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A blueprint for overcoming barriers to the use of nature-based coastal protection in Australia

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The global loss of coastal habitats is putting communities at risk of erosion and flooding, as well as impacting ecosystem function, cultural values, biodiversity, and other services. Coastal habitat restoration can provide a nature-based solution to the increasing need for climate adaptation on the coast while recovering lost ecosystems. Despite the benefits of using nature-based coastal protection to manage coastal hazards, there are scientific, socio-political and economic barriers to the broad use of this approach. Understanding the details of these barriers from the perspective of multiple stakeholders is essential to identifying solutions to overcome them. Using a workshop with participants that are key partners and stakeholders (from government, engineering consulting firms, and non-governmental organisations) in the management, design, and delivery of a coastal protection solution we aimed to: (1) gain a better understanding of the barriers faced by multiple stakeholders involved in the implementation of nature-based coastal protection; and (2) identify tangible solutions to these barriers to increase or support implementation, help focus attention on areas for future research, and inform pathways forward for the governance of nature-based coastal protection. We defined 19 barriers to nature-based coastal protection, but the primary ones that are experienced during the delivery of a project are a lack of: education and awareness; community support; necessary expertise and technical guidance; and uncertainty around: the risk reduction that can be achieved; planning and regulatory processes; and ownership of the structure. Two barriers that do not persist during the design stages of a project but are overarching as to whether nature-based coastal protection is considered in the first place, are government support and the availability of funding. The importance of these primary barriers changes depending on the method of nature-based coastal protection. We conclude by identifying both immediate actions and long-term solutions for enabling nature-based coastal protection in response to each of the primary barriers.

KEYWORDS

coastal engineering, nature-based solutions, stakeholder workshop, barriers and solutions, living shorelines

1 Introduction

Climate change and continued human population growth are causing an increase in environmental, social, and economic pressures. Globally, there has been a substantial loss of natural ecosystems due to human-induced rapid environmental change (HIREC), caused by habitat loss/fragmentation, over-harvesting, the spread of invasive species, and pollution, as well as climate change and its wide-ranging impacts (Sih et al., 2011). This includes loss of marine and coastal ecosystems, with an estimated 85% of oyster reefs (Beck et al., 2011), 22% of wetlands (Fluet-Chouinard et al., 2023) and 50% of coral reefs (Eddy et al., 2021) lost worldwide. Global habitat decline affects critical ecosystem services such as carbon sequestration, water quality and fisheries productivity and increases the susceptibility of coastlines to hazards such as erosion and flooding (Barbier et al., 2011). This can negatively impact human wellbeing (Bowler et al., 2010) and the cultural connections of Traditional Owners to natural ecosystems (Sangha et al., 2019). Due to the scale of habitat decline, there is an increased focus on restoration efforts that aim to recover (to some extent) the structure and function of natural habitats that were once present (Banks-Leite et al., 2020). Aside from the benefit of restoring habitat, restoration practices can also be harnessed to protect, manage, or restore natural or modified ecosystems to simultaneously benefit both humans and nature (Cohen-Shacham et al., 2016). One such example is nature-based solutions for coastal protection. While nature-based solutions may have ecological trade-offs (e.g., a different community of species compared to natural habitats; Bilkovic and Mitchell, 2013) and implementation challenges (Morris et al., 2024), there is increasing recognition that their application not only has the potential to assist in managing erosion and flooding, but also contribute to scaling up habitat restoration.

Along coastlines, the extent of erosion and flooding globally could increase by up to 48% by 2,100 due to climate-induced changes in hazard drivers (e.g., sea level rise and increased storminess) (Kirezci et al., 2020). The integration of natural systems such as dunes, coastal vegetation and biogenic reefs can offer nature-based solutions to these hazards by maintaining buffers against coastal erosion, increasing wave attenuation and promoting shoreline stabilisation (Duarte et al., 2013; Narayan et al., 2016). However, conventional approaches to coastal risk management have biased protection measures towards the construction of coastal protection structures such as seawalls and revetments. These structures have quantified and accepted design standards that give engineers and coastal managers confidence in the risk reduction provided for the design life of the structure (Scheres and Schüttrumpf, 2020). Growing evidence, however, has documented the significant environmental impact these structures have through the replacement and fragmentation of natural shorelines, which reduces biodiversity and ecological function (Chapman, 2003; Mayer-Pinto et al., 2018), increases the prevalence of invasive species (Dafforn, 2017), alters the landscape-seascape connectivity (Bishop et al., 2017), and can even cause downdrift erosion (Tavares et al., 2020). Further, these structures also need additional capital and operational investment for their ongoing maintenance, upgrade, and eventual replacement, particularly when faced with a changing climate. Through using living ecosystems, nature-based coastal protection can provide a sustainable structure that self-repairs after storm events (Gittman et al., 2014), adapts with climate change within limits (Rodriguez et al., 2014) and supports co-benefits such as biodiversity (Isdell et al., 2021). Despite the potential benefits, nature-based coastal protection is a novel technique that faces various barriers to implementation (Morris et al., 2024).

Australia's interest in nature-based coastal protection is increasing, with the number of implemented projects growing over the last 2 decades (Morris et al., 2024; www.livingshorelines.com.au). Some states (e.g., New South Wales and Victoria) have mandated a preference for restoring or enhancing natural protection including coastal dunes, vegetation and wetlands before considering other options to address coastal hazards (Morris et al., 2021). However, nature-based coastal protection is far from standard practice with a recent survey of coastal practitioners suggesting several key barriers: (1) few examples that could be used as precedent by coastal practitioners; (2) limited knowledge about the costs and benefits of living shorelines compared to conventional engineering structures; (3) lack of technical guidance and quantified performance standards; (4) complex jurisdictional management of the coast; (5) planning or regulation barriers; (6) limited community engagement and acceptance; and (7) few suppliers with expertise in the delivery of nature-based coastal protection/resilience projects (Morris et al., 2024). Similar barriers have also been identified by coastal practitioners in interviews and focus groups in the United States (DeLorme et al., 2022; Mednikova et al., 2023). In Australia, the implementation of coastal protection requires effective coordination and/or engagement among at least two levels of government, consultants or other experts, marine contractors, the community, and rights holders in a complex and not well documented process (Figure 1), the details of which vary between state and territory jurisdictions. The owners of the policy framework, funding and approvals (e.g., Government, land managers) may differ from the end users of the solutions (e.g., design experts and communities). Ultimately, it is the end users who are exposed to the outcomes of the decision-making process. Thus, there is a need to ensure the end users of

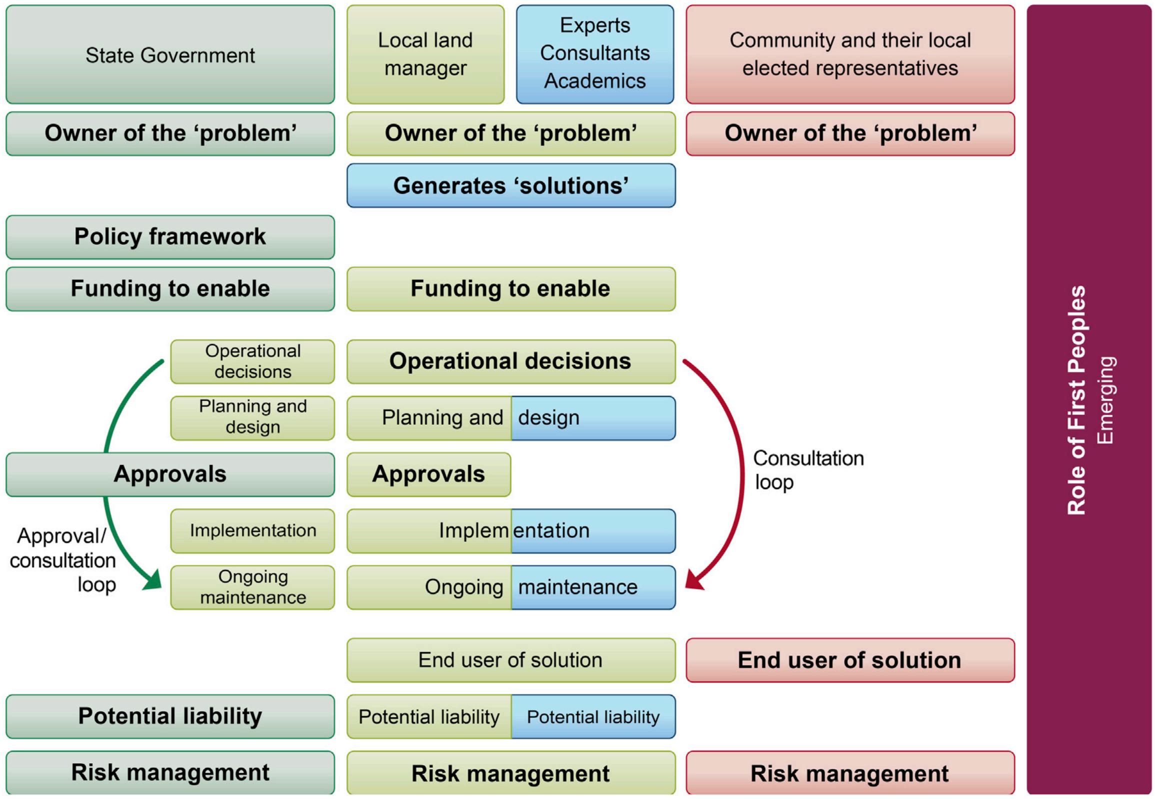

FIGURE 1
An overview of the process and stakeholders involved in the decision to use nature-based coastal protection, using Australia as an example (adapted from Boxshall et al., 2023). In Australia, state governments have the decision-making power over the coastlines, their development and management. Local land managers are responsible for developing and implementing coastal management plans and land-use planning decisions, operating within the regulatory and policy frameworks established by the state or territory government, and therefore play a key role in the on-ground application of nature-based coastal protection. Coastal managers working within state or local governments will often engage expert advice from consultants and academics for coastal erosion management solutions. The local land manager and elected councillors need to engage with the community as the primary end users for a socially accepted solution. Traditional Owners are key rightsholders in Australia with landowner and land manager roles and are custodians of Sea Country.

