National Marine Science Plan: White Paper on Green Engineering and Marine Urban Development

1 Abstract

Australia's coastal zone is suffering the collateral damage from continuing urban development and construction, expanding resource sectors, increasing population, regulation to river flow, and on-going land change and degradation. The global community is already watching Australia manage future development and industrial growth, particularly adjacent to a significant marine ecosystem, the Great Barrier Reef. While protection of natural coastal habitat is recommended, balancing conservation with human services is now the challenge for managers. Here we outline critical research needs for marine urban development and emerging engineering strategies that seek to mitigate impacts. We provide the strategic direction necessary to support management decisions for the protection of Australia's coastal zone.

2 Background

Continuing human population growth and corresponding expansion of coastal cities has contributed to a modern day multi-use seascape including natural and engineered habitat features [e.g. 1, 2] Along with essential ecological services for fisheries production [3], the modern day seascape is also expected to provide services essential for humans, such as residential living, recreation, commercial, navigation, wastewater disposal and tourism activities [4].

Australian coastal wetlands have also suffered from the collateral damage of coastal development [5], particularly following a mining boom over the past decade where small coastal towns have grown rapidly (e.g. Gladstone, Port Hedland). The challenge for coastal managers is to now balance ecological biodiversity and habitat protection at the same time as approving expansion of coastal centres and development. The basis for these management decisions should be supported by scientifically rigorous, long term, data. However, more often the precautionary approach is taken and monitoring follows construction or land use changes [6].

In Australia, research hubs exist in Universities and government agencies and there has been important collaboration across these institutes in the past. In the space of coastal marine ecology and processes, this collaboration is facilitated by a range of associations and institutes (e.g. Australian Marine Sciences Association; Australian Society of Fish Biology; Australian Coastal Society). Large scale, multidisciplinary, research projects exist overseas (e.g. Seattle Foreshore Armouring Program www. http://wa.water.usgs.gov/SAW/index.html; Urban Research on Biodiversity on Artificial and Natural coastal Environments (URBANE), http://urbaneproject.org/project), however, in contrast, only a single similar multi-organisational program is underway in Australian, completed through the Centre for Research on the Ecological Impacts of Coastal Cities (University of Sydney).

A major underlying challenge is funding of research in urban coastal seascapes, which is limited to highly competitive federal funding schemes (e.g. FRDC, ARC). There seems to be growing interest in local government authorities to support research by providing some funding for projects (e.g. Gold Coast City Council waterway planning, Sydney Councils). Alternatively, researchers are required to pursue non-traditional sources of funding (e.g. mining and resources sector). However, this has implications around the data collected potentially being subject to confidentiality. Funding through development offset schemes is another possible funding option, however, the efficacy of these funds in protection and conservation, more broadly, has been debated [7].

3 Relevance

The construction, operation and decommissioning of marine artificial structures have local and regional impacts on marine ecosystems including physical, biological and chemical disturbances.

Physical disturbances arise from the addition or removal of construction materials and the associated sediment resuspension. Native habitats are often damaged or destroyed, and associated assemblages lost. For example, up to 70% of coastlines have been modified globally [reviewed by 8, 9] and Sydney Harbour is often cited amongst these with 50% of the foreshore artificially armoured [10]. Estuarine infrastructures, such as marinas, are often hotspots of contamination from antifouling paints [11] and this has been linked to the facilitation of non-indigenous species [12-15]. Similarly, the homogeneity of design and construction materials has been posited as a driving force behind the establishment of a suite of fouling species that dominate artificial structures in harbours and coastal areas throughout the world [16, 17]. The construction of artificial structures in marine environments, for purposes including economical needs (power plants and oil platforms), coastal defence (breakwater and groins) and basic infrastructure, are forecast to increase considerably with the increasing urbanization of space and the predicted climatic changes [8, 18, 19].

