



Interdisciplinary solutions to enable nature-based solutions for coastal protection achieve ecological and engineering outcomes

Alice J. Twomey^{a,b,*} , Katherine Erickson^{a,c} , Melanie J. Bishop^d , Kris Boody^e , David P. Callaghan^f , Toni Cannard^g , Catherine E. Lovelock^{a,b} , Mariana Mayer-Pinto^c , Rebecca L. Morris^h , Andrew W.M. Pomeroy^h , Megan I. Saundersⁱ , Andy Steven^g , Nathan J. Waltham^j , Ana Bugnot^g 

^a School of the Environment, The University of Queensland, QLD 4067, Australia

^b Centre for Biodiversity and Conservation Science, The University of Queensland, QLD 4067, Australia

^c Centre for Marine Science and Innovation, School of BEES, University of New South Wales, NSW 2052, Australia

^d School of Natural Sciences, Macquarie University, NSW 2109, Australia

^e Sunshine Coast Council, QLD 4560, Australia

^f School of Civil Engineering, The University of Queensland, QLD 4067, Australia

^g CSIRO Environment, Queensland Bioscience Precinct, Brisbane QLD 4067, Australia

^h National Centre for Coasts and Climate, School of BioSciences, The University of Melbourne, VIC 3010, Australia

ⁱ CSIRO Environment, Hobart, TAS 7000, Australia

^j Centre for Tropical Waters and Aquatic Ecosystem Research, College of Science and Engineering, James Cook University, QLD 4810, Australia

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ABSTRACT

Nature-based solutions (NbS) present a promising approach to coastal protection, leveraging the natural capacity of coastal ecosystems to mitigate hazards. Despite their potential, the practical implementation of NbS faces obstacles, including a lack of clear guidance for design and implementation. In this study, we conducted interviews with 34 practitioners involved in NbS projects for coastal protection to (1) identify key perceived barriers and suggested/or realised solutions and (2) assess how these varied among practitioner groups, spanning Coastal Engineers, Coastal Engineering Scientists, Ecologists, and/or Project Managers. During the interviews, practitioners identified 34 distinct challenges to NbS implementation, falling into 14 categories and 345 solutions into 15 categories. Both challenges and solutions varied between practitioner groups. While all groups identified unfamiliarity with NbS as a key challenge, Coastal Engineers and Coastal Engineering Scientists had more design-focused views about NbS challenges (e.g. risk, technical guidelines and data deficits) and solutions (e.g. hybrid solutions). In contrast, Ecologists and Project Managers typically had more implementation-focused challenges (e.g. cost/lack of funding) and opportunity-driven solutions (e.g. community acceptance and education). The solutions most suggested by Coastal Engineers were for hybrid solutions, whereas Coastal Engineering Scientists suggested interdisciplinary teams. The anthropocentric-ecocentric gap between engineers and ecologists highlights the need for NbS teams to be interdisciplinary and utilise standardised language. Overcoming challenges to NbS will also require advocacy for government support and policy reform, along with early, meaningful engagement and capacity building with Indigenous people, which was identified as a crucial solution to current NbS challenges.

1. Introduction

Coastal ecosystems, including mangroves, salt marshes and shellfish reefs, among others, serve as effective nature-based solutions (NbS) for coastal erosion and flood mitigation (hereafter ‘coastal protection’),

owing to their capacity to attenuate waves, stabilise and accrete sediment (Jordan and Fröhle, 2022). NbS for coastal protection (hereafter, NbS for short) offer the advantage over conventional hard engineering solutions (e.g. seawalls, submerged breakwaters) in that they are less costly to establish and maintain (Hagedoorn et al., 2021; Narayan et al.,

* Corresponding author at: School of the Environment, The University of Queensland, QLD 4067, Australia

E-mail address: a.twomey@uq.edu.au (A.J. Twomey).

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2016; Sutton-Grier et al., 2018; Temmerman et al., 2013), can keep pace with sea level rise through vertical accretion (Bennion et al., 2024) and provide a variety of co-benefits including the enhancement of biodiversity, fisheries productivity, and blue carbon stores, thereby boosting fisheries, tourism and other dependent industries (Morales et al., 2022). The coastal habitats underpinning NbS can also be of considerable cultural value, including to Australian First Nation's people (Ferguson et al., 2025). Yet, despite the compelling case for NbS as both environmentally sustainable and effective coastal protection, their uptake remains slow (Morris et al., 2018; Saunders et al., 2022).

The slow uptake of NbS has sparked considerable interest in identifying the technical and socio-political challenges and barriers to implementation, e.g. Gain et al. (2022); Van der Meulen et al. (2023) and Saunders et al. (2022). While collaboration between engineering and ecological disciplines is key to the success of NbS (Scheres and Schüttrumpf, 2020), previous studies have focused on barriers and solutions to NbS from the perspective of individual practitioners, including government organisations, engineering and environmental consultants, and academics, among others (DeLorme et al., 2022). Engineers have identified technical barriers to NbS projects, including the absence of a publicly available evidence base for their effectiveness. Engineers have recognised a lack of NbS understanding, a lack of design standards and guidance for tender and construction, and monitoring and maintenance (Morris et al., 2024). By contrast, NbS practitioners cite key barriers as lack of awareness and expertise to deliver NbS, insufficient public and government support, complex permitting processes, and a lack of availability and funding support (DeLorme et al., 2022; Mednikova et al., 2023; Morris et al., 2024). Additionally, how Indigenous custodians of Sea Country are appropriately involved in approvals, project design and monitoring remains a challenge. Several solutions to these barriers have been proposed, including developing technical guidance documents, mandated NbS monitoring, streamlined approval pathways, and increased and diversified funding (DeLorme et al., 2022; Morris et al., 2024).

Understanding whether key barriers and associated solutions are consistent or differ among coastal practitioners is essential to identify the pathways forward for scaling NbS for coastal protection. Here, we interviewed 34 coastal NbS practitioners to compare how the perceived barriers and suggested and/or realised solutions to NbS design and implementation vary among the disciplines involved (Coastal Engineers, Coastal Engineering Scientists, Ecologists and Project Managers). While the primary focus of these interviews was on Australian practitioners, 6 of the 34 interviewees were based internationally, and many of the Australian practitioners had also worked on international projects. Consequently, our study provides an internationally relevant perspective. The interviews were designed to explore disciplinary differences in perspectives among individuals typically involved in decision-making for project design. By identifying key differences in perceptions and approaches among disciplines, this study provides recommendations for progressing the implementation of NbS.

2. Materials and methods

2.1. Participant recruitment

Participants in this survey (hereafter referred to as practitioners) were selected based on their past or present involvement in the conception, design and/or implementation of scaled NbS projects (Fig. 1). We excluded individuals (e.g. academic researchers) who had only worked on NbS in a theoretical context or on experimental methodologies that had not been scaled. Initially, potential participants were identified from the co-authors' networks. Other potential participants were added based on recommendations from respondents who agreed to be interviewed. A total of 88 participants were emailed, with 34 interviews conducted from September to December 2023. Five interviews were excluded as participants did not meet the inclusion criteria

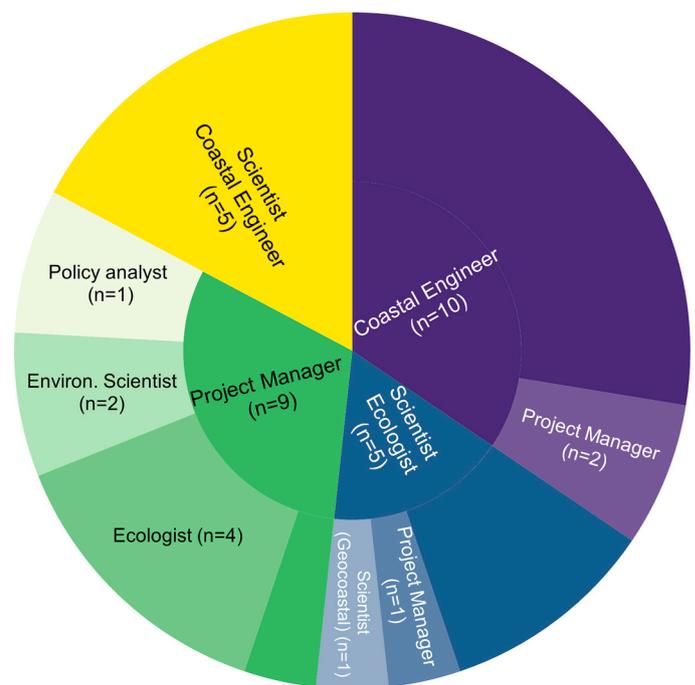


Fig. 1. Main role (centre of the circle) and background (outer circle) of interviews, $n = 29$.

requiring them to have worked on NbS implementation or design rather than theoretical research. In total, 29 participants provided interviews that were included in this study. Three participants provided written responses, and one gave both an interview and a written response. Though the resulting sample size was small, it was appropriate to the idiographic nature of the study (Brinkmann, 2014).

