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A roadmap to coastal and marine ecological restoration in Australia

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ABSTRACT

There is an urgent need for landscape-scale ecological restoration to reverse habitat loss and recover ecosystem functions and services. Given the unique nature of coastal and marine ecosystems a roadmap to overcome current barriers and guide transformative change is needed to achieve large-scale restoration. We conducted a national scale program of engagement with restoration practitioners, decision makers, industry, researchers, community groups, and Indigenous groups in Australia to map out the current state of implementation, barriers encountered and aspirations for the future. In collaboration with a graphic facilitator, we distilled the findings into ten guiding principles which are communicated through an engaging conceptual model. Here we articulate the ten guiding principles for large-scale coastal and marine ecological restoration and include discussion of the rational, the current state in Australia, and ideas for moving forward with respect to each principle. The principles are: 1) Co-design is central; 2) Fit-for-purpose governance; 3) No-gap funding; 4) Access to social, economic and biophysical data; 5) Evidence-based and transparent decision making; 6) Coordinated and at scale; 7) Robust monitoring, evaluation and reporting; 8) Clear strategy to adapt to climate change; 9) Nature-based solutions are implemented; and 10) Knowledge is shared effectively. We then evaluated the principles against three large-scale restoration programs in the UK, USA and Australia and found that their characteristics broadly adhere to each of the principles. Implementation of the roadmap is now necessary and will aid in achieving return of ecological functions in line with international commitments and societal goals.

1. Introduction

Ecological restoration at landscape scales is required to return lost ecosystem functions and services, support recovery of biodiversity, contribute to climate change mitigation and adaptation, and to support cultural values, communities and economies (Duarte et al., 2020; Saunders et al., 2020). Ecological restoration, defined as *the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed* (Gann et al., 2019), involves actions along a continuum of interventions ranging from reducing stressors to introducing biological material or reconstructing physical structures or hydrological regimes. Ecological restoration is a global priority and a key focus of initiatives such as the UN Convention on Climate Change, the UN Decade on Ecosystem Restoration, The Ramsar Convention, and the

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Kunming-Montreal Global Biodiversity Framework (GBF) (Obura et al., 2023; Waltham et al., 2020b). However, our ability to meet aspirations such as GBF Target 2 *To ensure at least 30 per cent of areas of degraded terrestrial, inland water, and coastal and marine ecosystems are under effective restoration* are challenged by the significant gap between what is currently happening, or even possible in terms of restoration, and what needs to be implemented (Saunders et al., 2020). Reconciling this gap is urgently required to help secure a safe and secure future for humanity (UNEP, 2021).

Coastal and marine ecosystems (Fig. 1) are ecologically, socially, and economically valuable. They contain high biodiversity compared to other ecosystems (Junk et al., 2006; Meli et al., 2014; Reaka-Kudla, 1997), contribute climate change mitigation and adaptation, support food security and livelihoods (Diedrich et al., 2022; Leauthaud et al., 2013; Convention on Wetlands, 2021), and underpin nutrient cycling and water filtration (Fennessy and Craft, 2011; Verhoeven et al., 2006). If equated to an economic value, they have been estimate to provide ∼ $47.4 trillion/year worth of ecosystem services globally (Davidson, 2014), including a conservative estimate of $447b in coastal storm protection of human life and assets (Costanza et al., 2021). However, widespread loss and degradation of coastal and marine ecosystems challenge the societal expectation that these values will be retained into the future (Babcock et al., 2019; Ford and Hamer, 2016; Thurstan et al., 2020). To meet high level societal aspirations set through international initiatives such as GBF Target 2, seascape-scale restoration is required to recover degraded coastal and marine ecosystems (Duarte et al., 2020; McAfee et al., 2021; Saunders et al., 2020).

Coastal and marine ecological restoration is a relatively new and developing field compared to terrestrial restoration and other coastal management strategies (Saunders et al., 2020). Active coastal and marine ecological restoration projects have typically been small scale (<1 ha), expensive compared to other management actions and terrestrial restoration, and variable in success (Bayraktarov et al., 2016). The largest spatial scales over which coastal and marine restoration has been accomplished varies by habitat – ranging from 2 ha for coral reefs, to 195,000 ha for mangroves achieved through a coordinated multi-decadal program (Saunders et al., 2020). Systemic barriers spanning environmental, technical, social, economic, and political realms challenge coastal and marine restoration (Bayraktarov et al., 2016; Butler et al., 2013; Lovelock et al., 2022; Maes et al., 2012; McLeod et al., 2018; Morán-Ordóñez et al., 2016; Sheaves et al., 2021; Stewart-Sinclair et al., 2020). Activities now occur within the context of ongoing coastal development and increasing impacts of climate change (Colombano et al., 2021; Sheaves et al., 2021).

Fig. 1. Restoration projects in Australia's coastal and marine ecosystems: A) Oyster reef, mangrove and saltmarsh restoration of a 'living shoreline' design, constructed in 2022 in Narooma, New South Wales (NSW), by The Nature Conservancy and NSW Department of Primary Industries; B) In Shark Bay, Western Australia (WA), researchers, Indigenous Malgana Rangers and a local tourism operator are trialling a range of hessian bags to increase attachment rates for *Amphibolis antarctica* seedlings; C) In 2017 the City of Gold Coast, Queensland, restored mangroves a as part of The Gold Coast Broadwater Parklands Mangrove Habitat Area; D) Researchers at the University of Western Australia are using 'green gravel', rocks with juvenile kelp attached, in an effort to restore 100 km of kelp along the coast between Kalbarri and Jurien Bay, WA; E) Coral larvae spawn slicks are collected from reefs and contained in floating pools (centre inset image) by researchers from the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and Southern Cross University, to determine optimal collection and transfer techniques of coral larvae (right inset image) to help scale-up coral restoration approaches. Image credits: A) Rebecca Morris, University of Melbourne; B) Rachel Austin, University of Western Australia; C) Angus Martin Photography for Glascott Landscape and Civil; D) Georgina Wood, University of Western Australia; E) Lauren Hardiman, CSIRO; centre inset: Southern Cross University.

A set of guiding principles that underpin scaling up of coastal and marine ecosystem restoration is needed. Existing guidance documents have been developed primarily with terrestrial ecosystems in mind, for instance the Restoration Opportunities Assessment Methodology (ROAM) (IUCN and WRI, 2014). The Society for Ecological Restoration's International Principles and Standards provide tools to support evaluation of restoration activities, such as the Recovery Wheel (Gann et al., 2019), but are mainly ecologically focussed and do not account for societal barriers such as funding and legislation. Coastal and marine ecosystems have unique ecological, biophysical, legal, governance, and socio-economic characteristics (Carr et al., 2003; Shumway et al., 2018) which can impede restoration (Stewart-Sinclair et al., 2020). For instance, coastal and marine ecosystems are highly dynamic, have more open population structures than terrestrial habitats, and are strongly influenced by both terrestrial and marine based stressors (Carr et al., 2003; Shumway et al., 2018). Coastal zones are subject to complex jurisdictional and governance arrangements; In Australia, local councils, state governments, or the Commonwealth government have decision making authority over coastal areas depending on the location (Bell-James et al., 2023b). Therefore, guiding principles designed through the specific lens of coastal and marine socio-ecological systems are needed.

