Environmentally Friendly Seawalls

A Guide to Improving the Environmental Value of Seawalls and Seawall-lined Foreshores in Estuaries

NSW GOVERNMENT

Office of Environment & Heritage

Catchment Management Authority Sydney Metropolitan

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Cover photos

Bobbin Head, Cowan Creek, Hawkesbury River (top); Spit Bridge, Mosman, Middle Harbour (left); Claydon Reserve, Kogarah Bay, Georges River (right).

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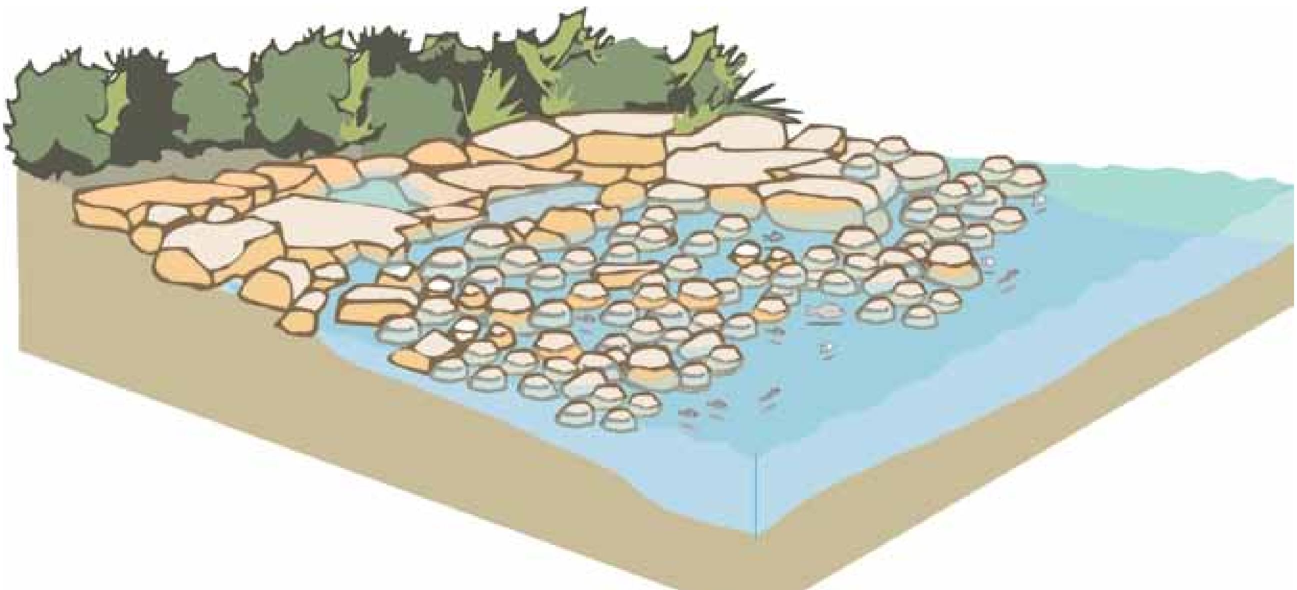

1 Introduction

Urbanisation has modified and continues to modify estuarine foreshores through the direct loss and the fragmentation of natural habitat and its replacement with reclaimed parkland, infrastructure, housing and other artificial structures such as jetties and seawalls. Seawalls in particular have become a dominant foreshore feature of urban estuaries, and the demand to build more and the need to repair existing seawalls is expected to increase in a bid to protect low-lying foreshore infrastructure from sea level rise associated with climate change. This has significant implications for the environmental health of estuaries, as the construction of seawalls results in the loss of natural intertidal habitats that are vital in providing a range of ecosystem functions.

In addition, traditional vertical seawalls have limited potential to provide habitat and other environmental services and are therefore poor surrogates. Hence, it is important that where seawalls are determined to be the most appropriate management tool for estuarine foreshores, they are built to minimise environmental impacts, more closely mimic natural foreshores and provide greater environmental value.

There are a number of options for both improving the environmental value of existing seawalls and creating new seawalls that have greater habitat potential than traditional designs. In addition, consideration of some basic guiding principles for building new seawalls will minimise impacts on estuarine processes and improve the environmental value of seawalls. This guideline describes these options and guiding principles using a number of examples of seawall projects.

Aims of this guideline

This guideline aims (1) to illustrate the environmental consequences of building traditional seawalls and to explain how seawalls differ from natural estuarine foreshores, and (2) to provide those involved in designing, approving, building or upgrading seawalls in estuaries with a range of options to improve the environmental value of seawalls and seawall-lined foreshores. Some techniques will not be suitable for all situations, so always seek qualified assistance in determining which options are appropriate.

Beyond the environmental aspects, many other structural and design issues will need to be considered when seawalls are upgraded or built. It is not the intent of this guideline to cover these. Always seek appropriate advice from qualified professionals.

This guideline does not include information on the approvals required to build a seawall. Please check with your local council.

2 Differences between natural and seawall-lined intertidal shorelines and their consequences

Seawalls are commonly used as foreshore protection structures in estuaries, with objectives such as armouring the shore against erosion and preventing inundation of low-lying areas. In the past, little consideration was given to the intertidal habitats that were destroyed or fragmented through the creation of seawalls, or how seawalls could be designed to more closely mimic natural shores. As a result, large sections of natural shorelines have been lined with seawalls (Figure 1), with a number of consequences.

Seawalls as intertidal habitats differ from natural intertidal habitats in:

- their substrate, composition and surface features, including provision of microhabitats (Chapman and Bulleri, 2003)
- their size and slope (Chapman and Bulleri, 2003)
- their ability to act as buffers between terrestrial and aquatic environments.

These differences limit the potential of seawalls to provide habitat for intertidal organisms (Chapman, 2006), resulting in lower species diversity and abundance. Hence, seawalls are poor surrogates for natural intertidal shores.

Figure 1: Examples of traditional seawalls built within estuaries of Sydney: concrete with smooth texture in Pearl Bay, Sydney Harbour (left), and vertical mortared sandstone blocks in Abbotsford Bay, Parramatta River (right).

2.1 Substrate, composition, surface features and microhabitats

Traditional seawalls provide a hard and homogeneous substrate of rock or concrete, often in areas of an estuary where natural hard substrate may be absent or sparse. This differs greatly from intertidal habitats such as saltmarsh, mangroves, mudflats, sandy beaches and swamp forests, which provide a 'softer' and highly diverse substrate of sediment and vegetation. The reduction, fragmentation and loss of intertidal habitats have implications for the variety of species that utilise them for shelter, spawning, nesting, breeding and food (Lee *et al.*, 2006). These include the decline or loss of species, ranging from commercially and recreationally important fish species to migratory waders, leading to whole ecosystem changes (Faulkner, 2004). Replacement of these natural intertidal habitats with seawalls favours only those species that require a hard substrate and can utilise the habitats provided on a seawall.

The habitat that seawalls provide is also vastly different from natural rocky intertidal shores. Natural rocky intertidal shores consist of a number of microhabitats, such as crevices, cavities, pools, boulders and overhangs, which often provide habitat for species not commonly found on more exposed parts (Figure 2). Seawalls offer little variety or complexity of habitat types, particularly those habitats that retain water or moisture during low tide, thus reducing species diversity (Chapman, 2003; Moreira *et al.,* 2007). For example, many of the mobile animals not found on seawalls are found in natural rocky intertidal shores in microhabitats that retain water or that remain damp during low tide, including tidal pools, crevices and the undersurfaces of small boulders (Chapman, 2003).

The material type, roughness, porosity and chemical composition of the substrate can also differ between seawalls and natural shores (Chapman and Bulleri, 2003). These can potentially determine the types and abundances of intertidal species present. With smooth concrete or sandstone faces, many seawalls differ from weathered, natural rocky intertidal shores with highly varied surface texture. This may be one of the reasons for the species differences (Bulleri, 2005). Research has also shown that concrete seawalls do not support the same diversity of species as sandstone seawalls (Connell and Glasby, 1999; Moreira, 2006), highlighting how preference for substrate can exclude certain species. In addition, introduced marine species in Sydney Harbour have colonised concrete surfaces in greater numbers than have native species, yet the opposite is the case on natural rocky reefs (Glasby *et al.*, 2007). This has possible implications for native biodiversity if seawalls built from concrete assist in the recruitment and spread of introduced species.

