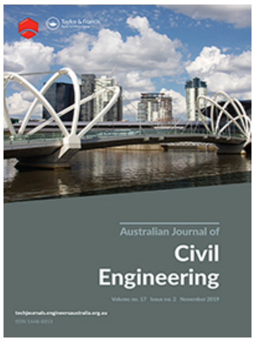

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Developing a nature-based coastal defence strategy for Australia

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ABSTRACT
Australia's rapid coastal population growth coupled with the increased risk of hazards driven by climate change creates an urgent need to start adaptation planning for the future. The most common solutions for protecting the coast (seawalls, breakwaters) are expensive and non-adaptive (i.e., they need to be rebuilt, upgraded and maintained in response to a changing climate). There is international precedence for the development of nature-based solutions (i.e., the integration of natural habitats such as coastal vegetation and biogenic reefs) as a cost-effective and sustainable approach to shoreline protection from erosion and flooding. The development of nature-based approaches has been supported by large interdisciplinary teams to inform policy and decision-making. Nature-based coastal defence is currently not a tool widely used in Australia. Key to their wider implementation is: (1) improved scientific knowledge; (2) effective governance; and (3) social acceptance. Recently implemented pilot trials need to inform industry-accredited guidelines that can be integrated into coastal management and government policy.

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Coastal management; coastal protection; ecological engineering

1. Introduction

Coastal habitats, such as dunes, biogenic reefs, and wetlands, are highly valued for the ecosystem services they provide (Barbier et al. 2011). One service that is attracting increasing attention from researchers and coastal managers is their ability to provide natural coastal protection (Temmerman et al. 2013). Climate change is increasing the risk of erosion and flooding through drivers that include accelerating sea-level rise, changing wave climate, and potentially more frequent storm events (Young, Zieger, and Babanin 2011; IPCC 2014). Coupled with this changing climate is an increase in global population, especially at the coast, which will increase exposure of people to existing and future coastal hazards (Firth et al. 2016). In Australia, the population is expected to grow from its current 25 million to between 37 and 49 million by 2066 (ABS, 2018) with a high proportion (85%) living within 50 km of the coast (ABS 2004). Consequently, climate change and coastal urbanisation is driving an increased need for investment in coastal protection infrastructure as occupation of the current hazardous zone increases.

A reliance on traditional-engineered structures (e.g., seawalls, breakwaters) for shoreline protection into the future is regarded to be unsustainable (Abel et al. 2011). In part, this is due to the high construction and maintenance costs of these structures, which are non-adaptive (i.e., they need to be rebuilt, upgraded or maintained) to future changes in climate (Hinkel et al. 2014). Equally, these structures often have substantial ecological costs through the replacement of diverse natural habitats with homogenous substrata that support low biodiversity (Chapman 2003) and often a high proportion of non-native species (Dafforn, Johnston, and Glasby 2009). Artificial structures can also have unintended consequences on coastal processes through enhancing erosion at areas beyond the placement of a structure (Fletcher, Mullane, and Richmond 1997). As political pressure grows to build costly coastal defences, there is an increasing effort to develop cost-effective, adaptive and socially accepted solutions for shoreline protection through nature-based defences.

2. Building the case for nature-based coastal defence

Natural ecosystems, which include dunes, salt marshes, mangroves, seagrass, shellfish and coral reefs, can provide protection against erosion and flooding through acting as a physical barrier to waves or creating an elevational profile that limits inland inundation by the sea (Gedan et al. 2011; Shepard, Crain, and Beck 2011; Duarte et al. 2013; Ferrario et al. 2014; Hanley et al. 2014; Ondiviela et al. 2014; Feagin et al. 2015; Narayan et al. 2016). These responses are the result of ecosystem processes, such as increased bed friction, local shallowing of water, sediment deposition and building of vertical biomass (Morris et al. 2018). Thus, where naturally present these habitats can provide substantial risk reduction. However, due to human-induced habitat destruction, these ecosystems

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have experienced as much as an 85% loss, globally, in habitat area (e.g. oyster reefs, Beck et al. 2011). Thus, nature-based solutions will often require the restoration or creation of new habitats (Spalding et al. 2014).

