URBANGROWTH NSW

Guiding Principles for Marine Foreshore Developments

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Disclaimer

These guiding principles aim to provide guidance in the ecologically sustainable design of marine foreshore developments. They offer conceptual and practical examples of potential designs, but each case must be fully assessed and modified to suit the respective constraints of individual developments. Any companies named in this report are provided as examples only.

Cover photo

Baseline survey on SCUBA of rocky reef community structure at Watsons Bay, Sydney using quadrats. Photo by Katherine Dafforn.

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1. EXECUTIVE SUMMARY

Currently around 86% of the Australian population and 90% of building activity are found within 50 km of the coast. To support this expanding development, Australian estuaries have been modified with urban structures. The number of foreshore developments and marine infrastructure will continue to increase in response to population and resource demands coupled with increasing storm severity and rising sea levels. The addition of these structures to the marine environment has significant implications for the ecological structure and function of estuaries and coastal zones.

The ideal management response to address the impacts associated with hard engineering of urban structures is to maintain and restore natural habitats and defences. Methods to protect our coastal zones against the adverse consequences of climate change and erosion include soft engineering approaches, such as managed realignment, which involves the removal of hard defence structures and restoration of natural coastal vegetation, and beach replenishment where sand is deposited on beaches to build up the surf zone and dune protection. Where these approaches are not possible, then increasingly we need to build ecologically sensitive marine foreshores.

These guiding principles for marine foreshore development are based on an extensive review of the marine eco-engineering literature and recent international foreshore developments. These guiding principles take into account the key aspects: (i) conserving and improving natural ecosystems while protecting human health and well-being; (ii) minimising and/or preventing depletion of natural resources; (iii) improving public access and mobility and (iv) engaging the community on environmental educational programs. These guidelines can also be used in future local and international foreshore developments to prevent, ameliorate and/or remediate environmental impacts and increase public use of the foreshore while maintaining sustainability.

Land-based developments demonstrate the application of multi-purpose objectives to buildings. "Green" roofs and walls, for instance, which are plant assemblages established on the tops and sides of buildings, reduce noise and heat escape by absorbing more sound and thermal energy than a hard surface. Recent evidence shows they can also reduce air pollution and trap stormwater. Further, "green" roofs and walls can be seeded with target species to create habitat for native plants, including rare and endangered species. The principles used in these land-based developments can also be applied to marine and coastal infrastructure.

Ecological or 'eco' engineering, the combination of ecological principles in the design, planning and construction of marine infrastructure, is increasingly used to reduce the impacts of new and existing marine foreshore developments and maximise potential

ecological outcomes. This is achieved by designing structures from the outset that provide multiple important ecosystem services. These multi-purpose objectives can be incorporated through a range of engineered and ecological applications and therefore provide flexible solutions for managers that can be modified depending on local conditions and community expectations.

Suggested objectives for the eco-engineering of new marine foreshore developments or retrofitting existing urban structures include native biodiversity maintenance, rehabilitation and restoration, invasion resistance, productivity, pollution reduction, enhanced nutrient cycling, storm buffering, recreation and education.

Steps to successfully design marine infrastructure and foreshore developments that minimise ecological impacts and provide multiple services are outlined below:
1 - **Determine the multi-purpose objectives to be achieved** from eco-engineering new developments or retrofitting existing foreshore structures.
2 - **Collate ecological and physico-chemical data on the local habitats and structures** where developments will occur (e.g. literature review).
3 - **Conduct a baseline survey** of the ecological and physico-chemical characteristics of the local habitat and existing structures, if relevant, at the development location and at the natural surrounding habitats.
4 – **Carry out necessary remediation works** if environmental conditions (e.g. legacy contaminants) are such that new structures are unlikely to support native biodiversity.
5 - **Define the practical eco-engineering or retrofitting designs appropriate for the foreshore developments** to achieve the initial multi-purpose objectives.
6 - **Monitor the ecological and physico-chemical characteristics** of the retrofitted structures or eco-engineered sections of the development at multiple timepoints and sites post-construction.
7 - **Evaluate whether the original multi-purpose objectives have been achieved** by the practical retrofitting and/or eco-engineering designs incorporated into the foreshore development.

Here we provide some practical strategies for eco-engineering new and existing developments and the ecosystems services that can be obtained/enhanced. These include physical modifications such as 1) increasing provision of missing habitats, 2) increasing total surface of structures, 3) using environmentally friendly materials, 4) reducing shading, 5) reducing organic matter decomposition, 6) limiting movement and 7) reducing chemical and physical disturbances. Examples of biological enhancements include 1) planting or transplanting native species to new/existing structures and 2) restoring native habitats.

The design and construction of multi-purpose coastal infrastructure - that minimise environmental impacts, while promoting ecosystem services - requires the input of

specialists, including, for example, ecologists, engineers and architects. Therefore, the planning and design of foreshore developments and construction of marine infrastructure should involve a multidisciplinary team. The intent of these guiding principles is to provide ecological perspective and advice on some of the aspects needed for sustainable use of natural resources. Guidance on other aspects of foreshore development should be sought from relevant professionals.

Beyond the general health and safety considerations identified here, other site specific and project specific issues will need to be considered when marine foreshores are retrofitted or built. It is not the intent of these guiding principles to conduct a risk assessment that is applicable to all developments, but to highlight the need for these assessments risks in every instance by qualified risk management specialists.

These guiding principles do not include information on policy or legislation associated with foreshore developments. Local, state and national government requirements must be investigated during the planning process.

2. INTRODUCTION

Currently around 86% of the Australian population and 90% of building activity are found within 50 km of the coast (www.abs.gov.au, accessed 02/12/2015). To support this expanding development, Australian estuaries have been modified with urban structures (Figure 2.1). The number of foreshore developments and marine infrastructure will continue to increase in response to population and resource demands coupled with increasing storm severity and rising sea levels (Bulleri and Chapman 2010). The addition of these structures to the marine environment has significant implications for the ecological structure and function of estuaries and coastal zones (e.g. Dafforn et al. 2015a).

Figure 2.1. An example foreshore development in Sydney Harbour and the urban marine structures at the waterline. Photo by Katherine Dafforn.

Foreshore developments present a range of ecological problems, including reduced native species diversity and the spread of introduced species (Bulleri and Chapman 2010, Dafforn et al. 2012). Construction within urban seascapes is responsible for the loss and degradation of important habitats such as sediments, rocky reefs, seagrasses, mangroves and wetlands (Figure 2.2). These habitats are not only highly productive, supporting a variety of species, including some economically important, but provide natural protection for the coastal zone

against storms and waves (e.g. Lenihan and Micheli 2001, Orth et al. 2006, Foster et al. 2013).

Figure 2.2. Natural habitats that are replaced or impacts by marine foreshore developments and urban structures include rocky reefs (top) and soft sediments (bottom). Photos by Katherine Dafforn.

The most common urban structures in Sydney Harbour include seawalls, breakwalls (also known as breakwaters), pilings and pontoons (e.g. Mayer-Pinto et al. 2015). Seawalls tend to be vertically oriented with a relatively homogeneous and uniform surface, which leads to a decrease on surface availability and structural complexity (Figure 2.3). Breakwalls are used to protect reclaimed land and important port areas. These tend to be composed of irregularly shaped boulders that disperse wave energy (Figure 2.4). Pilings and pontoons are

some of the more dense artificial structures found in estuaries and are introduced to support boating activities (Figure 2.5). The materials used in the construction of these structures change many of the physico-chemical characteristics of the habitats and the resources available for the resident organisms, which can impact on local diversity. Therefore, these structures support ecological communities different to those found on natural habitats (Glasby 1999a, b, c, Glasby and Connell 1999, Glasby 2000, 2001, Glasby and Connell 2001, Glasby et al. 2007, Dafforn et al. 2009b, Dafforn et al. 2012).

