioners reported that cost-benefit analysis provides the most compelling justification for taking or delaying action. Practitioners also repeatedly brought up the high costs associated with adaptation actions. On the other hand, practitioners working to include traditional ecological knowledge, and those from low-income countries, argue that cost-benefit analysis stymies action. While traditional cost-benefit analysis fails to account for local values, innovative approaches that include community studies can overcome this shortcoming (Godschalk et al., 2009). Additionally, bringing in an ecosystem services framework can ensure that the benefits provided by natural resources are included in cost-benefit analysis (Luisetti et al., 2014; Ruckelshaus et al., 2020). Future work could help to build capacity to develop and apply more complex versions of cost-benefit analysis or other decision frameworks (e.g., multi-criteria analysis) that expand beyond traditional approaches.

We also found that participants from urban settings were more likely to focus on protection strategies, such as building seawalls and dikes, than rural counterparts. Rural participants tended to consider retreat or nature-based solutions as physical strategies to adapt to rising sea-levels. These findings corroborate previous work by researchers looking at urban settings experiencing land subsidence as a proxy for future SLR, who found no evidence of people relocating because of rising relative water levels, as they enhance protection instead (Esteban et al., 2020). Another study focused on the small islands in the central Philippines recognized that short-term no regrets strategies could bolster the capacity of current residents. These strategies could stop more immediate forced migration and could lead to slower natural depopulation (retreat) of these vulnerable islands (Jamero et al., 2019). Other research into the limits of adaptation suggests that urban areas will continue to have engineered coasts with higher defenses, while rural areas will eventually retreat from the coast (Hinkel et al., 2018). Providing empirical evidence from practitioners helps to substantiate and expand our collective knowledge about actual societal responses and the needs of planners and decision makers.

Our Situating Contexts framework emerged as an approach for organizing and understanding the patterns behind specific planning challenges, approaches, and outcomes. However, for this project we did not rigorously evaluate the situating contexts themselves. For example, we did not gather extensive data on the values held by residents of specific cities. Information about residents and their relationship to government actions is imperative to limit conflicts between formal and informal adaptation actions (Cao et al., 2021). Nor did we conduct an analysis of the local resources available to each participant of the workshops. Rigorous analysis of the situating contexts could further develop contextual archetypes and provide novel insights and nuances beyond the traditional approaches that cluster places around income level or part of the globe. This could be used to improve SLR adaptation outcomes and reduce risks from SLR in the future.

4.2. Shared needs amongst participants

According to workshop participants their greatest science-specific need was for SLR information that was tailored to their local context thus capturing both specific geographic and cultural concerns. This need is demonstrated in a study of port decision makers around the world, which found that adaptation measures needed to be better suited to local circumstances (Ng et al., 2018). Researchers looking at the usability of scientific information suggest that interactions and customization improve the fit of information and help to move the data from useful to usable (Lemos et al., 2012).

Participants noted that centennial timescales and globally aggregated means which are the headline information of SLR science do not align with the local, decadal decisions that planners have to make most frequently. Studies in California, USA (Tribbia & Moser, 2008) and Denmark (Madsen et al., 2019), found similarly that local government officials needed more detailed localized information for near-term threats. This connects to important work that examines the types of SLR information needed based on a decision analysis framework (Hinkel et al., 2019). According to this framework decisions can be categorized by timeframes and risk tolerances and these categories can determine the ideal information type for those decisions. For example, long-term (up to 100 years and longer) decisions with low uncertainty tolerances need upper bound information, while those long-term decisions with medium uncertainty tolerances need adaptive or learning scenarios – an approach that is still being developed Volz and Hinkel, 2023. Testing this framework against stakeholder preferences could provide a useful way of furthering co-development of useful information between practitioners and SLR scientists.