Figure 2: Examples of the habitat complexity on natural intertidal rocky shores in the Parramatta River estuary (Iron Cove, top; Hen and Chicken Bay, bottom), highlighting the varied topography, crevices, pools that retain water, and ledges that remain damp at low tide.

2.2 Size and slope

Changing the natural foreshore slope from near-horizontal to near-vertical greatly reduces the amount of available intertidal habitat on seawalls. As natural intertidal shores can be tens of metres in width, the insertion of vertical seawalls reduces this to the tidal range bandwidth of the seawall (the area between low and high tide), up to 2m in Sydney (Figure 3) (Chapman and Bulleri, 2003). The size of a patch of intertidal habitat shows a positive relationship with the abundance and diversity of species living in it (McGuinness, 1984): in general, less habitat means fewer species and lower abundance.

In addition to the reduction in available soft sediment habitat, the reduction of habitat area can increase local species densities and force species that might naturally live metres apart to occupy the same patch (Chapman, 2006). This crowding into smaller areas increases competition, reducing organism size, density and breeding success (Moreira *et al.*, 2006). In addition, many intertidal plants and animals have been shown to be strongly influenced by the slope of the substrate: species type, abundance and behaviour can differ between vertical and horizontal shores (Chapman, 2007).

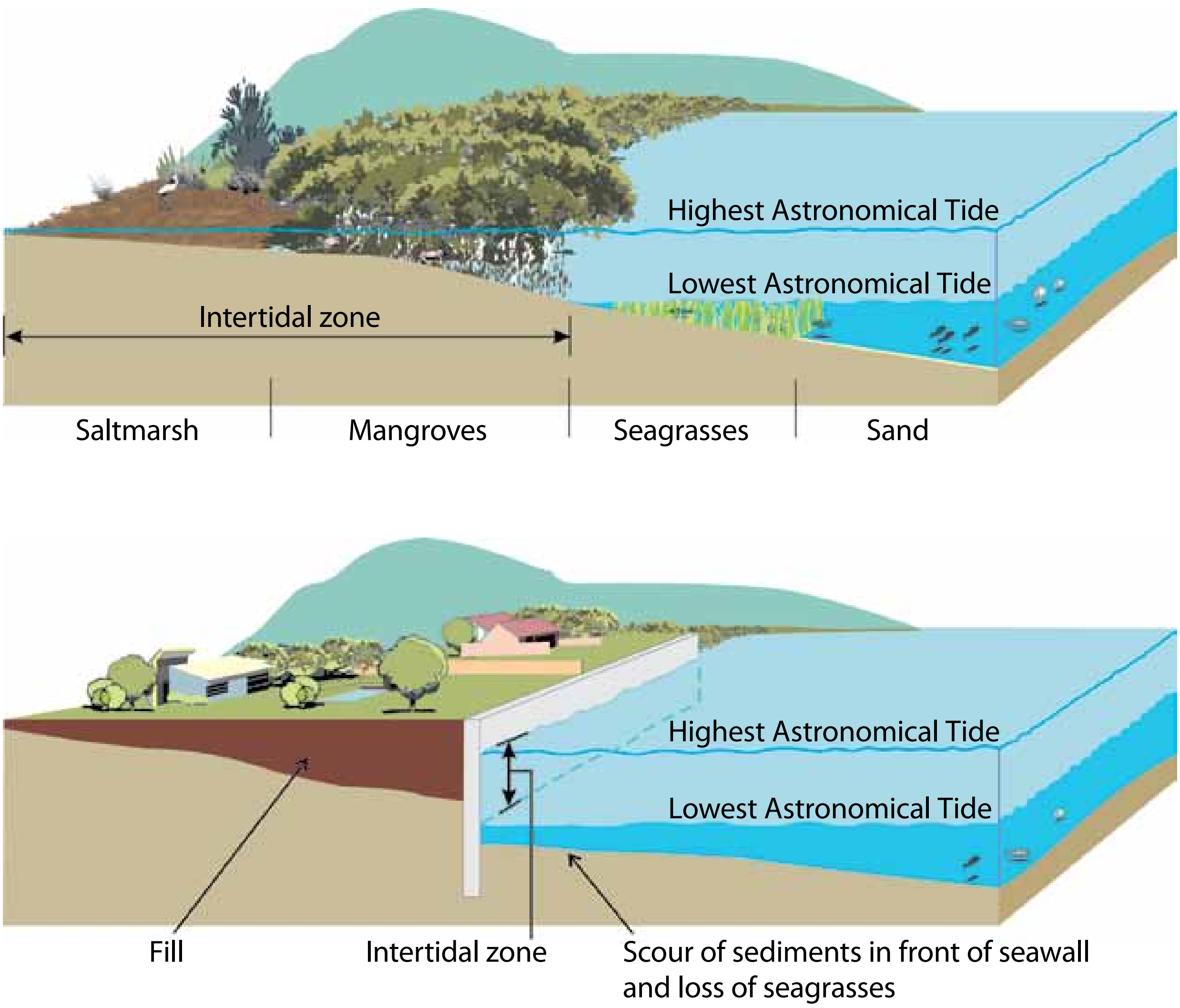

Figure 3: Comparison of a common low-sloping, estuarine shoreline (top) with a traditional vertical seawall, showing the substantial loss of intertidal area and important habitats such as saltmarsh, mangroves and seagrasses (bottom).

2.3 Ability to act as buffers between terrestrial and aquatic environments

Natural estuarine shores often consist of wetlands, with extensive mangroves and saltmarsh that form a buffer between terrestrial and aquatic habitats. They also generally have a low slope and dissipate energy from waves over a distance. Hence, natural shores can prevent erosion, reduce currents, attenuate waves and encourage sediment deposition and accretion. Intertidal wetlands also filter overland runoff, removing pollutants such as nutrients and sediments, helping to maintain good estuarine water quality.

While seawalls also act as buffers against shoreline erosion, their construction means that intertidal vegetation is removed or will eventually die off through prevention of tidal inundation. The ability to encourage sediment deposition and to filter catchment runoff is therefore lost, and flow patterns can be changed. Also, when a hard structure is built where there is potential for wave action or strong currents, erosion is generally exacerbated at the toe or ends of the structure. For example, a study of the impacts of seawalls on saltmarsh plants found that there was more sediment movement close to seawalls at high-energy sites and less fine-grain sediments than in natural saltmarsh foreshore sites as a result of an increase in energy from wave reflection (Bozek and Burdick, 2005). These changes can impact on adjacent seagrasses through burial, increased scour and increased turbidity. In addition, a change in sediment composition from fine-grained to coarse could alter benthic invertebrate and fish community composition of the area (Batton, 2007).

As seawalls act as a barrier between terrestrial and aquatic environments, they can stop the movement of natural wrack onto the shore, where it would gradually break down (Figure 4). Instead, floating wrack can build up and form mats in front of seawalls. Under these conditions, underlying seagrasses can be smothered or shaded, eventually dying off. In addition, sediments can become anoxic from the breakdown of decomposing wrack resulting in the mortality of benthic fauna (Cummins *et al.,* 2004). One study of benthic assemblages associated with seawalls in Lake Macquarie found that species richness and abundance were significantly reduced in sediments in front of seawalls compared with naturally sloping saltmarsh-vegetation foreshores (Chapman, 2004).