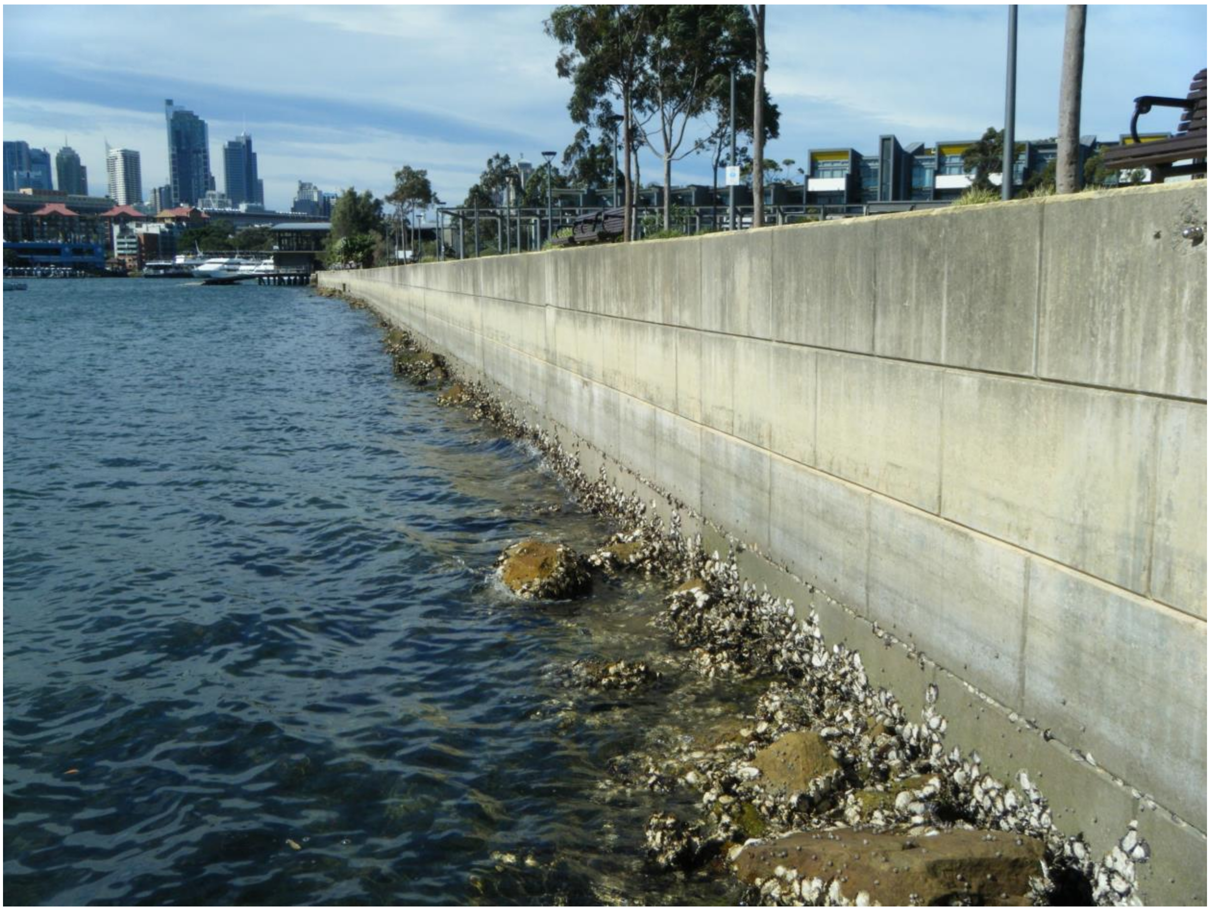

Figure 2.3. Seawalls are common protective barriers for foreshore developments, but their vertical orientation and low complexity has negative consequences for marine organisms (Browne and Chapman 2011, Chapman and Underwood 2011). Photo by Rebecca Morris.

Figure 2.4. Breakwalls (or breakwaters) are used to protect reclaimed land and important port areas. They tend to have gentler slopes and more complexity than other urban structures. Photo by Natalie Rivero.

The ideal management response to address the impacts associated with hard engineering of urban structures is to maintain and restore natural habitats and defences. Methods to protect our coastal zones against climate change include soft engineering approaches, such as managed realignment, which involves the removal of hard defence structures and restoration of natural coastal vegetation, and beach replenishment where sand is deposited on beaches to build up the surf zone and dune protection (see review by Dafforn et al. 2015a). Where these approaches are not possible, then increasingly we need to build ecologically sensitive marine foreshores.

Currently, most structures in the marine environment are built for a single purpose, such as coastal protection, tourism, energy or food production. Effective management of marine foreshore developments requires strategies that integrate ecological principles with the engineering designs (‘eco-engineering’) of urban structures to provide a range of solutions for different scenarios (Cooper and McKenna 2008). Seawalls and breakwalls foreshore developments can be built in ways to not only protect the local coastal area, but to also minimise environmental impacts and increase human well-being. The direct and indirect psychological benefits of “blue space” are increasingly being explored and therefore designs

that are built to facilitate or enhance human interaction with the marine environment have the potential to increase social benefits (White et al. 2010, Wheeler et al. 2012). Existing structures along marine foreshores can also be retrofitted with designs that add ecological and/or social value.

Figure 2.5. Pilings and pontoons support boating (above) recreational and foreshore infrastructure. Photo by Katherine Dafforn.

These guiding principles describe the concepts underpinning multi-purpose eco-engineering of new marine foreshore developments and retrofitting of existing marine urban structures. The practical application of eco-engineering and retrofitting solutions for foreshore developments are described using a number of examples of global foreshore projects.

2.1 Aims of these guiding principles

These guiding principles for marine foreshore development are based on an extensive review of the marine eco-engineering literature and recent international foreshore developments. These guiding principles take into account the key aspects: (i) conserving and improving natural ecosystems while protecting human health and well-being; (ii) minimising and/or preventing depletion of natural resources; (iii) improving public access and mobility and (iv) engaging the community on environmental educational programs. These guidelines can also be used in future local and international foreshore developments to prevent, ameliorate and/or remediate environmental impacts and increase public use of the foreshore while maintaining sustainability.

The design and construction of multi-purpose coastal infrastructure - that minimise environmental impacts, while promoting ecosystem services - requires the input of specialists, including for example ecologists, engineers and architects. Therefore, the planning and design of foreshore developments and construction of marine infrastructure should involve a multidisciplinary team. The intent of these guiding principles is to provide ecological perspective and advice on some of the aspects needed for sustainable use of natural resources. Guidance on other aspects of foreshore development should be sought from relevant professionals.

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These guiding principles do not include information on policy or legislation associated with foreshore developments. Local, state and national government requirements should be investigated during the planning process.

3. PHYSICO-CHEMICAL DIFFERENCES BETWEEN NATURAL AND URBAN FORESHORE STRUCTURES AND THEIR ECOLOGICAL CONSEQUENCES

Major physico-chemical changes that occur as a result of marine foreshore developments and some of their ecological consequences are identified in Figure 3.1.

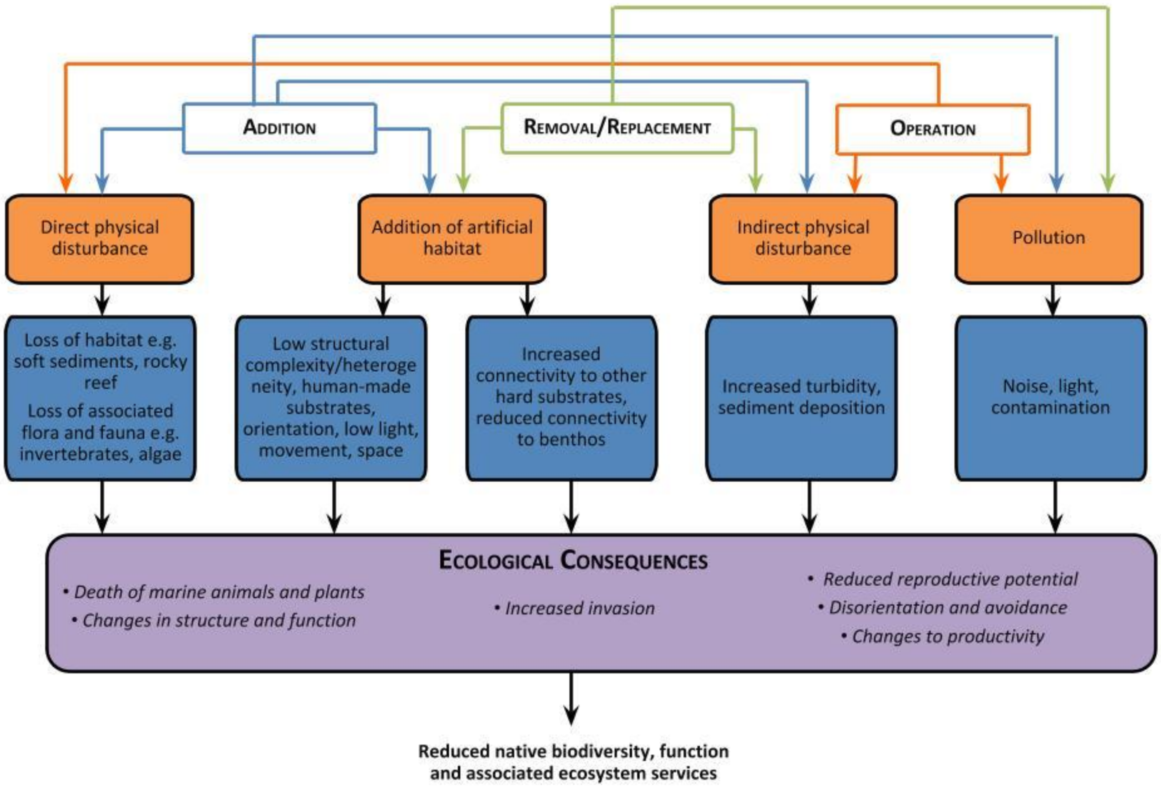

Figure 3.1. Conceptual diagram linking the engineering phases 1) addition, 2) operation and 3) removal/replacement of urban structures to habitat modification (orange boxes). Examples of the physico-chemical changes are described (blue boxes) and potential ecological impacts identified (purple boxes). From Dafforn et al. (2015a).

3.1 Direct and indirect physical disturbances associated with urban structures

The construction or removal of urban structures is associated with physical disturbances of the environment (Table 3.1, Figure 3.1), often resulting in the loss or damage of native habitats and associated organisms. Dredging during construction can displace large amounts

of sediment into the water column and removal of underwater structures increases turbidity that can negatively affect marine plants and animals (Gill 2005). Once constructed, structures alter water flow (Rivero et al. 2013) and sediment deposition, with negative consequences for biodiversity and productivity.

3.2 Addition of artificial habitat

The materials added during construction change the type of resources available for the resident organisms, for example by increasing the proportion of sheltered, shaded, vertical and floating surfaces (Table 3.1, Figure 3.1). Orientation (e.g. vertical vs horizontal surfaces), slope and the surface texture of construction materials also affect the colonisation of marine organisms (Coombes et al. 2009). Urban structures are usually homogeneous, lacking micro-habitats such as crevices, pits and pools, normally found on natural rocky shores. This reduced complexity results in fewer species living on these artificial habitats. These structural changes, among others, such as shading and movement, are some of the reasons that urban structures support different assemblages to those found in natural reef habitats (Moschella et al. 2005, Bulleri and Chapman 2010) and may facilitate non-indigenous species (NIS) (Dafforn et al. 2012). The addition of hard substrata on the marine environment by the construction of structures can also serve as 'stepping stones', facilitating the spread and establishment of NIS, increasing their numbers (Adams et al. 2014, Airoldi et al. 2015). NIS have been found to occupy up to 80% more space on pilings or pontoons compared to natural reefs (Dafforn et al. 2012). The physical design of artificial structures has, therefore, major consequences on the composition of ecological communities.