Practitioners repeatedly brought to the forefront their needs to communicate effectively about SLR. We found that practitioners have many audiences, including but not limited to other government officials, built environment professionals, impacted communities, and the general public. Within these multiple audiences exist diverse perspectives and long-held beliefs about climate change (Leiserowitz et al., 2014). Navigating these audiences and their potentially diverse perspectives requires an understanding of effective messaging (Leiserowitz et al., 2014; Moser, 2010). For example, one empirical study found that fear messages effectively get people's attention but fail to keep them engaged in long-term action (O'Neill & Nicholson-Cole, 2009).

Practitioners informed us that successful communication techniques to gain community support include sustained multi-interest stakeholder collaboration, participatory planning games, demonstration of benefits beyond economic performance, and clear design guidelines (Fig. 4). Each of these techniques is complex and requires a significant time investment. For example, others have shown that climate risk communication is a two-way dialogue between practitioners and community members (Nkoana et al., 2018). Our results support previous calls to better understand climate change communications (Moser, 2010), current examples of communication successes (Van Den Hurk et al., 2022) and suggest a need for focused research into messaging around SLR specifically.

This study, due to its global nature, expands the geographic scope of previous survey-based research on SLR practitioners (Geraldini et al., 2021; Hirschfeld et al., 2023; Madsen et al., 2019; McEvoy et al., 2021; Tol et al., 2008; Tribbia & Moser, 2008) and port managers (Ng et al., 2018). To deepen our understanding of practitioner needs, future projects could build on these methods and gather more information from parts of the globe not proportionally captured in this analysis. As shown in Table 1 our study showed a poorer representation of practitioner participants relative to continental Low Elevation Coastal Zone populations from Asia and an over representation from Europe, North America, and Oceania. Gaining a better understanding from parts of the globe with high coastal populations and high vulnerability is of the utmost importance. Analysis of other groupings such as delta and small island settings is also important as these locations are vulnerable to SLR (e.g., Rölfer et al., 2020). Equally, such groupings may bring out more commonalities among practitioners than global studies.

4.3. Building sustained institutional capacity

Throughout the workshops, practitioners described a fundamental barrier to the uptake of science into practice that is missing from much of the academic literature on the topic:

Depending on their situating context, practitioners face significant gaps in local capacity and capabilities. This cross-cutting theme relates to how practitioners develop new knowledge, interpret the abundance of available information, fundraise for adaptation, integrate different belief systems, and engage multi-interest stakeholders.

Through the co-production process of the workshops and the post workshop survey data we learned that participants are looking to develop local capacities through peer learning and interactions with SLR

Table 1
Showing for each continent 1) the percentage of our participants (A) 2) the percent of the low elevation coastal zone global population (B) (Nicholls et al., 2021), and 3) the relative representation (A/B).

Continent	Percent of our Workshops participants (A)	Percent of Low Elevation Coastal Zone population (B)	Relative Representation (A/B))
Asia	22 %	73.1 %	0.3
Africa	11 %	11.6 %	1.0
South America	3 %	3.5 %	0.9
Europe	13 %	6.6 %	2.0
North America	26 %	4.6 %	5.6
Oceania	25 %	0.6 %	42.7

scientists. Practitioners are engaged in processes involving heterogeneous sets of actors making decisions that are complex, multifaceted, and value-laden, which require social learning. Social learning in coastal management is critical to developing effective and adaptive coastal management approaches (Lockwood et al., 2012). A community of practice, which can facilitate such social learning, comprises a network with complex linkages that can facilitate the flow of information and learning across cultures and boundaries (Wenger et al., 2002). Researchers exploring the role of communities of practice through a case study in Australia found that local governments can manage coastal zones more effectively when they deliberately incorporate a community of practice into their work (Nursey-Bray et al., 2016). These workshops further support developing a global community of practice, with regional groups that reflect common conditions related to SLR, community attitudes, and access to technical information and resources.