This study was conducted under the University of Queensland human ethics approval project number 2023/HE001050 and CSIRO Reciprocal Ethics Clearance 161/23.

2.2. Sample instrument

Data was collected via unstructured interviews (Brinkmann, 2014) online that occurred over Zoom (v. 5.16.10) or Microsoft Teams (v. 1.6.00.29964). The interview questions were a mix of multiple-choice and open-ended questions addressing the participants' discipline and previous involvement in NbS (Q1–2), the key challenges of projects they were involved with (Q3–7), the pathways by which challenges were overcome (Q5), demographics (Q8–10) and views on co-benefits (Q11) (Supplementary 1). Due to the unstructured nature of the verbal interviews, respondents often provided detailed answers that extended beyond the options listed in the multiple-choice questions. The challenges from which respondents could select in the multiple-choice section of question 5 were identified from Saunders et al. (2022) - the most recent study on challenges associated with NbS at the time of this study. Verbal interviews were recorded on Zoom/Teams and transcribed using Fireflies.ai (v. 0.2.5). All interview transcriptions were manually checked against the audio, and mistakes were corrected.

2.3. Data analysis and interpretation

Transcriptions were imported into Taguette (Rampin and Rampin, 2021), an open-source software for qualitative data, and manually read and tagged to identify keywords and common themes among responses for each interview question. Responses were grouped according to which of the four professional disciplines the respondent self-nominated as: practising Coastal Engineers, Scientists with an ecology background,

Scientists with a coastal engineering background or Project Managers. For each question, long-form responses were manually reviewed to identify common themes, which were then grouped to highlight similarities and differences across responses. Responses were grouped by discipline and visualised as heatmaps, showing the frequency of responses within each discipline using R Studio (RStudio Team, 2021).

When interpreting responses, it is important to understand that the categorisation of challenges and solutions relied on respondents' language and context, leading to overlapping, nested, or overly broad categories. Some terms, like "risk" and "land tenure", were used inconsistently or ambiguously, limiting precise classification. For example, respondents typically defined a "hybrid solution" as a response to NbS challenges. However, by definition, a hybrid solution is not an NbS (i.e. living shoreline or nature-based coastal protection (Bilkovic et al., 2017)), although it incorporates natural elements. Differences in disciplinary language, especially between engineers and ecologists, further complicated categorisation and highlighted the lack of shared terminology among NbS practitioners.

Many respondents shared case studies illustrating how they overcame NbS design and implementation barriers. While space limitations prevent us from including all of them, we highlight several examples for each of the top three challenges in the Results section.

3. Results

The data is presented here with three key sections: 3.1 outlining the challenges (responding to questions 3–6), 3.2 outlining the solutions (responding to question 5), and 3.3 outlining the co-benefits (responding to question 11).

3.1. Participants

Of the 29 respondents, there were five Scientists in the area of Coastal Engineering and six Scientists in the area of Ecology, all of whom worked at universities; nine Project Managers split between government ($n = 7$; $n = 5$ local government, $n = 2$ in state government), and private companies ($n = 2$); and ten Coastal Engineers, employed by private firms ($n = 6$) and by government ($n = 4$; $n = 3$ in local, $n = 1$ in state government; Fig. 1).

Participants were mainly from Australia ($n = 23$), followed by the USA ($n = 3$), Hong Kong ($n = 1$), Belgium ($n = 1$) and the Netherlands ($n = 1$).

3.2. Comparing challenges to implementation across practitioner disciplines

Based on participants' responses from the 29 interviews, 34 separate challenges to implementing NbS for coastal protection were identified, which could be grouped into 14 themes (Table 1, Fig. 2). For example, 'permitting issues' and 'policy issues', though distinct challenges, were grouped as 'permits/policies', as the two issues are interrelated (Table 1, Fig. 2). Participants from the four disciplines identified a similar average number of challenges, 10.2–11.4 per person.

Unfamiliarity with NbS, data deficits (see Fig. 4) and difficulty with key stakeholder approvals (see Figs. 3 and 4 for more detail) were the top three challenges to implementation across all four disciplines.

Interestingly, 100 % of scientists with an engineering background identified the lack of technical guidelines as a challenge, but only 70 % of Coastal Engineers identified that barrier (Fig. 2). Almost all scientists with an ecological background identified a lack of funding as a challenge, but other disciplines mentioned this challenge less frequently (Fig. 2).

3.2.1. Deep dive into the most frequently experienced challenges – Unfamiliarity with NbS, Data deficits, Key stakeholder approval

Respondents generally identified that unfamiliarity with NbS was a

Table 1

Descriptions of key challenges to NbS for coastal protection implementation based on how the respondents defined or spoke about the challenge. Challenges in bold were listed as options in interview Question 5 (see Supplementary 1).

Challenge	Description
Cost/lack of funding	NbS costing more than traditional solutions, difficulties securing and maintaining funding for the duration of an NbS project, and the cost of failure.
Data deficit	Not having the scientific data and research needed to implement or support NbS.
Ecosystem connectivity issues	Multiple ecosystems interacting together - i.e. inability to predict the effect of connected ecosystems such as seagrass and mangroves combined.
Lack of technical guidelines	Lack of technical guidelines on how to design and build NbS solutions, such as engineering standards/manuals.
Land tenure	Difficulties of working on private/government land and difficulties of incentivising people to let NbS be built on their land.
Logistics/effort	NbS takes more time and effort to design than traditional solutions. We need to have certain materials available and good weather.
Permits/policies	The procedures to get permits and approvals, and navigate the legal pathways and rules (policies) when trying to build NbS.
Physical environment	The environmental context prevents NbS from being built, e.g., it is too urban, has high-energy waves, and lacks space.
Risk - requires higher certainty	NbS solutions have an uncertainty of outcomes as compared to traditional grey infrastructure solutions and, therefore, require more certainty in the form of testing, data, modelling, and funding.
Scale of the problem	The coastal hazard is too big, and difficult to try and use NbS to solve the problem.
Stakeholder reluctance	Stakeholders (such as communities, clients, and Councils) are reluctant to implement solutions and can oppose the approval and implementation.
Timescale	NbS need more time to stabilise in order to be effective, so they cannot be used when the coastal hazard mitigation needs to happen immediately.
Unfamiliarity with NbS	Unfamiliarity with and lack of education about NbS for engineers/clients/councils/communities. Includes misinformation in the media, such as greenwashing, that can confuse people or alter their perceptions.
Unknown interactions with the physical environment	Lack of understanding of how NbS will interact with the physical environment - how will the solution fit in with the ecosystem, and will there be adverse flow-on effects?

source of reluctance from stakeholders; hence, unfamiliarity with NbS and stakeholder approval are connected challenges. Respondents faced challenges with stakeholder approval due to a reluctance (fear/hesitance) to utilise NbS over traditional grey infrastructure options (Fig. 2), which they believed stemmed from unfamiliarity with NbS, high uncertainty of outcomes, risk adversity, or unwillingness to 'put in the effort' concerning addressing other challenges.