3.3 Pollution

Urban structures have also been linked to a variety of pollution sources (Table 3.1, Figure 3.1). This includes artificial light from urban areas during and after construction (Depledge et al. 2010), noise and vibration during construction (Gill 2005), or contamination associated with boating activity (Dafforn et al. 2009a). These changes in light and noise have consequences for behaviour and mortality of marine organisms such as birds and fish (Banner and Hyatt 1973, Blaxter et al. 1981, Becker et al. 2013, Davies et al. 2014). Boating infrastructures are often hotspots of contamination from antifouling paints (Rivero et al, 2013) and this has been linked to the facilitation of non-indigenous species (Piola and Johnston 2008). Furthermore, alterations in flow, reduced flushing and the retention of fine sediments around urban structures has been linked to the increased retention of contaminant (e.g. metals, excess nutrients) inputs (Rivero et al, 2013) and the likelihood of low oxygen environments (Nichols et al. 1986, Zhang et al. 2010).

Table 3.1. The physico-chemical differences between natural and urban foreshore structures and the associated ecological consequences. References are provided for the original studies that identified these ecological consequences.

Physico-chemical characteristics	**Ecological consequences**	**References**
Human-made substratum	Foreign materials result in different ecological communities.	(Anderson and Underwood 1994, Glasby 2000)
Low structural complexity/heterogeneity	Reduced native diversity because of fewer microhabitats and refuges.	(Chapman and Bulleri 2003, Chapman and Underwood 2011, Firth et al. 2014a)
Orientation and slope	Favours invertebrates over algae and often non-indigenous species	(Glasby 2000) (Glasby and Connell 2001) (Dafforn et al. 2012)
Low light	Inhibits native algal assemblages and favours non-indigenous invertebrates	(Glasby 1999b, c)
Reduced connectivity to benthos	Less accessible to key benthic consumers	(Glasby 1999c, Goodsell 2009)
Increased resource (space) availability	'Blank slate' favours opportunistic species such as non-indigenous species	(Glasby et al. 2007, Airoldi et al. 2015)
Movement	Floating structures are analogous to boat hulls and provide stepping stones for invasive species	(Glasby 2001, Dafforn et al. 2009b)
Pollution	Increased contamination and artificial light due to boating activities. Alterations in flow resulting in increased retention of fine sediments, contaminant inputs and the likelihood of low oxygen environments.	(McGee et al. 1995, Rivero et al. 2013, Davies et al. 2014)

4. *IDENTIFYING MULTIPLE PURPOSES FOR URBAN STRUCTURES THAT DELIVER BENEFITS FROM ECOSYSTEM SERVICES*

Where marine foreshore developments have the capacity to prioritise ecological solutions, soft engineering approaches are thought of as being better for the environment than built infrastructure. This is because soft engineering involves the manipulation of natural habitats, rather than hardening the foreshore with urban structures (Abel et al. 2011). Strategies, including managed retreat and restoration of important habitats e.g. mangroves and oyster reefs, are the most appropriate replacements for foreshore hardening because they provide a natural alternative to buffer increased wave energy and storm surges (Hoang Tri et al. 1998, Gedan et al. 2011). When soft engineering is not an option, ecologically-friendly and sustainable infrastructure and foreshore developments that provide multiple end-user benefits should be designed (Figure 4.1).

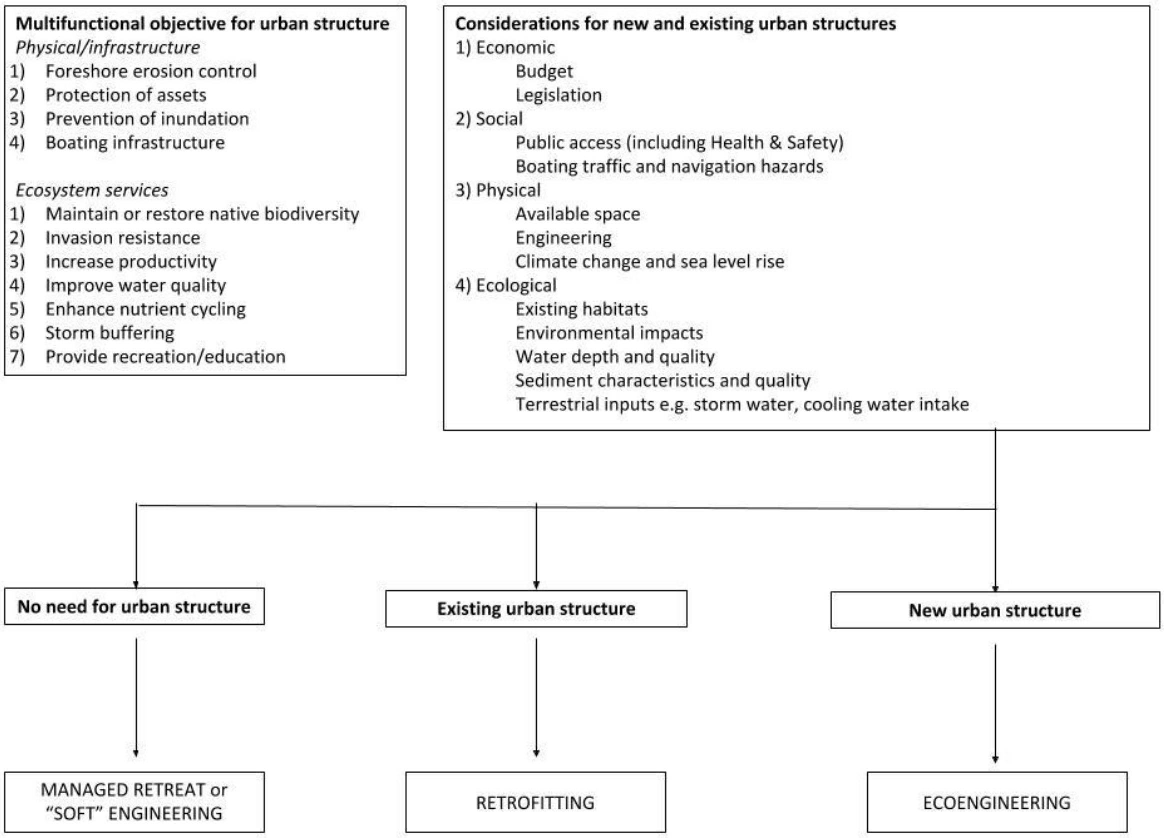

Figure 4.1. Diagram outlining key multi-purpose objectives for foreshore developments and considerations for new or existing structures. Adapted from DECC (2009).

Land-based developments demonstrate the application of multi-purpose objectives to buildings (Gaston et al. 2013). "Green" roofs and walls, for instance, which are plant assemblages established on the tops and sides of buildings, reduce noise and heat escape by

absorbing more sound and thermal energy than a hard surface (Rowe 2011). Recent evidence shows they can also reduce air pollution and trap stormwater (Czemiel Berndtsson 2010, Rowe 2011). Further, “green” roofs and walls can be seeded with target species to create habitat for native plants (Kadas 2006), including rare and endangered species. The principles used in these land-based developments can also be applied to marine and coastal infrastructure.

Ecological or ‘eco’ engineering, the combination of ecological principles in the design, planning and construction of marine infrastructure, is increasingly used to reduce the impacts of new and existing marine foreshore developments and maximise potential ecological outcomes. This is achieved by designing structures from the outset that provide multiple important ecosystem services (Figure 4.2). These multi-purpose objectives can be incorporated through a range of engineered and ecological applications and therefore provide flexible solutions for managers that can be modified depending on local conditions and community expectations.

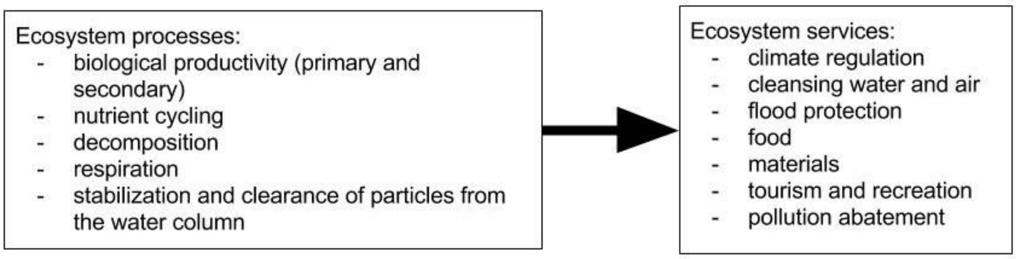

Figure 4.2. Ecosystem functioning is the processing of energy and material by ecosystems and can be quantified by measuring the rates of ecosystem processes (Frid and Crowe 2015). Ecosystem services can be defined as ‘contributions of ecosystems to human well-being’ (Frid and Crowe 2015).

Suggested objectives for the eco-engineering of new marine foreshore developments or retrofitting existing urban structures include native biodiversity maintenance and restoration, invasion resistance, productivity, pollution reduction, enhanced nutrient cycling, storm buffering, recreation and education (Figure 4.3).