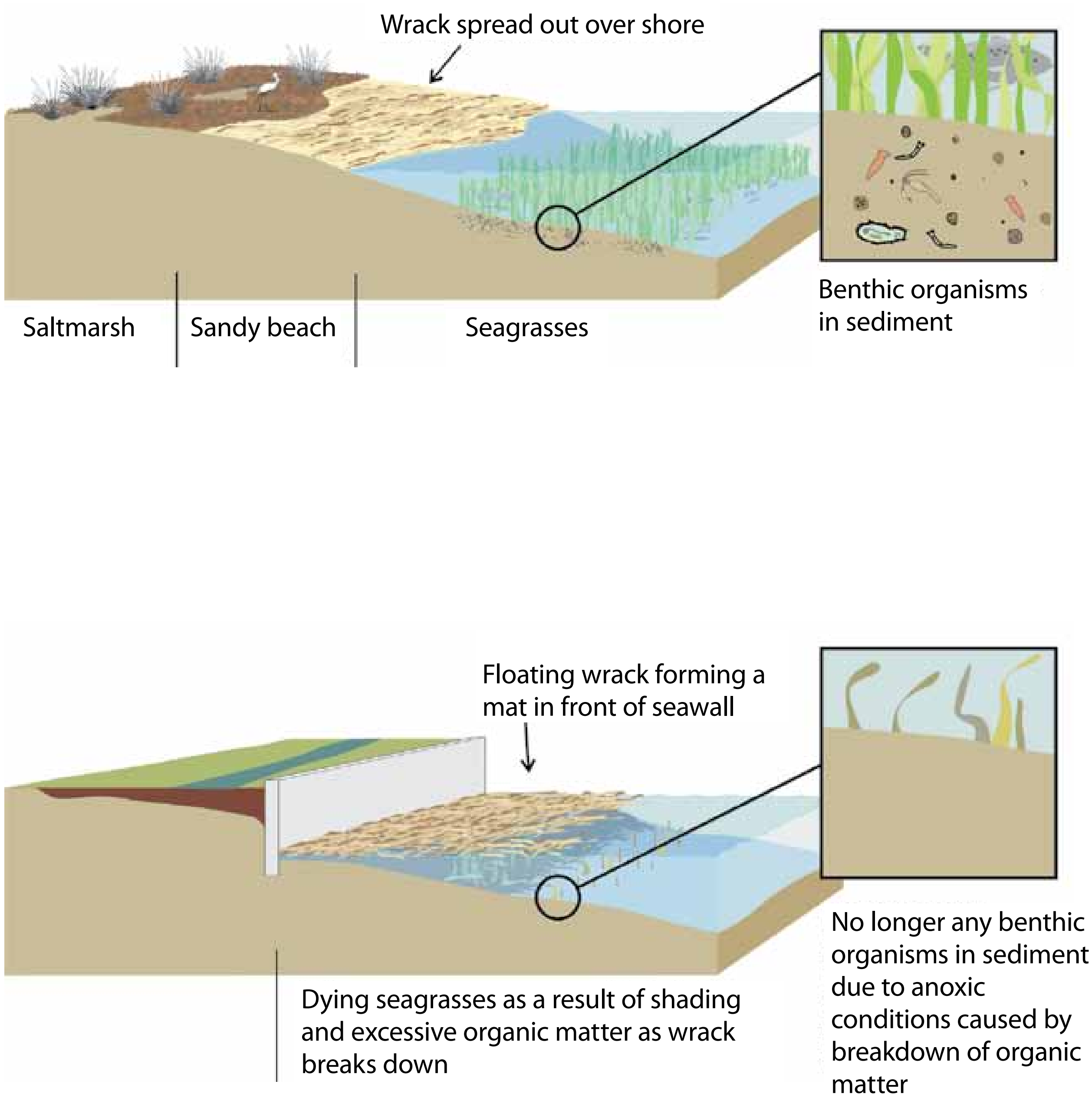

Figure 4: Comparison of a low-sloping estuarine foreshore with seagrass wrack allowed to break down naturally on shore (top) with a seawall forming a barrier to wrack and resultant impacts (bottom).

3 Techniques to improve the environmental value of seawalls

A variety of techniques can increase the environmental and habitat values of both existing and new seawalls. Figure 5 summarises these techniques, as well as the site constraints and considerations that will determine which techniques are possible or whether a seawall is even required. While individually some of the techniques may have limited effects, they can have considerable cumulative impact if combinations are applied to many seawalls and allowed to stay in place for the long term (Li *et al.,* 2005).

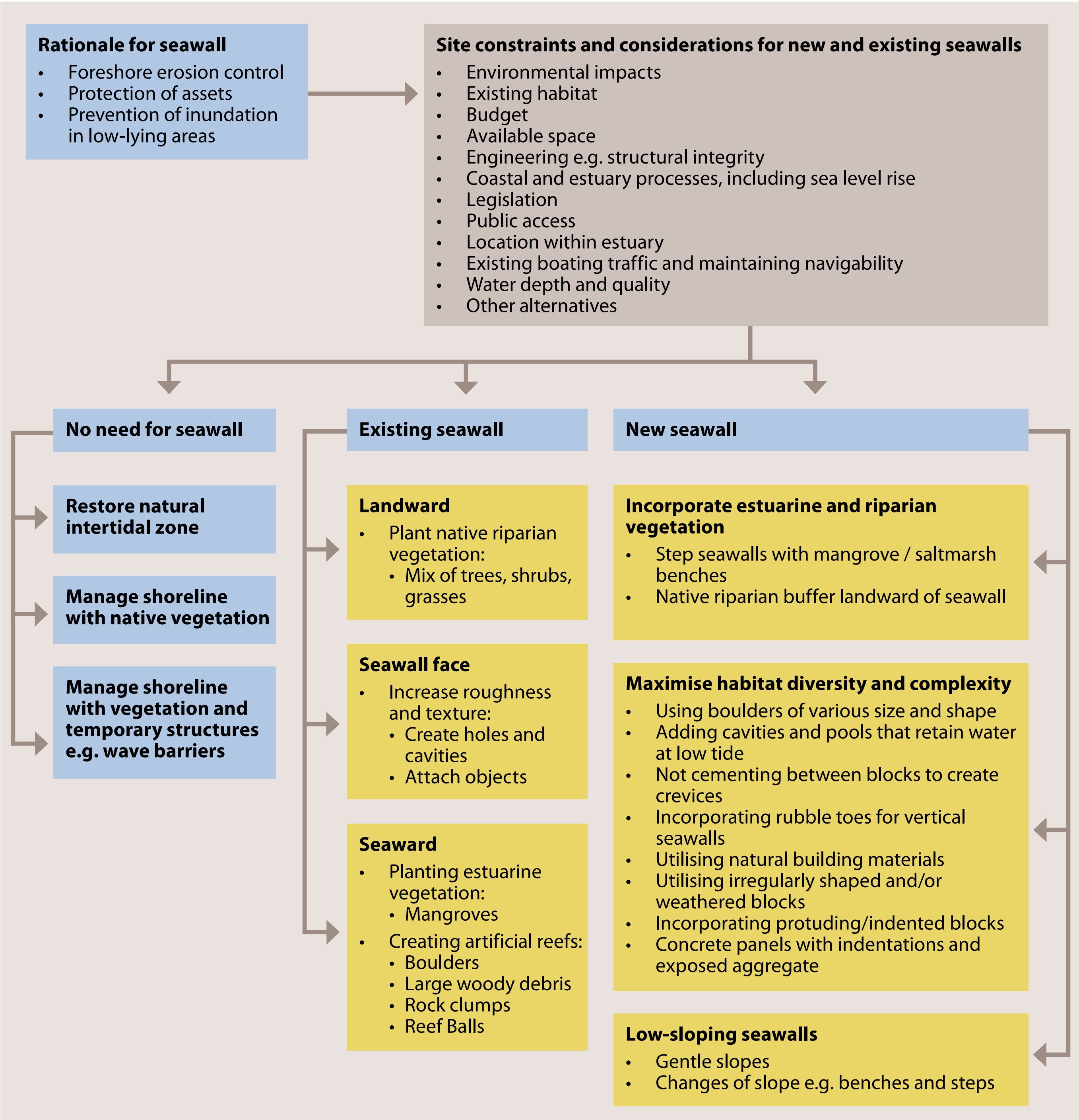

Figure 5: Summary guide for building new seawalls or modifying existing seawalls.

Techniques to improve the environmental value of seawalls are in their infancy, and as yet there is limited research into relevant examples of techniques and their benefits. Nevertheless, environmental rehabilitation projects utilising various techniques from Australia and around the world are having positive results.

As with the construction or rehabilitation of any structure on foreshores, the relevant local council and government agencies must be consulted before any seawalls are built or upgraded. Permits or approvals will be required.