Overall, the most reluctance was experienced from coastal engineers (engineers that respondents had worked with, excluding respondents themselves) and the government (Fig. 3). However, there were differences between disciplines. Coastal Engineers faced the most reluctance from other engineering colleagues (85 %), Ecologists from the community (85 %), Project Managers from the government (80 %), and Coastal Engineering Scientists experienced lower levels of reluctance (60 %) across the top four categories.

Additionally, most respondents (23/29) mentioned data deficits as a barrier to implementation (Fig. 2). More specifically, coastal engineers mentioned a lack of biological technical specifications, such as

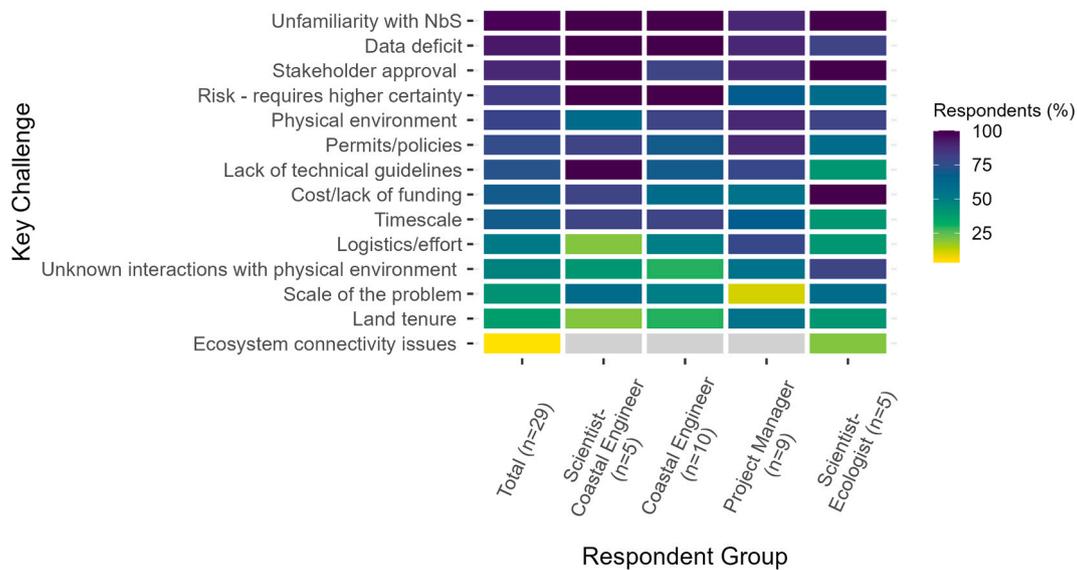


Fig. 2. Identified challenges to the implementation of NbS faced by different groups (total respondents $n = 29$; questions 4 and 5, [Supplementary 1](#)). Darker colours represent a higher percentage of respondents citing that challenge, and lighter colours represent a lower percentage. Grey boxes indicate no mention by the relevant discipline group.

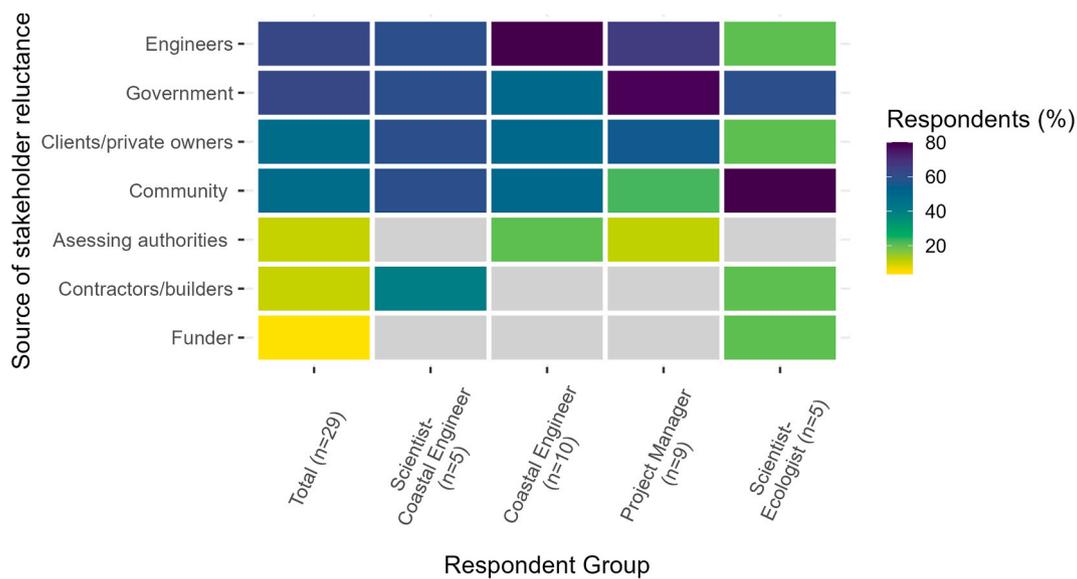


Fig. 3. Heatmap outlining the frequency of encountered reluctance from stakeholders identified by each respondent discipline group in response to Question 5 (see [Supplementary 1](#)). Grey boxes indicate no mention by the relevant discipline group.

appropriate plant species to use, projected growth rates of oysters/mangroves, and strength of biological materials like oyster shells (43 %) ([Fig. 4](#)). Ecologists mostly lacked long-term/monitoring data to confirm the validity of models in the field, how the NbS are performing, and how materials from NbS interact with the environment (75 %), and Project Managers lacked specific geomorphological specifications like sand movement models and LiDAR/bathymetry data (50 %). Coastal Engineering Scientists lacked numerical models of natural options like projected growth and provision of protection of mangroves or oysters (100 %). However, 30 % of all respondents thought that data deficits were inherent and unavoidable, and therefore, respondents thought adaptive solutions were needed to fill in knowledge gaps.

Overall, permits and policies were the most difficult challenges experienced, followed by the unfamiliarity with and need for education in NbS, and then risk (NbS requiring higher certainty, [Fig. 5](#)). Coastal engineers viewed risks caused by uncertainty in data and outcomes

associated with implementing NbS over more traditional grey infrastructure as the most significant challenge to implementation, whereas Coastal Engineering Scientists considered permits and policies more difficult. Ecologists considered the physical environment (spatial constraints, conditions for growth/establishment, etc.) a difficult challenge, whereas Project Managers viewed the lack of familiarity with NbS as the most difficult challenge to overcome. The lack of familiarity with NbS was the only challenge considered difficult for all four disciplines.

3.3. Solutions employed to overcome the challenges to NbS implementation

Based on participants' responses from the 29 interviews, there were 345 potential solutions raised to the implementation of NbS, 240 that have been put into practice in NbS projects and 105 suggestions. These solutions aligned with 15 broader themes ([Table 2](#), [Fig. 6](#)). For example,

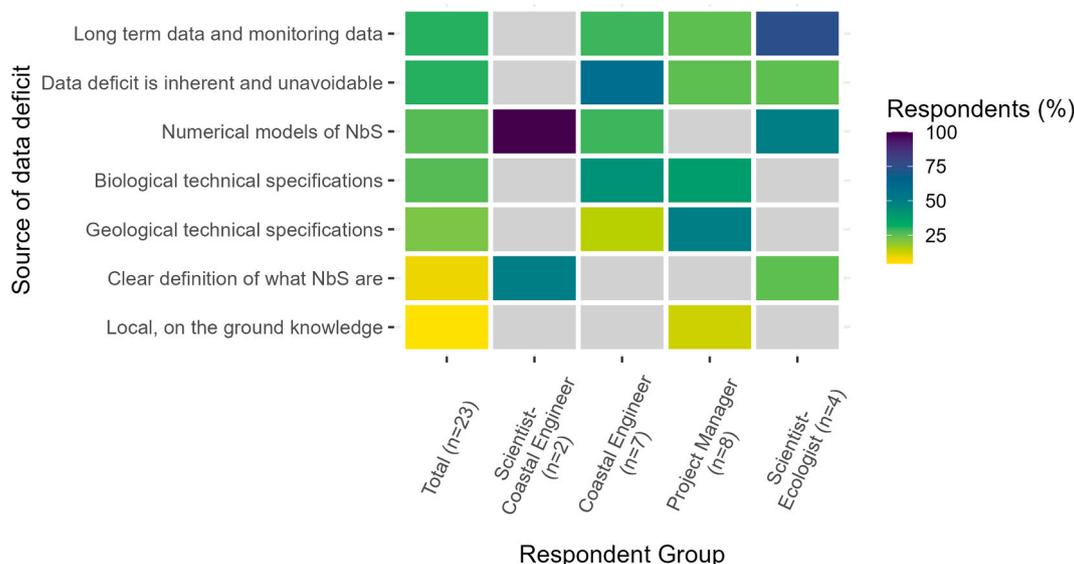


Fig. 4. Heatmap outlining the frequency of encountered data deficits from stakeholders identified by each respondent discipline group in response to Question 5 (see [Supplementary 1](#)). Grey boxes indicate no mention by the relevant discipline group.