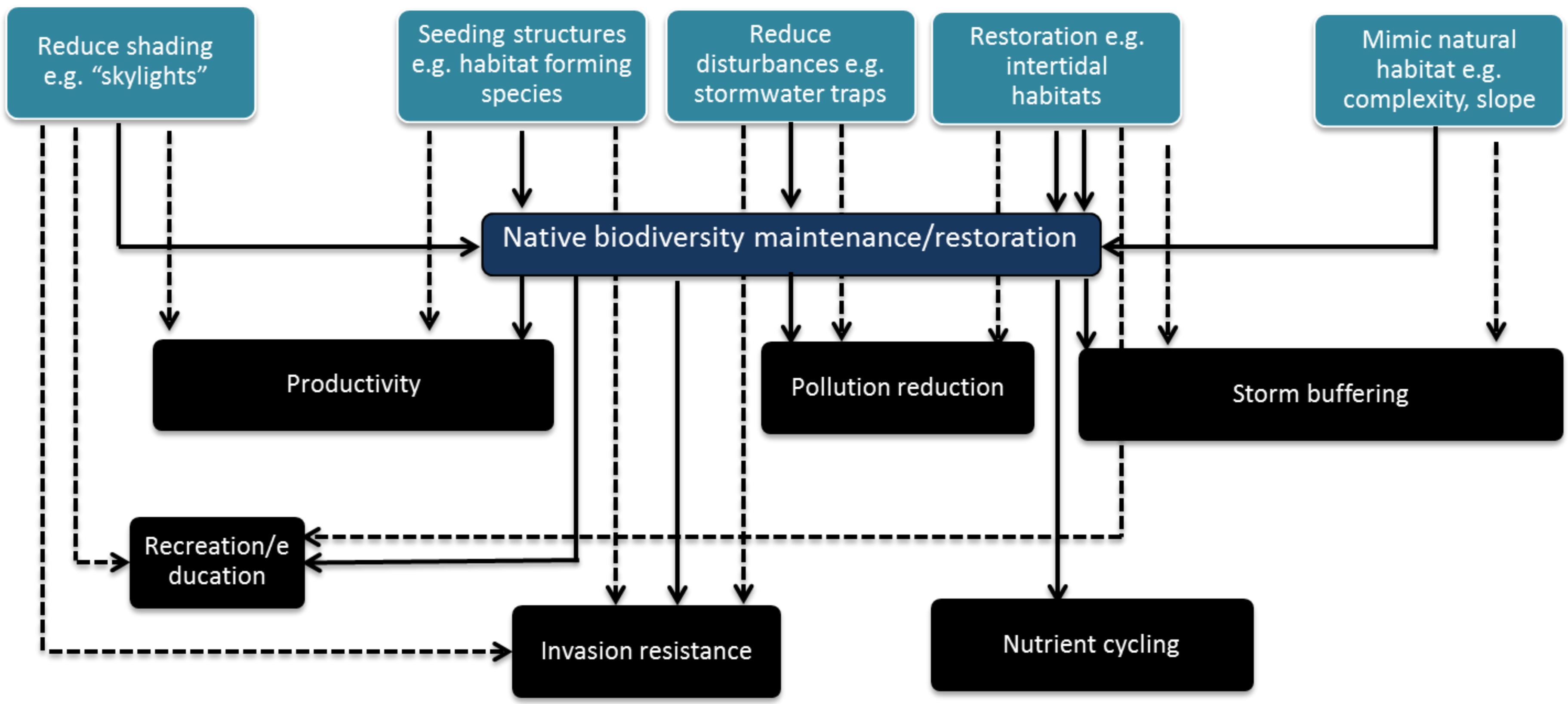

Figure 4.3. Conceptual framework identifying design solutions (green boxes) that will enhance native biodiversity (blue box) and also directly (dashed lines) or indirectly (black lines) through enhancing biodiversity achieve key multi-purpose objectives for the ecological engineering of marine foreshore structures (black boxes) (From Mayer-Pinto et al. in review).

4.1 Native biodiversity maintenance and restoration

The value of biodiversity in the United States alone has been estimated at $300 billion per year (Pimentel et al. 1997), which takes into account the role of biodiversity in maintaining ecosystem processes and improving human well being. Humans rely, socially and economically, on services provided by ecosystems such as production of food and climate regulation (Christensen et al. 1996). Such services are provided and maintained by healthy, functioning ecosystems (Figure 4.2), which are, in turn, dependent on biodiversity (e.g. Loreau et al. 2001, Naeem 2002, O'Connor and Crowe 2005). The observed changes in the composition and abundance of species on marine foreshore structures can have therefore the potential to cause significant changes in ecosystem functioning and the provision of services. Habitat-forming organisms such as seaweeds and oysters are particularly important players in the functioning of systems because they provide habitat for diverse macrofaunal assemblages (Brown and Taylor 1999, Kelaher 2002) and are a bottom up source of primary productivity. Similarly, consumers play important top-down ecological roles in marine communities from grazing to predation (Halpern et al. 2006). The absence and/or lower abundance of habitat-forming species, herbivores and predators on urban structures may alter the trophic structure and can have severe detrimental consequences to the provision of services (Duarte 2002, Beck et al. 2011, Crowe et al. 2013). Maintaining, rehabilitating or restoring native biodiversity should be therefore the primary and most crucial objective for any multi-purpose foreshore development because it supports the provision of many other ecosystem services (see below (2-7), Figure 4.2). One way to achieve this is to increase the available area of habitat on urban structures by building them with a gentler slope (Figure 4.2) or by adding some horizontal habitat on these structures (Chapman 2006). Increasing the complexity of structures by adding micro-habitats such as rock pools, crevices and pits have also been shown to increase their diversity (e.g. Chapman and Underwood 2011). An alternative to increase native diversity on foreshore developments is to transplant, or seed these structures, with key organisms (Figure 4.3), e.g. habitat-forming species (Perkol-Finkel et al. 2012). Active restoration is an important part in the management of marine infrastructure considering that recovery of algal and invertebrate communities may take up to 12 years (e.g. Foster et al. 2003, Jenkins et al. 2004).

4.2 Invasion resistance

Non-indigenous species (NIS) are organisms transported outside of their native range and are a major global source of biodiversity loss and economic costs, estimated to be up to US$97-137 billion (Lovell et al. 2006). The introduction of novel habitats when building artificial structures benefits fast colonising organisms, which is a common characteristic among NIS. Therefore, foreshore developments should incorporate designs to minimise this risk. Maintaining and restoring native biodiversity (discussed in (1)) would support greater

abundance and diversity of native species, consequently decreasing the resources available for the establishment of NIS (Figure 4.3). In addition, coastal and marine artificial structures often suffer from high levels of natural and anthropogenic disturbances such as sediment scour, high wave action, harvesting and maintenance work, which can favour the dominance of opportunistic and NIS (Airoldi et al. 2005, Airoldi and Bulleri 2011). Therefore, the implementation of designs and management practices that minimise these disturbances (Figure 4.3) – e.g. specific designs to dissipate wave energy and/or better maintenance work practices – will potentially minimise the colonisation of NIS on marine infrastructure.

4.3 Productivity

Productivity can be defined as the rate of generation of biomass of a system. Organisms such as seaweeds are primary producers - they fix solar radiation and this energy is transferred through food webs by consumers (herbivores and predators). The generation of biomass by consumers is secondary productivity. Low levels of primary productivity have the potential to constrain numbers of invertebrates and fish, impacting fisheries and the production of food. Foreshore structures such as pilings are often built in conjunction with piers that cause considerable shade on the associated structures (e.g. Marzinelli et al. 2011). In addition to reduced light availability, foreshore structures provide limited availability of space for the colonisation by seaweeds and invertebrates than natural reefs due to their vertical orientation. Habitat-forming seaweeds make a substantial contribution to the primary productivity of an ecosystem. Therefore, reduced abundance and/or biomass of these organisms on foreshore structures has the potential to cause substantial loss to primary productivity (Steneck et al. 2002, Beck et al. 2011) and have cascading effects at higher trophic levels e.g. consumers (fish and invertebrates). Designs of foreshore developments that reduce or eliminate shading (Figure 4.3) and increase space availability to support seaweed diversity are important to promote increased levels of primary productivity (Dafforn et al. 2012). In addition, increased complexity on intertidal and subtidal zones of urban infrastructure would increase diversity of invertebrates and fish (discussed in (1)), which would in turn, increase secondary productivity of the systems (Figure 4.3).

4.4 Pollution reduction

The water column and sediments around marine foreshore developments are often affected by high levels of pollution such as metals, hydrocarbons and excess nutrients. Sources from the landward side include stormwater runoff from impervious surfaces, groundwater seepage and from the seaward side, vessel activity. Increased levels of pollution can cause a loss of biodiversity and may also facilitate NIS (Johnston and Roberts 2009, Piola and Johnston 2009). Costs associated with pollution remediation are significant and therefore pollution abatement is increasingly incorporated into urban design (Gaston et al. 2013). In

marine developments and infrastructure, land-based solutions such as stormwater containment and recycling may be required to reduce pollutant contamination. Improvements in water quality near marine foreshore development sites can also be achieved by seeding structures with organisms that absorb inorganic contaminants (e.g. seaweed) or remove organic particles (Figure 4.3, e.g. suspension/deposit feeders (Gifford et al. 2005)). Restoration of habitats such as wetlands and salt marshes also has the potential to improve local water-quality conditions, while providing low-maintenance coastal protection (Figure 4.3, e.g. Leendertse et al. 1996, Woltemade 2000, Jordan et al. 2003). Therefore, there is an opportunity for eco-engineering of multifunctional structures to play a role in increasing water quality. However, the choice of the target species to be used for pollution abatement needs to be based on rigorous assessment of the species present in the area and local ecological conditions.

4.5 Enhance nutrient cycling

Nutrient cycling is the movement and exchange of organic and inorganic matter back into the production of living matter. At a local scale, ecosystems recycle mineral nutrients into the production of biomass. On a larger scale, nutrient cycling by ecosystems is part of biogeochemical cycles that underpins many essential services to society such as maintenance and provision of clean water and air. The construction of artificial structures causes significant physical disturbances in the marine environment, resulting in the damage or loss of the recipient native habitats and associated communities. One of the most impacted habitats by urban foreshore developments is soft-sediment. Artificial structures modify soft sediment habitats directly by reducing available habitat, for example, and indirectly, by altering key physical, chemical, and biotic parameters that result in secondary modifications to soft sediment landscapes. Soft-sediments are key components of healthy, functioning aquatic systems and underpin biogeochemical cycling and remediation of contaminants, among other ecosystem services (Snelgrove 1997, 1999, Bolam et al. 2002, Snelgrove et al. 2014). Therefore, designs of foreshore developments need to incorporate mitigation strategies to reduce impacts on soft-sediments, when possible, or to restore some of the functions potentially lost by the loss of these sedimentary habitats (Figure 4.3). The incorporation of natural habitat elements and materials into foreshore developments could help in the maintenance of important ecosystems services and functions. Rocks, or other natural hard materials, for instance, can be placed in strategic places to allow for the development of beaches. Also, some organisms, such as seaweeds and fish, play an important role in the cycling of nutrients. Seaweeds (and other primary producers) take up inorganic nitrogen to produce biomass. Fishes, on the other hand, recycle the nutrients they assimilate, providing fertilizer to important primary producers such as seagrasses and seaweeds through excretion (Figure 4.3). Consequently, an increase in the diversity and

abundance of these key species (discussed in (1)) could potentially enhance local nutrient cycling.