Australia leads the way in developing engineered solutions for existing marine urban structures. Seawalls have been engineered to enhance biodiversity through the addition of complexity and microhabitats with measured success [5]. The work has involved a number of stakeholders, including universities and local councils. Designs are also currently being tested overseas [20-22]. While this research has previously been limited to the design of heritage listed sandstone seawalls in Sydney Harbour [5, 23-25], the potential to expand this research to other existing and new structures is considerable.

Apart from the extensive shoreline of seawalls, Sydney Harbour is currently undergoing massive redevelopment at the Barangaroo site in Darling Harbour. There are further development plans for the Bays Urban Renewal Project and the Walsh Bay Arts Precinct. Together these developments have the potential to drastically change the foreshore of Sydney Harbour and could be designed from the beginning for multi-purpose objectives that include ecological benefits. Furthermore a significant amount of the Sydney Harbour shoreline is occupied by marinas and boating infrastructure – almost 10,000 marinas and moorings. Stakeholders from the boating industry could be engaged and benefit from the process of considered design for artificial structures before construction.

Plans to expand development (industry, agricultural, farming) across northern Australia to meet increasing demands for food and energy (mining and port facilities) supplies in Australasia [26] means that the risk of collateral damage from anthropogenic stresses is imminent. Part of this development region includes the Great Barrier Reef (GBR); extending approximately 2,300km along the Queensland coastline, it is one of the natural wonders of the world and a marine ecosystem of globally significant biodiversity, with extensive environmental, cultural, social and economic values [27]. Recognised as a World Heritage Area and National Marine Park, the GBR has a series of inscribed international agreements, and national and state legislation/policies in place for its protection and management [27]. The GBR lagoon has important tangible linkages with adjacent coasts and estuaries, which are connected as part of a larger nursery and feeding complex that supports the life histories of marine and freshwater species [28]. Many economically important fisheries (up to 62% of the commercial and 76% of recreational catch; [27] have a critical estuary lifecycle phase, and rely directly on connectivity of the reef, and coastal tidal and freshwater wetland features. However, many functional characteristics of this complex habitat are under threat owing to on-going agricultural runoff contributing to poor water quality, loss of natural freshwater wetlands as nursery habitat, expansion of city centres for increasing population and port expansions following increasing mining activities [6, 29]. Additional impacts come from illegal fishing that is placing these biodiversity and conservation values under serious threat [27].

The declining health and resilience of Great Barrier Reef ecosystems in response to continuing landscape and climate change has recently attracted media and community attention [29, 30]. These concerns led to a request from UNESCO (June 2011) for Australian government agencies to conduct a strategic assessment of the Great Barrier Reef World Heritage Area (GBRWHA). Central to this assessment was addressing exactly how future coastal development could continue while still satisfying conservation and protection obligations/responsibilities under the world heritage agreement. The assessment (draft released December 2013) highlighted weaknesses in knowledge and uncertainty in the design and implementation of coastal infrastructure projects that have led to repeated problems with the implementation and operation of coastal development and reductions to the extent of productive wetland habitats. These problems reflect adversely on developers and operators of coastal assets, even when complying with their legislative obligations; often there is no failure of governance or compliance, rather problems stem from incomplete knowledge and understanding of key values that prejudices effective decision making [30].

Further offshore there are an increasing number of energy platforms. There are 23 offshore platforms and installations in the Bass Strait and more than 15 offshore from North Western Australia. While oil and gas exploration platforms are well established in areas such as Western Australia and the Northern Territory, wind farms still face regulatory hurdles although there is increasing pressure to begin the shift of these structures offshore. No marine energy policies exist for Australia although there are various examples in the USA (National Ocean Policy) and the United Kingdom [31]. There are policies relating to offshore oil and gas exploration and some of these may be applicable to wind energy developments, but there is a need for better integration between different agencies. For example, any offshore platform located more than 3 nm away from the coastline requires planning permits from three levels of government including 1) the Federal government for siting the turbines, 2) the State government for any cables or substations between 0-3nm from the coastline and 3) local councils for any onshore structures. Apart from this, there is no regulatory body to oversee everything and monitor the potential environmental impact.