3.1 Techniques to improve existing seawalls

Improving the environmental attributes of existing seawalls can help improve the overall habitat at the site. Techniques can be applied to existing seawall surfaces, as well as to the estuary bed and adjacent land edge. Each treatment by itself provides a degree of benefit, while in combination benefits can be maximised.

3.1.1 Establishing estuarine vegetation such as mangroves directly in front of seawalls

Figure 6: A seawall with mangroves directly in front providing valuable habitat.

Where a seawall does not directly front deep waters and a beach or mud flat is present in front at low tide, mangrove seedlings can be planted as a fringing strip in front of the seawall to provide valuable habitat and encourage sediment deposition and toe protection (Figure 6). However, this option is not appropriate if the exposed mud flat is recognised as important shorebird habitat, particularly for migratory waders. This is because mud flats and other soft-sediment and low-lying vegetated habitats such as sand flats and saltmarsh are critical foraging areas for migratory waders, and most waders have a strong preference for estuaries with expanses of intertidal flats (DECC, 2008).

Screening and aesthetic advantages are added benefits of mangroves where the seawall or land use is unsightly. When mangroves are planted in front of exposed seawalls, protection of seedlings from waves and from flotsam and jetsam is recommended to maximise establishment (Stewart and Fairfull, 2008). Temporary wave barriers such as mesh fencing can be used. There are also many examples in Sydney estuaries where mangroves have been established or have re-established naturally in front of seawalls, in some cases among the gaps between the rocks making up the seawall (Figure 7).

In some situations, once mangroves and resultant sedimentation have sufficiently stabilised the shoreline, there may no longer be a need for the seawall, which could be removed to allow for further shoreline rehabilitation; for example, to re-establish coastal saltmarsh, which in NSW is an endangered ecological community.

Figure 7: Examples of seawalls with mangroves directly in front in the Parramatta River estuary (top and bottom), and a rock seawall with mangrove seedlings establishing amongst the gaps between the rocks in the Cooks River estuary (middle).

3.1.2 Providing a native riparian vegetation buffer landward of the seawall

Considerable research shows the importance of riparian vegetation in freshwater environments. Most, if not all, of the benefits are equally valid in estuaries; these include bank stabilisation, water quality improvement and habitat provision. Introducing a native vegetation buffer directly behind the top of seawalls and within the gaps amongst rock seawalls (Figures 8 and 9) creates habitat, shelter and a source of food, benefiting both terrestrial and aquatic species along the foreshore. Estuarine water quality could also be improved through filtration of pollutants in overland runoff before it enters the estuary.

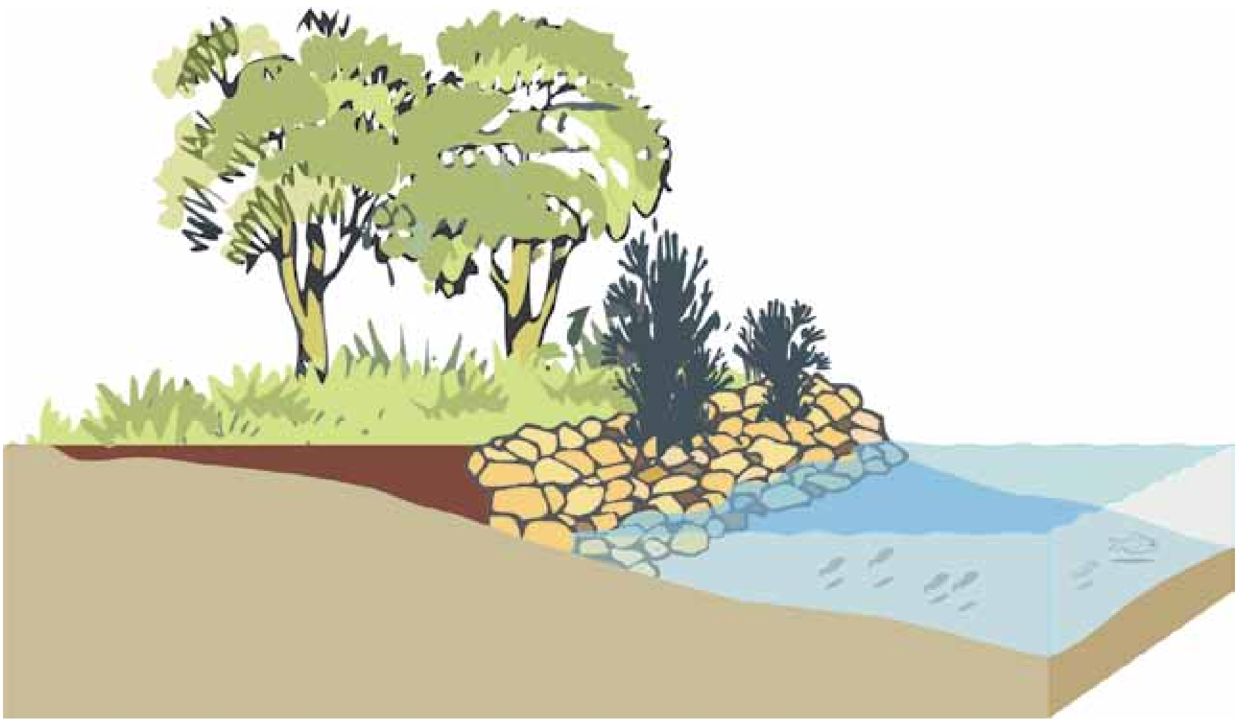

Figure 8: A seawall with a riparian vegetation buffer zone, including vegetation growing between the rocks of the seawall.

Figure 9: Examples of seawalls recently constructed with a native riparian vegetation buffer zone immediately landward along the Parramatta River at Ermington (above) and the Cooks River at Gough Whitlam Park (right).

3.1.3 Providing artificial reef habitat immediately in front of seawalls

In addition to activities at the land's edge, actions on the estuary bed immediately in front of seawalls can also enhance estuarine habitat by increasing the diversity of habitat types. Depending on the depth of the water, a variety of materials can be used to provide habitat, from woody debris to artificial reefs. These materials can provide a firm surface to allow attachment of organisms, provide shade and refuge for small fish, and assist with erosion control. This option is not appropriate where seagrasses have established in front of the seawall, as the reef structures would destroy this important habitat. In addition, it may not always be desirable to replace soft sediment habitat with artificial hard structures. Advice and approval should always be sought from the relevant government agencies.

Large woody debris in estuarine environments has a number of potential benefits:

- It creates habitat complexity
- It serves as a substrate on which fish and invertebrates may forage, find refuge from predators, and spawn
- It provides a substrate for organism attachment
- It contributes to a detritus-based food web (Curtiss *et al.*, 2006).

Hence, its addition to the base of seawalls could provide a number of benefits. The woody debris would need to be anchored, and breakdown would mean that it would have to be replaced every 5 to 30 years depending on size and type (Curtiss *et al.,* 2006). Boating safety must also be considered.

The addition of boulders in front of seawalls can also provide habitat, as well as structural protection to the toe of the seawall, preventing the underlying sediment from being eroded. For example, quarried sandstone boulders were rapidly colonised by a suite of species found on or under natural intertidal and subtidal boulders (Chapman, 2002). Boulders can be added just to the base of the seawall (Figure 10), or as habitat clumps placed intermittently along the seawall (Figure 11), or in boulder fields that extend close to the top of existing vertical seawalls (Figure 12). These options can be used to increase total habitat surface area and diversity, provide a gentler slope, and provide habitat complexity in the form of gaps and crevices among the loose boulders.

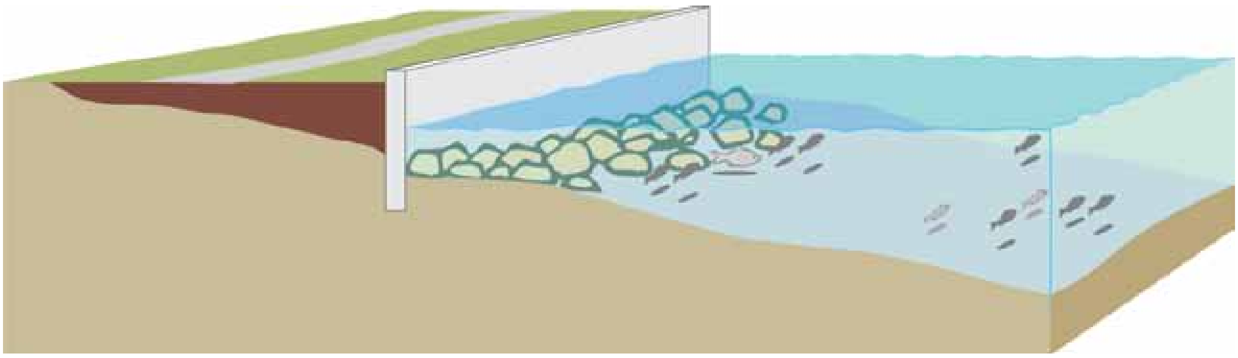

Figure 10: Boulders added just to the toe of the seawall to provide habitat and seawall stability.