4.6 Storm buffering

The construction of protective marine infrastructure is predicted to increase as a result of efforts to mitigate climate stressors such as storm surges and sea level rise. In Australia, more than $226 billion in commercial, industrial, road and rail, and residential assets are potentially exposed to inundation and erosion from climate change (Bradley et al. 2015). These developments often replace the natural protective foreshore habitats that traditionally act as storm buffers. As discussed above, ideally, foreshore protection should be done by conserving or restoring native habitats (soft-engineering approaches). Where this isn't possible, foreshore developments could incorporate natural habitat elements such as riparian vegetation, wood debris and oyster reefs. Rocks, or other natural hard materials, for instance, can be placed in specific ways and locations designed to reduce wave energy, consequently reducing erosion, while providing habitat for marshes (Smith 2006, Pires et al. 2009, Pires et al. 2013). Active restoration of systems such as mangroves, salt-marshes, seaweeds, seagrasses and oyster reefs can also be used in foreshore stabilisation practices, since these systems reduce erosion, providing natural protection against storms and waves (Figure 4.2, Orth et al. 2006, Beck et al. 2011, Pérez-Alberti et al. 2012, Foster et al. 2013). 'Hybrid designs', where natural infrastructure (saltmarsh, oyster beds) is built in front of built infrastructure (e.g. seawalls) can also be used to provide additional coastal protection, as well as enhancing natural habitat (Sutton-Grier et al. 2015).

4.7 Provide recreation/education

Many of the world's largest urban areas are situated on the coastline. As such, the foreshore environment of these coastal cities represents the main interaction between residents and the marine environment. Social acceptance can be one barrier to the modification of marine infrastructure. Research in Sydney, however, has shown high public support for eco-engineering projects to support biodiversity in Sydney Harbour (Morris et al. 2016). The social benefits of the interaction between residents and the marine environment are difficult to quantify, but in many cases interactions with "blue" or aquatic environments have more positive outcomes for health and well-being than "green" or terrestrial environments (Wyles et al. 2014). Currently though many marine foreshore developments are built to the waterline, removing important intertidal habitat that would be the main point of interaction for local residents. Multi-purpose marine foreshore developments have the potential to enhance educational and recreational opportunities for the general public (Dafforn et al. 2015a), if they can restore or build intertidal zones that are easily accessible (Figure 4.3). Furthermore, enhancing the subtidal to serve as 'living aquaria' for recreational zones and opening up viewing access could enhance the community awareness of the

importance of the marine environment (Figure 4.3). In addition, interactive trails along boardwalks can be implemented to promote learning of basic ecological concepts and the benefits of eco-engineering (Figure 4.4).

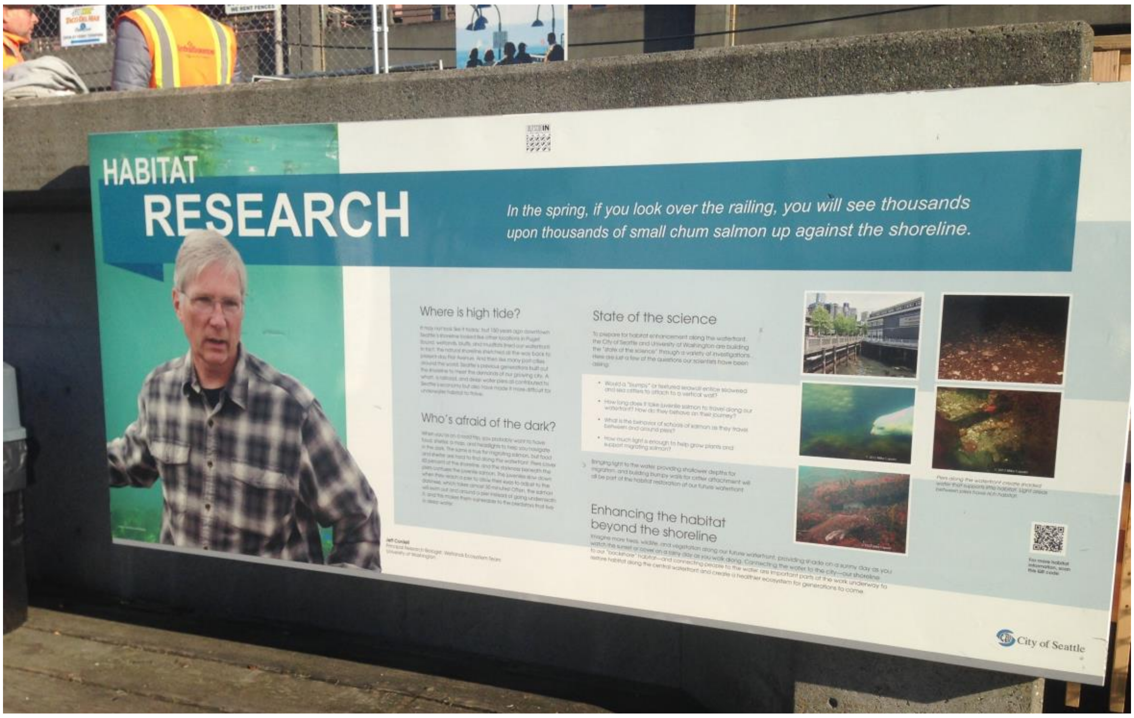

Figure 4.4. Example of interactive trails along the boardwalk of the Seattle Elliot Bay Foreshore Development. Educational signs have been used to explain basic ecological concepts behind reducing shading (top) and the research behind eco-engineering (bottom). Photos by Katherine Dafforn.

5. *GUIDELINES FOR THE DESIGN AND CONSTRUCTION OF FORESHORE MARINE DEVELOPMENTS*

Steps to successfully design marine infrastructure and foreshore developments that both minimize ecological impacts and provide multiple services are outlined below:

1 - **Determine the multi-purpose objectives to be achieved** from eco-engineering new developments or retrofitting existing foreshore structures (Figure 4.2). Clear objectives should be identified at the outset and evaluated upon the project completion.

2 - **Collate ecological and physico-chemical data on the local habitats and structures** where developments will occur (e.g. literature review). This step is key not only to avoid spending resources on information already existent, but also to identify important gaps of knowledge that can then be filled with a survey of the habitats of interest – the next step.

3 - **Conduct a baseline survey** of the ecological and physico-chemical characteristics of the local habitat and existing structures, if relevant, at the development location and at the natural surrounding habitats. These data will inform the practical application of retrofitting and eco-engineering guidelines. These data will also establish a baseline against which the successful implementation of the initial objectives should be evaluated, and therefore sampling should be done at multiple timepoints and sites before construction or modification.

4 – **Carry out necessary remediation works** if environmental conditions are such that new structures are unlikely to support native biodiversity. For example, sediment capping or remediation may be required to ensure that exposure to legacy contaminants through resuspension is reduced. Without these measures then eco-engineering objectives such as maintaining or restoring biodiversity, improving water quality etc. may not be achieved.

5 - **Define the practical eco-engineering or retrofitting designs appropriate for the foreshore developments** to achieve the initial multi-purpose objectives. This should be tailored according to the system, the type of existing or new structure(s) and the multi-purpose objectives (established *a priori*).

6 - **Monitor the ecological and physico-chemical characteristics** of the retrofitted structures or eco-engineered sections of the development at multiple timepoints post-construction. This step is fundamental because it is the only way to evaluate whether the initial established objectives were successfully achieved. Just as the baselines studies, monitoring needs to be spatially and temporally replicated and include the quantitative measures established in the baseline.

7 - **Evaluate whether the original multi-purpose objectives have been achieved** by the practical retrofitting and/or eco-engineering designs incorporated into the foreshore

development. Data collected during baseline and monitoring surveys should be compared and the degree to which each objective has been met evaluated. This evaluation should continue for the life of the foreshore development and new opportunities to retrofit structures identified and incorporated where appropriate.

Baseline assessments provide essential ecological and environmental information that is crucial for predicting and understanding potential impacts from developments (Ward and Jacoby 1992, Walton and Shears 1994). They also provide relevant information for the strategic design of structures to achieve the desired objectives. However, baselines are often conducted at a single site and time, and only focus on the most disturbed locations (Yang et al. 2012) or provide limited information (often qualitative) on very few ecological and environmental variables. Comprehensive baseline assessments for new foreshore developments should include adequate replication of development and reference sites as well as temporal replication, and incorporate a range of quantitative measures to inform mitigation strategies of for potential impacts (Keough and Quinn 1991, Underwood 1992). They should do the following:

a. identify the habitats that may be impacted by the development
b. quantify the impacts already present (if any)
c. link current and potential impacts to objectives for eco-engineering and retrofitting strategies

Measurements collected should be directly related to the established ecological objectives (Figure 5.1). For instance, if the ecological outcome expected is the maintenance of some critical (and pre-defined) services provided by marine systems, information should be collected on aspects of, not only the diversity of these systems (e.g. composition and abundance of species), but also on relevant functioning measures. The detection of impacts and or changes needs to be measured as an interaction between spatial and temporal components of variation against a variable background (Underwood 1991, 1992, 1997, Underwood et al. 2003). Thus, if the main objective of eco-engineering is to increase productivity of species associated with artificial structures, measurements of productivity should be collected before and after modifications of such structures.