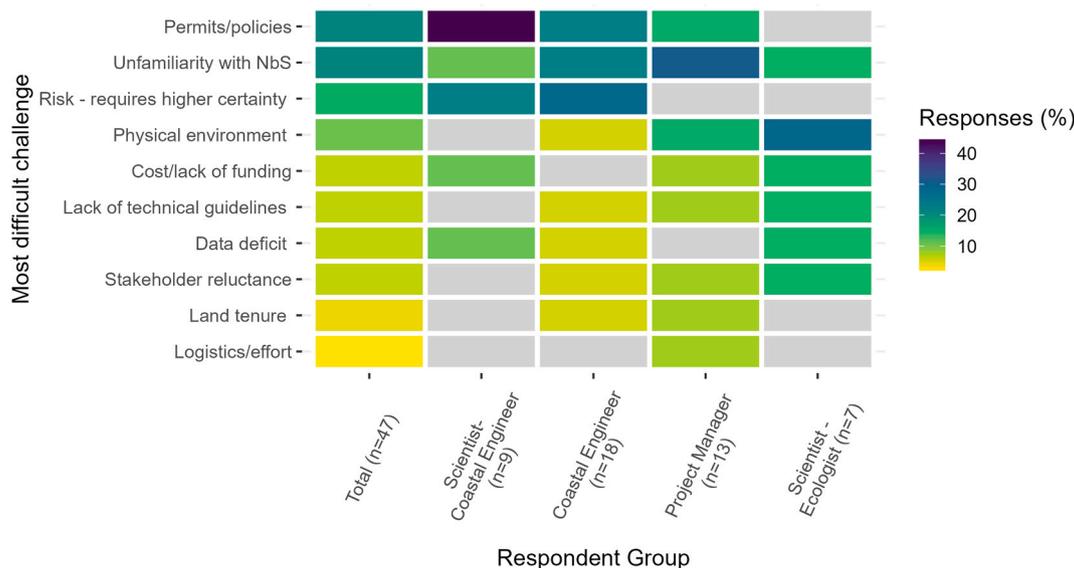


Fig. 5. The most difficult challenges to implementing NbS faced by each respondent discipline group in response to Question 7 (total respondents $n = 29$, total main challenges identified = 47, [Supplementary 1](#)). Note that some respondents provided two answers. Grey boxes indicate no mention by the relevant discipline group.

the respondents identified ‘using local low-cost bamboo’ and ‘using brushwood walls to protect saltmarsh seedlings’ as two unique solutions, but were both considered ‘Logistical solutions’ (Table 2, Fig. 6). Respondents provided between 1 and 21 individual solutions each, which they had put into practice, with Ecologists providing the most (10.4 pp), followed by Project Managers (10.3 pp), Coastal Engineering Scientists (7.2 pp) and Coastal Engineers (5.9 pp).

Community engagement, education of colleagues, community and councils, hybrid solutions (solutions that combine NbS and traditional alternatives) and multidisciplinary/international teams were the most frequently mentioned solutions (55–65 % of total respondents, Fig. 6). The least frequently mentioned solutions were government restructuring, better technical guidelines, and expanding the conceptual framework (each mentioned by only 14 % of all respondents).

Project Managers and Ecologists identified community engagement as a top priority to facilitate NbS implementation (Fig. 6). Project Managers also identified solutions via the design with co-benefits,

monitoring and maintenance, implementation in low-risk areas, and government assistance, more than all the other disciplines. Other solutions most mentioned by Ecologists included using modelling to prioritise NbS and creating an associated financial market. On the other hand, Coastal Engineers offered hybrid solutions as a top priority, and Coastal Engineering Scientists highlighted logistical solutions and multidisciplinary/international teams.

Most interviewees (83 %) offered suggestions (solutions not put into practice by the respondent who mentioned them) of how to address barriers to NbS (see [Supplementary 3](#) for more details). The most frequently mentioned suggestion by each interviewee included more research or case studies to show NbS is a viable option (41 % of interviewees mentioned this), government assistance with funding and management (31 %), better technical guidelines and standards (31 %), and greater community engagement (28 %). The solutions most frequently put into practice are those within the control of NbS practitioners (community engagement and education are the most common,

Table 2

Descriptions of the solutions outlined by respondents, highlighting the challenges that they may address (in order of most frequently mentioned) (more detail on specific solutions in [Supplementary 2](#)).

Solution	Solution description
Community consultation	Early, meaningful, and high-effort engagement with a variety of people – fishers, surfers, elders, youth, councils – to improve uptake and understanding
Education of colleagues, youth, and councils	Education of colleagues, youth, and councils through publishing work and formal courses (such as NbS short courses or undergrad courses) (see Supplementary 3 for data on NbS training of respondents)
Hybrid solution	Adding NbS elements to a traditional grey structure, such as biodiversity-friendly tiles to sea walls, to maintain the safety/integrity of the benefits of NbS Using hybrid options since NbS will not work in an area or will not get approved by stakeholders, so hybrid options are seen as perfect because they manage to be more environmentally friendly, whereas a true NbS would be logistically, financially, and socially impossible to use
Multidisciplinary, international teams	Working with multidisciplinary, international teams to diversify, inspire and collaborate
Logistical solutions	Practical design solutions such as pilots/trials using low-cost local materials
Research and case studies	More scientific research and case studies to help build the evidence base for NbS is a viable option
In-built monitoring and maintenance	Monitoring of projects and maintenance built into the construction/approval plan for NbS so that they are managed over their lifetime (and failures) at no "extra cost" to taxpayers
Design with co-benefits	Push for and design with co-benefits to improve the business case and stakeholder acceptance
Implement NbS in low-risk areas	Implementing NbS in low-risk areas - limited assets, no danger
Modelling/assessment to prioritise NbS	Modelling/assessment so that NbS are prioritised/made mandatory over grey infrastructure
Create a financial market	Creating a financial market to fund NbS projects, boost interest for landowners/private stakeholders. Encourage people to use NbS.
Improve approval and permitting pathways	Change approval and permitting pathways to make it easier to implement NbS
Expand conceptual framework to large-scale, proactive projects	Change our conceptual framework to prioritise large-scale projects, being proactive and future-proofing
Government to restructure funding and management	Government to do more - restructure funding cycles to be more long-term, help manage and provide specific supports/staff
Better technical guidelines and standards	Better technical guidelines and standards written for/by engineers and project managers

[Fig. 6](#)), while those requiring changes in local or state government remain largely unaddressed.

3.4. Maximising co-benefits is a priority

All respondents indicated that co-benefits were important for implementing NbS, except for two Coastal Engineers who expressed mixed feelings. Twenty per cent of Coastal Engineers thought co-benefits were absolutely important, lower than the 35–40 % of both Project Managers and Ecologists ([Fig. 7](#)). Sixty per cent of Coastal Engineering Scientists thought co-benefits were absolutely important. Between 50 % and 60 % of all the disciplines specifically mentioned that co-benefits were important and valuable for 'selling' the idea of NbS and would help get the community and council on board with and approving ideas,

except for Ecologists, where only 20 % mentioned this concept.