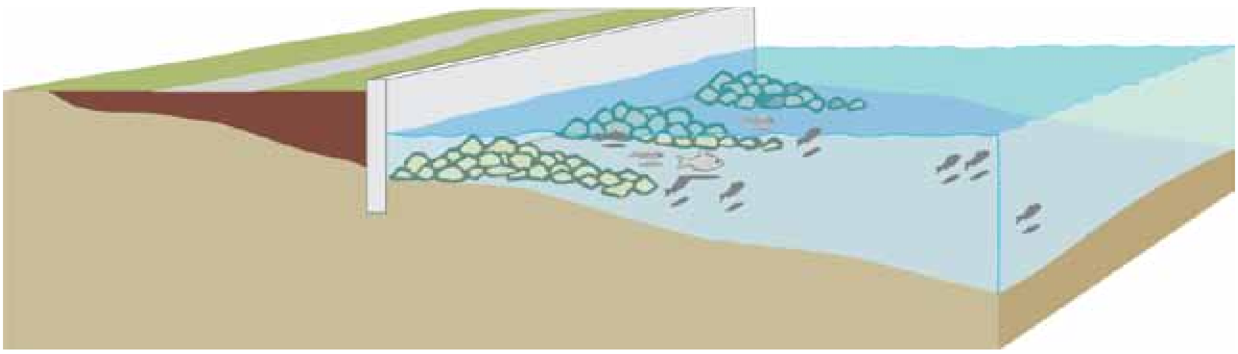

Figure 11: Boulders added as habitat clumps in front of the seawall separated by gaps.

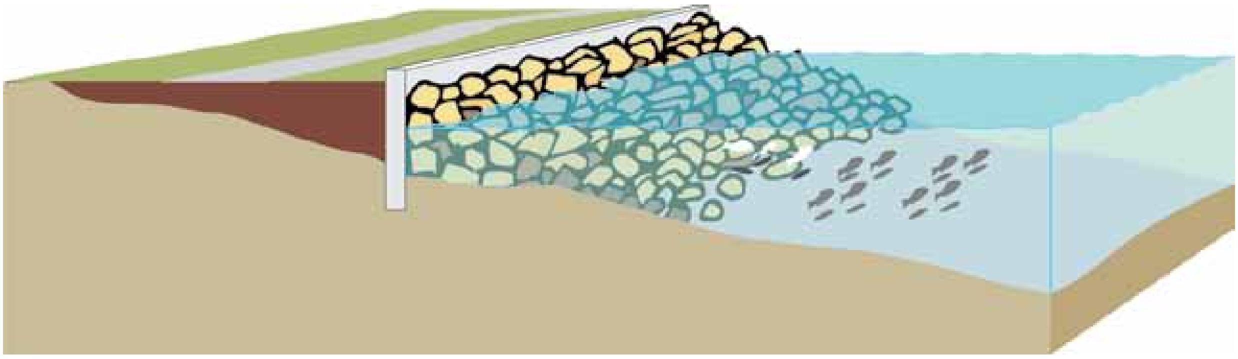

Figure 12: Boulder seawall added to near the top of existing vertical seawall to increase habitat and replace existing seawall.

Boulders have been added up to the top of an existing vertical seawall at Quakers Hat Bay, Sydney Harbour, both to improve habitat and to provide structural integrity to a degraded and failing seawall (Figure 13). A study is currently under way to evaluate the consequent ecological changes (Chapman, 2007). So far, data indicate that the crevices among the boulders do indeed support a greater abundance of animals (Chapman, 2007). Boulder seawalls have also been found to be beneficial to certain fish species, such as the mangrove jack in Queensland estuaries, which utilise the crevices between the rocks as refuge (Figure 14) (Derbyshire, 2006).

Figure 13: Before (above) and after (right) shots of seawall habitat improvement works at Quakers Hat Bay, Sydney Harbour, showing how the boulders were used to increase total habitat surface area and complexity to a traditional vertical stone block seawall.

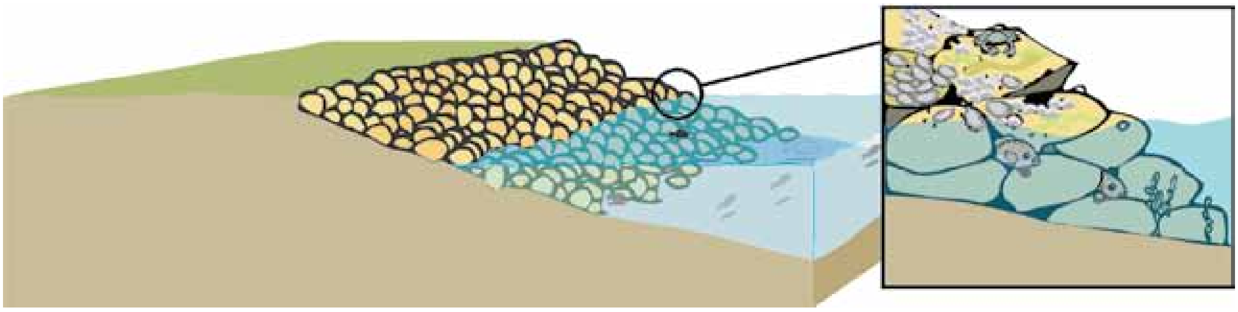

Figure 14: A boulder seawall with fish and other organisms utilising the crevices between the rocks as sheltered habitat.

The placement of artificial reefs, such as Reef Balls (http://www.reefballaustralia.com.au/), has been used to enhance the habitat along canals and seawalls, both in Australia and overseas. Reef Balls are hollow concrete structures designed to restore or create reefs for ecological enhancement and improved fishing (Figure 15). Their design allows aquatic animals to move in and out of holes, and provides places for animals to hide from predators. Their advantages include their durability and stability, which make them suitable for relatively high-energy environments, their natural appearance once colonised, their availability in a number of sizes and styles, and their capacity to enhance the local ecosystem by providing an additional substrate for settlement of epibiota that then provide a source of food for other species (Lennon, 2003). Research is currently under way on the benefits of Reef Balls in NSW estuaries as a fisheries enhancement tool (NSW DPI, 2009).

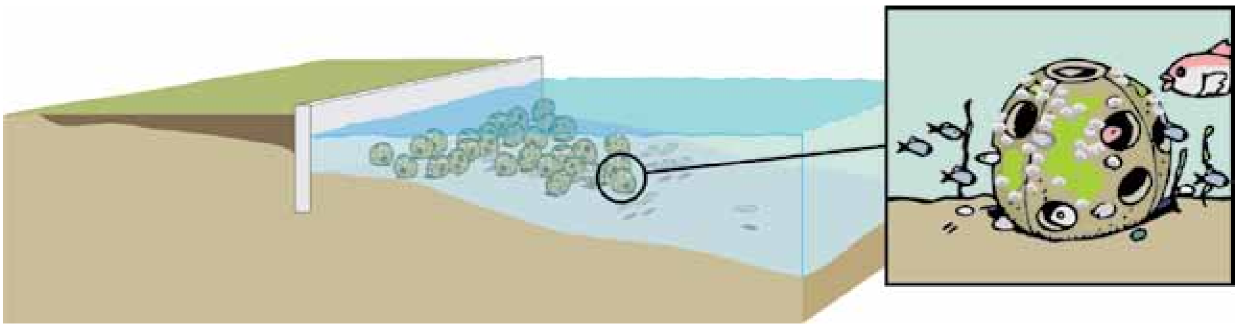

Figure 15: Reef Balls used to increase habitat in front of a seawall. Enlarged section shows colonisation by organisms and improved habitat and food availability for fish.