When foreshore structures are already present in the area, scientists should be able to provide information on the assemblages living on these artificial habitats compared to natural habitats. The type of information collected (e.g. via literature review and field surveys) will depend on the objectives to achieve, but some examples include (i) which species (or taxa) are absent/present in each type of habitat; (ii) what are their abundances; (iii) key functional groups present at each habitat; (iv) whether these species are native or non-indigenous species (NIS); and (v) the productivity of the natural vs artificial habitats. Information on the types of modifications and/or designs that could be applied to achieve the objectives proposed should also be provided.

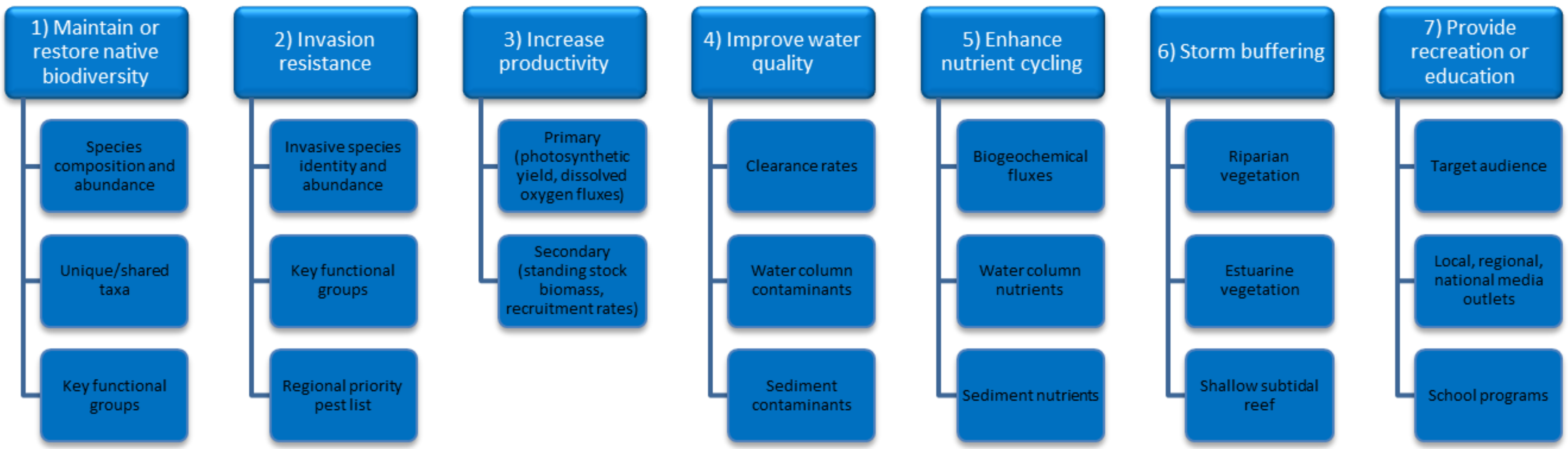

Figure 5.1. Examples of multi-purpose objectives for retrofitting or eco-engineering of foreshore developments and potential measures to be collected as baseline data. (From Mayer-Pinto et al. in review).

6. PRACTICAL TECHNIQUES FOR MULTI-PURPOSE FORESHORE DEVELOPMENTS

Here we provide some practical strategies for eco-engineering new (Figure 6.1) and existing (Figure 6.2) developments and the ecosystems services that can be obtained/enhanced.

New marine foreshore developments - eco-engineering

Landward

- Restore native habitat
  - Plant native riparian vegetation
- Reduce chemical/physical disturbance
  - Limit groundwater contaminants entering the catchment (e.g. fertilisers on green space)
  - Recycle storm water and reduce catchment inputs
  - Reduce impervious surfaces
  - Consider ecological implications of cooling water intake/output location

Intertidal & Subtidal

Physical enhancements

- Incorporate natural building materials (local substrates) or eco-friendly building materials where possible
- Maximise habitat diversity, complexity and provision of refuges
  - Incorporate boulders and blocks of various sizes and shapes
  - Incorporate rocky pools and other features that retain water in the intertidal (ES1,3,7)
  - Create pits, crevices and ledges* (ES1,7)
  - Reduce the angle of the slope by building stepped structures and combining with protruding/indented blocks and boulders (ES1,2,6)
  - Create depressions to allow for sediment deposition (ES1,3,4,5)
  - Attach habitat-forming seaweed mimics* (ES1,2)
  - Provide attachment hooks for live species transplants (ES1)

Biological enhancements

- 'Plant' new structures
  - Habitat forming seaweed (ES1,2,3,4,5)
  - Native mobile grazers (ES1,2)

Seaward

- Restore native habitats
  - Incorporate sediment depressions, or reef structures (ES1,4,5,6)
- Reduce physical disturbance
  - Boat exclusion zones (ES1,4)
  - Limit vessel speed/wash (ES1,4)

Figure 6.1. Practical techniques for eco-engineering new foreshore developments and the ecosystem services that can be obtained/enhanced. ES = ecosystem service provided by implementation. 1 = maintain or restore native biodiversity, 2 = invasion resistance, 3 = Increase productivity, 4 = Improve water quality, 5 = Nutrient cycling, 6 = Storm buffering, 7 = Provide recreation/education. Techniques for eco-engineering the area to the landward and seaward sides of the development are also suggested. Adapted from DECC (2009).

Existing marine foreshore developments - retrofitting

Landward
- Plant native riparian vegetation (ES1,3,4,6,7)

Intertidal & Subtidal
Physical enhancements
- Increase provision of missing habitats
  - Excavate pits and crevices of varying sizes (ES1,2,7)
  - Attach ledges* (ES1,7)
  - Attach habitat-forming mimics* (ES1,2)
- Use of environmentally friendly materials
  - Environmentally friendly concrete
  - Local natural rock and wood
- Reduce shading
  - Reduce angle of slope (ES1,2,3,6)
  - Add light penetrating surfaces (ES1,2,3,7)

Biological enhancements
- 'Plant' or transplant native species
  - Habitat forming seaweed (ES1,2,3,4,5)
  - Native mobile grazers (ES1,2)

Intertidal
Physical enhancements
- Increase provision of missing habitats
  - Excavate pools of varying sizes (ES1,7)
  - Attach water-retaining features* (ES1,7)
- Increase total surface
  - Reduce angle of slope
  - Increase large and medium-scale complexity

Biological enhancements
- 'Plant' or transplant native species
  - Filter feeding bivalves (ES1,2,3,4,5)

Subtidal
Physical enhancements
- Reduce organic matter deposition
  - Debris traps (ES4,5)
- Limit movement
  - Use fixed structures rather than floating (ES1, 2)

Seaward
- Restore native habitats
  - Remove debris (ES1,3,4,5,6)
- Increase connectivity to benthos
  - Reduce basal slope with the addition of boulders or reef balls (ES1,3,6)

Figure 6.2. Practical techniques for retrofitting existing foreshore developments and the ecosystem services that can be obtained/enhanced. ES = ecosystem service provided by implementation. 1 = maintain or restore native biodiversity, 2 = invasion resistance, 3 = Increase productivity, 4 = Improve water quality, 5 = Nutrient cycling, 6 = Storm buffering, 7 = Provide recreation/education. Techniques for eco-engineering the area to the landward and seaward sides of the development are also suggested. Adapted from DECC (2009).

6.1 Physical enhancements

6.1.1 Increase provision of missing habitats

Habitat complexity on artificial structures can be enhanced by the creation of water retaining features for intertidal areas, pits, crevices and ledges and the addition of mimics of habitat-forming organisms. Rocky pools in the intertidal can be major sources of native biodiversity and represent a significant recreation possibility in urban foreshores.

For example, the "Bioblock" is a purpose-built boulder designed to provide a range of microhabitats, such as crevices, overhangs and water retaining features that can be incorporated into new breakwalls. A "Bioblock" has been deployed in the subtidal zone of a breakwall in Wales and proven successful in enhancing native biodiversity (Firth et al.

2014a, Firth et al. 2014b). Future similar designs could seek to include multiple units in both the intertidal and subtidal zones of new foreshore developments.

Similarly, sediment-retaining features such as pits or depressions could be added to foreshores to offset the sedimentary habitat that is often lost from the seabed during construction (Figure 6.3).

Figure 6.3. Sediment-retaining features designed to enhance sediment biodiversity include these intertidal pits at Dover Park, Sydney. Photo by Katherine Dafforn.

Larger water retaining features have been retrofitted to heritage structures, such as seawalls (Figure 6.4) and eco-engineered into residential foreshores in Sydney, Australia (Figure 6.5). Adding flowerpots to seawalls is a relatively cheap and simple enhancement that had measured success at restoring intertidal diversity e.g. mobile species previously lacking from heterogeneous seawalls (Browne and Chapman 2011, Morris 2015). Incorporating water-retaining features into new foreshore developments provides greater flexibility to design structures that are physically more similar to natural rock pools, but may be more expensive and require an extensive design phase. It is also important to consider the type of designs used when adding complexity to artificial structures. The creation of some microhabitats that increase shading may inadvertently increase NIS biodiversity instead of native biodiversity or may increase both (Dafforn et al. 2012).

Figure 6.4. Heritage structures, such as seawalls in Sydney Harbour, Australia, have been modified to increase biodiversity through the addition of water retaining features (i.e. flower pots) with measured success (Browne and Chapman 2011, Morris 2015). Photo by Rebecca Morris.

Figure 6.5. Water-retaining features have been incorporated into foreshore designs in Carss Park, Sydney to provide missing rock pool habitat. Photo by Katherine Dafforn.