Ecologists, Project Managers and Coastal Engineering Scientists mentioned approximately four different co-benefits each, whereas Coastal Engineers mentioned fewer, on average 2.5 per person. The top three co-benefits mentioned the most were improved biodiversity (terrestrial and marine animals were mentioned), socio-cultural benefits for the community, and the enhancement of fisheries and/or recreational fishing ([Fig. 8](#)). Project Managers, Coastal Engineering Scientists, and Ecologists mainly expressed this. On the other hand, Coastal Engineers mentioned public amenity/recreation, diving/surfing, and aesthetics/beautification the most. Ecologists mentioned blue carbon/sequestration the most out of all the disciplines, whereas Project Managers highlighted habitat enhancement, water quality and First Nations (Indigenous) engagement.

Engagement with First Nations people was seen as the 8th most important co-benefit and was mentioned by 7 out of 29 interviewees across all four disciplines, albeit sparingly by Coastal Engineering Scientists. First Nations communities were acknowledged as 'key stakeholders' in discussions (by one interviewee; 2 others talked about 'working together' with First Nations groups), though they were not identified as resistant stakeholders.

3.5. Case study examples

This section provides an example of how the three most common NbS challenges have been overcome (further case studies are outlined in [Supplementary 4](#)).

3.5.1. Challenge 1. Unfamiliarity with NbS

3.5.1.1. Solution 1.1 Facilitating the sharing of expertise with policy and decision-makers, contractors. A Project Manager interviewed noted the difficulty that infrastructure teams in local government agencies faced in finding time to review extensive guidelines and reports on NbS. To address this, a coastal engineering scientist was invited to give a presentation that outlined the benefits and merits of NbS, aiming to facilitate a cultural mindset shift within the agency. The coastal engineering scientist's presentation included a compelling visual comparison, illustrating the design life expectancy and effectiveness of traditional engineering versus NbS solutions. This straightforward and easy-to-understand graphic made a substantial impact, effectively communicating the advantages of NbS to the council members. This approach helped overcome the agency's initial lack of understanding, proving that expert presentations could significantly aid in educating and shifting perceptions towards more sustainable infrastructure solutions.

Similarly, another project involved workshops by an Ecologist/Scientist to share expertise about NbS with marine contractors (constructors and engineers). NbS were relatively new and unfamiliar to these people, prompting many questions such as "What are NbS? What does it mean? How do they work?" These workshops were conducted in person and online and aimed to bring everyone to the same level of understanding. The workshops consisted of three modules: explaining why NbS are useful (highlighting their superior ecosystem functions compared to grey infrastructure), how to determine the site suitability of different shorelines for various NbS options, and the design criteria necessary to construct a living shoreline successfully. Targeting contractors was crucial because they handled the "actual implementation," but the training was "beneficial for everybody". This initiative was successful, and as the ecologist/scientist noted, they had successfully "overcome" that challenge and are now "in a pretty good place with that". The workshops also included sessions for different agencies and audiences, explaining the reasoning behind recommended design criteria.

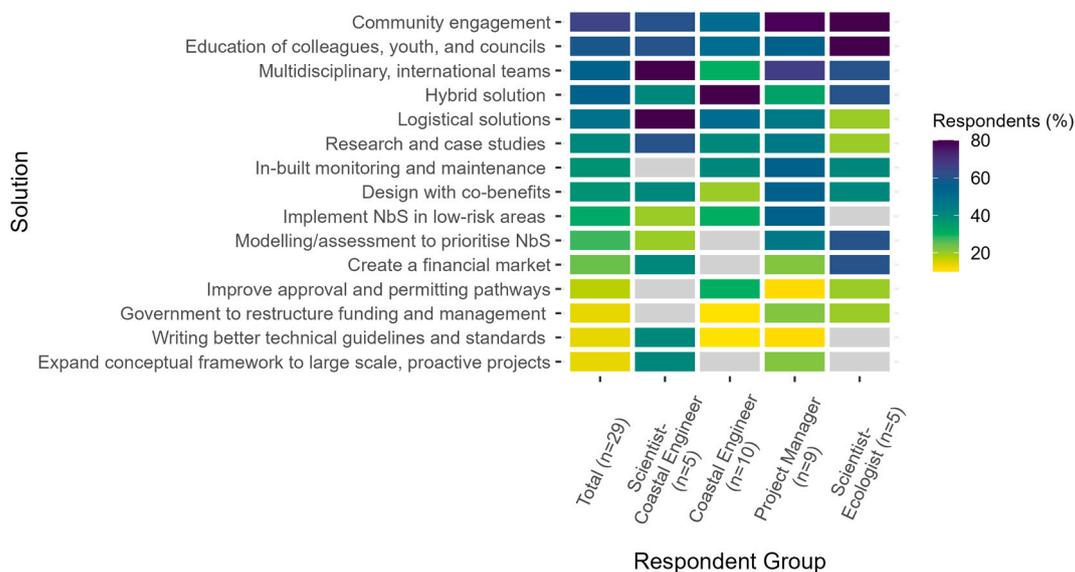


Fig. 6. Heatmap outlining the frequency of solutions completed in practice for NbS implementation identified by each respondent discipline group in response to Question 5 (see Supplementary 1). Grey boxes indicate no mention by the relevant discipline group.

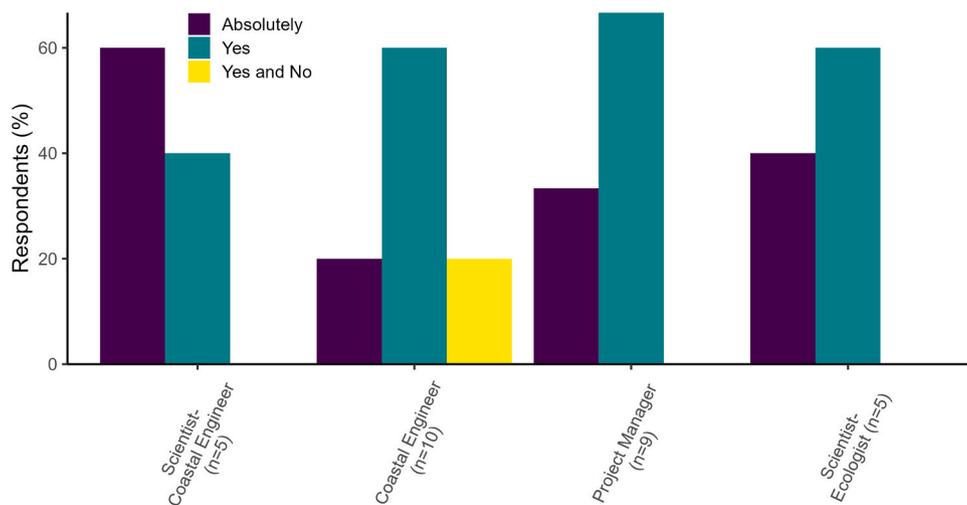


Fig. 7. The percentage of respondents in each discipline that thought that co-benefits were essential to implementing NbS ("absolutely"), that co-benefits were important ("yes"), or thought they had both positives and negatives ("yes and no"), in response to open-ended Question 11 (see Supplementary 1).

3.5.2. Challenge 2. Data deficits

3.5.2.1. Solution 2.1 Data sharing: providing evidence for NbS efficacy. A Coastal Engineering Scientist and their team implemented NbS, such as mangroves and saltmarsh, to address riverbank vulnerability. Through a decade-long effort to build strong scientific support, they developed an evidence-based decision support system. As the scientist explained, "My personal experience has been through a combination of evidence-based solutions. So, this decision support system for riverbank vulnerability had been something we spent ten years building the science behind. And so, it removed the emotion of if it was right or wrong; we had some very strong science supporting the outcome, which made the regulator more willing to go with the solution."