Nature-based coastal defence may be a cost-effective alternative to artificial structures as the cost of creating a habitat can be much less than building a traditional structure (Ferrario et al. 2014; Narayan et al. 2016). The perceived risk of using a natural habitat alone for coastal defence can be mitigated through the use of hybrid approaches, which combines natural habitats with some hard elements (e.g., rock sills with mangroves or saltmarsh) (Sutton-Grier, Wowk, and Bamford 2015). Hybrid approaches can also extend the range of environments suitable for nature-based coastal defence (i.e., from low to higher energy; Figure 1). Natural habitats have the potential to adapt with changes in sea level rise (Rodriguez et al. 2014) or local subsidence (Casas, La Peyre, and La Peyre 2015), providing there are the resources and space for habitat accretion (Mitchell and Bilkovic 2019). In addition, nature-based coastal defence can show greater resilience to storms than artificial structures, and have the ability to self-repair after the event (Gittman et al. 2014). Although it is recognised that nature-based solutions are not maintenance-free (Mitchell and Bilkovic 2019), maintenance costs are likely to be much lower than artificial structures that need to be re-built when damaged.

2.1. Co-benefits of nature-based coastal defence

Although there is a strong case to be made for nature-based coastal defence as an effective and climate-resilient solution to shoreline protection, the expected co-benefits further increase their cost-effectiveness. The natural ecosystems highlighted consist of important habitat-forming organisms that support a unique and diverse assemblage of coastal species (Gittman et al. 2016b). Many of these species are of high commercial value; coastal vegetation and biogenic reefs provide nursery habitat for juvenile fish and invertebrates, which sustain viable fisheries (Scyphers et al. 2011; Gittman et al. 2016a) as well as play host to many vulnerable and endangered species.

Coastal habitats provide water purification through the absorption of inorganic contaminants and/or removal of organic particles through water filtration (Gifford et al. 2005; Galimany et al. 2017). Perhaps one of the most valuable co-benefits in terms of climate change mitigation is the potential of vegetated habitats to store carbon, termed 'blue carbon' (McLeod et al. 2011). Blue carbon ecosystems contain some of the highest carbon stocks per unit area on the planet and show potential to sequester large amounts of carbon over timeframes that are relevant to climate change mitigation (Donato et al. 2011; McLeod et al. 2011; Lovelock and Duarte 2019). Consequently, in Australia, the inclusion of blue carbon ecosystems in the Federal Emissions Reduction Fund are currently being discussed (Kelleway et al. 2017).

In addition to these supporting (i.e., habitat for organisms) and regulating (i.e., moderation of environmental conditions and quality) services, significant social value is provided by these ecosystems through tourism, recreation, education and research (Barbier et al. 2011). The expected co-benefits provided by nature-based coastal defence can, therefore, contribute to Australia's national targets around biodiversity, water quality and carbon emissions (e.g., Australia's Biodiversity Conservation Strategy 2010–2030; National Water Quality Management Strategy; Climate Solutions Fund), in addition to coastal protection. However, it is noteworthy to add that structures that are nature-based may not deliver the same services as natural habitats (Bilkovic and Mitchell 2013); thus, co-benefits need to be individually monitored along with the efficacy of shoreline protection.

3. International exemplars for nature-based coastal defence

There is a growing trend in the use of nature-based coastal defence in parts of Europe and the United States

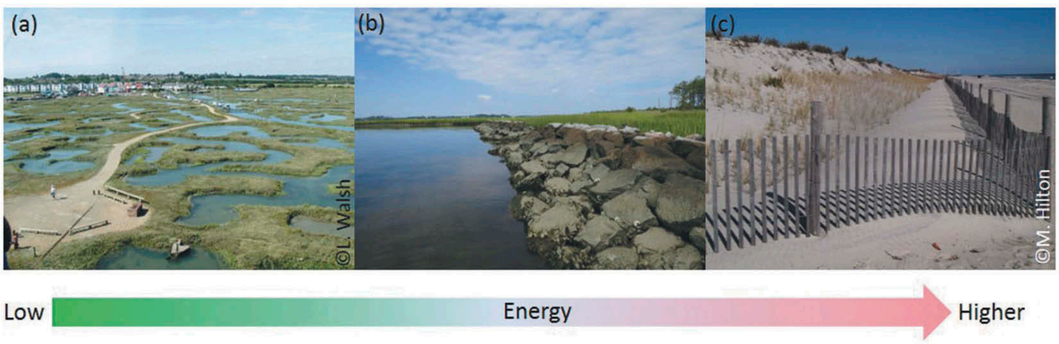

Figure 1. International examples of nature-based coastal defence: (a) managed realignment to accommodate saltmarsh in the United Kingdom; (b) rock sills with saltmarsh in the United States; and (c) dune construction in the United States. Solutions that use only natural features may be more suited to lower-energy conditions, while hybrid solutions can be used in higher energy environments.