coastal protection assets are involved in initial decision-making to avoid disempowerment, especially if the end use is impacted due to decisions outside their control, as has occurred with other environmental management decisions (e.g., Hunsberger et al., 2005; Reed, 2008). All rightsholders and stakeholders have an important role in the decision-making process. Therefore, a clearer understanding of the barriers faced by all involved is crucial to increasing support and use of nature based coastal protection.

Previous assessments in Australia to understand the support for nature-based methods, or the challenges to implementation, have focused on the perspective of the general public (Strain et al., 2022) as well as local and state government (BMT, 2021; Morris et al., 2024). A key stakeholder group that has yet to be assessed is engineering consultants whom are often employed by landowners or managers to develop mitigation options to coastal hazard risk. Integrating natural habitats into coastal protection has previously been identified as a challenge for engineering consultants (Scheres and Schüttrumpf, 2020). Through a workshop with federal, state and local government representatives (often the 'client') and consultants from national engineering consultancy firms, as well as one non-governmental organisation (often the 'designers'), we aimed to gain a better understanding of the barriers faced by multiple stakeholders involved in the implementation of nature-based coastal protection. A second aim of the workshop was to identify tangible solutions to these barriers to increase or support implementation, help focus attention on areas for future research, and inform pathways forward for the governance of nature-based coastal protection.

2 Methods

The 1.5-day workshop was held at The University of Melbourne, Australia on 20–21 June 2023 and was attended by 31 participants (Table 1). The workshop participants were selected based on their professional roles, which included coastal management and/or climate adaptation or implementing actions to mitigate the risk of coastal hazards. Our aim was to have half of the participants represent the different levels of government from across Australia, and the other half represent the engineering consulting firms that design and deliver coastal protection works across different jurisdictions. The participants were identified and invited through a collaborative process that involved the authors, engagement specialists and end-users, and was based on

TABLE 1 Workshop participants by category.

Participant category	n	Description
Consultants	15	Representatives from 10 national engineering firms
Federal Government	4	Four teams within the Department of Climate Change, Energy, the Environment and Water (DCCEEW)
State Government	5	Participants that are involved in managing the coast and coastal protection (NSW, QLD, SA, VIC, WA)
Local Government	4	Participants that are involved in representing the coastal councils (NSW, SA, VIC, WA)
Non-Government Organisations	2	The Nature Conservancy
Other	1	National Environmental Science Program Marine and Coastal Hub (workshop funder)

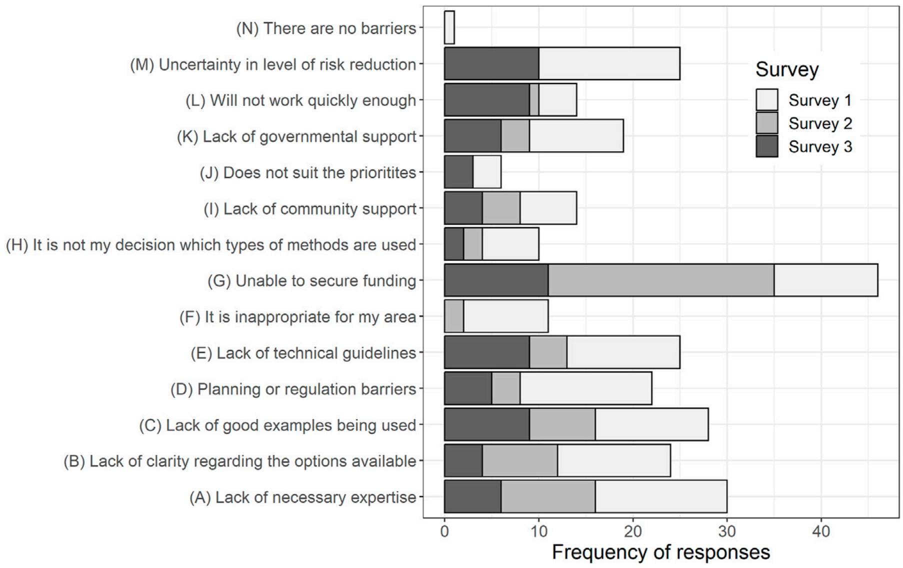

FIGURE 2
The frequency of responses identifying different barriers to nature-based coastal protection across three surveys: Survey 1 (Morris et al., 2024; N = 67); Survey 2 (National Forum on Coastal Hazards, Fremantle, March 2023; N = 41); Survey 3 (this study; N = 13). Note that "(M) Uncertainty in the level of risk reduction" is a missing data point in Survey 2.

professional judgement using extensive networks (e.g., DeLorme et al., 2022).

2.1 Pre-workshop survey

Prior to the workshop, an online survey (via Qualtrics) was sent to the participants from the engineering consulting firms. This survey was based on a previous survey that had been completed predominantly by government representatives. The previous survey had been administered on two separate occasions (Figure 2), the first online as part of building the Living Shorelines Australia database (see Morris et al., 2024) and the second during a nature-based coastal protection workshop at the Australian Coastal Councils Association National Forum on Coastal Hazards (March 2023, Fremantle, Australia; see Supplementary Methods). The survey included five questions and was designed so that it should not take more than 5 minutes to complete. The survey included questions with multiple-choice, Likert scale, and open answers; the latter allowed participants to expand on their perspectives of the barriers to nature-based methods (Supplementary Table S2). The first two questions identified which state the respondent primarily worked in and whether they (or their team/organisation) had used nature-based methods to reduce the risk of hazards for coastline assets. The third question asked for the respondent's agreement (strongly agree, agree, neither agree or disagree, disagree, strongly disagree) with a list of barriers identified in the previous surveys. The last two questions asked whether the respondent (or their team/organisation) faced any additional barriers when implementing nature-based methods, and if yes, to describe those barriers. The survey results were presented to all participants at the start of the workshop and were used to design the first workshop activity (described below).

2.2 Workshop

The workshop was divided into 5 sessions that used a diversity of methods and contexts to help identify barriers and solutions to the implementation of nature-based coastal protection. For the purpose

TABLE 2 An overview of the workshop sessions, expected outcomes and activities.

Session	Expected outcomes	Activities
1. Introduction	• Shared definition of nature-based coastal protection • Share the barriers communicated through previous surveys	• Presentation on nature-based coastal protection and the survey results • Menti activity for participants to add any other barriers that had been missed from previous surveys
2. Barriers and solutions	• Identify the priority barriers that need to be addressed • Define solutions for the priority barriers	• Dot-sticker traffic light priority system was used in breakout groups to rank all barriers, and the top two barriers from each group were communicated • A barrier was given to each breakout group to identify solutions. Groups then rotated among barriers to add additional solutions and ranked the solutions using the dot-sticker traffic light system • Individuals were asked what the most needed solution was to enable nature-based coastal protection using Menti
3. Scenario 1	• Conceptualise the barriers and solutions using a common coastal asset protection problem	• Presentation on the common coastal asset protection problem and design steps • Breakout groups identified the barriers at each design stage, wrote them onto cards and grouped them onto the venue wall • Each breakout group was given one design stage and identified solutions for each barrier. These were added to cards and placed on the wall beside the barrier • Individuals were asked what the most important barrier was and three things that could be done to solve the barrier using Menti
4. Scenario 2	• Conceptualise the barriers and solutions using an open coast protection problem	• Breakout groups worked through the design stages using the barriers from Scenario 1, and decided whether barriers were removed, or if there were new barriers • As above, groups identified solutions to the barriers • As above, a Menti activity was done for individual feedback on the most important barrier to solve with three solutions
5. General discussion	• To capture any additional reflections on barriers or solutions to nature-based coastal protection	• Participants were placed in their stakeholder groups and asked to identify immediate and future actions that could be taken by the group they were representing to better enable nature-based coastal protection • A whole-participant open floor group discussion

of the workshop, nature-based coastal protection was defined according to the national guidelines (Morris et al., 2021) as the creation or restoration of coastal habitats for hazard risk reduction. This includes the rehabilitation of existing degraded habitats, restoration of those historically present, or the creation of new habitats in ecologically suitable areas. Typical habitats included in nature-based coastal protection are beaches and dunes, saltmarshes, mangroves, seagrasses and kelp forests, coral and shellfish reefs, alone or in combination. Nature-based methods can restore the habitat alone ("soft" approach), or in combination with hard structures that support habitat establishment ("hybrid" approach). The key aim of nature-based coastal protection is to restore the ecological processes and functions that underpin the delivery of the natural coastal protection service. The workshop involved both individual responses, which were collected using an online interactive presentation tool (Mentimeter) and small breakout groups (~5 people), where pen-and-paper responses were used to collect data (Table 2). Breakout groups were composed of a mix of different stakeholders.