Reef Balls have been used to increase habitat along canals and seawalls in Mandurah in Western Australia (Lennon, 2003). Similarly, in Tampa Bay, Florida, USA, Reef Balls have been placed at the foot of seawalls in canals to provide habitat for oysters and other epibiota, which in turn provide food sources and foraging areas for fish, crabs and prawns. The hard-bottom communities formed by the oysters colonising the Reef Balls have also been found to help stabilise bottom sediments, resulting in reduced turbidity (Clark, 2000).

3.1.4 Providing variation of texture and form on the seawall surface

Increasing seawall roughness and texture has been investigated in Seattle, USA, to provide surface conditions more conducive to the growth of organisms and to increase surface area for colonisation. One of the aims was to provide additional food sources for other estuarine life that feed on the colonisers (Curtiss *et al.,* 2006).

Roughness could be added in a variety of ways to existing seawall faces, including by embedding objects such as prefabricated hollow concrete knobs (Figure 16) and adding large woody debris (Curtiss *et al.*, 2006). Weight and the potential to be damaged by floating debris may limit the use of some designs to more sheltered parts of estuaries (Curtiss *et al.,* 2006). Other options such as cutting small holes into the seawall to form crevices could be considered in solid-block seawalls where structural integrity could still be assured, as could leaving holes and cracks in degraded seawalls during maintenance (Derbyshire, 2006).

Embedding objects in the seawall and making holes and gaps in it are options best suited to the lower ends of larger river estuaries or drowned river valley estuaries such as Sydney Harbour, where aquatic diversity is greatest. However, they will still provide benefit to other estuary areas.

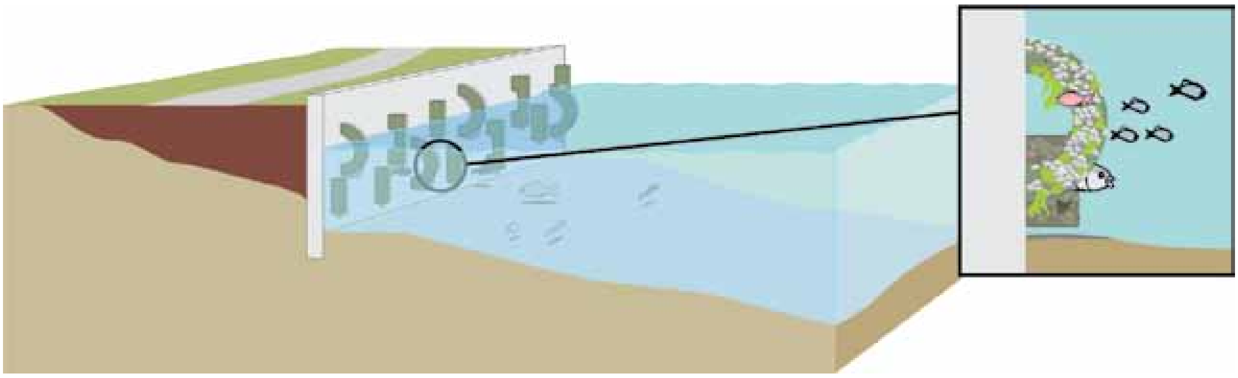

Figure 16: Objects added to a seawall to increase surface area for colonisation and usable habitat for various species.

3.2 Design principles for new seawalls

When a new seawall is planned, there is considerable scope to incorporate a number of design principles that will bring greater environmental and habitat benefits than vertical, smooth, concrete seawalls. As a general rule for all seawalls, shoreline vegetation should be retained where possible and planted where appropriate. Key principles are outlined below:

1. Decide whether a seawall is even needed, or whether other, more environmentally favourable options could be used, such as native vegetation and temporary wave barriers.
2. Maximise the incorporation of native riparian and estuarine vegetation into the structure.
3. Maximise habitat diversity and complexity by incorporating microhabitats such as pools, crevices, boulders and ledges, and by maximising surface roughness and texture.
4. Create low-sloping seawalls or incorporate changes of slope to maximise habitat surface area.

3.2.1 Is a seawall in fact needed?

When the primary reason for building a seawall is erosion control, consider 'softer' options first, such as methods utilising native vegetation. If native vegetation by itself will not be enough to stop erosion, then consider temporary structures designed for later removal once vegetation is established and the shoreline is stabilised.

One such successful method involves utilising wave barriers and estuarine vegetation such as mangroves to stabilise the shoreline. Wave barriers that have been used include 'rock fillets' (Figure 17), anchored timber logs or fences, temporary plastic mesh fencing (Figure 18) and coir logs. These wave barriers are placed roughly parallel to and about 3 to 5 m in front of the eroding bank to dissipate wave action. They are built to a height that corresponds to the mean high water level, with gaps between solid barriers to allow fish passage and natural recruitment of mangrove seedlings. They work by creating an area of still water in front of the eroding bank, which accumulates sediment and provides a habitat that is suitable for either transplanting mangrove seedlings or the natural regeneration of mangroves and other salt-tolerant plants. Once a dense stand of mangroves is established, remove the temporary wave barriers to leave only a natural vegetated shoreline. This may be more difficult with rock fillets.

This technique represents an ecological solution to the problem of bank erosion and has been used with success along the Shoalhaven, Manning and Hastings river estuaries. It has significant advantages over traditional bank protection methods such as seawalls, as the whole design is focused on establishing a wide band of mangroves in front of the eroding bank, as well as re-establishing upper bank revegetation (Skelton, 2003).

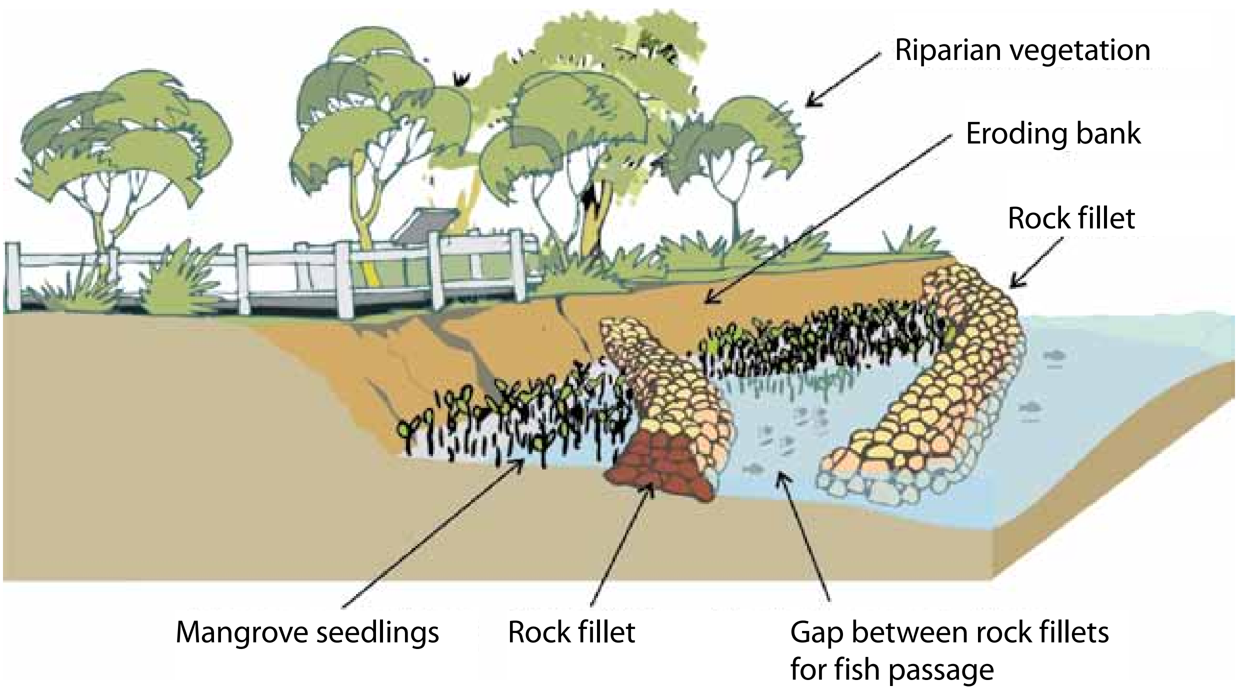

Figure 17: Placement of rock fillets in front of an eroding bank to provide shelter for establishing mangroves, and incorporation of native vegetation on the bank for further habitat and stabilisation benefits.