(Case studies 1, 2, 3). Two main enablers for this implementation have been: (1) pilot and/or local demonstration projects; and (2) legislative support (Borsje et al. 2017; Esteves and Williams 2017; Pace 2017).

3.1. Pilot and/or local demonstration projects

Pilot projects have been cited as key to the success of the wider implementation of nature-based solutions (Borsje et al. 2017). As the scientific understanding of many nature-based approaches is still in its infancy (Bouma et al. 2014; Morris et al. 2018), pilot projects can facilitate large interdisciplinary research programmes to increase the predictability of these systems. For instance, accompanying the mega sand-nourishment pilot (21 million m^3 sand across 128 ha) known as the 'Sand Engine' in the Netherlands are extensive research programmes across six different disciplines: coastal safety; marine and terrestrial ecology; hydrology; geochemistry; and governance (Borsje et al. 2017). These strong knowledge alliances among different disciplines, research institutes, government and industry are supported by an organisational platform (Dutch network of coastal science) that coordinate yearly conferences to facilitate collaboration (Borsje et al. 2017). Interdisciplinary teams are essential to the evaluation of nature-based coastal defence (Morris et al. 2019b). This is not only from the ecological and engineering perspectives of understanding how to design nature-based solutions but also from economic and socio-political perspectives to understand their cost-effectiveness compared to traditional structures, social acceptance and regulation. Even where there is enough scientific information to implement a particular nature-based solution more broadly, social acceptance can be a barrier, especially where large areas of the foreshore are privately owned (Wowk and Yoskowitz 2017).

Local demonstration projects on public land is one way to increase public acceptance of nature-based shoreline protection alternatives (Nordstrom and Jackson 2013). Local demonstration projects are example nature-based solutions inserted into different communities to increase their public profile. For example, the Wetlands Board in Norfolk, Virginia, USA uses the City's successful public demonstration sites to justify permit decisions that favour living shorelines on private land (Du Bois 2017). Local demonstration projects require local and/or state government leadership in the use of nature-based solutions on public land, in addition to grant funding to provide financial support for installation and monitoring. As with pilot projects, local demonstration projects should be used to increase the scientific knowledge of these systems, and some experimental trialling may be acceptable as long as successes and failures are appropriately reported to the community (Du Bois 2017). Local demonstration projects can also be used to train marine contractors in living shoreline techniques, as a lack of knowledgeable living shoreline designers, regulators and contractors is another barrier to their wider implementation (Du Bois 2017). A bottom-up approach has been most common in the implementation of nature-based coastal defence, where support and interdisciplinary research at local levels has led to acceptance at higher levels of governance.

3.2. Legislative support

Legislative support can come from a local, state or national level. In the United States, Maryland's 2008 Living Shorelines Protection Act was the first state-wide effort to promote nature-based coastal defence over traditional structures. Under this act, living shorelines are the preferred method for coastal protection. Landowners must apply for an exemption that demonstrates that living shorelines are not suitable for a particular area if traditional structures are proposed, such as in areas that are highly erosive or have high-energy conditions (Case study 1). However, prior to this act, Kent County, Maryland, introduced local laws in 2002 also favouring living shorelines. In Virginia, USA, a general permit for living shorelines has been developed under state law, which includes an expedited process that lowers the cost and time associated with permit application and review to incentivise the use of living shorelines (Du Bois 2017; Pace 2017). These examples highlight that, in the USA, efforts are coming from a local and state level. In contrast, in the Netherlands, a method of using sand nourishment to reduce coastal erosion called 'dynamic preservation' was implemented into national law in 1990 (Borsje et al. 2017). Following this law, the policy of sand nourishment changed from being reactive (small amounts of sand placed after a storm event) to proactive (larger nourishment volumes designed to work with natural coastal processes). This change in mindset from management being reactive to failure to taking a more forward-thinking approach is essential for the implementation of nature-based coastal defence. Further, when nature-based coastal defences are regarded as engineering structures for shoreline protection, this can lead to financial support for their construction or reconstruction following storm events (e.g., for dunes in Case Study 2).