2.2.1 Session 1 – Barriers

In the first session, breakout groups were provided a sheet of paper pre-printed with a list of barriers that had been identified in previous surveys. The groups were asked to rank the importance of each barrier using a dot sticker traffic light priority system (red = a major barrier that needs to be addressed immediately; yellow = a major barrier that needs consideration for addressing soon; green = a minor barrier that needs a little work; and blue = this is not a priority right now). After the barriers were ranked, each group identified their top two priority barriers to be addressed. These top barriers were collated and synthesised (duplicates removed).

2.2.2 Session 2 – Solutions

One priority barrier was assigned to each breakout group. Each group was asked to identify a list of solutions that would overcome their assigned barrier. Using a World Café style research method (www.theworldcafe.com), groups then rotated around the tables, adding solutions to each barrier and ranking them. While each group reviewed the solutions, the participants were asked to each rank the solutions using the same dot sticker traffic light priority system. As this session was undertaken without a particular context (i.e., without reference to a specific scenario or case study), the outcome was a broad overview of prominent, 'front of mind' barriers and potential solutions for enabling nature-based coastal protection. The relevance and context-specific nature of these barriers and solutions were then explored using two hypothetical case studies in the following two sessions.

2.2.3 Sessions 3 and 4 – Contextualised barriers and solutions

In sessions 3 and 4, participants were asked to consider two case studies and to identify the barriers that may be presented throughout a typical coastal protection project design process: (1) functional design; (2) concept design; (3) preliminary design; (4) approvals; (5) detailed design; (6) tender phase; and (7) construction. The design process was described to the participants at the start of the activity, and any questions were clarified prior to commencement (see Supplementary Table S3 for description of design stages).

The first case study was a common coastal asset protection problem set on the urban fringe of a city that is located on an estuary or bay affected by wind-driven waves resulting in erosion (i.e., a low-energy environment). Participants were asked to consider a nature-based coastal protection solution specifically; the solution had to rely only on the nature-based solution and could not integrate conventional engineered structures (except to support the establishment of the habitat). In breakout groups, the participants worked through the design stages of the project to deliver a nature-based coastal protection solution in that scenario and to identify any barriers that would be encountered at each stage. Each barrier was documented on a separate yellow card, which was then posted under the design stage title to which it related on a central glass wall. At the conclusion of the activity, identified barriers that were substantively similar were grouped but remained under the relevant design stage. Finally, the breakout groups were assigned one design stage and asked to detail the solutions for each barrier. These solutions were documented on blue cards that were posted next to the relevant barrier.

The second case study focused on erosion problems along the urban fringe of an open, energetic coast. For this case study, a hybrid approach of a conventional engineered structure with a nature-based method was allowed due to the more energetic conditions present. For this case study, the participants were asked to evaluate whether the barriers from the first case study still existed in the second case study. If the barrier remained, no action was required; however, if the barrier was removed, participants were asked to provide justification for the removal of the barrier on a white card that was posted next to the barrier. New barriers that emerged and any additional solutions to previously posted barriers that were identified were documented and posted using the same approach as for Case Study 1 (and if not, why not) or if new barriers emerged. Solutions to the barriers were also defined, as before.

2.2.4 Session 5 – General discussion

In this final session, participants were placed in their stakeholder groups and asked to identify immediate and future actions that could be considered (and ideally actioned) by the group they represented to better enable nature-based coastal protection.

2.3 Data analysis

The data were qualitatively assessed using thematic and content analyses. A list of barriers were defined from the workshop (Table 1) and these were used as themes to group the barriers identified for the seven design stages in the case study activities. The solutions were also grouped into themes according to the most frequently cited barriers for each design stage. There was an overlap among the solutions identified in the first activity that mapped the broad barriers and solutions to nature-based coastal protection and the case study activities. Therefore, these solutions were combined into one narrative to identify the most prominent solutions proposed through the workshop. Similarly, the group responses were cross-checked with the individual responses acquired through the online activities to ensure no themes for the barriers or solutions were missed.

3 Results and discussion

3.1 Barriers to nature-based coastal protection

The top five barriers identified in the pre-workshop survey of the coastal engineering consultants, defined as the barriers where more than 50% of the respondents either agreed or strongly agreed that a barrier existed, were: (1) a lack of funding; (2) uncertainty in the level of risk reduction; (3) a lack of technical guidelines; (4) a lack of good examples being used; and 5) will not work quickly enough (Figure 2, 3A). These top barriers identified by the coastal engineering consultants were generally aligned with the previous surveys of (predominantly) state or local government representatives that we have undertaken in Australia (Figure 2; Morris et al., 2024). Other barriers that the consultants identified included a lack of examples/evidence of long-term performance, education, and awareness within key stakeholder groups such as government agencies and the community, uncertainty in ongoing maintenance costs, and the perceived risk of failure of nature-based coastal protection.

There were similarities between the more commonly agreed barriers among participants from the survey (Figure 3A) and those that were ranked as a major barrier that needed immediate attention in the breakout groups (Figure 3B). Twelve of the fourteen barriers were considered major barriers by at least 50% of the participants (Figure 3B). A lack of funding, uncertainty in the level of risk reduction, lack of technical guidelines, and the perception of risk were ranked as the major barriers needing solutions to be immediately addressed. Planning or regulation barriers and lack of examples/evidence for long-term performance were also ranked as major barriers that needed to be addressed soon.

Although most survey respondents agreed with the barrier that nature-based coastal protection would not work quickly enough (Figure 3A), it was ranked as a minor barrier that needs a little work. One justification for this was that the urgency of coastal protection is context-specific and dependent on the project objectives and method used. Conversely, more survey participants disagreed that a lack of community support was a barrier to nature-based coastal protection (Figure 3A). However, it was ranked as a major barrier that needed addressing soon (Figure 3B). One reason for this is that while there may be general community support for nature-based coastal protection (e.g., Strain et al., 2022), local communities can have a "not in my backyard" perspective that can determine whether a project goes ahead or is successful. For example, mangrove restoration is often hampered by negative public perceptions that mangroves can restrict shoreline views and access and provide habitat for dangerous animals or insects that are vectors for disease (Dahdouh-Guebas et al., 2020).

There was more division on the ranking of governmental support as a barrier to nature-based coastal protection, with 60% ranking this as a minor barrier versus 40% ranking as a major barrier that needs immediate attention (Figure 3B). It was noted that the level of governmental support varies by state due to state-level coastal policy and management. For example, New South Wales and Victoria have specific coastal policies that support or prioritise (in the case of Victoria's Marine and Coastal Policy, 2020 and the Coastal Management Act, 2016 in NSW) nature-based coastal

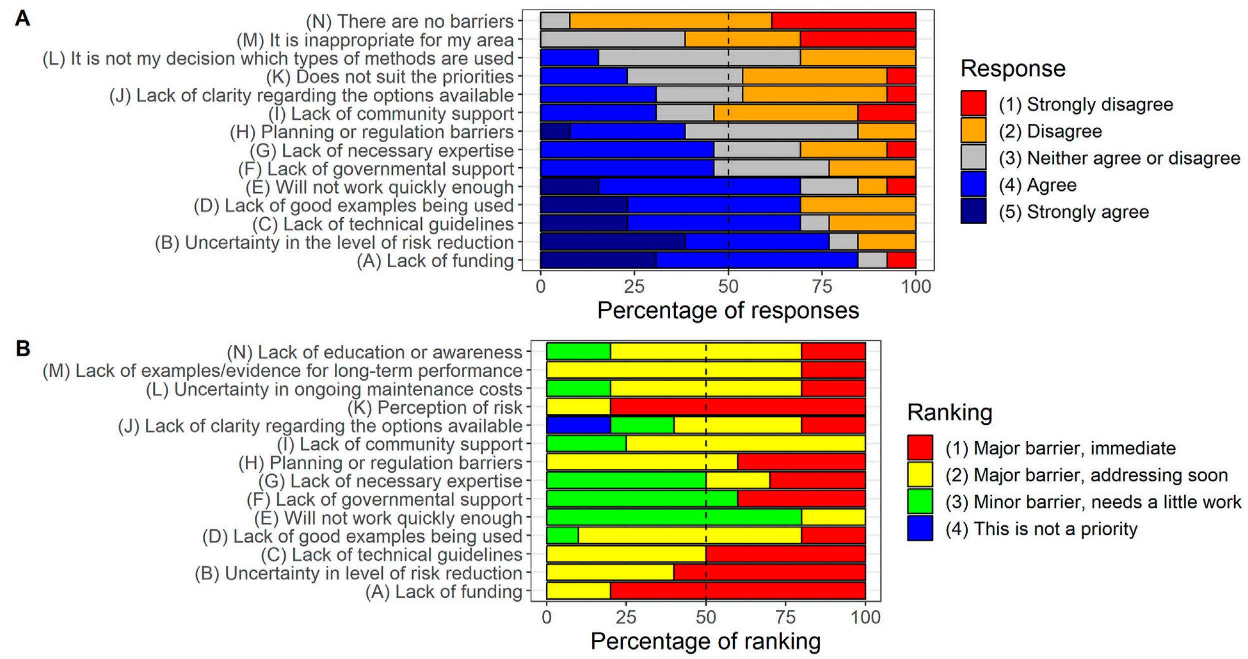

FIGURE 3
Results of the pre-workshop survey **(A)** evaluating which barriers are most important and **(B)** ranking barriers in relation to priority for action. Note the list of barriers is not the same in **(A)** and **(B)**, as the barriers for **(B)** were based on the results from **(A)**.