The research, primarily conducted by coastal engineers, including the interviewed scientist, indicated that while some wave energy was tolerable, excessive wave energy would prevent the growth of saltmarsh and mangroves. Consequently, boats were banned in a specific stretch of the river to protect the vegetation, allowing only waterskiing activities that caused less wake. This scientific evidence made it easier for the local

government authority and the public to accept the temporary loss of recreational amenities. It helped justify the ban on boats for a year to allow the vegetation to be established. In addition to data deficits, the scientist emphasised the necessity of evidence to avoid the intense, high-drama social challenges previously encountered in the local community. The key solution here is that data sharing of NbS project outcomes and existing tools is important to increase the global body of evidence for NbS efficacy.

3.5.3. Challenge 3. Stakeholder reluctance

3.5.3.1. Solution 3.1 Non-technical site visits for stakeholders. To overcome stakeholder reluctance, project leaders organised field days and walkthroughs for local government members, bringing practitioners and their consultants to demonstrate the proposed methods. This hands-on experience was crucial in proving the methodology's effectiveness to local government members unfamiliar with NbS. As the Project Manager noted, "They're [the NbS proposed] a bit groundbreaking" and needed to be demonstrated to the local government agency to show evidence that

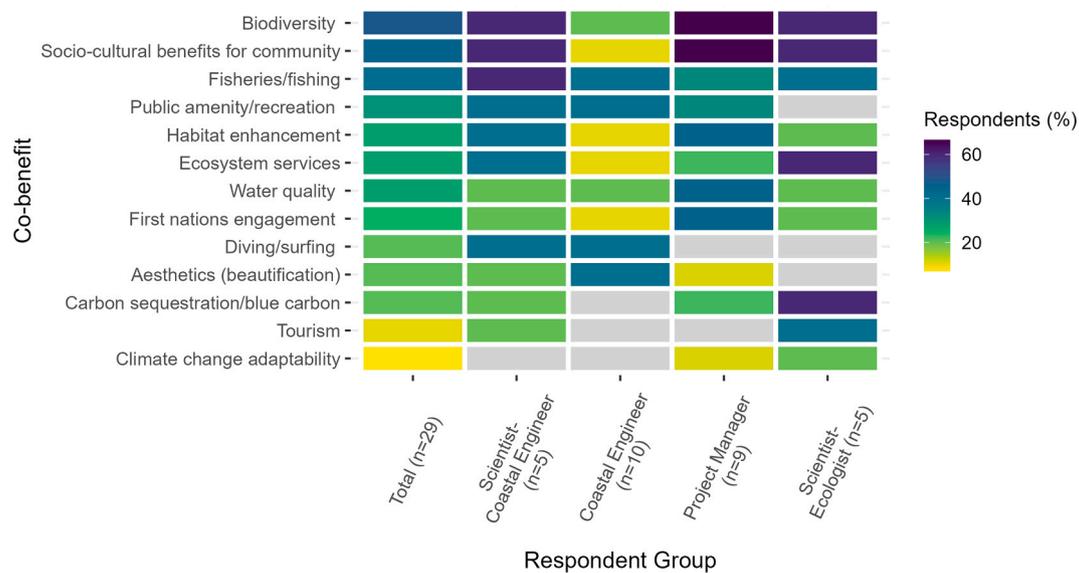


Fig. 8. Heatmap outlining the frequency of mentions of each co-benefit by discipline in response to Question 11 (see [Supplementary 1](#)). Grey boxes indicate no mention by the relevant discipline group.

NbS worked.

These efforts facilitated networking and communication among stakeholders, helping them learn from one another. The project team successfully showcased the benefits of NbS through direct exposure and consultations, ultimately gaining the necessary support for the project. The approach highlighted that “we can learn a lot from each other if people network right and communicate, ” leading to acceptability, approval and implementation.

4. Discussion

4.1. Diverse perspectives and complementarity of expertise between disciplines

The findings of this study illustrate the diverse perspectives among different disciplines regarding the challenges and solutions associated with implementing NbS. While all groups identified unfamiliarity with NbS as a key challenge, Coastal Engineers and Coastal Engineering Scientists generally had more design-focused views about NbS challenges (risk, technical guidelines and data deficits) and solutions (e.g. hybrid solutions). In contrast, Ecologists and Project Managers typically had more implementation-focused challenges (cost/lack of funding) and opportunity-driven solutions (community acceptance and education). Coastal Engineers and Coastal Engineering Scientists also identified more challenges than Ecologists and Project Managers and provided the fewest solutions, which may speak to their ‘risk-oriented’ tendency (Fig. 9). There were also some differences between Coastal Engineers and Coastal Engineering Scientists. Coastal Engineers most suggested hybrid solutions, whereas Coastal Engineering Scientists suggested interdisciplinary teams. These results show a ‘spectrum’ of challenges and concerns that favour different solutions for different discipline groups.

Existing literature highlights the importance of collaboration between engineers and ecologists for successful NbS outcomes (Saunders et al., 2022; Scheres and Schüttrumpf, 2020). Mitsch (2014) suggested that projects run solely by a single discipline are likely to fail. For example, projects driven only by engineers may fail due to the lack of ecological and biological training, and if run solely by restoration ecologists, whose focus is on ecosystems reaching the conditions of reference ecosystems, may also fail to achieve successful NbS coastal protection objectives (Mitsch, 2014). The lack of collaboration between

these disciplines may be explained by the results of this study, which demonstrates the unique values and knowledge bases held by these two groups. Coastal Engineers typically focused on the design of the NbS and thought of project success in achieving a reduction of the coastal hazard with minimal risks to people. Scientists and Project Managers, on the other hand, tended to think about project success as a broader range of metrics (e.g. co-benefits as well as coastal hazard reduction).

The differences in opinions among representatives of different disciplines mean that while there are many perceived barriers to NbS implementation, those are unique to the goal of the discipline working on the project. Given that Engineers encounter challenges that Ecologists do not normally encounter and vice versa, this study showed that working together and sharing relevant NbS expertise can help overcome challenges.

4.2. Identified challenges and experienced challenges do not align

Our results showed that the most common challenges (‘unfamiliarity with NbS’, ‘data deficits’ and ‘stakeholder approvals’) were generally different to the most difficult-to-overcome challenges (namely ‘permits/policies’, ‘risk’ and ‘unfamiliarity with NbS’). This trend generally aligns with results from other NbS reviews. A review of 43 Australian NbS projects using the scientific literature identified barriers when implementing NbS into policy or practice, including lack of research, data and monitoring, the challenge of navigating trade-offs, conflicting interests of stakeholders and the need for collaborative governance (Zhu et al., 2023). Whilst the lack of research, data, and monitoring was the most frequently mentioned challenge, it ranked as the 2nd most important challenge and the 7th most difficult challenge to implementation. Zhu et al. (2023) identified conflicting interests of stakeholders as the 2nd most mentioned challenge, whereas our study identified the reluctance of stakeholders rather than the conflict between them and ranked this as the 3rd most mentioned challenge and the 8th most difficult challenge to overcome. This study did not identify collaborative governance as a challenge, but it was listed as the 4th most mentioned solution to overcome barriers to NbS implementation.

Similarly, in 59 coastal and estuarine NbS case studies analysed across Europe, 13.5 % reported that biological and ecological data was a critical gap, and 12.2 % said the physical site-specific data was a critical gap (Morales et al., 2022). These support the results from this study, which identified ‘data deficits’ as the 2nd most mentioned challenge to



Fig. 9. Comparison of priorities between disciplinary groups, highlighting the top priorities (>65 % of respondents identified the option) for each group. Some groups had many priorities that were equally mentioned.

implementation. Our study showed that the large differences in perspectives between disciplines may explain the differences between previous studies. The differences between these studies and ours may stem from disciplinary focus: the global literature review concentrated on scientists’ perspectives, while the European study examined case study literature without aligning with any particular disciplinary viewpoint. Unlike previous work, this study teases out the role that different disciplinary perspectives play in formulating challenges and solutions.