4 Science Needs, Gaps and Challenges

Here we identify four important and basic aspects of marine urban management that have significant knowledge gaps requiring research: (1) green engineering, (2) managed retreat and soft engineering, (3) maritime spatial planning, and (4) marine development offsetting.

4.1 Green engineering

To effectively manage new and existing marine artificial structures Australia must invest in research that integrates ecological principles with the engineering designs of these structures. Ecological or ‘green’ engineering in urbanised marine environments is an emerging field with global significance. Fundamental and applied research projects in this area are essential for the future management of artificial structures in the marine environment.

The design of “green” buildings and spaces in terrestrial systems has rapidly improved following the understanding that urban areas can be planned not only to fulfil the accommodation of people and infrastructures, but also to incorporate the provision of important ecosystem services, including pollution reduction, temperature control, carbon storage, flood and stormwater regulation, habitat provision for target species, recreation and education [32].

SCIENCE GAPS & CHALLENGES: Marine developers have only just begun to design for multifunctional landscapes providing a range of environmental, social and economic functions [33], but ecological targets and principles are still too rarely incorporated and often lack clear definitions. Defining ecological outcomes for urban structures must include considerations of how to minimise impacts to native ecosystems and preserve critical ecological functions [9]. The consultation of relevant scientists by engineers and coastal managers during the planning stages of all artificial structures is crucial to maximise ecological outcomes and generate more research in this area.

NATIONAL BENEFIT: Existing structures may pose an ecological risk through their removal. For example the physical disturbance resulting from removal of an offshore platform may be more ecologically costly than allowing them to remain and using them for a new purpose. Similarly, heritage structures such as seawalls can be enhanced with green engineering.

4.2 Managed retreat and soft engineering

Managed retreat and soft engineering are two alternatives to standard hard engineering solutions that should be considered in the planning stages of a project. Managed retreat involves allowing an area of land that was often previously reclaimed to become exposed to flooding, facilitating retreat of the land-sea border landwards [34]. This is a method rarely implemented in Australia, but may become increasingly important as sea levels rise further [35]. In addition, it is often a cheaper management option to the upgrading or repair of existing hard defences [34].

Soft engineering coastal management practices use the maintenance and manipulation of natural habitat such as beaches and sand dunes as coastal defence. In Australia, coastal managers employed beach nourishment practices for 130 beaches between 2001 and 2011, mainly to protect coastal infrastructure and public beach amenity [36]. A further method for protecting foreshores is to introduce structures which encourage the growth of natural reefs that can help prevent erosion of the shoreline, for example in the United States oyster castles have been successfully employed where oyster spat attach to and grow on reef structures [37, 38].

SCIENCE GAPS & CHALLENGES: Research projects into the suitability, effectiveness and impact on biodiversity and ecological functioning of managed retreat in Australia is needed. Only 17% of the Local Government Areas employing beach nourishment practices monitor to assess the effectiveness or any impacts of the projects [36]. Management plans should include appropriate monitoring of the project to increase knowledge of the efficacy of soft engineering approaches. Challenges include funding for regular monitoring, and the collaboration of managers, engineers and ecologists to employ different management solutions.

NATIONAL BENEFIT: Managed retreat and soft engineering are thought of as being better for the environment, because they involve the maintenance and manipulation of natural habitats, rather than hardening the coast with artificial structures. Soft engineering provides coastal protection, but in addition maintains amenities such as beaches for the public.

4.3 Maritime spatial planning

The spatial scale to which such structures can affect the marine environment can range from 10s of m to kms [9]. Importantly, the spatial arrangement of how artificial structures are constructed can determine, not only the spatial scale of the impact, but also the type of impact caused. Considering the potential damage that artificial structures can cause in the marine environment, where and when such structures are constructed should be regulated, taking into consideration essential ecosystem services provided by marine systems. For instance, up to 8600 km^2 of seabed habitat in the United Kingdom is forecast to be lost due to urban development [39], but the consequences for ecosystem services provided by this habitat remains unknown.