protection as an adaptation option, whereas this is not the case for other states (Morris et al., 2021). Similarly, federal, state and local governments have different roles and responsibilities in coastal management (Figure 1) and therefore, by not defining the government level or state, this likely contributed to the more varied rankings. Indeed, this ranking activity led to a better definition of the barriers (Table 3), and a recognition that many of these barriers are interrelated. For example, the lack of examples (of nature-based coastal protection) being used is linked to a lack of evidence for long-term performance, which is also related to uncertainty in ongoing maintenance costs. Similarly, a lack of technical guidelines can be a reason for a lack of examples being used and clarity in the options available, as well as confidence in the expected performance of nature-based coastal protection. A lack of dissemination of shared learnings, uncertainty in ongoing ownership or tenure and liability and indemnity were other major barriers added by participants.

3.2 Conceptualisation of barriers in a common coastal protection scenario

The prevalence of the nineteen identified barriers changed throughout the stages of a nature-based coastal protection project (Figure 4). A lack of technical guidance was most frequently cited as a barrier (Figure 4) and appeared in all seven design stages. The percentage of responses for barriers was similar among design stages, except for "detailed design" that had approximately half of the responses of the other design stages, and 60% of these were related to a lack of technical guidance (Figure 4). The following sections describe the nature of the barrier at different design stages.

3.2.1 Lack of funding

Funding as a barrier to nature-based coastal protection was identified only once each in the functional and concept design stages. This contrasts the pre-workshop survey, where funding was identified as the greatest overarching barrier when not conceptualised in the case study (Figure 3A). The primary problem identified for funding was that the funding model typically used by most funders is a reactive model where the money is spent on pressing, high-risk issues rather than strategically planning for future problems. Such a funding model means there is a lack of investment for nature-based coastal protection, impeding growth in confidence for their use. This is despite some states (e.g., New South Wales and Victoria; Morris et al., 2021) having policies that preference the use of nature-based methods over conventional engineered structures. If and when such policies will translate into a greater allocation of coastal protection funding for nature-based solutions is, at present, unclear. Regardless of the policy context, there was broad recognition for the need for increased capital expenditure on nature-based coastal protection, as budgeting for pilot and full-scale assessments is integral to embedding them successfully into standard coastal management. Funding is therefore a barrier to implementing nature-based coastal protection in the first place. However, once there is an agreement in specific projects that a nature-based option needs to be considered or used, then this barrier decreases. Even with funding, it may be insufficient to cover the time required by consultants or contractors engaged on the project to investigate and design (from first principles) nature-based coastal protection options that they may be less familiar with, which links with some of the technical barriers and lack of expertise discussed below.

TABLE 3 A list and description of the barriers to nature-based coastal protection.

Barrier	Description
Lack of clarity regarding the options available	The different types of nature-based coastal protection that can be considered, and their inclusion in existing compendiums
Lack of community support	Support for nature-based coastal protection from the local community that could be adjacent landowners, regular users of the area and may include Traditional Owners
Lack of data on the costs and benefits	Data availability that would underpin a multi-criteria analysis or benefit-cost analysis to evaluate different coastal protection options
Lack of education or awareness	Lack of understanding of nature-based coastal protection (including its definition) within different stakeholder groups such as government, the community, consultants
Lack of funding	Funding availability and the confidence to spend money on nature-based coastal protection
Lack of good examples being used	Reference projects that span a range of techniques, environments and at scale
Lack of governmental support	Leadership provided by all levels of government to support the implementation of nature-based coastal protection
Lack of long-term performance evidence/examples	The ability of nature-based coastal protection to be adaptive in a changing climate and maintain the risk reduction required
Lack of necessary expertise	The availability of expertise to procure, design and construct nature-based coastal protection, and better integration of existing expertise into the process
Lack of technical guidelines	Lack of (accessible) information on project scoping, concept to detailed design, life cycle costs, construction, maintenance, and monitoring
Planning or regulation barriers	Refers to gaps for enabling nature-based coastal protection in strategic planning, approvals, permits and consents
Risk – level of reduction	The risk reduction that can be achieved by nature-based coastal protection supported by suitable scientific evidence
Risk – coastal hazard	Coastal hazard risks present at a site for which the solution needs to be designed
Risk – reputational	The damage that project failure might have on an individual's organization's reputation
Risk – liability	Risks related to individual professional indemnity insurance that under common law consultants must show due care, skill and diligence Risks related to the organization that takes ongoing liability (i.e., for maintenance/monitoring/operation, and potential unintended negative impacts it causes) for the structure
Risk – marine spatial planning	Risks of the structure to other users, e.g., health and safety for the community, navigational risk for boating
Uncertainty in ongoing maintenance and monitoring costs	The upkeep and monitoring required for nature-based coastal protection and the operating costs associated with this
Uncertainty in ongoing ownership/tenure	The consideration of nature-based coastal protection as an asset and who has ongoing responsibility for the structure
Will not work quickly enough	The natural component may take time to develop that does not align with the timeframes needed to provide protection

(Continued in next column)

TABLE 3 (*Continued*) A list and description of the barriers to nature-based coastal protection.

3.2.2 Lack of data on the costs and benefits

Often a business case needs to be put forward using a multi-criteria analysis or cost-benefit analysis to compare nature-based coastal protection with other options, such as conventional coastal protection structures (Gittman and Scyphers, 2017; Morris et al., 2021). This was identified as a barrier in the concept design and approvals stage. A lack of information on the capital and operating costs associated with nature-based coastal protection can affect decisions during the concept design stage. For instance, it was recognised that nature-based coastal protection is often preferred for its potential to provide several co-benefits such as carbon sequestration, bioremediation or biodiversity enhancement (Morris et al., 2021). However, there is a lack of data on the full suite of benefits provided by nature-based coastal protection that can be used in a cost-benefit analysis, including some co-benefits, such as non-market value benefits, and benefits that are difficult to cost (Rogers et al., 2019). This can also prevent a case being built for the full public benefit of a nature-based coastal protection at the approvals stage.

3.2.3 Perception of risk

The risk of a nature-based coastal protection project contains many elements, including: the coastal hazard risk, risk reduction provided by the nature-based method, liability and reputational risk and risk associated with marine spatial planning (e.g., health and safety, navigation) or any unintended consequences (e.g., introducing invasive species or diseases with revegetation or seeding of organisms). Although there are standard methods for assessing coastal hazard risk, for example, through local, regional or national coastal hazard assessments, this was identified as a barrier seven times in the functional and concept design stages (Figure 4A). This barrier included a lack of understanding about the relevant coastal processes and the cause of the problem, the assets, values and uses at risk, and the data to support this. This problem is not specific to nature-based coastal protection, as a lack of knowledge about the general coastal hazard risk can also be an issue for conventional engineering structures. However, part of this barrier is related to what additional data about the environment are needed to inform the successful use of a nature-based coastal protection in relation to the ecology of the habitat, including relevant climate change parameters to adopt in the design and the availability of this