The overall goal of this article is to describe guiding principles that can be used at a programmatic level when planning large-scale coastal and marine ecological restoration. The specific aims are to: 1) Communicate ten guiding principles for successful landscape-scale coastal and marine restoration developed using insights from the Australian context; 2) Evaluate the principles against the strategies for three existing programs for landscape-scale restoration. Throughout we highlight priority areas for research and action. While the research supporting the article is based in Australia, coastal ecosystems and societies globally receive broadly similar benefits from, and face similar challenges to restoration of, coastal ecosystems; therefore, the research is likely to have broad international application.

2. Approach

The principles build from learnings acquired through a nationally funded research project exploring coastal and marine ecological restoration as well as Nature-based Solutions (NbS) for the purpose of coastal hazard asset protection in Australia. NbS are *actions to help protect, manage and restore the environment while delivering tangible and sustainable benefits for people* (IUCN, 2020). NbS can include restoration, but are primarily aimed at achieving societal outcomes, and do not necessarily aim to restore an ecosystem to a baseline or reference state. Considering these two concepts together allows a flexible interpretation of the goals of restoration. It also acknowledges that in highly modified land- or seascapes, and in the era of climate change, a return to baseline condition is not always possible, but NbS which align with restoration techniques and concepts and are biodiversity positive may be feasible.

The project consisted of six activities (Fig. 2) conducted in 2021–2022 which elicited and synthesised information from Australian restoration researchers, decision makers and practitioners regarding barriers and enablers for restoration. Briefly, activities included: 1) a national-scale survey addressing motivations for and barriers to restoration; 2) workshops with the project team and end-users; 3) a targeted survey of Indigenous Australians to gain their perspectives and experiences with restoration and NbS; 4) a literature review of datasets and models used to predict coastal protection benefits from restoration and NbS; 5) compilation of case studies from experts nationally; and 6) synthesis of information gained from activities 1–5 into guiding principles for coastal marine ecological restoration using an arts-based methodology. This paper reports on findings from activity 6 with the methodological approach described further below; further information on the overall project is available in the full report (Saunders et al., 2022).

Arts-related research is defined as *research that uses the arts, in the broadest sense, to explore, understand and represent human action and*

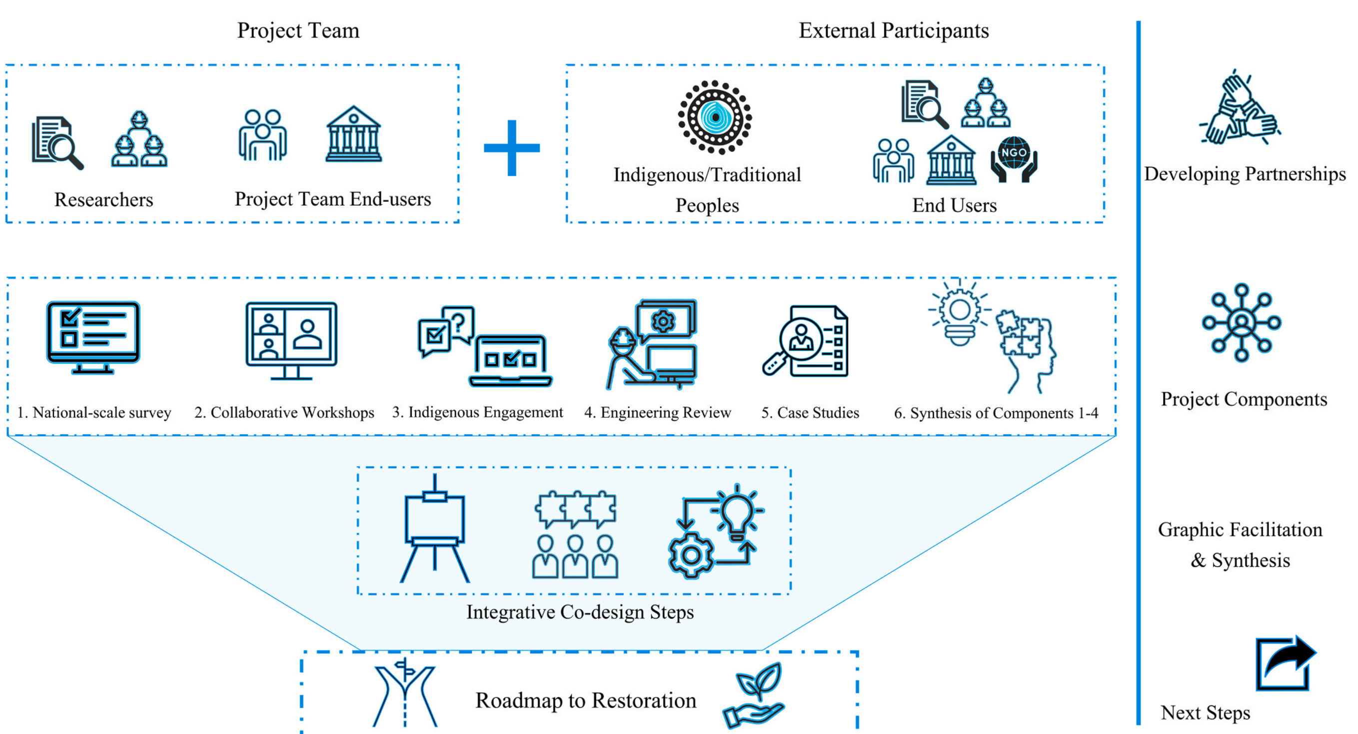

Fig. 2. Approach used to develop the roadmap to coordinated landscape scale coastal and marine ecosystem restoration in Australia. The Roadmap to restoration was constructed through elicitation with >140 participants and end users of restoration research in Australia. The project consisted of six research components. To develop the set of principles underpinning the roadmap, the information from components 1–5 was distilled into key headline topics that built the narrative around the definition of the principle, the rational for the principle, and examples of the principle or the desired state of the principle in component 6. As part of this roadmap development, the team engaged assistance of a graphic facilitator to capture, synthesize, and articulate the overall roadmap visualisation for the project.

experience (Savin-Baden and Wimpenny, 2014). Arts-based methods incorporate the arts as a means of better understanding and rethinking important social issues (Barone and Eisner, 2011). The arts-based methodology herein involved members of the research team working closely and interactively with a graphic facilitator to develop and illustrate the ten guiding principles. Core members of the research team first presented a set of draft principles to the illustrator at which point they worked together to refine them. The research team then articulated the rational for the principle, the current state and the desired state in the Australian context, and key priorities for research and practice. The graphic facilitator created hand-drawn imagery which illustrated those concepts and the connections among them. An iterative process with members of the research team and graphic facilitator involving several preliminary concept versions of the imagery was conducted prior to agreement upon the final version.