Furthermore, the spatial arrangement of marine artificial structures has the potential to affect the connectivity of marine organisms. The construction of coastal and offshore infrastructure results in the creation of islands of artificial substrates and modified habitats surrounded by natural habitats. The isolation of these islands may be compounded if the hydrodynamics and physical characteristics of the structures restrict the transportation of larvae and food [40]. As climate change drives species range shifts, the designs of different artificial structures may restrict (e.g. breakwalls enclosing marinas) or enhance (e.g. dense configurations of pilings and pontoons) these movements [41]. In other cases, however, the design of the structures may enhance connectivity. Marine artificial structures that are built a few hundred metres apart and extending over entire coastlines (e.g. North Adriatic) can facilitate the introduction and dispersal of non-indigenous species, while offering unsuitable habitat to many natives [42, 43]. Spatial and conservation planning of the urban development in marine environments is therefore as important as in terrestrial and urban habitats, and should be used to prevent or mitigate the impacts of artificial structures.

SCIENCE GAPS & CHALLENGES: In Australia, all construction works require an Environmental Impact Statement to be approved under the Environmental Planning and Assessment Act. According to the United Nations Convention on the Law of the Sea (UNCLOS), States are required to protect and preserve the marine environment [UNCLOS Article 194 (5); 44] and at least 10% of the coastal and marine areas should be protected by 2020, through the Convention on Biological Diversity (CBD) Aichi target 11 [44]. However, construction works in the marine environment are poorly defined and urban sprawl is not fully regulated. Consequently, the construction of marine artificial structures often lacks long-term assessments of their potential impacts on these systems.

NATIONAL BENEFIT: Regulation and planning on where and how (i.e. distribution and spatial scale) artificial structures are going to be built in the marine environment will allow a decrease in the footprint of such structures, with direct consequences to the diversity and functioning of marine systems and, consequently to human well-being.

4.4 Marine development offsetting

In many cases urban development and/or its impacts are inevitable, due to social and economic reasons. To limit such effects, biodiversity offsets should be considered in the context of a mitigation hierarchy [45]. Such hierarchy includes a 4-step procedure: 1) to avoid development on hotspots of diversity or areas with threatened species; 2) to reduce the footprint of the development, i.e. to reduce the impacted area or the impact itself; 3) restoration or rehabilitation to remedy the effects of the development; and 4) the implementation of offset measurements to compensate for any residual effects [modified from 45, 46].

Offset policy goals vary from 'no net loss' to 'net gain' and are potentially a powerful tool for balancing conservation and development [46], including the predicted urban sprawl in marine environments. Offset policies are, however, not appropriate for impacts on areas that provide irreplaceable biodiversity, habitats or systems that may take decades or centuries to restore or for those habitats or systems for which restoration techniques are unknown [47]. Systems such as the Great Barrier Reef (GBR) are not, therefore, appropriate for offset policies.

SCIENCE GAPS & CHALLENGES: One of the major challenges to marine development offsetting is the lack of knowledge on long-term impacts of such developments on essential ecosystem services provided by marine systems. Losses and gains used in offset policies need to be measured in the same metric to demonstrate ecological equivalence. If the impacts of construction are not yet established, the use of offsets is not appropriate.

Although the Australian Government has specific policies on environmental offsets for urban developments, the application of such policies remains a challenge due to an inability to determine equivalence when discussing diversity and service [48]. Much research is needed in this area to develop, not only, better valuation techniques, but also ways of establishing equivalence among species, habitats and services that are appropriate, accurate and feasible. Furthermore, the 'net gain' or 'no net loss' goals are dependent on the baseline against which performances are measured [48].

NATIONAL BENEFIT: The inclusion of ecosystem services as specific 'targets' into management and conservation policies as well as offset policies, if applied in a hierarchical context, will ensure that important services provided by marine systems are not going to be lost.

5 Perspective and Specific Science Priorities

Here we outline the general priorities for green engineering and marine urban development over the next 5, 10 and 20 years, and then detail specific priorities for four important and basic aspects of marine urban management: (1) green engineering, (2) managed retreat and soft engineering, (3) maritime spatial planning, and (4) marine development offsetting (5.1-5.4).