Figure 18: Mangrove seedlings planted in front of an eroding bank along the Shoalhaven River, with the use of temporary mesh fencing as a wave barrier and to protect establishing mangroves from debris. Photo—Allan Lugg, Department of Primary Industries.

3.2.2 Maximising the use of native riparian and estuarine vegetation

Seawalls can incorporate both native riparian vegetation behind them and estuarine vegetation within them. The technique is similar to that of the rock fillets, where a front rock barrier is used for initial shoreline protection. However, the horizontal platform of estuarine vegetation directly behind the barrier is established over a fill layer, which is then backed by further rock protection and native riparian vegetation. This creates a step-type structure that incorporates a bench of estuarine vegetation that receives either daily or less frequent tidal inundation, depending on whether mangroves or saltmarsh are to be established (Figure 19). The heights of the front rock barrier and bench need to be selected so as to provide adequate wave protection and tidal inundation. In addition, consideration should be given to sea level rise by allowing for future adjustments to be made to levels.

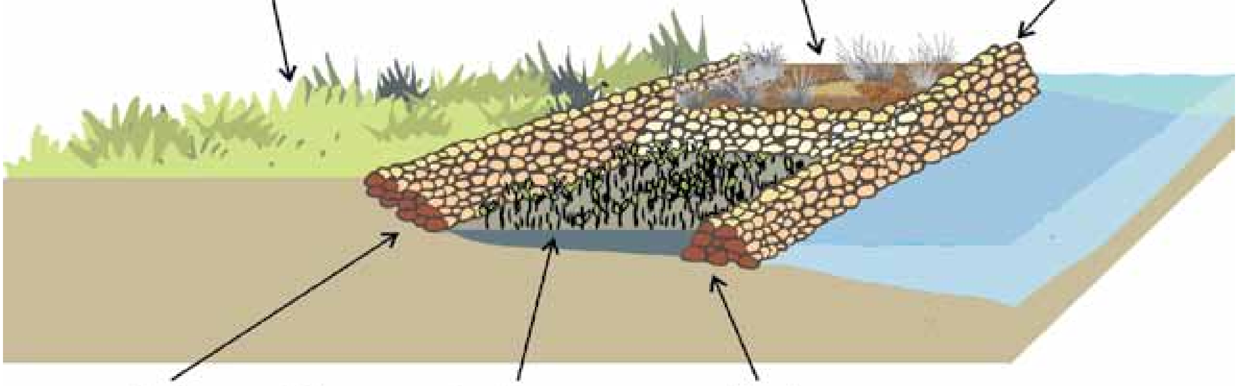

Figure 19: A step-type seawall incorporating a bench of both mangroves and saltmarsh.

There are two ways in which this type of design can be incorporated into an existing shoreline. First, always consider cutting back into the existing shoreline to create the estuarine bench so as to avoid reclamation of the intertidal and/or subtidal area. The second option involves creating the structure seaward of the existing shoreline. This approach is not suitable for many locations as reclamation may mean destroying the existing habitat seaward of the seawall. This second option may be better justified where it can be clearly demonstrated through historical aerial photographic evidence that the foreshore has eroded back over a number of years, or where significant space limitations exist, or where known acid sulphate soils must not be disturbed.

An example of where this method has been applied with good success is in Kogarah Bay, on the Georges River, where a step seawall incorporating saltmarsh was constructed to replace an existing degraded seawall with low biodiversity (Figure 20). Similar designs have also been incorporated at Pittwater and the Cooks River in Sydney.

Figure 20: Before (right) and after (below) shots of the seawall at Kogarah Bay, Georges River, showing a step-type seawall with a bench of saltmarsh vegetation.

3.2.3 Maximising habitat diversity and complexity

The physical complexity of seawalls should be maximised wherever possible to increase habitat availability and diversity. Physically complex structures offer increased opportunities for shelter of organisms and more area for colonisation, resulting in greater species diversity and abundance. Examples of how to do this are described below:

- Creating seawalls out of mixed sized and shaped boulders that are placed and keyed together without cement. This creates more habitats than homogeneous structures owing to the spaces between the boulders (Figures 21 and 22). Utilising different rock sizes and shapes will provide greater habitat diversity and a variety of different sized and shaped spaces to accommodate various species and life-cycle stages (Lennon, 2003).

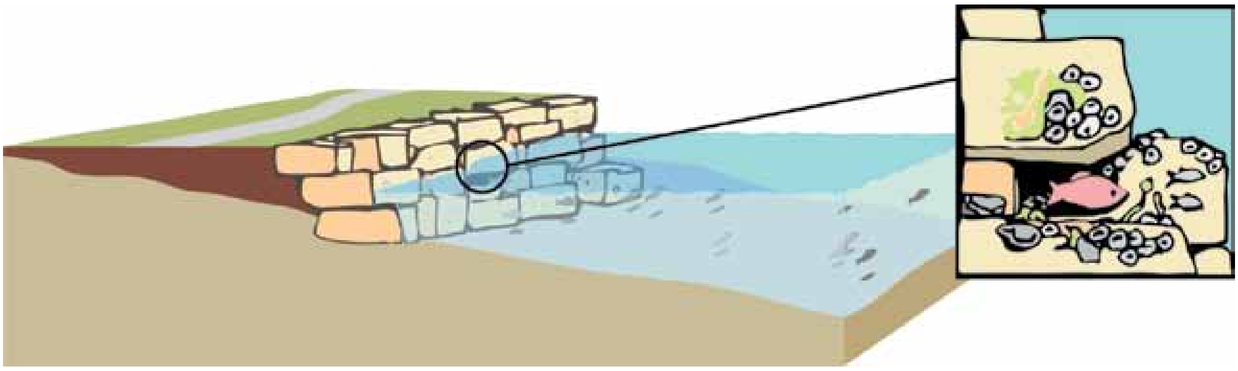

Figure 21: A seawall made from boulders of various size and shape with spaces between boulders providing sheltered habitat for organisms.

Figure 22: Example of a seawall made from boulders of various size and shape placed together without cement in McCarrs Creek, Pittwater.

- Adding cavities and pools that retain water during low tide (Figures 23 and 24). If the face of the seawall is made with cavities and holes of various sizes, these features provide sheltered habitat and increase overall surface area for colonisation. The provision of small 'rock-pools' in vertical seawalls supplies habitat for species such as sea-hares, sea urchins and octopus, which are not normally found on seawalls (Chapman, 2003).