Australian coastal and marine environments span from temperate to tropical, and densely to sparsely populated locations, which are the foci of a multitude of land- and water-based activities, providing a rich diversity of environmental and social and economic contexts. Like coastlines globally, Australian coastal ecosystems have been degraded through habitat fragmentation, invasive species, pollution, reclamation, hydrological modification, and climate change (Babcock et al., 2019; Creighton et al., 2016). The recent Australian State of the Environment Report concluded coastal and marine environments were in poor condition and, along with the National Marine Science Plan, made strong recommendations for more coordinated management, protection and restoration (National Marine Science Committee, 2015; Treloar et al., 2016). Despite this degradation, Australian coastal and marine ecosystems provide tremendous social and economic value. The Great Barrier Reef contributes $6.4 billion/year to the economy (Economics, 2017); the Great Southern Reef has a net worth of $10 billion/year in fishing and tourism revenue (Bennett et al., 2015); and saltmarshes and mangroves provide coastal protection values which would cost ~$228 billion to replace with seawalls to provide the same benefit (Australian Bureau of Statistics, 2022). While it is useful to articulate the value in economic terms, the values of coastal and marine ecosystems cannot all be represented in this framing. For instance, local communities and Indigenous groups often have deep place-based relationships with coastal environments. Such socio-cultural connections are embedded in meanings, values and identity, and relate to local ecological knowledge and practice, livelihood dynamics, governance and access, and bio-cultural interactions (Poe et al., 2014).

3. Ten guiding principles for coastal and marine restoration

3.1. Principle 1: Co-design is central

The *Co-design is central* principle recognises that restoration is a complex endeavour requiring input from actors with diverse expertise, spanning project implementation, research, governance and decision-making (Fig. 3, Figure S1). Partnerships among diverse organisations and in particular leadership and involvement of local communities are key components for restoration success globally (Saunders et al., 2020). Co-design, defined as *to design (something) by working with one or more,* involves developing genuine partnerships and engagement with the various actors with a stake in the costs, decision making, implementation, and outcomes. Co-design is an essential step in the planning of restoration and is recommended to be conducted before the commencement of any project (Lupp et al., 2021). It helps to build and extend acceptance and ownership of programs, delivering direct and indirect value outcomes for all actors.

Here we place particular emphasis for 'Co-design is central' with respect to meaningful inclusion and participation of Indigenous peoples. The *United Nations Declaration on the Rights of Indigenous Peoples* (UNDRIP) states that Local Communities and Indigenous Peoples have rights over coastal and marine spaces (United Nations General Assembly, 2009), and there is a right to withhold consent for activities occurring within their traditional territories (Articles 11, 12, 19 and 31).

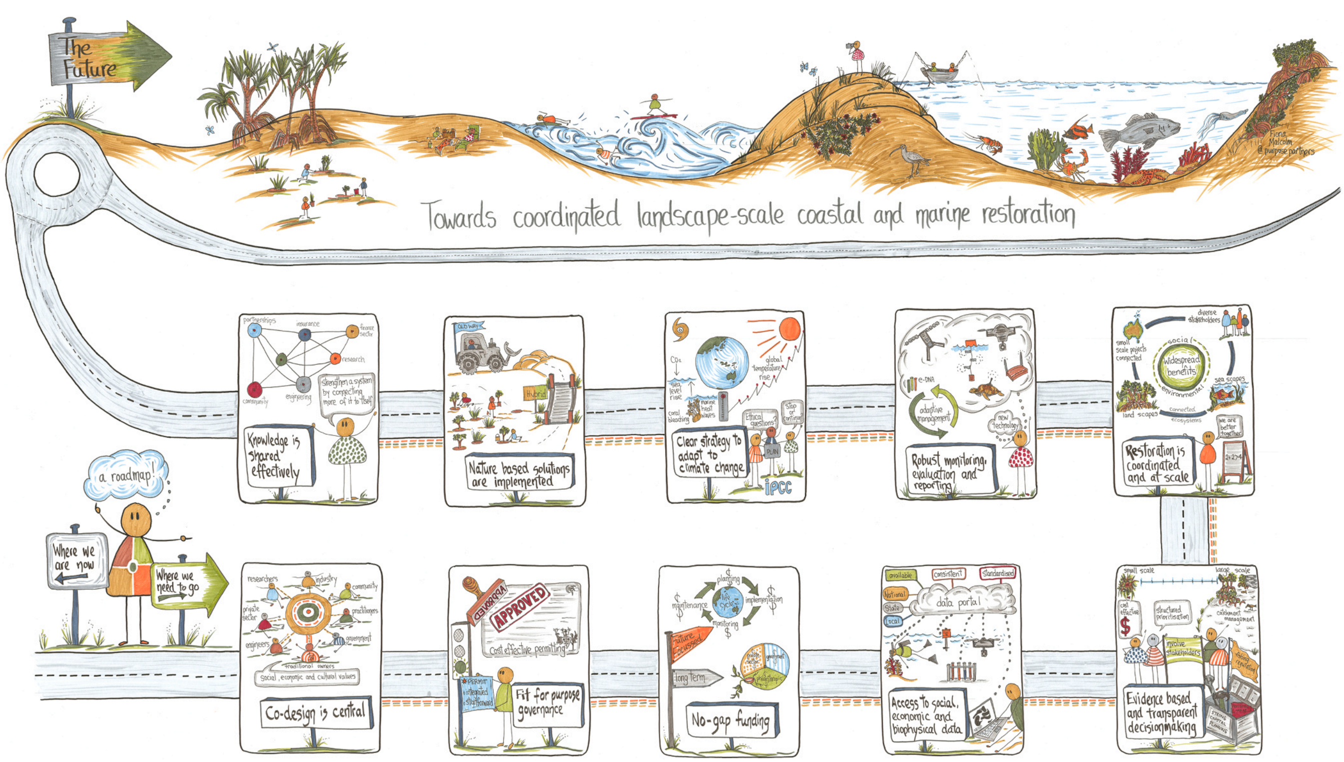

Fig. 3. Ten guiding principles towards a roadmap for coordinated landscape scale coastal and marine ecological restoration. The roadmap was created based on information gained through elicitation with >140 practitioners, decision makers and researchers of coastal and marine ecological restoration in Australia. Image created by Fiona Malcolm, Purpose Partners, in collaboration with the project team and stakeholders. Reproduced *with permission* from Saunders et al. (2022).

These rights are yet to be adequately incorporated within many international, national and local government-level practices (Carmona et al., 2023), but there is a movement towards recognition of decision-making and cultural responsibilities over environmental spaces and as such the need for co-production of adaptation pathways (Hill et al., 2020; Reyes-García et al., 2019). The Society for Ecological Restoration (SER) *International Principles and Standards for the Practice of Ecological Restoration* (Gann et al., 2019) Principles 1 & 2 highlight the necessity for diverse engagement and knowledge systems, including Traditional Ecological Knowledge and Local Knowledge (Grice et al., 2012). In Australia, Co-design (or co-creation) is identified in the Indigenous partnership principles of the Australian National Environmental Science Program (National Environmental Science Program, 2021). Relationships based on reciprocity rather than extraction will be key to developing successful partnerships which yield benefits to all parties (Saunders et al., 2024).