For the next 5 years – For new and existing engineering projects, regular monitoring needs to be incorporated into the operational framework for Local Government Areas. Scientists, engineers and coastal managers will need to collaborate to make decisions on primary research questions and get funding for projects. A policy should therefore be developed that requires engineers and managers to consult with relevant coastal scientists during the planning stages of any coastal development.

Communication between scientists and end users needs to be improved for the effective application of ecological enhancement in coastal management. Therefore the organisation of a scientific advisory panel will be essential to mediate the collaboration between scientists and end users. Effective collaboration will allow more research to be generated on ecological enhancements in the near future.

Monitoring and impact assessment need to be regulated for the construction in marine systems and research efforts should be concentrated in determining basic mechanisms on how these structures impact (or add value to) marine habitats as well as further understanding links between diversity, functioning and ecosystem services.

For the next 10 years – Ecological enhancements and their success needs to be assessed using realistic ecological targets, measured over a suitable time scale, and long-term data collection is needed. Legislation framework should be developed that will target specific ecosystem services provided by marine systems as well as the diversity and functioning linked to these services. End user focussed guidance documents should be developed and published for better uptake of ecological enhancements with end users, giving clear operational guidelines.

For the next 20 years - An operational framework of research and innovation, funding and policy development with membership representing all levels of government, community, industry and academic institutes. Continue to modify and improve engineering designs, in collaboration with engineers, which is supported by long term, coordinated, monitoring data.

5.1 Green engineering

Early green engineering of seawall designs that aimed to increase biodiversity by increasing the slope and complexity or by adding habitat met with varying degrees of success. Adding blocks and boulders to increase the slope of seawalls resulted in no increases in biodiversity on the seawalls and assemblages remained different to those on natural reef. However, increasing the surface complexity of seawalls resulted in increased colonisation by mobile invertebrates not normally found on the surfaces of the structures. Creating cavities in or on these structures added to this complexity and in some designs the additional habitat created conditions that facilitated colonisation by rockpool species. Subsequent designs that incorporated a range of strategies such as the Bioblock and mimicked more closely the complexity of natural reefs [22] were more successful at encouraging native species colonisation. Green engineering of seawalls continue to progress with the recent development of the “flowerpot 2.0” design, but there are a range of enhancements yet to be tested on existing structures and greater potential for to enhance new structure through implementation of green engineering principles from the planning stages.

Although Australia leads the way to some extent in the green engineering of seawalls, the potential to extend these principles to other marine developments remains in its infancy. Recent foreshore developments in North America begun to implement green engineering principles at the planning stage [49]. Construction engineers on the Vancouver Convention Centre development implemented solutions to reduce local impacts of seawalls to natural sedimentary habitats by building stepped structures (“habitat skirts”) that incorporate horizontal surfaces with pits for sediment accumulation. Future foreshore developments in North America are also introducing novel designs to reduce the ecological impacts of shading from marine infrastructure. Innovations have included the creation of boardwalk windows and “skylights” designed to maximize light penetration beneath the structure e.g. designs for the Elliot Bay Seawall in Seattle. These developments are very new and their capacity to maintain or restore natural assemblages is yet to be rigorously assessed [but see 50]. Carefully designed survey and experimental work similar to the progressive development of seawall ecological engineering will be required to test the effectiveness of foreshore developments at maintaining and restoring native biodiversity [24].

For the next 5 years – Managers need to continue learning from terrestrial green engineering and artificial reef designs. Continued research into the potential for multipurpose designs that provide important ecosystem services should be a priority.

For the next 10 years – As research in this field progresses the efficacy of designs for multipurpose artificial structures should be examined with a systematic review and meta-analysis.

For the next 20 years – Multipurpose designs will be incorporated into future marine developments at every stage (planning, construction and decommissioning).