In Europe, existing European Union Directives, although not living shoreline specific, greatly influence the implementation of managed realignment to make room for the re-establishment of saltmarshes for coastal defence (Case Study 3). For example, under the Floods Directive, EU countries must map flood risk to people and assets along the coasts, and create flood risk management plans. This must be done in coordination with the Water Framework Directive to ensure that flood risk management does not influence water quality or the ecological status of estuaries and coasts (Esteves and Williams 2017). In the United Kingdom, the Department for Environment Food and Rural Affairs (Defra) published the Making Space for Water strategy

International examples of nature-based coastal defence: Case study 1

Living shorelines in Maryland, United States

Approach: Living shorelines using saltmarsh restoration with and without sills (Maryland Department of the Environment, 2008) in Maryland, USA. Sills can be constructed of oyster reef (Morris et al. 2019a) or rock fillets (Figure 1b).

Drivers for use: In this area, living shorelines are driven by the use of environmentally-friendly shoreline protection. There is a focus on lower-energy environments (those that suffer 0.3 – 2 m erosion yr^{-1}) where living shorelines are considered successful at erosion control and supporting natural biodiversity (Chesapeake Bay Foundation, 2007).

Research-based, legislative and/or financial support: Under the 2008 Living Shorelines Protection Act, living shorelines are the preferred method for erosion control in the state. Living shorelines must be used as a default, unless it can be demonstrated that these methods are not feasible (e.g., excessive erosion, high energy environments, space is too narrow for habitat). The Maryland State Government has produced structural shoreline stabilisation maps that denote high-energy shorelines where traditional coastal protection structures are recommended. Under these circumstances land owners must go through a living shoreline waiver process. Marine contractors take responsibility for a living shoreline for 2 years post-construction (www.dnr.maryland.gov). There is a clear permitting process for implementing a living shoreline and this process has been streamlined through a Joint Federal/State application (Luscher et al. 2006). The state government offers several grants and low- or no- interest loans to support the construction of a living shorelines on public and private land (www.dnr.maryland.gov).

Barriers: Limited number of marine contractors with knowledge/expertise in living shorelines. Lack of science on the effectiveness of living shorelines for different types of shores, under a range of energy regimes and storm conditions (Subramanian et al. 2006).

Co-benefits of approach: Saltmarshes with sills can increase the abundance and diversity of fish and crustaceans relative to unvegetated habitat around bulkheads, and provide nursery habitat for juveniles (Gittman et al. 2016a). Vegetated living shorelines may also come with a substantial carbon sequestration benefit (Davis et al. 2015). However, ecological communities may not mimic those in natural saltmarshes, thus understanding trade-offs among ecological services is an important area of research (Bilkovic and Mitchell 2013).

(Defra 2005a), which specifies management realignment as the preferred approach for managing flood risk in rural areas (Esteves and Williams 2017). This strategy is implemented through shoreline management plans developed by local authorities, although these are not legally binding (Esteves and Williams 2017). Across the different areas globally where nature-based coastal defence is growing, some legislative support is common in all cases. However, the approach has varied significantly, and will have to be navigated based on the governance structure and existing laws in different countries.

4. Nature-based coastal defence in Australia

In Australia, the local governments are responsible for land-use planning decisions, operating within the regulatory and policy frameworks established by the state or territory government (Australian Government 2015). Thus, decisions around the implementation of nature-based coastal defence will be made at a local and state level. The Australian Government has, however, funded climate change information and adaptation guidelines, for example, through the Climate Change Risks to Australia's Coast report (Department of Climate Change 2009) and the National Climate Change Adaptation Research Facility (NCCARF). While reports from the Australian Government (Department of Climate Change 2009) and NCCARF (Kirkpatrick 2011) emphasise the coastal protection value of existing natural habitats, there is no national guideline on implementing nature-based coastal defence in place of traditional structures for protection.

4.1. Local examples

Beach nourishment is commonly used around the major urban centres of Brisbane, the Gold Coast, Sydney, Melbourne, Adelaide and Perth to protect structures from erosion and maintain beach amenity (Cooke et al. 2012). However, a majority of projects used small volumes applied frequently in reaction to an event, rather than as long-term nature-based defence planning, such as in the Netherlands' example above (Cooke et al. 2012).