At present in Australia a wide range of restoration activities are being conducted by diverse and collaborative groups; nevertheless, much of the work is conducted in silos related to organisations, habitats, jurisdictions, and other factors (Table S1). There are however examples of regional to national scale coastal and marine restoration conducted by multiple partners, such as the Blue Heart tidal wetland project in southeast Queensland (Iram et al., 2022), and the national Reef Builder oyster restoration program (TNC, 2023). Notably, while 80 % of stakeholders surveyed in Australia indicated that Indigenous Groups are involved in project activities in some form, the sentiment from Traditional Owners is that they have not been meaningfully engaged (Table S1) (Saunders et al., 2022). Within the Australian marine science community more broadly it is recognised that more meaningful engagement with Indigenous communities is needed (e.g. Hedge et al., 2020).

As we move forward there will be a need to create stronger links between people conducting diverse restoration activities, includes among practitioners, researchers, Traditional Owners, communities, industry and others, with knowledge brokers potentially playing a key role to connect diverse groups (Karcher et al., 2023). Importantly, we will need to consider, take care, and work with Indigenous groups to assess how or whether targets such as GBF Target 2 will meet the needs of Traditional Owners. Guidance for how to achieve successful partnerships among Indigenous and non-indigenous groups (Table 1) is needed. Steps towards this aim have been taken in the Australian coastal and marine restoration community, for example, for the Reef Restoration Adaptation Program (Taylor et al., 2019) and the National Environmental Science Program (McLeod et al., 2018; Saunders et al., 2024). More broadly, the Australian Institute for Aboriginal and Torres Strait Islander Studies (AIATSIS) Code of Ethics for Aboriginal and Torres Strait Islander Research provides four principles for Indigenous engagement by the research sector (AIATSIS, 2020) including themes of: Indigenous self-determination; Indigenous leadership; impact and value; and sustainability and accountability (AIATSIS, 2020). Guidance can be gained from experience internationally. For instance, in South Africa five principles to integrate Indigenous and Local Knowledge (ILK) in coastal and ocean management were developed (Rivers et al., 2023). These include adopting contextual approaches; increasing transparency and two-way communication; increasing access to information; amending legislation to form a stronger connection between marine spatial planning and Indigenous knowledge; and amending legislation related to access to coastal and marine regions (Rivers et al., 2023).

3.2. Principle 2: Fit-for-purpose governance

Fit-for-purpose governance frameworks that are straight-forward to interpret and navigate enable the implementation and scaling up in number, size, quality and outputs of marine restoration (Fig. 3, Figure S2). Fit-for-purpose permitting and approvals processes for restoration ensure that well designed and beneficial projects can

Table 1
Key research needs and actions identified for each of ten principles for coordinated landscape scale coastal and marine restoration based on research conducted in Australia.

Principle	Research needs and Actions
1: Co-design is central	Develop guidance and co-design principles for restoration researchers, practitioners and decision makers to effectively engage and co-design with Traditional Custodians. Establish a well-funded national scale Coastal Restoration & Nature-based Solutions Indigenous Advisory Panel. Develop training in coastal restoration processes for Traditional Custodians to conduct restoration maintenance, monitoring and evaluation as fee-for-services activities on Country.
2: Fit-for purpose governance	Evaluate the policy and legislative environment underlying coastal and marine restoration and NbS to establish recommendations to inform transparent fit-for-purpose policies. Conduct scoping of the legal and policy risks of conducting restoration, for instance, in protected areas, such as Marine Parks, Ramsar sites and World Heritage areas, and in the context of multiple layers of land management.
3: No-gap funding	Investigate innovative financial mechanisms for restoration which consider the advantages and disadvantages of a range of financing options, including blended funding models. Embed marine restoration & NbS within The Taskforce on Nature-related Financial Disclosures (TNFD), which offers a future path to engage the financial sector in restoration to address risk. Identify and implement learnings from successful international large scale funding models.
4: Access to social, economic and biophysical data	Invest in national spatially consistent data sets for information, including habitat maps, bathymetry, ecological processes and functions, governance, and social and economic indicators. Develop standardised frameworks to represent social and cultural values. Make existing data available in standardised and comparable formats.
5: Evidence-based and transparent decision making	Develop frameworks to underpin structured evidence-based approaches for decision making and prioritisation with attention to how decision-making needs vary across spatial scales. Synthesize information regarding effectiveness and outcomes from existing projects to evaluate the evidence for restoration across the technologies which are currently available.
6: Restoration is coordinated and at scale	Identify and design technologies suitable for larger scale restoration interventions and develop the business case to demonstrate economies of scale. Identify models for effective collaboration and implementation across jurisdictional and ecosystem boundaries.
7: Robust monitoring, evaluation and reporting	Develop standardised framework for reporting outcomes of restoration projects and fund a central coordinator to maintain the interface. For example, Restor (https://restor.eco/), and the Mangrove Tracker Tool by the Global Mangrove Alliance. Invest in technologies and architecture for networks of national restoration monitoring, including *in situ* and remote sensing approaches, to facilitate collection, reporting and sharing of data on outcomes.
8: Clear strategy to adapt to climate change	Develop conceptual models of the impacts of climate change on coastal and marine ecosystems and how they will affect outcomes of restoration to communicate to decision makers. Use these to underpin development of guidelines for restoration decision making within the context of future climate change.

(*continued on next page*)

Table 1 (*continued*)

Principle	Research needs and Actions
	Implement well-funded research programs to increase knowledge and capacity for restoration in the context of climate change.
9: Nature-based solutions are implemented	Conduct research to characterise efficacy and risk of using NbS for coastal hazard protection in a changing climate. Explore concepts of liability if NbS projects fail, and opportunities to de-risk implementation. Identify specific barriers to implementation of NbS for coastal protection faced by engineers, consultants and coastal councils, and identify solutions to those barriers.
10: Knowledge is shared effectively	Increase communication within the restoration community, for instance through national networks such as the Australasian Coastal Restoration Network (ACRN). Identify partnership opportunities and champions of restoration and NbS at scale outside of existing restoration networks, for example in insurance, finance and engineering sectors. Support ecological learning and capability of these sectors.

proceed with checks and balances on activities so that risks of negative outcomes or adverse effects is low, and that poorly designed projects with low probability of success are prevented. Governance that is not fit-for-purpose delays, increases the costs of, or prevents, restoration programs from proceeding (Bell-James and Lovelock, 2019b; Shumway et al., 2021).

Legislative barriers are one of the top three barriers to coastal and marine restoration (Saunders et al., 2022) (Table S1) and NbS for coastal protection in Australia (Morris et al., 2024). There are different policies and legislation applicable to restoration in every state and territory (Bell-James et al., 2023a; Bell-James et al., 2023b; Shumway et al., 2021) and the interpretation of these is complex and can vary among individuals within permitting authorities (Bell-James et al., 2023b). Specialised skills and knowledge are required to navigate the permitting processes, which precludes involvement in restoration from many communities, including Traditional Owner organisations. Permitting criteria and approval processes are typically more aligned with reducing or preventing environmental harm from development or pollution than with biodiversity enhancement (Bell-James et al., 2023b). For instance, many restoration projects are assessed under policies such as the Environment Protection (Sea Dumping) Act 1981 or development approvals pathways (Bell-James and Lovelock, 2019a). The process to obtain approvals can take several years and is expensive.