5.2 Managed retreat and soft engineering

Managed retreat is rarely practised in coastal management in Australia. In 2012, the NSW Government moved from its policy recommending state-wide sea level rise planning benchmarks to limit new developments in low-lying areas, instead supporting individual council management policies, relaxing the rules on the use of seawalls and encouraging temporary coastal protection works from minor storm events. In contrast, managed retreat has become the preferred approach in the United Kingdom, with 51 projects implemented at the end of 2012, and is therefore where most of the research globally has been generated on this subject [51]. With the predicted sea level rise, coastal managers should be considering all available options for coastal protection, and managed retreat may become increasingly important in the future. With increased sea levels, maintenance of sea defences in some areas may no longer be viable due to the high cost of repairing these structures; managed retreat is often a cheaper alternative for coastal defence [34]. Further, managed retreat may be an effective way to protect critically important saline coastal wetland habitat, such as mangroves and salt marsh [52].

If managed retreat is going to be used successfully in Australia, then resources should be allocated for research into the suitability and effectiveness of this strategy for use as coastal protection and the impact on biodiversity and ecosystem functioning. As the United Kingdom is the world leader in this research, coastal scientists and managers working in Australia can learn from the data already generated there. One soft engineering approach, beach nourishment, is employed frequently in Australia to protect coastal infrastructure and maintain public amenity, however only a small percentage of these projects are monitored for success and impacts [36]. In contrast, in the United States biological monitoring is done at the dredge and fill sites as a requirement of the permit [53]. This is a good approach, as nourishment practices needs knowledge of erosion rates, effects of storms and wave action in specific locations to be successful, and best practice involves regular monitoring to improve understanding of the ecological impacts of soft engineering [36].

For the next 5 years – Where coastal development or reconstruction of hard coastal defences is occurring in Australia, managers need to consider whether an alternative method such as managed retreat is more appropriate. Scientific modelling [52] may be a useful tool in helping identify whether managed retreat is a viable management option in specific areas.

For the next 10 years – Data needs to be generated assessing the success of managed retreat and soft engineering as effective coastal defence in Australia, including the restoration of biodiversity and ecological functioning.

For the next 20 years – Research needs to be incorporated into marine policy for sea level rise and coastal management, and operational guidelines written for end users.

5.3 Maritime spatial planning

Spatial planning in the construction of artificial structures is essential to prevent and/or reduce impacts that urban development might have on the marine environment. Understanding some of the mechanisms on how artificial structures impact systems, such as how they facilitate the spread of invasive species or how can they fragment marine habitats, is necessary to devise specific regulations on how and where such structures should be built (when no alternative option is available).

For the next 5 years – Managers need to plan where and when artificial structures should be built within the coastal seascape. Strict guidelines on the construction should be set, incorporating their possible footprint, when unavoidable, as well as a context-specific spatial planning (i.e. each type of structure will have specific guidelines and recommendations).

For the next 10 years – Development of an Australian Marine Spatial Information System (AMSIS) will be essential to support spatial planning of artificial structures in the coastal and offshore zone. This could incorporate data and support from the current AMSIS initiative by Geoscience Australia.

For the next 20 years – Comprehensive zoning plans for the marine and coastal zones of Australia will be needed to aid decision makers and ensure that spatial planning for marine artificial structures meets the needs of multiple stakeholders.

5.4 Marine development offsetting

Offset policies might be successfully used to reduce the footprint of artificial structures when residual impacts of the construction still exist, after avoidance and mitigation measures. It is imperative, however, that this policy is done not only as a last resource (when all prevention, reduction and restoration measurements are not enough to avoid an impact), but also with sound scientific knowledge attached to it. Although Australia has a very specific set of offsets policies under the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act), such policies will not be successfully applied on coastal urban development regulations until suitable monitoring and long-term impact assessments of artificial structures is implemented.

Although ecosystem services are increasingly being incorporated into management and conservation policies [54-56], research on where and how these services are distributed, especially in marine environments is a massive gap in our research. In addition, the relationship among diversity, functioning and services need to be further elucidate, e.g. whether targeting biodiversity, for instance, is an efficient and appropriate proxy to ecosystem services and vice-versa. Also, adding value (social, economic or environmental) to specific areas, an essential step to develop not only offset policies, but also cost-benefit analyses, is still a challenge, with many ethical and moral issues involved [57].