4.3. Most frequently utilised solutions do not align with the most frequently experienced challenges

Interestingly, despite data deficits being the second most mentioned challenge, solutions to overcome this problem (research and case studies) were only the 6th most mentioned solution (Fig. 10). This mismatch might be because this solution is often out of the hands of project proponents, and hence it is a significant barrier to the implementation of NbS. Certainly, many other studies suggest that data deficits are a key roadblock to NbS success (Moraes et al., 2022; Ommer et al., 2022; Saunders et al., 2022; Scheres and Schüttrumpf, 2020; Schmidt-Traub, 2021; Zhu et al., 2023) and that new data is needed to ensure NbS success (Dunlop et al., 2024; Morris et al., 2019; Van der Meulen et al., 2023). To solve this challenge, there needs to be better reporting of outcomes, centralised repositories for data sharing, including for failed attempts, and more investment in research and development (R&D) to support experimental projects.

4.4. NbS practitioners suggest that co-benefits are what make NbS more attractive than traditional solutions

Co-benefits are widely purported to be essential to the successful implementation of NbS (Alves et al., 2019; González-García et al., 2023; Raymond et al., 2017), and in some locations, co-benefits receive financial credits, such as for blue carbon storage or pollutant removal (Branosky et al., 2011). While co-benefits were only mentioned as a specific solution by 11 NbS practitioners here, co-benefits were regarded as a solution to stakeholder reluctance and challenges around cost/lack of funding, two of the key challenges to NbS implementation. However, our study ranked them 7th out of 15 key solutions for NbS implementation. This low ranking was due to Coastal Engineers showing

reservations about co-benefits’ importance. Reluctance from Coastal Engineers generally came from negative previous experiences and challenges with the surety of outcomes. For example, one Coastal Engineer gave an example where at the onset of a project, co-benefits were ‘sold’ as a good idea, “...then at the end, it didn’t quite deliver...”. The respondent pointed out that overselling the co-benefits led to a disappointed community and increased reluctance towards NbS generally. Another Coastal Engineer discussed the need to ‘be realistic’ about the costs and benefits of an NbS compared with traditional infrastructures such as submerged breakwaters, stating that you need to know, “...what is your offset on how much it’s going to cost you versus how much life you get out of wall?”. Ultimately, while it has been demonstrated that NbS can be several times cheaper than submerged breakwaters for the same level of coastal protection (Narayan et al., 2016), the solution needs to be structurally sound and have surety of outcomes that are not typically guaranteed for NbS as they are for traditional infrastructure (Saunders et al., 2022).

Despite these variations in perceived importance, a majority from each discipline acknowledged co-benefits’ utility in promoting NbS to stakeholders like communities and councils. These insights emphasise the strategic importance of co-benefits in gaining broader acceptance and implementation of NbS in coastal areas.

Numerous papers extensively discuss the importance of co-benefits, but few delve into the importance and application of Traditional Ecological Knowledge (TEK) in NbS for coastal protection. Successful examples of First Nations engagement were provided in our study. Three such examples include:

First Nations communities are referred to as being a ‘key stakeholder’: “There was the connection to country for the local Traditional Owners. They have historically been users of the [habitat] in the river that was lost. And so, this restoration project was actually an opportunity to reconcile that to a degree”.

Employment of First Nations rangers: The Project Manager on this project believes strongly in co-design, having Aboriginal groups in at “the ground floor” – “that’s really critical, that stakeholder engagement all the way through in terms of design and location”.

Paying First Nations companies (e.g. divers and planters) to build NbS. This project used funding “...to help pay [First Nation’s] divers and the saltmarsh team for their planting and their monitoring...”.



Fig. 10. Identified solutions mapped to the possible identified challenges they may solve with width representing how frequently the solution was mentioned – ranging from n = 4 (narrowest) to n = 19 (widest).

While many papers mention that engaging with First Nations peoples is important, published examples can be difficult to come by, with limited literature explaining how to facilitate this engagement (see [Saunders et al. 2024](#) for examples). First Nations co-design, which encompasses meaningful engagement, shared projects, equity, the use of TEK, and leadership and ownership by First Nations communities, is increasingly recognised as vital to the future of ecological and restoration science and environmental management in Australia and for NbS generally ([Saunders et al., 2022](#)). In particular, moving from ‘engagement’ of First Nations to leadership or co-design with First Nations people can help (i) overcome data gaps through traditional knowledge, (ii) warrant key stakeholder approval, (iii) gather community support, and (iv) deliver co-benefits via cultural services. Despite its importance, interviewees have not explicitly identified First Nations co-design as a solution. Instead, ‘First Nations engagement’ was noted as the eighth most mentioned co-benefit and contributed to the need for ‘Multidisciplinary, international teams’ essential for the design and implementation of projects.

Key issues described that hinder co-design and meaningful engagement with First Nations include “short funding cycles” that prevent meaningful relationships, as the engagement with First Nations groups may take longer and the difficulty in engaging with relevant First Nations experts due to limited capacity to commit time to projects.

5. Conclusions

This research has highlighted important distinctions in the challenges faced by various NbS practitioner groups and has offered practical solutions to address them. While some commonalities between experienced challenges exist, the synthesis of results indicates a notable divide: Ecologists and Project Managers tend to focus on opportunity-driven solutions, whereas engineers prioritise risk management. This may be reflective of the role of the practitioner, as Ecologists identified more implementation-relevant challenges, whereas engineers experienced design-relevant challenges. Moreover, what might be perceived as an important challenge to overcome for a Coastal Engineer may not be seen as a challenge for Ecologists. Like many other studies, this leads towards a ‘call to action’ for better communication between disciplines ([Lovelock et al., 2024](#)), highlighting the need for guidance that balances the goals of both engineering and ecology ([Dunlop et al., 2023](#)). The study also found that implementing NbS is hindered by regulatory barriers, funding uncertainty, disciplinary silos, and a lack of standardised guidance. For effective policy, governments should support flexible permitting, interdisciplinary co-design, regionally adaptable standards, and long-term funding with monitoring. Bridging engineering and ecological goals through shared metrics and capacity-building will enable more resilient, locally appropriate, and widely accepted NbS projects. In addition to policy changes, NbS practitioners should aim to clearly articulate and agree on goals (e.g. reduce coastal hazards) and subgoals (e.g. co-benefits) that restore ecosystems for both humans and the environment ([van der Meulen et al., 2019](#)).

CRedit authorship contribution statement

Morris Rebecca: Writing – review & editing, Conceptualization. **Mariana Mayer-Pinto:** Writing – review & editing, Conceptualization. **Lovelock Catherine:** Writing – review & editing, Conceptualization. **Toni Cannard:** Writing – review & editing, Conceptualization. **Callaghan David:** Writing – review & editing, Conceptualization. **Kris Boody:** Writing – review & editing, Conceptualization. **Ana Bugnot:** Writing – review & editing, Writing – original draft, Methodology, Funding acquisition, Conceptualization. **Bishop Melanie:** Writing – review & editing, Conceptualization. **Waltham Nathan:** Writing – review & editing, Conceptualization. **Katherine Erickson:** Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation. **Andy Steven:** Writing –

review & editing, Conceptualization. **Twomey Alice J.:** Writing – review & editing, Writing – original draft, Visualization, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Saunders Megan:** Writing – review & editing, Conceptualization. **Pomeroy Andrew:** Writing – review & editing, Conceptualization.

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.

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Appendix A. Supporting information

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Data availability

The data that has been used is confidential.