These are not new challenges, but they will require a major review of the relevant legislation currently restricting restoration (Bell-James and Lovelock, 2019b) (Table 1). Updated permitting processes for restoration and NbS will ideally be tailored to 'nature-positive' activities rather than being assessed using permitting pathways designed to protect against negative environmental impacts. Developing a set of standards for restoration and NbS that also considers local policies and laws will provide the guidance necessary for prospective proponents to move projects forward.

3.3. *Principle 3: No-gap funding*

The no-gap funding principle highlights that sufficient funding is required for a restoration project for its full life-cycle, including planning, permitting, implementation, monitoring, adaptive management and maintenance for protection of the restored asset (Fig. 3, Figure S3). Funding over timescales appropriate to restoration programs ensures that maintenance is implemented in perpetuity, which is needed to realise maximum returns on initial investments (Holl and Howarth, 2000). Ecological restoration occurs over years to decades, and there are funding schemes with requirements to ensure long term outcomes. For example, coastal restoration projects aimed at carbon sequestration are required to have a 25 or 100-year permanence period (Lovelock et al., 2023).

The timing and availability of funding were the top two barriers to coastal and marine restoration identified by stakeholders in Australia (Table S1) (Saunders et al., 2022). The current quantum of funding is very small compared to the extent of degraded ecosystems and the estimated value of coastal ecosystem services (Costanza et al., 2021). Ecological restoration is a long-term process with recovery taking many years or decades (Gann et al., 2019; Lovelock et al., 2023), but marine restoration projects are typically monitored for only a couple of years (Bayraktarov et al., 2016; Saunders et al., 2022). While major restoration efforts are underway in Australia and globally, on-going investment can be difficult to secure for maintenance, continuation of works (Sánchez-Arcilla et al., 2022), or monitoring and evaluation of outcomes (Holl and Howarth, 2000). The current short-term funding regime which operates on a project-by-project basis effectively blocks capture of long-term data which is necessary for a complete understanding of restoration outcomes (Abbott et al., 2020; Weinstein and Litvin, 2016; Zedler, 2016). However, there are examples of restoration programs which successfully leverage multiple finance sources. For example, the Blue Heart tidal wetland restoration project in Southeast Queensland, Australia, leverages funding from the private sector via the local water provider (UnityWater) as an offset for nutrient pollution, the Queensland Government's Land Restoration Fund, and the Commonwealth Government's Blue Carbon Ecosystem Restoration Grants scheme (DCCEEW, 2022; Carbon Market Institute, 2021; Iram et al., 2022). Similarly, major investment to remove accumulating aquatic water weeds on the palustrine wetlands in the Great Barrier Reef have been achieved through an ongoing annual fund that is an arrangement between local government, local Natural Resource Management (NRM), water infrastructure board and landholders (Davis et al., 2017; Waltham et al., 2020a).

Moving forward there is a need to update the funding model for restoration. Blended finance models which including investments from governments, philanthropy and the private sector (Canning et al., 2021) offer a useful mechanism to leverage multiple sources of funding. Embedding restoration into the The Taskforce on Nature-related Financial Disclosures (TNFD), which aims to enable business and finance sectors to assess, report and act on their nature-related dependencies, impacts, risks and opportunities, could help to raise the funds needed to scale up restoration (Table 1) (TNFD, 2023). In Australia a voluntary Nature Repair Market was announced in March 2023, which aims to facilitate private sector investment into restoration (DCCEEW, 2024).

3.4. *Principle 4: Social, economic, and environmental data are available*

This principle explicitly recognises that biophysical, social and economic data is critical for the planning and implementation of successful restoration projects (Fig. 3, Figure S4) (Sheaves et al., 2021). Along with knowledge of the ecological niche of target species, these data are essential for the development of GIS-based and other restoration suitability models, which can be used to identify and prioritise the most suitable sites for restoration (e.g. Adame et al., 2015; Saunders et al., 2017). These data are also critical for identifying key limiting factors such as poor water quality or absence of suitable substrate. High resolution, spatially explicit data need to be freely available and accessible to natural resource managers, Indigenous groups, scientists and restoration practitioners in a format that can easily be included in models and decision tools. Lack of data availability reduces capacity to make evidence-based decisions and may contribute to inequity in resource distribution.

Australia has a wealth of spatial data in comparison to many other jurisdictions, which are collected and compiled at local to national scales. These data are curated by a range of Federal, State, and Local government departments, as well as Non-Governmental Organisations (NGOs), the private sector and academic institutions. Many are available through open access portals (e.g. Geosciences Australia Data Cube, The Australian Open Data Network, Integrated Marine Observing System). However, with many of the data portals managed by state or local authorities, there is inconsistency in the parameters they include, their resolution, the way in which they have been collected, and the level of intersection between datasets in different realms (terrestrial, estuarine, coastal, or marine). With data held by many different organisations it can be challenging for restoration practitioners and decision makers to navigate the availability and format of datasets. Inconsistencies in data can be an impediment to projects seeking to prioritise site selection across jurisdictional boundaries, and at larger, national scales. For example, recent efforts to collate and harmonize data to underpin management of Blue Carbon resources have identified significant gaps in coverage and reporting across jurisdictions (e.g. Brock et al., 2022; Hagger et al., 2022a). Though data on biophysical parameters, such as temperature, salinity and bathymetry are available for coastal waters, they are often not well resolved in shallow water and intertidal areas. Spatial data on social and economic factors such as stakeholder perspectives on support for restoration are less widely available (Howie, 2022). At present, repositories of monitoring data from previous restoration projects against which to assess efficacy and determine the design of future projects is limited. Data on the economic costs and benefits of previous restoration projects and on ecosystem service provision can assist in building community support for restoration (Barbier, 2017; Bayraktarov et al., 2016; Stone et al., 2008).

A key action moving forward is to invest in national spatially consistent and cohesive data sets for key data required to inform restoration decision making. These include habitat maps, bathymetry, ecological processes and functions, governance, and social and economic indicators (Table 1). This will require developing standardised frameworks to represent social and cultural values. Ideally, data will be made available in standardised and comparable formats. As we move to multi-habitat seascape scale restoration (Vozzo et al., 2023), the availability of spatially consistent data for multiple habitats to underpin restoration decision making will become even more important.