Climate services, developing actionable climate information for use in planning, are best provided through co-production interactions between practitioners and technical experts (Beier et al., 2016; Vogel et al., 2016). The co-production process provides a structure for dialogue and the structuring of science information to serve the diverse needs apparent across the workshops. Expanded climate services could benefit practitioners' need for improved science translation, uncertainty characterization, compound threat analysis, observations and data provision, adaptation policy options, and culturally diverse decision frameworks. These services cannot be based on the "deficit model" of science communication where people (such as scientists) assume that providing high quality information will ensure that practitioners make more rational decisions regarding coastal climate risk (Irwin, 2014). Instead, climate services need to be culturally sensitive, help build local capacity, and recognize the complex context within which practitioners operate. While not explictly mentioned in the workshops, boundary workers and organizations may play a role in facilitating better climate services.

Taken together communities of practice and climate services can help to build local adaptive capacity, which is essential as sea levels continue to rise (Hirschfeld et al., 2020). However, these interventions alone will not address the full breadth of barriers to SLR adaptation, which include technological limits, economic and financial barriers to adaptation, and social conflicts (Hinkel et al., 2018). In the end we want these communities to develop transferable knowledge and approaches that can be exchanged and applied to other coastal areas, as appropriate.

5. Conclusions

The challenge of adapting coastal communities to SLR requires both local action and global collaboration. The workshops identified multiple ways that science and practitioner communities can work together to develop adaptation responses, from problem definition and data collection to planning, funding, implementation and monitoring the effectiveness of adaptation. Practitioner participants in the workshops identified three concrete ways to foster burgeoning connections, build a global network of collaborators, and support capacity building across disciplines and contexts.

First, there was substantial support and interest in the development of more online engagement opportunities. Online dialogues and workshops create opportunities for practitioners to learn from each other, engage with other groups (e.g. SLR scientists), stay connected to relevant case studies and leading practices, and collaborate on knowledge products better suited for context-specific decision-making. The virtual workshops analyzed in this paper demonstrated this idea. Our increased virtual mobility post-pandemic facilitates this type of interaction and removes the barrier of travel for any interested participant to engage.

Second, building on singular online engagement opportunities, practitioners identified an interest in forming a global community of practice. This community could support longer-term iterative collaborations and convenings, create knowledge-exchange networks that address gaps in local capacity, develop shared languages and practices for communicating SLR information to multi-interest stakeholder groups, and disseminate leading practices to the broader practitioner community. Building on these workshops one such community is beginning to take shape under the name "Practitioner Exchange for Effective Response to Sea Level Rise (PEERS)".

Third, there are diverse technical coastal management needs amongst practitioners that go beyond traditional SLR scenarios and include information on extremes, geomorphology, compound flooding scenarios, etc. These needs can be met by building local adaptive capacity, by supporting improved coastal climate service provision (Le Cozannet et al., 2017), and by expanding the reach of such coastal climate services. These co-produced workshops provide an example of how to structure the dialogue and knowledge exchange that could iteratively meet the diverse needs of communities addressing rising seas apparent across the workshops.

CRediT authorship contribution statement

Daniella Hirschfeld: Conceptualization , Funding Acquisition , Writing – original draft, Writing – reviewing & editing , Visualization , Investigation , Methodology , Supervision , Resources , Project administration. **Ray Boyle:** Data Curation , Writing – original draft , Visualization , Investigation , Formal analysis , Methodology. **Robert J. Nicholls:** Conceptualization , Funding Acquisition , Writing – original draft , Writing – reviewing & editing , Investigation , Methodology , Resources . **David Behar:** Conceptualization, Funding Acquisition, Writing – reviewing & editing, Investigation, Methodology, Resources, Project administration. **Miguel Esteban:** Conceptualization, Writing – reviewing & editing, Investigation, Methodology, Supervision. **Jochen Hinkel:** Conceptualization, Funding Acquisition, Writing – reviewing & editing, Investigation, Methodology. **Gordon Smith:** Funding Acquisition, Investigation, Methodology. **David J. Hanslow:** Investigation, Methodology.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that has been used is confidential.

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