International examples of nature-based coastal defence: Case study 2

Beach and dune construction, New Jersey

Approach: Strategies include the building of dunes using earth moving equipment to scrape sand from the beach, minimal beach nourishment for emergency protection against storms, and large-scale storm berm and dune nourishment (Nordstrom et al. 2011). In the latter case, dunes can develop through the natural accumulation of wind-blown sand. They are more normally encouraged to form using vegetation and sand fences or constructed to a specific form as part of the nourishment process (Figure 1c). Dunes can be constructed with or without hard cores (Nordstrom 2019).

Drivers for use: Dunes and beaches are designated as engineering structures to provide shoreline protection. U.S Army Corps of Engineers guidelines identify dunes with periodic nourishment as the least environmentally damaging structural method of reducing storm damages at a reasonable cost (USACE, 1999).

Research-based, legislative and/or financial support: There is a decrease in storm-related damage when properties are protected by a constructed dune and wide nourished beach (Nordstrom and Mauriello 2001, Dundas 2017). Municipal property purchase and dune–building programmes and ordinances implemented immediately following storms (Nordstrom et al. 2002); Coastal Zone Management Rules (1978) and The New Jersey Shore Protection Master Plan (1981) that encourages state-wide non-structural approaches to shore protection (Nordstrom and Mauriello 2001) supports the use of beaches and dunes for shore protection. Designating and maintaining beaches and dunes as engineering structures allows the Federal Emergency Management Agency to reimburse municipalities for sediment lost during damaging storms at a 65/35 federal/non-federal cost share (Nordstrom et al. 2002). The municipal contribution can be provided through the Shore Protection Stable Funding Act (1992). Since 1998 this Act has provided US$25 million annually for shore protection works. Additional financial support is provided indirectly through participation in The National Flood Insurance Program (1968) and the reduction in insurance premiums for properties protected by sand dunes (Nordstrom et al. 2002, Dundas 2017). A complementary "Coastal Blue Acres Program (1995)" provides funds for the purchase of coastal properties prone to storm damage, or that buffer or protect other lands from storm damage; thus, providing land for dune construction and protection.

Barriers: Public and municipal resistance due to concerns of reduced ocean views, reduced privacy, difficulties in obtaining perpetual easements from landowners, and cost (Nordstrom and Mauriello 2001, Dundas 2017). Federal and state taxpayers are subsidising the protection of assets for a very small number of individuals who have chosen to reside in a high-cost, high-risk location; and the appropriateness of such expenditure can weaken support for dune construction.

Co-benefits of approach: Constructed beaches and dunes can increase habitat for shorebirds and coastal flora; however only large-scale renourishments provide the opportunity for enhanced backshore habitat (Nordstrom et al. 2011). Increases in beach width allows for increased recreation and tourist activities; but raises concerns about visitor traffic and privacy. Created dunes allow retention of the semblance of a 'natural' shoreline and associated aesthetic values and can increase housing prices of protected beachfront properties (Dundas 2017).

For other coastal ecosystems (i.e., vegetation and biogenic reefs), there are few examples of their use in nature-based coastal defences in Australia (Morris et al. 2018).

In northern New South Wales, a hybrid approach using rock fillets (or rock sills; Figure 2a) has been relatively widely used to stabilise estuarine banks to facilitate mangrove and saltmarsh ecosystems (Jenkins and Russell 2017; Taylor 2017). This approach was pioneered in the late 1990s by Rivercare staff who undertook successful trials in Taree (Taylor 2017). Since, a number of other local authorities have adopted this technique in bank stabilisation projects. Rock filleting has been supported by the state government through grants (e.g., the Habitat Action Grant) and permit approvals. Despite the relatively long history of rock fillets in NSW, projects are still largely done based on previous experience. Reports that present data on the success of projects or design specifications are scarce.