3.5. Principle 5: Evidence-based and transparent decision making

The *Evidence-based and transparent decision making* principle requires that the best available science (data and models) and wisdom (knowledge) informs all stages of the restoration process (Fig. 3, Figure S5) (IUCN and WRI, 2014). Decision making for restoration occurs across many spatial and temporal scales, ranging from decisions around where to locate interventions at the local scale, to which habitats or states to allocate investment at the national scale. Evidence-based and transparent decision making informed by science can produce more effective policy decisions, and as a result, lead to beneficial outcomes, and equitable, rational, and cost-effective resource distribution (IUCN and WRI, 2014). Strong evidence is needed to support decisions around whether restoration will be the best option compared to other actions, such as habitat protection, pollution management, and fisheries regulations, or when restoration actions need to be coupled with other interventions (Possingham et al., 2015; Saunders et al., 2017). This principle strongly connects to the principle of *Co-design is central* because eliciting best available wisdom and making ethically sound decisions requires that landholders, local communities, and Traditional Owners are involved in the decision-making process. Importantly, there is a need to move beyond an extractive colonial process where knowledge, wisdom, or culture is taken and used by others, to a process of co-design by Traditional Owners, for Traditional Owners.

In contrast to the systematic conservation planning approaches which were used to design and implement Marine Protected Areas, such as the Great Barrier Reef Marine Park (Kenchington and Day, 2011), decision making and planning for marine restoration in Australia has at times been relatively opportunistic. For instance, decisions for where to site projects have sometimes depended on political will or governance opportunities (Table S1). Due to short funding timelines "shovel ready" projects which meet permitting criteria have been prioritised leading to suboptimal outcomes (Bell-James et al., 2023b).

Developing frameworks to underpin structured evidence-based approaches for decision making and prioritisation with attention to how decision-making needs vary across spatial scales is required (Table 1) (Saunders et al., 2022). Concepts from spatial conservation planning can be applied here, which use modelling tools to help achieve maximum benefits for minimum costs and can address the trade-offs inherent in complex multi-objective resource management problems (McBride et al., 2010; Wilson et al., 2011). Structured Decision Making is one approach to evidence based decision making, and consists of seven steps: 1) decide on goals, 2) set objectives, 3) identify actions which can be used to meet those objectives, and parameterise their costs, feasibility and constraints; 4) predict the benefits that the actions can achieve relative to the objectives; 5) identify trade-offs, 6) make a decision, 7) act, monitor and learn (Gleason et al., 2021). These approaches to coastal and marine restoration in the published literature are rare [but see (Adame et al., 2015; Lester et al., 2020)], but variations on these steps are increasingly being used by practitioners in some settings. For instance, uptake of the Restoration Opportunities Assessment Methodology, ROAM, by mangrove practitioners (IUCN and WRI, 2014).

3.6. Principle 6: Coordinated and at scale

This principle highlights that a coordinated approach to land- or seascape scale restoration can help to overcome many of the challenges precluding widespread uptake and implementation (Fig. 3, Figure S6). Coordination ensures that trade-offs among multiple objectives are identified and reconciled, ensuring that there is a portfolio of projects which achieve diverse objectives, such as shoreline protection, fisheries enhancement and cultural benefits (Hagger et al., 2022b). When considering these trade-offs it will be important to recognise that some objectives may need to take priority over others, such as protecting or restoring areas with particularly high place-based cultural and spiritual connections. Economies of scale can be reached when projects are coordinated, for instance through aggregation of adjacent land holders in wetland restoration projects, such that greater benefits are accrued for less cost per unit (Canning et al., 2022). Agreement among coordinated land holders on shared goals increases the spatial extent of wetland restoration activities by orders of magnitude (Hemmerling et al., 2023; Lupp et al., 2021). Coordination ensures that projects within programs don't adversely affect each other, or otherwise result in negative societal impacts. For instance, preventing the installation of a series of projects which ultimately negatively affect navigation, transportation or hydrodynamic processes (e.g. Twomey et al., 2022).

At present in Australia there is a sense that most restoration is conducted at a project rather than programmatic scale, and that, with notable exceptions, such as The Nature Conservancy's Reef Builder Program which aims to rebuild Australia's lost shellfish reefs (TNC, 2023), and the Reef Restoration Adaptation Program which aims to develop solutions to help the Great Barrier Reef adapt to climate change (McLeod et al., 2022), there is a lack of coordination among most restoration initiatives (Saunders et al., 2022). The extent of coastal and marine restoration to date in Australia is unknown, although the Australian Coastal Restoration Network (https://www.acrn.org.au/) database and the Living Shorelines Australia database (https://www.livingshorelines.com.au) offer some information on past projects (Campbell-Hooper et al., 2015; Purandare et al., 2024). Socio-cultural barriers such as permitting and legislation, unclear land tenure, lack of funding, and limited community engagement remain barriers to coordination and scaling up (Bell-James et al., 2023b; Shumway et al., 2021). Frameworks such as the Queensland Government's 'Whole of

Ecosystem Values Based Framework' (DES, 2022) articulate how management actions link across spatial and temporal scales. For example, they describe how catchment land uses affect river run-off and flow-on effects to coastal systems.

Innovation of new technological and socio-ecological approaches to scaling up coastal and marine ecosystem restoration is required (Table 1) and in progress. For corals, technological methods to harvest coral spawning slicks to re-seed degraded reefs are in developmental phase (e.g. Doropoulos et al. 2019). For kelp, collaboration with the fishing industry to harvest climate range-shifting sea urchins which otherwise graze macroalgae is helping to restore temperate reefs (Cresswell et al., 2023). For coastal wetlands, the innovation of the transparent and repeatable Blue Carbon Method for tidal reintroduction (Lovelock et al., 2023), has allowed new investment into restoration of mangroves and saltmarshes (DCCEEW, 2022). Concepts of 'multi-habitat' restoration which coordinate restoration across multiple habitats in the seascape are becoming forefront to many practitioners. This approach aims to harness cross-habitat processes whereby one habitat provides a function (e.g., wave attenuation, sediment stabilisation, water filtration) that enables the growth and expansion of another habitat (Gillis et al., 2017; Vozzo et al., 2023).

3.7. Principle 7: Robust monitoring, evaluation and reporting

Robust monitoring and evaluation of outcomes of restoration against stated objectives is necessary to assess whether restoration was successful and to improve future restoration practices (Fig. 3, Figure S7) (Eger et al., 2022a). The absence of, or inadequate, reporting on projects' actions and outcomes hampers opportunities to learn from past successes and failures, and, consequently, improve on future restoration practices (Bernhardt et al., 2005).

Although most restoration and NbS projects in Australia do consider requirements for monitoring in some form during the planning and implementation stages, such requirements differ geographically and according to the available funding (Table S1). Many restoration projects do not have clearly stated goals and objectives, which makes evaluation of outcomes relative to objectives impossible or open to interpretation (Mayer-Pinto et al., 2017). Different metrics are reported and data are inconsistently recorded and stored, making tracking progress difficult. Data from restoration projects are not usually published or made publicly available. Interestingly, progress towards a standardized reporting framework for mangrove restoration globally is underway. Adequate funding for monitoring and evaluation was identified as a barrier to the implementation of monitoring activities, while lack of time, resources and organizational support was identified as major barriers to the publication of monitoring outcomes. These issues link back to Principle 4 – *Access to social, economic and biophysical data*.