6.1.2 Increase total surface and connectivity to benthos

Past research has shown a positive relationship between diversity of organisms and the area of intertidal habitat available (Hawkins and Hartnoll 1980, Firth et al. 2014a). To restore the number of native species on existing seawalls and pilings (and/or maintain their numbers on future developments), one alternative is to increase the available area of intertidal habitat on foreshore structures by building them with a gentler slope – similar to those found on natural reefs at Sydney Harbour (Johnston et al. 2015) – or by adding horizontal habitat on these structures (Chapman 2006). Another alternative when space is limited is to use a stepped structure or increase the area of intertidal habitat through the addition of large and medium protruding/indented blocks and boulders (Figure 6.6).

Figure 6.6. Large and medium scale complexity have been increased at Headland Park, Sydney by the addition of sandstone boulders that vary in size and shape. Photo by Katherine Dafforn.

6.1.3 Use of environmentally friendly materials

Ecologically friendly materials that not only improve performance and durability, but also reduce ecological stress and encourage the development of natural communities (e.g. ECOncrete®) could be used in marine foreshore developments where natural alternatives are unavailable. Recent attempts to modify the composition of materials used on marine and coastal infrastructure have been encouraging, with reported higher invertebrate and fish diversity on and around modified structures than on those built with traditional materials (Ido and Shimrit 2015). In addition, the incorporation of natural habitat elements and materials, such as riparian vegetation, wood debris and oyster reefs, into techniques of foreshore stabilization is an increasing practice worldwide as an alternative to hard armouring of the coasts (Cooper and McKenna 2008, Gedan et al. 2011). This approach can be used in new foreshore developments, for instance, by placement of rocks or other natural hard materials to reduce wave energy, consequently reducing erosion, while providing natural habitat for organisms, e.g. marshes and/or allowing for the development of beaches (Smith 2006, Pires et al. 2009, Pires et al. 2013).

6.1.4 Reduce shading

Recent foreshore developments in North America have implemented eco-engineering principles at the planning stage (Leonard and Kullmann 2010). For example, construction engineers working on the Vancouver Convention Centre foreshore implemented solutions to reduce local impacts of seawalls to natural sedimentary habitats by including those as stepped structures ("habitat skirts").

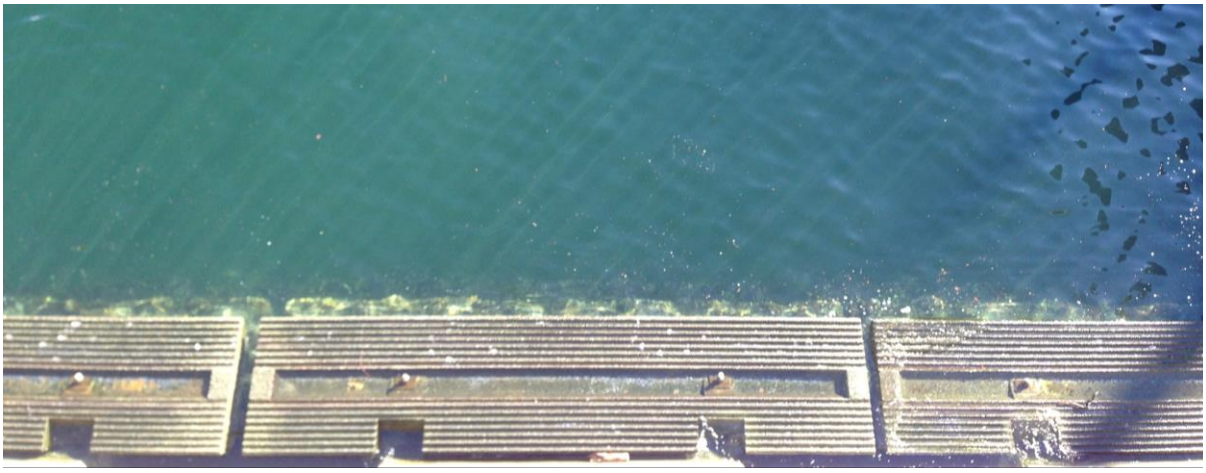

Figure 6.7. Vancouver Convention Centre "habitat skirt" is a stepped structure that extends below the waterline from the intertidal to the subtidal and provides zonation for different organisms to recruit to. Photo by Katherine Dafforn.

To increase the number of algae on these structures, a possible design is to use transparent materials or build the piers with gaps wide enough to allow the passage of light to pilings and/or seawalls underneath it (e.g. Dyson and Yocom 2014). In Seattle, USA, experimental work has been done to try to increase light availability on usually shaded seawalls, but results are still not available (Dyson and Yocom 2014). In Australia, such attempts have not yet been done.

Other foreshore sites in North America are also undergoing extensive redevelopment. The Elliott Bay Seawall project will stretch more than 2 km along the Seattle foreshore and aims to introduce novel designs that 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.

Figure 6.8. Seattle Elliot Bay foreshore development has extensive boardwalks with integrated glass panels (left) or metal grills (right) to allow the passage of light to the pilings and water column beneath. Photo by Katherine Dafforn.

6.1.5 Reduce organic matter deposition

The vertical surfaces of foreshore structures create are frequently subject to physical disturbance from waves and boat activity as well as biological disturbance from fish feeding. As a result large amounts of organic matter tend to be removed from these vertical surfaces and deposited in the sediments adjacent to structures. Apart from reducing the slope of the structure (e.g. 6.1.2), debris traps (e.g. horizontal ledges) could also be added to structures such as pilings to trap this organic matter at various points before reaching the sediments. Alternative solutions include reducing vessel activity or vessel speed near urban structures.

6.1.6 Limit movement

The floating movement of pontoons that are sometimes present in foreshore developments presents a similar physical environment to a vessel hull upon which many NIS are transported. The potential for NIS to jump from one floating structure to the next has resulted in pontoons being described as hotspots of NIS (Dafforn et al. 2012). Therefore, wherever possible the use of floating structures in foreshore developments should be substituted for fixed structures that can be retrofitted or eco-engineered for positive ecological outcomes (e.g. 6.1.1).

6.1.7 Reduce chemical/physical disturbance

Chemical disturbances such as the introduction of metals and fertilisers by storm water runoff can have significant impacts on native animals and plants (Ghedini et al. 2011). Similarly physical disturbances can resuspend sediment with associated impacts on light attenuation and turbidity, which may negatively affect native animals and plants. Wherever

possible, foreshore developments should consider land-sea connectivity in the assessment of contaminant risk, and work to reduce inputs. Reducing the use of fertilisers on green space, collecting and recycling storm water, and replacing impervious surfaces with natural filtration systems might achieve this. The placement of cooling water intake/output pipes and infrastructure should also be considered with respect to potential impacts of these temperature changes on marine organisms.

In areas where the main objective is to maintain or restore native biodiversity then protection from physical disturbances is essential and might be achieved by boat exclusion zones or limiting vessel speed and wash. Since these areas are likely to be of significant recreational and/or educational value then interactions might be best from viewing platforms or underwater observing stations rather than allowing extensive boating activity.

6.2 Biological enhancements

6.2.1 "Plant" or transplantation of native species

Foreshore structures could be used to restore some of the lost biodiversity from urbanised estuaries through transplantation and "planting" of targeted marine species (Dafforn et al. 2015b). These should be species that were identified as missing or with low abundances during baseline surveys of foreshores structures or species that might provide desired functions. For example, "planting" of threatened marine species has been experimentally tested on breakwalls in the Mediterranean (Perkol-Finkel et al. 2012). This experiment had great success, with the transplanted habitat-forming seaweed *Cystoseira barbata* having greater survival (>30%) on artificial structures compared to adjacent native habitat.

In Sydney Harbour, the habitat-forming species *Ecklonia radiata* has been successfully transplanted between reef and pilings (Marzinelli et al. 2011). "Planting" foreshore structures with subtidal habitat-forming seaweeds such as *E. radiata* and intertidal habitat-forming seaweeds such as C*orallina officinalis* or *Homosira banksii* is a relatively cheap and simple enhancement that requires attachment points built into new developments or added to existing structures (Figure 6.9). Furthermore, if retrofitting, most artificial surfaces tend to be vertical or heavily shaded; thus, seeding these structures with a photosynthetic organism would require further measures, such as adding openings or "skylights" to reduce shading. Although similar results can also be achieved by simply providing suitable habitats so these target species can colonise and thrive, this will take much longer. Where the transplantation of living seaweeds is not achievable then seaweed mimics might be considered if they provide similar habitat potential, although this is less desirable.

Key functional groups that might be considered for transplantation to new or existing urban structures include native mobile grazers and benthic predators. In Sydney Harbour these include whelks, limpets, chitons, urchins and seastars. They play an important role in

regulating food chains, nutrient cycling and may provide a natural defence against some non-indigenous species (Dumont et al. 2011). To supplement and speed natural recruitment mobile grazers and benthic predators might be collected from nearby reefs and transplanted to new or existing foreshore structures. In all cases of transplantation, the amounts and identity of transplant organisms should be considered in relation to their abundance in the original donor habitat and possible future interactions with the recipient habitat. For example, transplants of oysters should take into consideration the potential for disease transfer between donor and recipient locations.