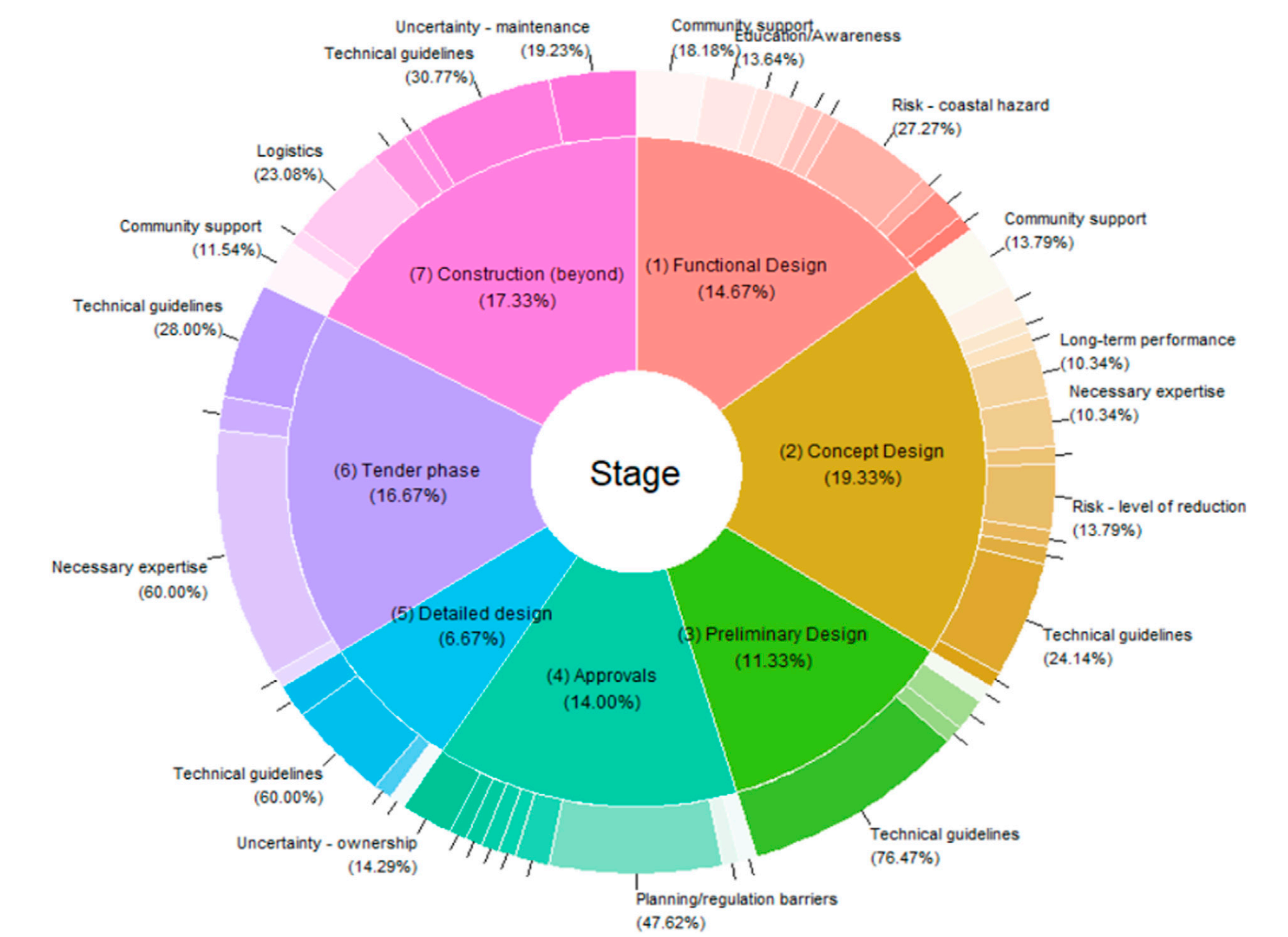

FIGURE 4
Prevalence of the top barriers throughout different design stages identified by participants. The inner pie chart represents the percentage of responses for each design stage. The outer pie chart represents the percentage of responses for each barrier within a design stage. Barriers where the percentage responses were ˃ 10% are labelled.

information to use in a multi-criteria analysis. At the concept design stage, whether a nature-based coastal protection can address the coastal hazard risk was cited as a barrier, which also relates to a lack of technical guidance. The main issue is the small evidence base (e.g., developed from case studies relevant to Australia) on the effectiveness of nature-based coastal protection over both short and longer time scales to inform a design basis (i.e., design life and efficacy), which also reduces confidence in spending money on what is often viewed as a "trial" (Morris et al., 2024). A lack of understanding about the effect of nature-based coastal protection also perpetuates into the approvals stage of a project where evidence on impacts to coastal processes is required.

A lack of an evidence base for nature-based coastal protection and technical guidelines increases liability and reputational risk and these barriers were present in each stage from approvals as well as concept design. At the approval stage, there was a lack of clarity in the pathway for nature-based coastal protection and who takes ongoing liability for the asset. For example, an NGO may be contracted by a local or state government to construct a shellfish reef, but it is not practical (or financially feasible) for that NGO to take liability for a structure they do not subsequently own or manage. A lack of confidence or track record may result in inadequate support or approval. Engineering consultants are required to have Professional Indemnity Insurance that under Common Law a consultant must show that they have acted as another engineer would have, showing due care, skill and diligence. When a client makes a breach of professional duty claim, the consultant supports their actions with sufficient evidence base. Such evidence base can include references to Australian (or International) standards, guidelines for coastal protection structures, site-specific studies, or other evidence showing how or why they have followed engineering guidance and where they have not for a particular reason. An engineering standard or guideline is not always a requirement when there is a better accessible evidence base to use. Engineering consultants often do not have time, resources or mandate to undertake extensive research, so they rely on the best available accessible science. Therefore, the science needs to be in a usable format for consultants, as without an evidence base a project may not be signed off at the detailed design stage due to liability risk. Failure of any project can be a reputational risk to the organisations involved, and this risk is often perceived to be greater with newer technology where there is a lack of examples or precedent. Significant liability risks are transferred to the contractors building the structure during the tender and construction stages. Due to the low number of nature-based coastal protection projects in Australia (Morris et al., 2024), local contractors may not have the experience, and there is uncertainty about the contract performance criteria during and after a build, and the potential warranty that can be offered on a nature-based structure.

3.2.4 Lack of technical guidelines

A lack of technical guidelines was listed 44 times and was present across all project stages, particularly during the design stages (concept design and detailed design) and during the tender process and construction stage. In the concept design stage, the main barrier was a lack of methods and validation data for modelling the effectiveness of nature-based coastal protection, either singly or as multiple habitats. It was also noted that there was a disconnect between the ecological and coastal engineering knowledge that has been previously acknowledged (Morris et al., 2019; Scheres and Schüttrumpf, 2020). In the preliminary design stage, the main barrier was the lack of design standards for nature-based coastal protection that include aspects such as the required width, density, and materials of the structure, as well as the habitat requirements of the species, such as water quality and sediment type and design events and design life. A lack of knowledge on the resilience of the ecological component until fully established was also listed as a barrier–this is related to ongoing maintenance if a nature-based structure is damaged during the establishment phase - as well as being able to identify the triggers for changing an adaptation pathway. Gaps in detailed design codes/guidance were similarly a barrier in the detailed design stage, as were the time and resources required to navigate the available science and to determine what constitutes "best science". Further, there is a lack of knowledge on what performance indicators should be used for nature-based coastal protection and as well as for safe and efficient construction methods. In the tender phase, there were challenges mainly related to a lack of experience and precedence in setting tender criteria for nature-based coastal protection, including detailed technical specifications, bill of quantities, material sourcing and cost estimates, and monitoring and evaluation conditions. In the construction phase, the barriers were centred around two components. The first barrier relates to the complexity of using non-standard construction methods and a lack of guidance on who should build and how nature-based coastal protection should be built safely and efficiently. The second barrier is the lack of guidelines on monitoring and evaluating the performance of nature-based coastal protection, resulting in a lack of clarity on whether and when the structure is working or has still yet to be established. These barriers can make it difficult to determine a breach of construction contract for build quality.

3.2.5 Lack of good examples

A lack of good examples as a barrier was present in the functional and concept design stages, where in these initial stages of a project, practitioners are looking to large-scale exemplar projects that have worked locally (i.e., in the same region, state or nationally in Australia) or in similar environmental conditions. This barrier relates to the uncertainty in the level of risk reduction and lack of technical guidance for nature-based coastal protection, as data from local case studies can contribute to an evidence base that can increase the business case for them being used elsewhere. Further, local examples not only aid the case for technical effectiveness, but also the complexity of obtaining approvals. For example, due to the success of the first example of a hybrid shellfish reef breakwater for erosion control in the state of Victoria, Australia, a second hybrid shellfish reef was constructed along the same peninsula in response to another erosion issue (Roob et al., 2022). Similarly, in the United States, private shoreline homeowners neighboured by seawalls were more likely to choose a seawall for their property than a nature-based method (Scyphers et al., 2015).

3.2.6 Lack of necessary expertise

In the initial stages of a project (functional and concept design), having the right interdisciplinary expertise in the team was identified as an important step. The absence of expertise to design a nature-based coastal protection was first identified in the preliminary design stage but was more prevalent in the tender phase, where it was listed as a barrier 15 times. The lack of expertise spanned multiple stakeholders within the project, including the project officer/manager responsible for the tender, the consultants who designed the nature-based structure, and the contractors who built it. A lack of experience among project officers in setting tender criteria, identifying the appropriate contractors and setting appropriate contracts/negotiations with the preferred contractor was identified. The availability of consultants and contractors tendering was also identified as a barrier due to a lack of skillset and willingness to tender because of a low market demand for nature-based coastal protection and the concurrent high market demand for more conventional coastal protection infrastructure, which does not incentivise upskilling workers to provide the necessary expertise.

3.2.7 Lack of governmental support

A lack of governmental support was only identified once in the case study scenario in the tender phase due to the lengthy procurement processes in place. However, a lack of a proactive approach from government in providing leadership on some of the other barriers (e.g., guidelines, example projects, planning and regulation) was considered a major impediment to upscaling nature-based coastal protection and, therefore, like funding, may be considered an overarching barrier.