There is a clear need to determine and report successes and failures of restoration practices in Australia and worldwide (Eger et al., 2022a; Gatt et al., 2022) (Table 1). Having a common, standardized set of metrics across restoration and NbS projects, and incentives to make those publicly available where appropriate, would allow the consolidation of metrics being recorded, and advance our quantitative understanding of restoration and NbS success (Eger et al., 2022a), without 'losing' the local knowledge and relevance. Access to data for the effectiveness of actions is needed in general, as well as for particular contexts, such as planning adaptive measures for threatened species and protected places in response to climate change (Mason et al., 2021).

3.8. Principle 8: Clear strategy to adapt to climate change

This principle recognises that coastal and marine ecosystems are, and will increasingly be, exposed to climate change symptoms (Babcock et al., 2019) and that clear strategies to adapt to climate change will be required for all restoration programs to ensure future success (Fig. 3, Figure S8). Climate smart strategies can incorporate predictions for changes in ecological processes, functions, ecosystem migration, and human responses to climate stressors and how those responses may impact coastal ecosystems. Planning climate smart restoration will involve reconciling challenging issues, such as uncertainty in the outcomes of species translocations (Seddon, 2010), and uncertainty in the functioning of novel ecosystems (Hobbs et al., 2009). Challenging decisions will need to be made around what circumstances to keep going or to give up on restorations actions and instead pivot to hybrid NbS or novel interventions as environmental conditions become unsuitable (Vergés et al., 2019). Coastal planning strategies can include allowing for landward migration of coastal ecosystems and providing clear guidance on how to manage changing land tenure due to sea-level rise.

In Australia, climate smart coastal and marine restoration is in the research rather than implementation phase. For example, the Reef Restoration Adaptation Program (RRAP) is a research program investigating how to conduct climate smart restoration for coral reefs in the Great Barrier Reef, but there are no similar programs for other geographies or marine ecosystems (Table S1). In our survey we found that most researchers and practitioners are considering the impacts of climate change in restoration planning, but there is no clear agreement or guidance on how to explicitly account for climate change impacts (Saunders et al., 2022). Several frameworks to support coastal restoration and climate change adaptation have been developed (Palutikof et al., 2019; Sivapalan and Bowen, 2020). However, there are no technical guidelines that provide specific designs for adaptation strategies such as managed retreat. There is limited consensus on how to plan for the impacts of marine heatwaves and warming temperature on restoration projects. However, innovative research is identifying warm tolerant genotypes which could potentially be used in climate smart restoration, for instance in kelp (Coleman et al., 2020; Eger et al., 2022b; Layton et al., 2020).

As climate change progresses robust science that informs planning for restoration with climate change will result in more cost-effective interventions and beneficial outcomes for coastal ecosystems and for the people who rely on them. As a first approach, the development of conceptual models of the impacts of climate change on coastal ecosystems and restoration programs will help decision makers and practitioners make informed decisions (Table 1). Ultimately, there will be a need for well-funded research and development programs which aim to develop innovative solutions to restoring coastal and marine ecosystems in the context of climate change (Table 1).

3.9. Principle 9: Nature-based solutions are implemented

The full return to a previous ecosystem state is not feasible in all locations. Nevertheless, NbS using more resilient habitats and biota may be feasible, and NbS can therefore be considered in environments where restoration to a baseline state is unfeasible or will not achieve the ecosystem services that are desired (Sutton-Grier et al., 2015). NbS are nature-positive hybrid approaches that provide ecological benefits while meeting practical objectives, such as shoreline protection (Fig. 3, Figure S9) (IUCN, 2020). NbS for coastal protection, also known as 'living shorelines' (Bilkovic et al., 2017) or 'nature-based coastal defence/protection' (Morris et al., 2018) can provide benefits over conventional engineered structures (e.g., seawalls, revetments) which are commonly used to address coastal hazards. Natural systems are adaptive to changes in climate (Rodriguez et al., 2014) and can self-repair after storm events (Gittman et al., 2014). Living shorelines have the potential to provide several co-benefits such as biodiversity provision, fisheries support or carbon sequestration (Morris et al., 2018).

In Australia, NbS for coastal hazard protection are not commonly implemented in comparison to conventional engineered structures (Morris et al., 2018). In our survey of NbS researchers, practitioners and decision makers most (95 % percent of survey respondents) state that there is support for NbS within their organisation, however, only two thirds of those respondents implement an NbS (Saunders et al., 2022).

One of the barriers to NbS is that coastal works are typically conducted by local or state governments, and in turn advised upon by engineering consultancies, for whom ecological principles are not deeply engrained (Scheres and Schüttrumpf, 2020). A major challenge to the adoption of NbS is that engineers design and certify coastal defence structures to function within a particular range of conditions over a design lifetime. For example, to protect coastal assets in conditions ranging up to a particular category of storm event. However, it is not currently possible to certify nature-based solutions for coastal hazard protection for particular frequency or intensity of storm events because of uncertainties in how habitat forming species will establish, grow, function, and persist (Scheres and Schüttrumpf, 2020).

Despite these challenges, the use of nature-based coastal protection has been growing nationally for the last two decades, particularly using dunes, beach and mangrove ecosystems (Morris et al., 2024). Synthesising learnings from past and current NbS projects and working closely with local and state governments and the engineering sector will help to de-risk the implementation of NbS for industry. Priority research questions include characterising the efficacy and risk of using NbS for coastal hazard protection; exploring concepts of risk and liability if projects fail, and identifying specific barriers to uptake and adoption (Table 1).

3.10. Principal 10: Knowledge is shared effectively

Coastal marine restoration requires collaboration from many actors (Fig. 3, Figure S10) (Ens et al., 2015; Hahs and Evans, 2015). Effectively sharing knowledge about causes of restoration success or failure is essential to learn from past experiences and to move forward successfully. Knowledge sharing is one of the key elements of relationship building, and the development of meaningful partnerships is a common elements of restoration success (Sánchez-Arcilla et al., 2022).

There are a range of organisations in Australia aimed at connecting people engaged in the ecological restoration sector and facilitating knowledge sharing. These include the Australian Coastal Restoration Network, The Society for Ecological Restoration Australia, and the Australian Marine Sciences Association, which hosts restoration symposia at its annual conference. That said, there is a desire for better communication among geographies, ecosystem types, organisations, and stakeholder groups (Table S1).

Scaling-up requires connection and engagement within regional to national networks of restoration researchers, decision makers and practitioners as well as with a broader suite of actors, including the general public, the engineering sector, where there is capability to implement NbS at scale, and the finance sector. For the latter, momentum is building to make supply chains more transparent and sustainable, for instance through The Taskforce on Nature-related Financial Disclosures (Table 1) (TNFD, 2023). Ecological restoration is not a top priority for these sectors, or likely within their current capability, therefore education, knowledge sharing and empowerment are required.