For the next 5 years – A program of on-going monitoring of major coastal structures is necessary, in order to determine exactly how the newly created habitat adds to the ecology of the receiving environment.

For the next 10 years – Clear guidelines for marine development offsetting should be introduced into policy to direct funds towards future research.

For the next 20 years – Monitoring and revision of offsetting policies will be necessary to match the progress in green engineering and increasing/changing pressures from marine development.

6 Realisation

To move forward in the management of marine developments we require a clear definition of what constitutes a "marine artificial structure". We propose that the term includes boating infrastructure (e.g. marinas, pilings, pontoons), coastal and foreshore defence infrastructure (e.g. seawalls, groynes, breakwaters), offshore energy installations (e.g. gas and oil extraction, wind farms), artificial reefs, offshore aquaculture facilities, swimming enclosures, residential canal estates, and boat ramps and bridge crossings. Currently these are differentially managed and subject to different guidelines and regulations. Priority should be given to the implementation of suitable impact assessments and long-term monitoring programs to the construction of any artificial structure on coastal and oceanic systems, including those in private land. Assessments should include not only possible long-term effects of construction at a local scale, but also analyses and predictions on magnitude and long-term effects of structures on regional scales, e.g. impacts on connectivity of systems [6] and introduction of invasive species [9]. These assessments need also to include modes to prevent, minimise or mitigate possible impacts. Concurrently, research is needed to investigate the possible uses of biodiversity offsets in the marine environment to develop a framework that can be implemented with sufficient baseline data. In the United Kingdom, a report was recently issued investigating the scope for application of biodiversity offsets to the marine environment, using hypothetical case studies for a windfarm and tidal barrage project to develop understanding of how offsets may be planned [58]. A similar approach may be a useful starting point for the application of offsets to artificial structures in Australia's marine environment. Regulations and guidelines on urban development in the marine environment need, however, to be integrated on a national level. Impacts of these constructions might occur over large spatial scales, which are beyond political and social boundaries; therefore, legislation should reflect such impacts.

6.1 Strategic research policies for Australia

Here we outline the key strategic research policies for marine urbanisation in Australia and rank them in order of priority.

1) A long term research program into the impacts and changes in ecosystem structure and function from the construction of artificial structures.
2) Applied research into the potential for managed retreat and soft engineering options to remove the need for foreshore and coastal infrastructure.
3) Applied research into the potential for green engineering designs to maintain and restore biodiversity and support ecosystem functioning.
4) Research into multipurpose opportunities for artificial structures e.g. combining offshore energy structures with fisheries productivity.
5) Zoning and spatial planning of marine artificial structures
6) Mapping of diversity and ecosystems services. Further knowledge on these aspects will aid in establishing ecological equivalence to be used in future offset policies. Ecological equivalence needs to be established and losses due to the impact from the construction of artificial structures need to be measured in the same metric as the gains due to offsets.
7) National approach to research into the efficacy of and optimisation for offsetting marine developments.

6.2 Information, communication and education

There is a growing amount of research on the ecological enhancement of artificial structures, but application of this in coastal management is still in the early stages [59]. Communication between multiple stakeholders is crucial to an effective national marine urban policy/system and the integration of green engineering into the planning, design and construction of coastal structures. Differences in the objectives of coastal scientists, managers and engineers can be a barrier to good communication, however the use of an 'interpreter' or 'knowledge broker' to translate information between scientists and end users may be a way to overcome this [59, 60]. Knowledge brokers to facilitate collaboration between coastal managers, scientists and engineers should be used in more projects in Australia to determine whether this increases the effectiveness of communication. End user focussed guidelines exist in Australia for seawalls [61], but managed retreat, soft engineering and other hard engineering management options need to be included, as well as an operational framework for implementation of ecological enhancements. The main challenge is the allocation of funds to support knowledge brokers. In addition, the establishment of a science advisory committee to act as a boundary organisation can further facilitate knowledge transfer and collaboration between stakeholders [60, 62].