3.2.8 Lack of community support

A lack of community support was predominantly highlighted as an important barrier in the initial design stages. However, this barrier emerged again in the final stage of construction. Community support is an important aspect of any coastal protection project and can be controversial among different stakeholder groups (e.g., beachfront homeowners versus beach users). A nature-based coastal protection may have different space requirements (i.e., increased development setback needs), a different aesthetic, and possibly different function to a conventional coastal protection structure. Therefore, a potential barrier includes not fully understanding community expectations, uses and values and the community's ability to understand coastal hazard risk, consequences and cost or the desire to embrace change. Balancing community co-design with engineering design and how and when to engage with the community were also identified as potential barriers in the concept design stage where there is a risk to project success of not getting sufficient community buy-in versus the time cost of extensive engagement. Another important Rightsholder group is Traditional Owners, and a lack of understanding of Traditional Owner cultural values and connection to Sea Country was identified as a barrier. In the construction phase, "bad press" that may impact community support was identified and may particularly apply to nature-based coastal protection that takes time to develop and grow and may appear unfinished or not working in the early stages. For example, mangroves growing behind constructed rock fillet structures can take 10–15 years to resemble a natural mangrove fringe (Morris et al., 2023). In some cases, a lack of community support has also led to vandalism of projects, such as the removal of mangrove plantings due to local community opposition (McManus, 2006).

3.2.9 Lack of education or awareness

A lack of education or awareness can be broadly linked to a lack of stakeholder support and expertise and was identified as a barrier in the initial stages of a project when conceptualising the values of nature-based coastal protection (e.g., should it achieve ecological goals, engineering goals or both). This barrier relates to a lack of a common definition or understanding of nature-based coastal protection. For example, having a clear position (e.g., a policy position) on what a "hybrid" solution means or the distinction between a novel habitat and a restored habitat can help avoid unintended consequences such as greenwashing.

3.2.10 Planning or regulation barriers

Planning and regulation barriers were initially identified in the preliminary design stage but occurred predominantly during the approval process, where time, cost and capacity barriers to obtaining approvals were identified. The approval process for nature-based coastal protection is unclear due to the lack of clarity on the regulation of intertidal and subtidal areas, which varies across jurisdictions, and can involve multiple approval processes with multiple agencies that differ across the states. The interaction of the approval process for nature-based coastal protection with other environmental legislation was also unclear, and it was noted that there is no fast-tracked approval pathway, even in states where nature-based methods are preferred in the policy. Thus, it is not enough for a government to prefer nature-based coastal protection in policy, they also need to lead a first step change in policy to practice (e.g., through the planning system or regulations like consents). There is a barrier in the capability of teams within state government to understand and adopt the policy, which then blocks the land managers and designers of the solutions in implementation of nature-based coastal protection.

3.2.11 Long-term performance

A lack of understanding about the long-term performance of nature-based coastal protection was identified in the initial design stages and was specifically related to the climate sensitivity of the ecological component in terms of the ability for adaptation and options for retreat under future conditions. Nature-based coastal protection is often cited as having the ability to adapt to climate change, however, this will depend on their design and environmental conditions (Mitchell and Bilkovic, 2019).

3.2.12 Uncertainty in ongoing maintenance and monitoring costs

The barrier of ongoing maintenance was identified in the concept design stage but became more prevalent in the detailed design and construction phases. At all phases, the concern was similar and related to who was responsible for conducting and resourcing ongoing maintenance associated with nature-based coastal protection. A lack of guidance about the maintenance required and the associated costs also contributed to the uncertainty. This uncertainty, as well as some funding schemes preferencing new "shovel-ready" activities (i.e., excluding maintenance), can make the case for funding project maintenance harder than funding a new project and can become a disincentive if maintenance costs are likely to be high.

3.2.13 Uncertainty in ongoing ownership/tenure

The agreement of long-term ownership was first identified as a barrier in the functional design stage but was noted a further three times in the approvals stage, where the ownership and ongoing management need to be defined. If the relevant parties cannot agree on long-term liability, a project cannot proceed. There was also a question around whether nature-based coastal protection is an asset, for example, is there a point in time where a nature-based method is considered a natural system rather than a coastal protection asset or will there always need to be some ownership ensuring it is still meeting its objectives like a conventional coastal protection structure.

3.2.14 Logistic barriers

An additional barrier was identified in the construction phase of a nature-based coastal protection project related to logistics that may not be a consideration in conventional engineered coastal protection projects. These included factors such as construction needing to be timed around seasonal availability of plants or recruitment of organisms or favourable weather conditions, the operation of construction equipment in ecologically sensitive areas, and access to the site for ongoing monitoring. It was also noted that the added complexity of nature-based coastal protection may reduce superintendency resources and staff availabilities.

3.3 Solutions for enabling nature-based coastal protection

The solutions identified predominantly fell into two categories: tangible actions and longer-term solutions or aspirations with linked actions (Figure 5). Solving the barriers of a lack of funding and government support was considered overarching to the entire framework of implementing nature-based coastal protection. Other solutions identified were linked to specific tasks during the design process that collectively would allow progression through this current process (Figure 5). The following sections describe the details of the solutions identified.

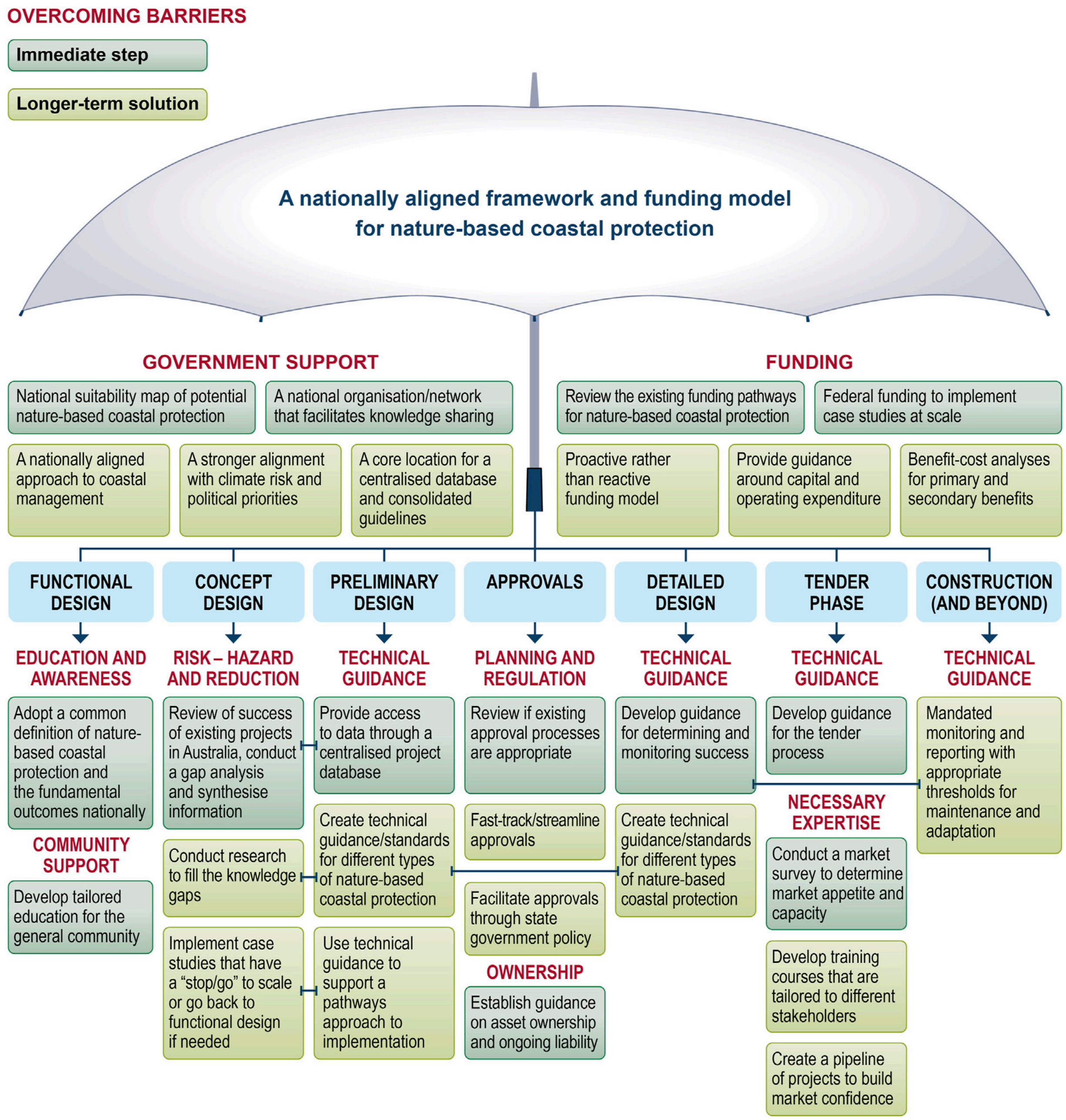

FIGURE 5
An overview of the key solutions identified to overcome barriers (red text) to implementing nature-based coastal protection. Solutions were categorised as immediate steps that could be taken (dark green boxes) that may then inform longer-term solutions (light green boxes). Blue lines indicate interconnected solutions across different design stages.