References

- Alves, A., Gersonius, B., Kapelan, Z., Vojinovic, Z., Sanchez, A., 2019. Assessing the Co-Benefits of green-blue-grey infrastructure for sustainable urban flood risk management. *J. Environ. Manag.* 239, 244–254.
- Bennion, V., Dwyer, J.M., Twomey, A.J., Lovelock, C.E., 2024. Decadal trends in surface elevation and tree growth in coastal wetlands of Moreton Bay, Queensland, Australia. *Estuaries Coasts* 1–17.
- Bilkovic, D.M., Mitchell, M.M., Toft, J.D., La Peyre, M.K., 2017. A primer to living shorelines. *Living Shorelines*. CRC Press, pp. 3–10.
- Branosky, E., Jones, C., Selman, M., 2011. Comparison tables of state nutrient trading programs in the Chesapeake Bay watershed. *World Resour. Inst. Fact. Sheet*. (<http://www.wri.org/publication/comparison-tables-state-nutrient-trading-programs-chesapeake-bay-watershed>).
- Brinkmann, S., 2014. Unstructured and semi-structured interviewing. *Oxf. Handb. Qual. Res.* 2, 277–299.
- DeLorme, D.E., Stephens, S.H., Collini, R.C., 2022. Coastal hazard mitigation considerations: perspectives from northern Gulf of Mexico coastal professionals and decision-makers. *J. Environ. Stud. Sci.* 12 (4), 669–681.
- van der Meulen, F., van der Valk, B., Finkl, C., Makowski, C., 2019. Coastal management practices. *Encycl. Coast. Sci.* 501–510.
- Dunlop, T., Glamore, W., Felder, S., 2023. Restoring estuarine ecosystems using nature-based solutions: towards an integrated eco-engineering design guideline. *Sci. Total Environ.* 873, 162362.
- Dunlop, T., Khojasteh, D., Cohen-Shacham, E., Glamore, W., Haghani, M., van den Bosch, M., Rizzi, D., Greve, P., Felder, S., 2024. The evolution and future of research on Nature-based Solutions to address societal challenges. *Commun. Earth Environ.* 5 (1), 132.
- Ferguson, R., Joyce, K.E., Reepmeyer, C., Groom, R., Pollard, K., 2025. A scoping review of Indigenous Cultural Mapping of coastal, island, and marine environments. *Environ. Sci. Policy* 164, 103991. <https://doi.org/10.1016/j.envsci.2025.103991>.
- Gain, A.K., Rahman, M.M., Sadik, M.S., Adnan, M.S.G., Ahmad, S., Ahsan, S.M.M., Ashik-Ur-Rahman, M., Balke, T., Datta, D.K., Dewan, C., 2022. Overcoming challenges for implementing nature-based solutions in deltaic environments: insights from the Ganges-Brahmaputra delta in Bangladesh. *Environ. Res. Lett.* 17 (6), 064052.
- González-García, A., Palomo, I., Codomo, A., Rodeghiero, M., Dubo, T., Vallet, A., & Lavorel, S. (2023). Co-benefits of nature-based solutions exceed the costs of implementation.
- Hagedoorn, L.C., Addo, K.A., Koetse, M.J., Kinney, K., van Beukering, P.J., 2021. Angry waves that eat the coast: An economic analysis of nature-based and engineering solutions to coastal erosion. *Ocean Coast. Manag.* 214, 105945.
- Jordan, P., Fröhle, P., 2022. Bridging the gap between coastal engineering and nature conservation? A review of coastal ecosystems as nature-based solutions for coastal protection. *J. Coast. Conserv.* 26 (2), 4.
- Lovelock, C.E., Bennion, V., de Oliveira, M., Hagger, V., Hill, J.W., Kwan, V., Pearse, A.L., Rossini, R.A., Twomey, A.J., 2024. Mangrove ecology guiding the use of mangroves as nature-based solutions. *J. Ecol.*

- Mednikova, M.E., Whitcraft, C.R., Zacherl, D., Nichols, K.D., 2023. Knowledge gaps and research priorities in living shorelines science: insights from stakeholder interviews throughout the US Pacific Coast. *Bull. South. Calif. Acad. Sci.* 122 (1), 33–50.
- Mitsch, W.J., 2014. When will ecologists learn engineering and engineers learn ecology? *Ecol. Eng.* 65, 9–14.
- Moraes, R.P., Reguero, B.G., Mazarrasa, I., Ricker, M., Juanes, J.A., 2022. Nature-based solutions in coastal and estuarine areas of Europe. *Front. Environ. Sci.* 10, 829526.
- Morris, R., Strain, E.M., Konlechner, T.M., Fest, B.J., Kennedy, D.M., Arndt, S.K., Swearer, S.E., 2019. Developing a nature-based coastal defence strategy for Australia. *Aust. J. Civ. Eng.* 17 (2), 167–176.
- Morris, R.L., Konlechner, T.M., Ghisalberti, M., Swearer, S.E., 2018. From grey to green: Efficacy of eco-engineering solutions for nature-based coastal defence. *Glob. Change Biol.* 24 (5), 1827–1842.
- Morris, R.L., Pomeroy, A.W., Boxshall, A., Colleter, G., Dack, D., Dunlop, A.R., Hanslow, D., King, S., Magini, A., O'Malley-Jones, K., 2024. A blueprint for overcoming barriers to the use of nature-based coastal protection in Australia. *Front. Environ. Sci.* 12, 1435833.
- Narayan, S., Beck, M.W., Reguero, B.G., Losada, I.J., Van Wesenbeeck, B., Pontee, N., Sanchirico, J.N., Ingram, J.C., Lange, G.-M., Burks-Copes, K.A., 2016. The effectiveness, costs and coastal protection benefits of natural and nature-based defences. *PLOS ONE* 11 (5), e0154735.
- Ommer, J., Buccignani, E., Leo, L.S., Kalas, M., Vranić, S., Debele, S., Kumar, P., Cloke, H.L., Di Sabatino, S., 2022. Quantifying co-benefits and disbenefits of Nature-based Solutions targeting Disaster Risk Reduction. *Int. J. Disaster Risk Reduct.* 75, 102966.
- Rampin, R., Rampin, V., 2021. Taguette: open-source qualitative data analysis. *J. Open Source Softw.* 6 (68), 3522.
- Raymond, C.M., Frantzeskaki, N., Kabisch, N., Berry, P., Breil, M., Nita, M.R., Geneletti, D., Calfapietra, C., 2017. A framework for assessing and implementing the co-benefits of nature-based solutions in urban areas. *Environ. Sci. Policy* 77, 15–24.
- RStudio Team. (2021). *RStudio: Integrated Development for R*. In (Version 1.4.1717) RStudio. (<http://www.rstudio.com/>).
- Saunders, M., Waltham, N., Cannard, T., Sheppard, M., Fischer, M., Twomey, A., Bishop, M., Boody, K., Callaghan, D., & Fulton, B. (2022). A roadmap for coordinated landscape-scale coastal and marine ecosystem restoration. *Cairns, Australia*.
- Saunders, M., Fischer, M., Vozzo, M., Chewyng, K., Malcolm, F., Liddell, B., Cooley, R., Cassady, J., Bugnot, A., & Waltham, N. (2024). *Identifying and overcoming barriers to marine and coastal habitat restoration and nature-based solutions in Australia: Pathways to Aboriginal and Torres Strait Islander inclusion and co-design in restoration*. (<http://hdl.handle.net/102.100.100/659205?index=1>).
- Scheres, B., & Schüttrumpf, H. (2020). Nature-Based Solutions in Coastal Research—A New Challenge for Coastal Engineers? APAC 2019: Proceedings of the 10th International Conference on Asian and Pacific Coasts, 2019, Hanoi, Vietnam.
- Schmidt-Traub, G., 2021. National climate and biodiversity strategies are hamstrung by a lack of maps. *Nat. Ecol. Evol.* 5 (10), 1325–1327.
- Sutton-Grier, A.E., Gittman, R.K., Arkema, K.K., Bennett, R.O., Benoit, J., Blich, S., Burks-Copes, K.A., Colden, A., Dausman, A., DeAngelis, B.M., 2018. Investing in natural and nature-based infrastructure: building better along our coasts. *Sustainability* 10 (2), 523.
- Temmerman, S., Meire, P., Bouma, T., Herman, P., Ysebaert, T., De Vriend, H., 2013. Ecosystem-based coastal defence in the face of global change. *Nature* 504 (7478), 79–83. <https://doi.org/10.1038/nature12859>.
- Van der Meulen, F., Ijff, S., van Zetten, R., 2023. Nature-based solutions for coastal adaptation management, concepts and scope, an overview. *Nord. J. Bot.* 2023 (1), e03290.
- Zhu, D., Zhang, Y., Kendal, D., Fraser, L., Flies, E.J., 2023. Nature-based solutions in Australia: a systematic quantitative literature review of terms, application and policy relevance. *Nat. Based Solut.*, 100092.