Effective communication between scientists, engineers and managers is fundamental in environmental enhancement research and application. The publication of end user focussed guidance documents has been found to be an effective way to link science and policy in the United Kingdom [59]. Currently in Australia, there are few policies that can be used to support the application of green engineering in coastal development. This is in contrast to other countries, for example the United Kingdom where recent legislation now demands ecological consideration in new developments [59]. Policies however are often research driven, green engineering is a relatively new field in coastal science and there is a need for more and longer-term research in this area. This research is interdisciplinary, and requires collaboration between scientists, community, industry and government in order to be successful. Effective communication between scientists, engineers and managers during the planning, design and construction of coastal defences will ensure that ecological enhancements are incorporated in a way that allows the design to be tested in a scientifically robust way. This data can then be used to increase the knowledge of the environmental benefits of ecological enhancements, informing research-driven policy. In Australia, communication between scientists and end users could be improved by using an individual ('knowledge broker') or scientific advisory panel ('boundary organisation') to mediate knowledge transfer between the stakeholders involved [60]. As sea levels rise and coastal urbanisation increases, research into sustaining coastal biodiversity is a scientific priority; therefore a legislative or policy driver stipulating the consideration of ecological enhancement in coastal development in Australia is needed.

6.3 Funding and coordination

To achieve the key strategic research priorities outlined above requires funding and a strategic plan for expenditures over the next 20 years. Long-term funding of basic research into the impacts of artificial structures in the marine environment will be crucial to underpinning any management plans. Basic research into how such structures facilitate invasive species and their effects on functioning will progress understanding of factors that should be targeted in future planning, construction and decommissioning of artificial structures. Research on the distribution of biodiversity and ecosystem services in the marine environment, from coastal to oceanic areas, will be crucial to developing a regulatory framework on the construction of artificial structures.

Government funding through the Australian Research Council provides opportunities for such basic research through discovery and linkage grants, but only for a limited number of applications. Applied research funding opportunities exist through spatial offsetting and developer contributions. Where possible, these could be incorporated into linkage grant applications that further facilitate the involvement of multiple stakeholders. These could then be applied to e.g. the creation of novel materials and construction techniques that more closely match natural conditions.

Co-ordination of funding acquisitions and allocations will require a panel of experts that incorporates multiple stakeholders. The issues surrounding the management of artificial structures are multi-disciplinary and relevant stakeholders will include ecologists, engineers, economists and social scientists. We also advocate the identification of 'knowledge brokers' [e.g. 59] to act as intermediaries or interpreters that translate between producers and users of knowledge e.g. research and policy.

Success in the efforts of this working panel will require improved integration of policies and guidelines between state and national legislation relating to marine developments and artificial structures. Furthermore, environmental impact assessments associated with marine developments should include specific guidelines relating to artificial structures that identify opportunities for 1) alternatives, 2) restoration, 3) improvements.

6.4 Training and infrastructure

Science communication and public education is essential for an effective marine urban policy and the application of ecological enhancement in coastal management. The organisation of state, or a national working group would establish an infrastructure for effective communication between the government and international research groups. The primary role of the working group would be the promotion of the high quality research of Australia's marine scientists, providing independent advice to the government. The working group would be responsible for creating international links with other research groups worldwide, to develop a best practice for coastal management.

Public support for urban conservation is crucial. The research involves redesigning structures people come into contact with everyday, and end users, like councils, value the opinion of the community. For the public to make an informed decision about coastal research, scientists need to be able to communicate their work in a way that is informative, but easily accessible. All scientists should be trained to be able to communicate effectively across a broad range of groups, from outreach in schools to adults, and should engage regularly with the public. Collaboration with council and industry partners will help public education through setting up interpretive signs at ecologically enhanced sites. Promoting public awareness of key environmental issues can aid the acceptance and support of a project, encouraging the community to raise concerns about these environmental problems with councils and other organisations to help develop improvement within their area.

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