3.3.1 Government support

A nationally aligned approach to coastal management (i.e., across federal, state and local government) was identified as a top priority for advancing nature-based coastal protection. A key step in this process was establishing a national network/ organisation/guidance body on nature-based coastal protection that could drive a national framework and coordination. This national coordinating body would centralise technical guidance, facilitate knowledge sharing through a national project database, and support a proactive funding model to advance the implementation of nature-based coastal protection. The national project database could leverage from the existing Living Shorelines Australia database that provides an online portal of information on current projects (Morris et al., 2024). In the United States, two national organisations that support the application of living shorelines are the U.S. Army Corps of Engineers and the National Oceanic and Atmospheric Administration (NOAA). These organisations have provided guidelines for the use of nature-based coastal protection (Bridges et al., 2015), streamlined national permitting processes (Nationwide Permit 54 – Living Shorelines) and funded living shorelines projects that are then made publicly available in an online database (https://storymaps.

arcgis.com/stories/edc3cc67b37f43a5a815202f81768911). Further, high-level government support was provided by the Biden-Harris Administration in the US through the release of a Roadmap for Nature-Based Solutions to Fight Climate Change, Strengthen Communities, and Support Local Economies (The White House, 2022).

Other tools that were identified for inclusion in the guidance provided by a national body were state and national overlays of nature-based coastal protection suitability that could inform alignment with climate risk, political and other priorities, scale of funding required, and aid in community socialisation. A living shoreline suitability map has been developed for the state of Victoria, Australia (Young et al., 2023) that could be used as a starting point for other regions or states. This map was based on previous suitability modelling that has been used in several US Atlantic and Gulf coast states to encourage greater use of nature-based methods (e.g., Berman and Rudnicky, 2008; Nunez et al., 2022).

3.3.2 Funding

A proactive rather than reactive funding model was the key solution for overcoming funding availability for nature-based coastal protection. One of the main aspects of a proactive funding model was the inclusion of more diverse funding models through both public and private investment. Currently, most nature-based coastal protection projects are funded through capital expenditure for coastal protection works (Morris et al., 2024). There is, however, the recognition that nature-based coastal protection can provide other ecosystem functions and services that may align with different funding mechanisms. An evaluation of the alignment of nature-based coastal protection with other current and proposed funding mechanisms could be a first step in this process, for example, from carbon credits for projects that are eligible through the Emission Reduction Fund (Lovelock et al., 2023) or biodiversity credits via the Nature Repair Market (Parliament of Australia, 2023). There is increasing support at the federal level for enhancing risk and resilience to climate hazards, which may support States with proactive nature-based approaches to coastal hazard risk mitigation (e.g., through the National Emergency Management Agency, Disaster Ready Fund Act 2023). The development of a specific market-based instrument to incentivise uptake (e.g., coastal resilience credits) could be a longer-term solution. It was noted, however, that in states where most of the foreshore is publicly owned (e.g., 96% is state government managed in Victoria), market-based instruments may not incentivise nature-based coastal protection as the money from the credits earned does not go back to the land manager. Consequently, it will be important to identify where market-based instruments may disincentiv*ise* nature-based coastal protection.

Another identified priority within a proactive funding model was the allocation of national-level funding to implement a few iconic/large-scale nature-based coastal protection projects that will help to increase the uptake and act as an "enabler" for more funding and projects, as well as add data on effectiveness and co-benefits. An exemplar for this is the 2021–2025 Australian Government's Blue Carbon Conservation, Restoration and Accounting Program that is funding restoration activities and environmental-economic accounting for five national demonstration project sites to help scale up investment in coastal blue carbon ecosystems (Saunders et al., 2022). This program is also developing a guide for measuring and accounting for the benefits of restoring coastal blue carbon ecosystems and establishing a blue carbon restoration and accounting community of practice. The blue carbon program could be used as a blueprint for establishing a nature-based coastal protection program with the same aim of upscaling investment in more sustainable coastal adaptation solutions. Better guidance on the capital and operating expenditure required for nature-based coastal protection was also identified as a priority, as well as the integration of this into benefit-cost models for both primary (i.e., habitat restoration and coastal protection) and secondary benefits (i.e., other services) to contribute to the business case that attracts diverse investment.

3.3.3 Education and awareness

Better clarity on what is accepted as a nature-based coastal protection and what is not was identified as a priority. Previous research has shown that terminology for nature-based coastal protection differs across the world (Smith et al., 2020). Further, given the different ecology, environmental and socio-political landscapes among various countries, and even within a country, there will be diverse approaches to nature-based coastal protection. Thus, national guidance on a common definition for nature-based coastal protection and examples of these in an Australian context would provide a clearer pathway for the technical guidelines that need to be developed for these methods. This was particularly highlighted in the open coast case study (discussed further in Section 3.4).

3.3.4 Community support

There was a need identified for greater community engagement around coastal hazard risk and potential solutions, of which one could be nature-based coastal protection, as well as project-based engagement with specific communities where nature-based methods were being implemented. It was acknowledged that many of the barriers to stakeholder support could be mitigated by early engagement in the project planning process and through the provision of tailored education for the general community relevant to their perceptions, concerns, and values. To provide informed education materials, it will be important to understand the community perception (both private shoreline homeowners as well as the general users of public space) of coastal hazards and nature-based coastal protection (e.g., Strain et al., 2022; Guthrie et al., 2023). Key aspects of a community engagement plan could include opportunities for community reference groups to discuss nature-based coastal protection and engage in participatory planning, a process for reporting back to the community in local projects and ongoing maintenance and monitoring by citizen scientists. There is also a need to partner with Traditional Owner communities to better understand the opportunities for nature based coastal protection to support the protection of cultural values and assertions for Sea Country.

3.3.5 Technical guidance

The main steps to developing technical guidance were identified as: 1) Identify what types of nature-based coastal protection should be included in a design code; 2) Meta-analysis/review of existing projects and information available; 3) Conduct a gap analysis to identify where information is unavailable; 4) Conduct research to fill the knowledge gaps; and 5) Write standards. The technical guidance required differed throughout the design stages, and thus the guidelines developed needed to cover aspects such as: what the problem is (driver/hazard); type of nature-based coastal protection and guidance for implementation (including evidence-based formulas); material specifications; suitability of scale; climate change impacts; the tender process; and monitoring required including definitions on what success is in terms of ecology and engineering. While there have been efforts to write guidance documents for nature-based coastal protection (Morris et al., 2021; Bridges et al., 2022), detailed design specifications that engineers can apply are still missing.

It was highlighted that developing technical guidance would provide an evidence base that would reduce the risk of using nature-based coastal protection from both a hazard risk reduction and liability perspective. However, it was also recognised that to progress the knowledge and implementation of nature-based coastal protection while technical guidance is under development, an adaptation pathways approach can be utilised, where projects are allowed to fail and have a "stop/go" to go back to functional design if needed or upscale if successful. Careful communication of the risk of failure and thresholds for decisions to stakeholders and the community is required, as well as a greater acceptance of this risk by stakeholders.

3.3.6 Policy and regulation

Clarity in the approvals process for nature-based coastal protection was identified as a priority for overcoming barriers to permitting. A first step in this process was identified as an evaluation of the current approvals process in each state. A long-term solution was the development of a fast-tracked or streamlined nature-based coastal protection approvals process that is appropriate for this activity rather than other types of development. With a three-tier government structure in Australia, the approval process can be complex, requiring permits from multiple agencies (Shumway et al., 2021). This governance structure is similar to the United States, but there is a federal nationwide permit (Nationwide Permit 54) has been developed specifically for living shorelines. This federal process is combined with a state permitting process, in which some states have also developed streamlined permitting processes to incentivise waterfront property owners to use a living shoreline over conventional hard structures (e.g., Virginia and Florida; Virginia Marine Resources Commission, 2015; Barry et al., 2019). Another long-term solution was the support of fast-tracked approvals through State government policy and a high-level strategy that supports a preference for nature-based coastal protection and, therefore, facilitates approvals. While some states currently have strategies that support nature-based coastal protection, these policies are relatively new and the approach to facilitating nature-based protection projects through the approvals processes is still developing. Regulations and consents need to be adapted to new policies to remove barriers to nature-based coastal protection.

3.3.7 Ownership

Asset ownership and ongoing liability was identified as a key piece of guidance that needs to be provided for nature-based coastal protection. This will need to involve a strong consultation process with landowners and managers, core approval agencies and the stakeholders involved in implementing nature-based coastal protection (e.g., consultants, contractors, academics, NGOs).

3.3.8 Necessary expertise

The problem of expertise was relevant to both a desire to tender for nature-based coastal protection projects and having the skills required to deliver these projects for consultants and contractors. A key step identified in overcoming these barriers was a market survey of marine contractors, to determine the extent of the problem by assessing appetite and capacity to deliver nature-based coastal protection projects. A longer-term solution was to identify a government-led pipeline of nature-based coastal protection projects, highlighting the number of projects and funding committed to developing confidence in the market. Alongside this is the development of training courses to upskill consultants and contractors, potentially including a government-funded certification process as nature-based coastal protection providers and monitoring. Given nature-based coastal protection often requires a multi-disciplinary team, a framework to enable networking of up-skilled consultants would also allow for such teams to be more readily formed under the frequently short timeframes of tender submissions.