In South Australia, the Estuary Care Foundation has been successful in implementing pilot living shoreline projects supported by community grants through the state government (www.estuary.org.au). The Foundation has been trialling mangrove, seagrass and oyster rehabilitation for erosion control (Figure 2b). In 2018, the first two nature-based coastal defence pilot studies in Victoria were implemented in Port Phillip

International examples of nature-based coastal defence: Case study 3

Managed realignment in the United Kingdom

Approach: In the UK, saltmarsh habitats have been created for coastal protection in multiple locations across southeast England and Wales (Defra 2005b, Esteves 2014). These projects have focused on creating new spaces for saltmarsh vegetation to be planted or establish naturally, through the realignment of the coastal protection line and controlled tidal restoration (Figure 1a; Esteves and Williams 2017).

Drivers for use: The main drivers for these actions are focused around the need to: (1) prevent the loss and degradation of coastal habitats and associated biota; (2) manage the risk of coastal flooding and erosion for people and infrastructure; and (3) reduce the costs of building and maintaining artificial structures (Luisetti et al. 2011, Esteves and Williams 2017).

Research-based, legislative and/or financial support: The implementation of these projects has been driven by EU directives including the Birds Directive, the Habitats Directive, the Water Framework Directive, and the Floods Directive, which have been designated to protect and restore coastal habitats (Esteves and Williams 2017). Other UK specific policies include the Flood and Water Management Act (2010) and the Making Space for Water Strategy (Esteves and Williams 2017) and specific regional Shoreline Management Plans (Luisetti et al. 2011). This legislation aims to reduce the risk of coastal flooding and erosion to people and deliver environmental, social and economic benefits (Esteves and Williams 2017).

Barriers: In the UK the creation of new saltmarsh habitats requires long-term and strategic planning, which has often been difficult to achieve because of the complex nature of private property rights, social acceptance and the uncertainties in predictions of future climatic conditions (Esteves and Williams 2017).

Co-benefits of approach: Created saltmarshes can act as potential sinks of pollution, relative to nearby agricultural lands (Teuchies et al. 2012). These habitats could also provide important biodiversity benefits for birds and fishes, and recreational amenity (Esteves 2014). However, in many cases, the ecosystems services of created saltmarshes are not equivalent to those of natural saltmarshes and further research is required to optimise their design and ecological functions (Esteves 2014)

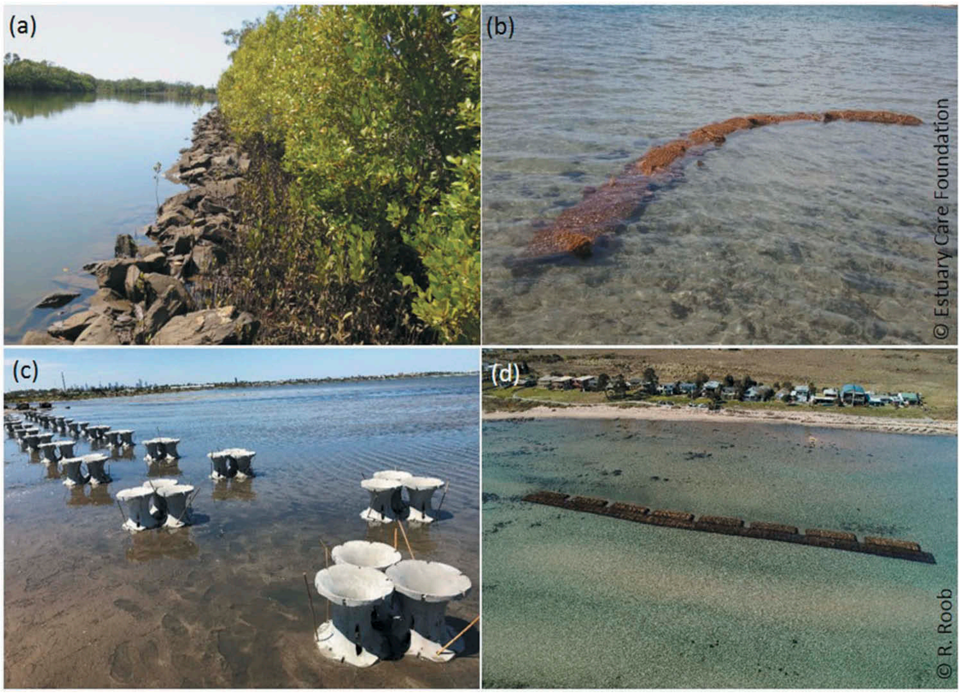

Figure 2. Examples of nature-based coastal defence in Australia: (a) rock fillets with mangroves in New South Wales; (b) bagged shell for oyster reef construction in South Australia; (c) pods to shelter mangroves in Victoria; and (d) mussel reef breakwater in Victoria.