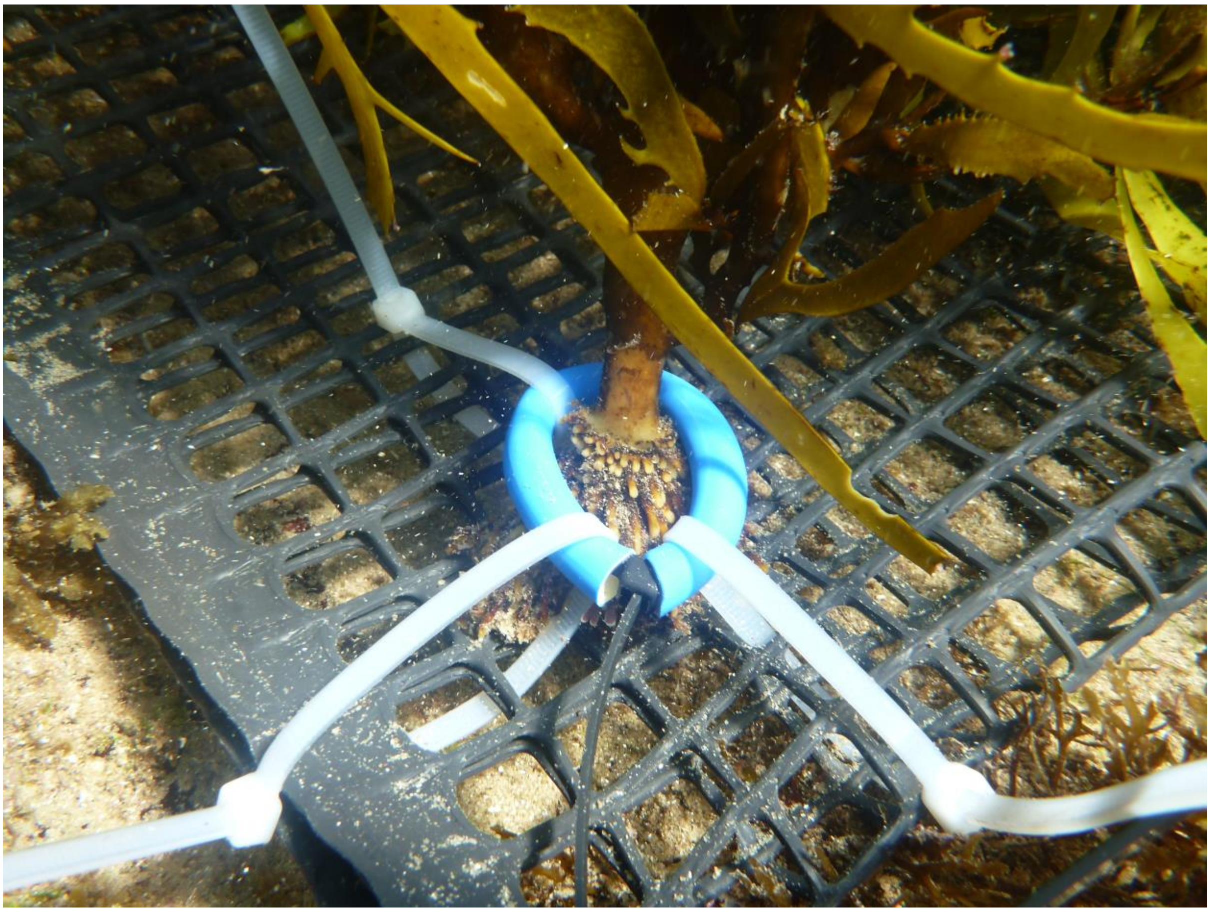

Figure 6.9. Attachments used to “plant” habitat-forming seaweed. Photo by Adriana Verges.

6.2.2 Restore native habitats

Important intertidal and subtidal habitats are lost when foreshore developments are built to the waterline. These include intertidal habitats such as rocky shore, beaches and native vegetation such as mangroves that provide an important source of social interactions with the marine environment. Wherever possible, new foreshore developments should attempt to restore intertidal habitat, either by incorporating a sloping intertidal zone into the design (e.g. Figure 6.6) or retreating to allow the development of an intertidal zone (Figure 6.10)

Figure 6.10. The Elliot Bay Foreshore development in Seattle has incorporated areas of managed retreat to allow for the development of pocket beaches. These support recreational activities and support biodiversity. They are also commercially important because they provide a food source and habitat for migrating salmon. Photo by Katherine Dafforn.

On the landward side of foreshore developments, native riparian vegetation should be planted that can act as stormwater filters and traps to reduce the contaminant run off into the marine environment. On the seaward side of foreshore developments, thought should be given to creating healthy sedimentary environments with depressions created at increasing depths to allow for sediment deposition. Where appropriate, structures ("castles") might also be deployed to support oyster reef creation or provide habitat for fish (Figure 6.11). However, the replacement of any soft sediment habitat with additional hard substrate should be carefully considered. Sediment retaining features should be considered where the natural habitat is sedimentary.

Figure 6.11. Oyster “castles” prepared for deployment in San Francisco, United States.

7. HEALTH AND SAFETY CONSIDERATIONS

Where practical strategies for eco-engineering or retrofitting structures are considered for new and/or existing foreshore developments then a comprehensive risk analysis should be done. This could include such considerations as what the level of public interactions will be with the area that is being eco-engineered or retrofitted.

If public interaction with the area is likely to be high then biological, physical and chemical risks should be investigated and could include for example cuts from oysters, slips on algae, trips and falls. These will all be dependent on the types of physical and biological strategies that are implemented.

Any risk assessment should consider that this is a living and dynamic foreshore and therefore risks will change over time. Therefore current (12 months), emerging (2-3 years) and future (>3 years) risks should be assessed.

Hazards need to be identified and risks prioritised so that the appropriate risk controls can be implemented. In each case any risk that may cause harm should be assessed to determine if the hazard can be eliminated, replaced or barriers can be constructed.

Beyond the general health and safety considerations identified here, other site specific and project specific issues will need to be considered when marine foreshores are retrofitted or built. It is not the intent of these guiding principles to conduct a risk assessment that is applicable to all developments, but to highlight the need for these assessments risks in every instance by qualified risk management specialists.

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9. GLOSSARY

Assemblage

A group of species (or taxa - see definition below) in a particular place and/or habitat.

Beach replenishment

The process of adding sand to an eroding shoreline to create a new beach or to widen the existing beach.

Benthos

The community of organisms that live on, in, or near the seabed.

Biodiversity

Describes the variety of all living things in different habitats.

Biomass

A measure of the weight of organic material (animals, sediment, plants). Rates of biomass change can be used as a proxy for community productivity.

Breakwalls

Hard structures (often constructed of large and interlocking boulders) built to protect coastal, boating or foreshore infrastructure from destructive forces.

Contamination

Can include chemical pollutants such as metals hydrocarbons, excess nutrients or fertilisers, or physical pollutants such as macro or micro debris.

Decomposition

The process by which organic substances are broken down and matter recycled. Bodies of living organisms begin to decompose shortly after death.

Ecological community

A group of marine organisms (e.g. algae, invertebrates and fish) associated with a particular habitat (e.g. shallow sub-tidal reef)

Eco-engineering

An emerging research field that integrates ecology and engineering in the design of marine infrastructure

Ecological function

Biological processes (e.g. photosynthesis and growth) undertaken by marine organisms within the ecological community.

Ecological structure

The composition or relative abundance of various marine organisms within the ecological community.

Ecosystem services

The contributions of ecosystems to human well-being' e.g. climate regulation and cleansing of water.

Foreshore development

Construction of buildings and infrastructure along the foreshore of urban coastal cities and to the waterline.

Habitat

An area that provides a home and resources for particular animals, plants and other organisms.

Hard engineering

The controlled disruption of natural processes by using human-made structures e.g. coastal defences that protect from erosion and wave action.

Hard substrate

Hard surfaces in the marine environment (e.g. sandstone seawalls and rocky reef) that are colonised by sessile invertebrates (e.g. barnacles, oysters)

Herbivore

An animal that feeds on plants.

Intertidal habitat

The area along the coastline that is submerged at high tide but exposed at low tide.

Invasive species

A species that was transported outside of its native distributional range by humans (intentionally or unintentionally), and established a self-sustaining population in a new area. The species has a recorded negative ecological or economic impact in the non-native range.

Macroalgae

Large habitat forming seaweeds (e.g. kelp).

Managed realignment

A soft engineering strategy that involves the removal of hard defence structures and restoration of natural coastal vegetation.

Mangroves

Trees and shrubs that grow in saline coastal sediment habitats.

Mobile invertebrates

Invertebrates (small animals without backbones) that can move around in their habitats (e.g. amphipods and shrimp).

Native species

A species that occurs naturally in a particular region and may be endemic (only found in that region).

Natural structure

Naturally occurring structures that provide habitat for marine organisms (e.g. rocky reef, mangroves).

Non-indigenous species (NIS)

A species that was transported outside of its native distributional range by humans (intentionally or unintentionally), and established a self-sustaining population in a new area. The species may or may not have a recorded negative ecological or economic impact in the non-native range.

Nutrient cycling

The movement and exchange of organic and inorganic matter into living matter.

Organism

Any living system such as an animal, plant or bacterium.

Physico-chemical characteristics

The physical and chemical variables in marine systems including for example temperature, salinity, turbidity.

Pilings

A foundation or support for marine infrastructure. Often composed of steel, concrete or wood.

Pontoons

A floating dock for recreational or commercial vessel berthing. Often composed of plastic or fibro-cement.

Predator

Animal that feeds on other animals.

Productivity

The rate of production of new biomass by an individual, population of community. Primary productivity refers to the energy produced by photosynthesis or chemosynthesis of plants and bacteria. Secondary productivity refers to the biomass produced by herbivores and predators.

Restoration

The practice of renewing and restoring degraded, damaged or destroyed ecosystems and habitats in the environment.

Seagrass

Community of marine flowering plants that provide important habitat for a variety of animals.

Seawalls

Protective hard structure built to absorb wave energy and reduce flooding/inundation.

Sediments

Seabed habitat consisting of mud, sand, gravel and shelly debris that supports a high diversity of animals and functions such as nutrient cycling.

Sessile invertebrates

Invertebrates that colonise hard substrates and anchor themselves permanently (e.g. barnacles and oysters).

Soft engineering

The use of ecological principles and practices to reduce erosion and achieve the stabilization and safety of shorelines and the area surrounding coastlines, while enhancing habitat.

Subtidal habitat

Marine habitat that is permanently submerged.

Taxa

A scientific unit used to describes a group of similar (e.g. shape or feeding mode) organisms.

Urban structure

Human-made structures (e.g. pilings and seawalls) that have an engineering purpose (e.g. defence or boating) and may be colonised by marine organisms.