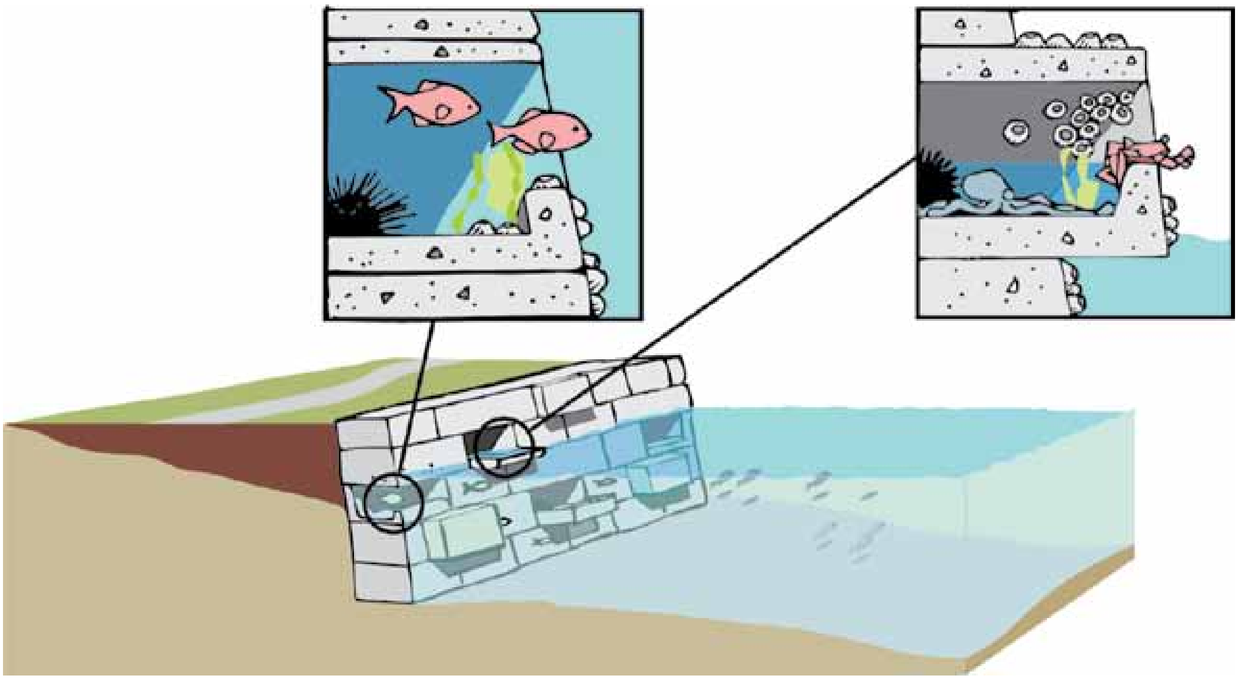

Figure 23: A seawall with blocks that extend outwards to create a varied surface, and cavities to provide sheltered intertidal-pool and subtidal-cave habitats for a variety of organisms.

Figure 24: A seawall at McMahons Point, Sydney Harbour, purposely designed to include pools in the structure for habitat, and boulders at the toe for additional habitat.

- Not cementing between blocks. This will provide crevices that can protect intertidal species (Figure 25). Where cementing between blocks is unavoidable, indenting the cement would at least allow small crevices (Derbyshire, 2006).
- Incorporating a rubble toe where a solid vertical seawall is necessary (Figure 10), which will provide reef-like habitat directly in front of the seawall, or deploying other artificial reef structures (Figure 15). However, the habitat diversity benefits that the addition of rocks and other hard artificial reef structures create need to be weighed against the possible negative impacts of loss of existing soft sediment habitat.
- Maximising roughness and surface texture variation of the seawall face. Roughness can be added by creating a seawall face with concrete panelling made from various sizes of exposed aggregate and indentations (Figure 26), by using irregularly shaped or weathered blocks (Figure 27), or by building the seawall face with protruding blocks and ledges and indented blocks (Figure 23).

Figure 25: Examples of seawalls from Iron Cove, Parramatta River (left), and the Cooks River at Tempe (below) created without cement between the blocks to leave crevices, which provide valuable habitat.

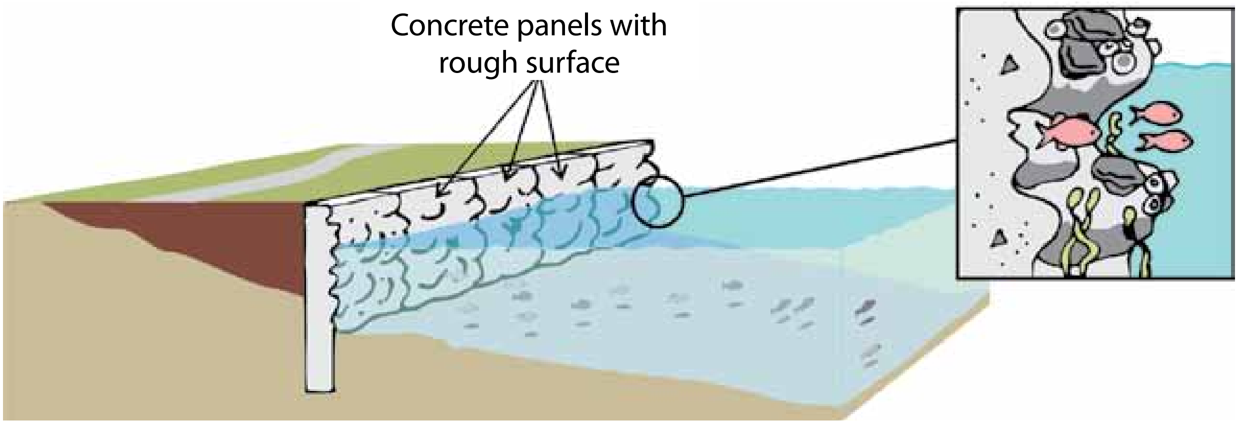

Figure 26: A seawall made from concrete panels with varied form and rough texture to increase colonisation by organisms and to enhance the overall seawall habitat.

- Building the seawall with materials most compatible with the natural environment. Materials that encourage settlement and growth of epibiota provide foraging areas for species that feed on epibiota, as well as providing natural refuge for fish. For example, natural materials such as untreated wood (Figure 28) and rocks may provide more 'natural' habitat than artificial materials such as concrete, steel and plastic (Department of Fisheries and Oceans, 2002). However, wood may be less robust and long-lasting than desired in many situations. Rocks are especially durable and stable in estuarine environments. Preference should be given to rock types found on nearby natural rocky shores. If concrete is going to be used, the surface should be made rough and textured as described above (Figure 26).

Figure 27: Example of a seawall with weathered sandstone blocks, Iron Cove, Parramatta River (right).

Figure 28: Example of a seawall made out of logs, Elvina Bay, Pittwater (left).

3.2.4 Creating low-sloping seawalls or incorporating changes of slope

The use of a gentle slope is advantageous for a variety of reasons, and is far more representative of natural intertidal shores. For maximum benefit, the gentler the slope of the seawall the better, as it will help mimic natural foreshores more closely. This can be created by using slight slopes or by including benches or steps in the seawall (Figure 29), and has been applied very successfully at Bobbin Head, Cowan Creek, in the Hawkesbury River estuary (Figure 30). As many intertidal plants and animals are affected by slope, incorporating benches and steps provides both horizontal and vertical surfaces and may lead to greater diversity of species.

Figure 29: Example of how a seawall can be created with changes in slope by including steps, helping to increase total surface area; Iron Cove, Parramatta River.

Figure 30: A seawall created at Bobbin Head, Cowan Creek, Hawkesbury River estuary, which highlights a number of the design principles discussed, including gentle slopes and a variety of habitats.

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Glossary

Anoxic	Without oxygen
Aquatic	Operating or living or growing in water
Artificial reef	Human-made underwater structure designed to provide habitat for aquatic organisms
Benthic	Bottom-dwelling
Biota	All living organisms (plants, animals etc.)
Detritus	Organic matter formed by the decomposition of plants and animals
Epibiota	Plants and animals that attach and grow on hard surfaces
Forage	Search for food
Highest Astronomical Tide (HAT)	The highest tide which can be predicted under any combination of astronomical conditions and average weather conditions. Higher tides can occur under extreme weather and ocean conditions
Homogeneous	Same, alike, or unvarying in consistency or components
Intertidal	Of the area of land between the extent of the highest and lowest astronomical tides
Introduced species	Plant or animal species that has been introduced by humans, deliberately or accidentally, to a place where it does not occur naturally
Invertebrate	An animal without a backbone
Lowest Astronomical Tide (LAT)	The lowest tide which can be predicted under any combination of astronomical conditions and average weather conditions. Lower tides can occur
Migratory waders	Birds that forage in the intertidal zones of bays and estuaries, as well as freshwater wetlands, and migrate from their breeding habitats overseas to Australia for spring and summer
Organism	Any living thing, including plants, animals and bacteria
Riparian	Land which adjoins, directly influences, or is influenced by a body of water
Seawall	Protective structures of any form built parallel to the water's edge to protect the shore and prevent inland flooding and inundation. Structures include sloping rock revetments and solid vertical and near-vertical retaining walls
Substrate	The surface on which an organism lives or grows, such as the surface of seawalls, reefs, the estuary bed or a sandy beach
Subtidal	The zone of the shoreline that is below the low tide level and is always covered by water
Terrestrial	Operating or living or growing on land
Turbidity	The cloudiness or haziness of water caused by suspended particles
Wrack	Aquatic plant matter that accumulates on the shore

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