Table 1. Key questions to be addressed in guidelines for nature-based coastal defence (NBCD).

Questions	Example considerations
When is NBCD a viable alternative to traditional structures?	• Value of infrastructure that needs protection • Erosion rate • Environmental suitability for habitats
What are the risks associated with NBCD?	• Resilience of an ecosystem to disturbance
What are the life cycle costs?	• Recovery of an ecosystem after disturbance • Habitat maintenance, e.g. weeding, rubbish removal
What are the timelines required and the payoff of an early investment?	• Time for colonisation and growth of natural habitats • Forward thinking versus reactive investment
What are the range of approaches that can be used in different environments?	• Erosion rate and exposure to waves • Soft versus hybrid approaches • Type of species based on habitat suitability
What are the contributions or trade-offs for other ecosystem services?	• Co-benefits of NBCD for other services • Trade-offs of services, e.g. social amenity, ecological value

Bay and Western Port Bay: (1) a mussel reef; and (2) hybrid mangroves (Figure 2c,d) through state government grant programs (authors unpublished data). While nature-based coastal defence is in its infancy in Australia, recent efforts are taking a similar bottom-up approach as seen in the case studies above (see section, 'International exemplars for nature-based coastal defence') to provide the knowledge needed for their wider implementation.

5. Conclusions: towards a nature-based coastal defence strategy for Australia

Key to the wider implementation of nature-based coastal defence in Australia is: (1) improved scientific knowledge; (2) effective governance; and (3) social acceptance. A significant barrier to the implementation of nature-based coastal defence is having the right knowledge at the local government level to make a case for nature-based over traditional solutions. Further, these solutions need to be industry accredited (i.e., by Engineers Australia) with guidelines made available to coastal managers and contractors to inform on-ground implementation. Key questions to be answered in guidelines are listed in Table 1 (for further discussion see also, Bouma et al. 2014; Mitchell and Bilkovic 2019; Morris et al. 2019b). These guidelines need to be accompanied by state policy that can be acted on by coastal managers.

Currently, in Australia, we are at the stage of providing proof-of-concept through pilot and local demonstration projects to raise awareness and improve the knowledge of nature-based coastal defence. While lessons learned from other locations globally can be applied to new projects, it is also important to understand how nature-based coastal defences function in an Australian environmental, political and social context. Fundamentally, shoreline protection needs to move away from being reactive to failure to forward-thinking; nature-based coastal defences in most cases are not designed to be a short-term solution. Furthermore, interdisciplinary research needs to facilitate new policies and decision-making. This is going to require effective collaboration among engineers, ecologists, social scientists, industry and government.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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Benedikt J. Fest is an ecosystem ecologist with a background in soil atmosphere greenhouse gas exchange processes and soil carbon sequestration. He is currently working on methods to improve spatial representativeness of carbon stock and carbon sequestration measurements in Blue Carbon ecosystems (mangroves, saltmarshes, seagrass beds). As a Research Fellow in the National Centre for Coasts and Climate at the University of Melbourne he is investigating the blue carbon co-benefits of nature-based coastal defence.

David M. Kennedy is a coastal geomorphologist with a strong interest in the dynamics of coastal landforms and their sensitivity to environmental change. He is currently Director of the Office for Environmental Programs, Deputy Chief Investigator for the NESP-funded National Centre for Coasts & Climate and leader of the coastal erosion theme. His expertise cover a wide range of coastal systems from sandy beach to coral reefs and rocky shores.

Stefan K. Arndt is a plant ecophysiologist with a strong background in plant stress physiology, biogeochemistry and carbon and greenhouse gas cycling in forests. He is currently the program leader of the Blue Carbon theme in the National Centre for Coasts and Climate at The University of Melbourne, where he investigates the carbon cycling of living shorelines with a focus on mangrove forests.

Stephen E. Swearer is a marine environmental scientist with a broad background in fish biology, fisheries management, marine ecology and environmental pollution. He is currently the Director of the National Centre for Coasts and Climate, where his research focuses on developing solutions for addressing the impacts of overabundant species, habitat loss and climate change in marine and coastal ecosystems in partnership with government and industry.

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