4. Evaluating the roadmap against existing programs

To test the applicability of the principles we conducted a brief evaluation of three large-scale coastal and marine restoration programs against each principle. The programs include: The United Kingdom Managed Realignment Program, Restore America's Estuaries in the USA, and The Reef Restoration and Adaptation Program for the Great Barrier Reef in Australia. To conduct the evaluation, we reviewed publicly available information from websites, papers and reports, and identified whether there was any evidence for each of the principles for each program (Table S2). We found that all three programs have evidence for meeting nearly all of the principles. However, comprehensive scoring for each principle for each program would be subjective and was deemed out of scope for this research. Below we identify a few principles for each program which are particularly pertinent.

4.1. UK managed realignment program (UKMR)

The Managed Realignment Program of the United Kingdom is a restoration and NbS approach whereby coastal defence structures are breached, relocated, or removed. This increases space for coastal ecosystems such as tidal flats and saltmarshes, typically with the aim of enhancing flood protection. The first planned retreat commenced in 1994 with the LeBranche Wetlands project and continues today with more than 151 projects covering more than 44,500 ha. The largest project within this program, the Medmerry Managed Realignment (MMR) project (Table S2) aligns particularly to the principles of *Co-design is central*, *Robust monitoring, evaluation and reporting*, and *Nature-based Solutions are implemented*. The MMR project resulted from the findings of a Coastal Defence Strategy report which stated that implementing NbS for erosion and inundation was appropriate. Co-design was central to the implementation of the MMR, which involved a consortium of residents and 23 stakeholder groups. Due to the high number of stakeholders involved, many different technical, summary and monitoring reports have been published with different foci; however, these are not stored in a central location. Larger individual projects like the MMR were coordinated well among numerous local government regions and actively involved multiple stakeholders. The framing of the overall Managed Realignment program allows for coordination over larger scales than the individual projects alone.

4.2. Restore America's Estuaries

Founded in 1995, Restore America's Estuaries (RAE) is the lead on the national alliance for ten coastal conservation groups dedicated to restoring and conserving America's estuaries and coasts. There is evidence that RAE aligns with all of the roadmap principles, in particular it demonstrates *No-gap funding*, *Coordinated and at scale*, and *Knowledge is shared effectively* (Table S2). As the unified voice for coastal conservation, RAE has been successful in advancing the science and practice of habitat restoration in America. This has been most effectively demonstrated through the delivery of numerous on-the-ground projects, through enabling science into coastal and estuarine ecosystems, and through the facilitation of high-level meetings with all levels of government and industry; all of which improved the future course of the nation's estuaries. In 2022, the RAE successfully advocated for the release of major national government investment to curb emissions and to combat the negative impacts of climate change (approximately US $2.6B). The RAE also worked with the government for a US$3B investment provision for coastal restoration from the Bipartisan Infrastructure Law in 2021, and a bi-partisan US$1.7B spend to fund RAE priorities. Ongoing funding has enabled coordinated and scaled restoration through different programs that seek to restore coastal areas and watersheds over entire regions (e.g. Southeast New England Program, National Estuary Program). The collective strength of the RAE network and its forward-looking focus on restoration and preservation of America's estuaries has strengthened its profile and position at the negotiating table when governments are formulating policy and funding provision. The success of this program and the impact extends down through the alliance of conservation groups, so that funding reaches ground-level projects. The success of this program is celebrated biannually, with regularly more than 1000 participants sharing learnings, results, and knowledge.

4.3. Reef restoration adaptation program – great barrier reef, Australia

The Reef Restoration and Adaptation Program (RRAP) is a collaborative research and development program that commenced in 2020 with the intent to devise solutions to restore, repair and create a resilient Great Barrier Reef (Table S2). Three roadmap principles were at the forefront of the program: *Co-design is central*, *Evidence-based and transparent decision making*, and *Clear strategy to adapt to climate change*. The

Stakeholder & Traditional Owner Engagement subproject of RRAP consists of three working areas seeking to maximise engagement and social considerations, especially by Traditional Owners and local communities, and to implement adaptive management and governance. The approach to compartmentalising the program into subprojects that are working toward a common goal allows the program to achieve coordinated restoration research strategies which are intended to be applicable at scale and which respond to climate change. A sub-program on Modelling and Decision Support aims to help decision-makers guide investment and action through the provision of high-quality prioritisation models. Recognising the challenges that policy and permitting can present to restoration progress, the RRAP includes a research subprogram with the focus of identifying policy and permitting pathways. RRAP is currently in Phase 1 which ends in 2025, at which point it will become more apparent whether each of the subprograms accomplished the goals outlined at the onset of the program. Given that RRAP is fundamentally a Research and Development program it remains to be seen what on-ground outcomes will be achieved.

5. Conclusions

Despite many recent major advances, there remains a substantial gap in implementation of coastal and marine restoration and NbS at landscape scale. The roadmap presented herein is intended to form the basis of a conversation supporting transformational change from small scale and uncoordinated projects towards large regional to nationally coordinated approaches to coastal and marine restoration. These have potential to improve the environment and natural assets, while generating jobs and providing communities with economic and social benefits. Following the roadmap has potential to elevate the state, condition and function of coastal and marine assets, to increase our capacity to adapt to climate change, and to boost the social, cultural and economic wellbeing of coastal peoples.

As the pressure and momentum to scale up ecological restoration in coastal and marine ecosystems increases, the roadmap presented here can inform large-scale, coordinated, climate smart landscape scale restoration which will ultimately provide measurable, long-term benefits to the environment and society. Doing so will enable countries to help meet national and international commitments CBD Kunming-Montreal Global Biodiversity Framework. Full consideration and support of the guiding principles outlined in the roadmap by all levels of government, both nationally and internationally, is needed to enhance the resilience and function of coastal and marine ecosystems.

CRediT authorship contribution statement

Megan Saunders: Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Supervision, Visualization, Writing – original draft, Writing – review & editing. **Toni Cannard:** Conceptualization, Formal analysis, Investigation, Visualization, Writing – original draft, Writing – review & editing. **Mibu Fischer:** Conceptualization, Formal analysis, Investigation, Visualization, Writing – original draft, Writing – review & editing. **Marian Sheppard:** Formal analysis, Investigation, Writing – original draft, Writing – review & editing. **Alice Twomey:** Formal analysis, Investigation, Writing – original draft, Writing – review & editing. **Rebecca Morris:** Investigation, Writing – original draft, Writing – review & editing. **Melanie J. Bishop:** Writing – original draft, Writing – review & editing. **Mariana Mayer-Pinto:** Conceptualization, Writing – original draft, Writing – review & editing. **Fiona Malcolm:** Conceptualization, Visualization, Writing – review & editing. **Maria Vozzo:** Formal analysis, Investigation, Writing – original draft, Writing – review & editing. **Andy Steven:** Funding acquisition, Investigation, Writing – review & editing. **Stephen E. Swearer:** Investigation, Writing – review & editing. **Catherine E. Lovelock:** Investigation, Writing – review & editing. **Andrew W. M. Pomeroy:** Investigation, Writing – review & editing. **Ian McLeod:** Writing – review & editing. **Nathan J. Waltham:** Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Visualization, Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Megan Saunders reports financial support was provided by by CSIRO Oceans and Atmosphere (now Environment) and the Australian Government under the National Environmental Science Program. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data underpinning the research are available online

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Appendix A. Supporting information

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