3.4 Conceptualisation of solutions in a hybrid open coast scenario

The conceptualisation of the barriers and solutions in a hybrid open coast scenario reinforced the importance of collating information that demonstrates the use of nature-based coastal protection in a variety of environmental situations. The biggest challenge in using nature-based coastal protection on the open coast was an industry definition and recognition of what constitutes a "hybrid nature-based coastal protection" option in the spectrum of green-grey solutions. This definition became much more important when combining conventional coastal protection structures with a nature-based component to avoid "greenwashing" where the solution is essentially a protect/engineering solution with some ecology added (i.e., more akin to hard ecological engineering techniques that aim to ecologically enhance conventional engineered structures; Firth et al., 2020). There are existing guidelines that articulate what is meant by nature-based coastal protection (e.g., Bilkovic et al., 2017; Morris et al., 2021), however an additional guideline/manual could further explore the delineation of soft (i.e., fully nature-based) and hybrid nature-based coastal protection and the design principles that should be used in each case as a solution to this barrier. For example, approaches that are already relatively commonly applied to the open coast include an offshore breakwater, artificial reef or onshore seawall combined with beach nourishment, or a seawall buried in a dune. If these approaches are considered hybrid nature-based coastal protection, then many of the barriers related to the risk of uncertainty in the level of hazard reduction and liability and lack of technical guidance are reduced or removed in the design process (Figure 6). This is because there is a greater precedence for their use, and guidelines and standards are already available for designing, constructing, and maintaining conventional engineering structures and beach nourishment. However, the meaningful integration of

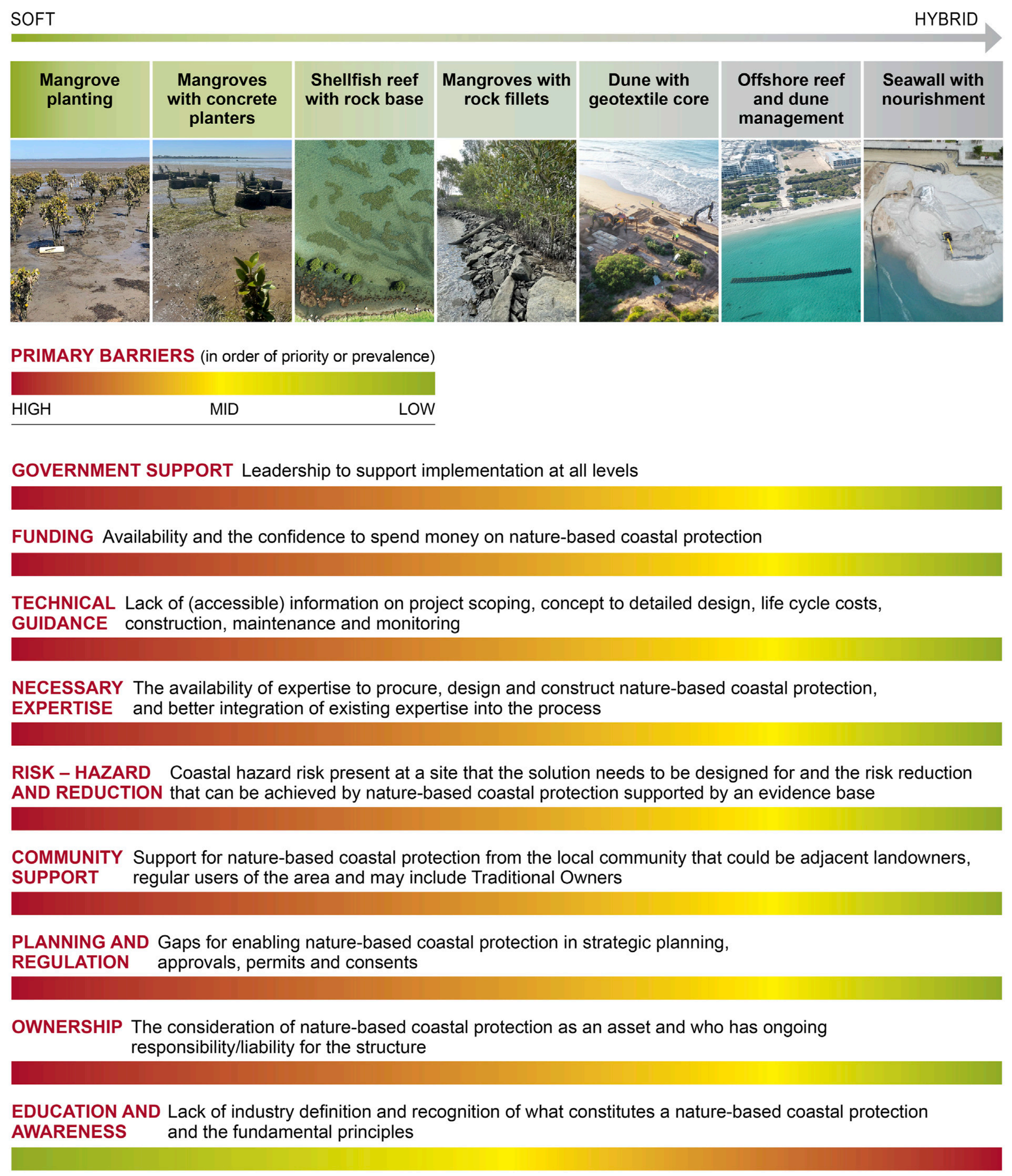

FIGURE 6
The change in the importance of primary barriers to nature-based coastal protection based on the method used along a continuum of soft to hybrid. Note the coastal protection measures given are examples only, the continuum and type of nature-based coastal protection will vary depending on the site-specific context (e.g., sheltered versus open coast).

ecology into these solutions and the interaction between the engineered and nature-based components were still identified as research gaps that need technical guidance. If commonly used options are not considered nature-based coastal protection, then more innovation may be needed for open coast options, and this re-introduces similar barriers to the initial scenario.

4 Conclusion

While nature-based methods are frequently cited as a more sustainable alternative to conventional coastal protection structures (e.g., Ferrario et al., 2014), there is little research examining the barriers and, importantly, the solutions to upscaling this approach (except see Molino et al., 2020; DeLorme et al., 2022; Mednikova et al., 2023). While this study focused on the Australian viewpoint and from an engineering perspective, many of the general barriers and solutions to nature-based coastal protection identified align with the perceptions of coastal professionals and decision-makers in the United States, where research has also been done on this topic (Molino et al., 2020; DeLorme et al., 2022; Mednikova et al., 2023). The barriers identified spanned scientific, socio-political and economic domains, and thus the variety of solutions proposed will need to be led by different stakeholders involved in the decision to use nature-based coastal protection. By conceptualising the barriers and solutions using hypothetical case studies of nature-based methods, we identified both immediate actions and long-term solutions for enabling nature-based coastal protection. While many of these solutions will need to be actioned at the national level, as localisation of information is important in supporting the use of nature-based methods (DeLorme et al., 2022), it would be useful to have a global definition and recognition of what constitutes a nature-based coastal protection option that can be consistently used.

Technical guidance was a key scientific need identified throughout the design process, however, designers (e.g., consultants) and decision-makers (e.g., government) need to apply this guidance as it becomes available and to support data collection. If created, technical guidance needs to be properly implemented, such that designers (e.g., engineers) are made aware of its existence, can easily access it, and can be educated to effectively use it. Increasing the availability of technical guidance will reduce the risk associated with delivering a nature-based coastal protection project, but there was also emphasis placed on the need for stakeholders to become more accepting of risk to progress the development of a knowledge base. While there is support for nature-based coastal protection, there is a need for all project stakeholders to develop models of risk distribution. Furthermore, there is a need for greater acceptance of sub-optimal performance until the establishment of a sufficiently large-scale evidence base that can be used to inform and refine new as well as existing methods. Although many coastal management decisions are made at a local or state level in Australia, there is a desire for centralised information at a national level. This aligns with the needs articulated by coastal practitioners in the United States (DeLorme et al., 2022). A nationally coordinated organisation for nature-based coastal protection can give greater confidence at a state and local level that there is a consistent method for implementing this approach. When nature-based solutions are applied at a large scale and for a wide range of conditions, it will be possible to gather the evidence, expertise, experience and methodologies necessary to establish nature-based coastal protection at a level consistent with conventional coastal engineering approaches.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by University of Melbourne Human Research Ethics Committee. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

Author contributions

RM: Conceptualization, Formal Analysis, Funding acquisition, Investigation, Methodology, Writing–original draft. AP: Conceptualization, Investigation, Methodology, Writing–original draft. AB: Investigation, Methodology, Writing–review and editing. GC: Investigation, Writing–review and editing. DD: Investigation, Writing–review and editing. AD: Investigation, Writing–review and editing. DH: Investigation, Writing–review and editing. SK: Investigation, Writing–review and editing. AM: Investigation, Writing–review and editing. KO'M-J: Investigation, Writing–review and editing. SSu: Investigation, Writing–review and editing. MT: Investigation, Writing–review and editing. FV: Investigation, Writing–review and editing. JW: Investigation, Writing–review and editing. EZ: Investigation, Writing–review and editing. SSw: Conceptualization, Funding acquisition, Investigation, Methodology, Writing–original draft.

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Conflict of interest

Authors GC and EZ were employed by Water Technology. Authors DD and EZ were employed by Arup. Author AD was employed by Alluvium Consulting. Author KM-J was employed by BMT.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fenvs.2024.1435833/full#supplementary-material

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