Cardno Ecology Lab

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Marine and Freshwater Studies

Assessing and Managing the Ecological Impacts of Long-term Coastal Protection Works

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Cover Image: Natural rock revetment: Kogarah Bay, Sydney. Photograph: Cardno Ecology Lab.

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Summary

Climate change and associated sea level rise threaten coastal infrastructure around the world. The most common responses include beach nourishment and "hard engineering" solutions such as breakwaters, seawalls, revetments, and groynes. However, these often have unintended physical and ecological impacts on the coastal environment and it is important that such works are appropriately assessed to minimise environmental impacts.

The NSW Government is implementing a Coastal Erosion Reform Package which, under the provisions of the *Coastal Protection and Other Legislation Amendment Bill 2010* currently before Parliament, will allow private landholders to build emergency coastal protection works. To facilitate this, the Department of Environment, Climate Change and Water (DECCW) is drawing up guidelines for the assessment and management of coastal protection works. Cardno Ecology Lab was commissioned to provide the technical underpinning for these guidelines in relation to ecological aspects. This report reviews literature on ecological impacts of coastal protection works, identifies measures that can improve their environmental performance, specifies the minimum information needed to assess proposed works and outlines basic post-construction monitoring requirements.

The nature and extent of impacts of coastal protection works depend on a number of factors including:

- The type of protection work (e.g. seawall, beach nourishment, etc.),
- The scale of the work,
- The location of the protection work (e.g. estuary, ocean beach, etc.),
- The nature of the surrounding environment (e.g. intertidal soft sediments, rocky reef, seagrass, algal beds, etc.).

Most coastal protection works have the effect of destroying natural habitat and reducing biodiversity and recent research has focussed on increasing the structural complexity of artificial structures to enhance biodiversity. Relatively simple design considerations for structures such as seawalls and revetments can result in dramatic improvements to the diversity of plant and animal life that they can support. There has, however, been little progress in mitigating the effects of hard structures designed to arrest erosion on ocean beaches as these inevitably exacerbate the problem, necessitating further interventions such as beach nourishment or construction of groynes. In such environments, therefore, the first consideration should be to review the need for armouring and to explore alternatives.

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1 Introduction and Scope

Climate change and associated sea level rise threaten coastal infrastructure around the world. A common response to this threat is the implementation of coastal protection works such as beach nourishment or "hard engineering" solutions including breakwaters, seawalls, revetments, and groynes. Experience has shown, however, that such solutions often have unintended physical and ecological impacts on the coastal environment. It is therefore important that such works are appropriately assessed to minimise environmental impacts.

The NSW Government is implementing a Coastal Erosion Reform Package which, under the provisions of the *Coastal Protection and Other Legislation Amendment Bill 2010* currently before Parliament, will allow private landholders to build emergency coastal protection works. To facilitate this, the Department of Environment, Climate Change and Water (DECCW) is drawing up guidelines for the assessment and management of coastal protection works. Cardno Ecology Lab was commissioned to provide the technical underpinning for these guidelines in relation to ecological aspects. This report comprises the following:

- Brief desktop review of potential impacts on coastal ecosystems from a range of possible protection options including seawalls, groynes, revetments and beach nourishment,
- Specification of the minimum information and assessment requirements to be included in any environmental assessment of coastal protection works,
- Identification of possible avoidance, mitigation, rehabilitation and offset options for potential ecological impacts from different types of works,
- Identification of ecological monitoring requirements that can measure/verify impacts and define trigger points for further action in the context of consent conditions,
- Heads of consideration for consent authorities when assessing a development application from an ecological perspective.

2 Ecological Impacts of Coastal Protection Works

All coastal protection works have the potential to cause unintended impacts on the local environment. The nature and extent of these impacts depend mainly on the following factors:

- The type of protection work (e.g. "hard" structures such as seawall, or "soft" protective works such as beach nourishment),
- Scale of protection work (e.g. short vs long seawalls, groins, small vs extensive areas of beach nourishment),
- The location of the protection work (e.g. estuary, ocean beach, etc.),

- The nature of the surrounding environment (e.g. intertidal soft sediments, rocky reef, seagrass, algal beds, etc.),
- The frequency with which protective structures are maintained.

Similar structures can have different impacts depending on their location and potential impacts may be different if combinations of coastal protection works (i.e. beach nourishment and groynes) are employed.

The type of artificial structure built can influence the structure of marine and estuarine communities that develop on it. There is evidence that hard artificial structures like seawalls can facilitate the establishment of exotic and/or invasive species (Bulleri and Airoldi 2005, Glasby *et al*. 2007, Vaselli *et al*. 2008), but little evidence of invasive or pest species in soft habitats created or maintained by beach nourishment.

Because the *Coastal Protection and Other Legislation Amendment Bill 2010* will allow the construction of emergency coastal protection works, it is likely that the works would be smaller in scale than those commonly implemented on public lands. The majority of research on impacts of protective structures is derived from large-scale projects and relatively little ecological information is available on impacts of the smaller-scale structures likely to be built under the above legislation.

Whatever their scale, impacts on marine ecology can be considered on two time scales: impacts associated with their construction and those associated with maintenance of the structure. Because structures built under the *Coastal Protection and Other Legislation Amendment Bill 2010* are likely to be small in scale, it is likely they will require more frequent maintenance compared to larger-scale structures. Time scales of disturbances are important to consider because they can impact differently on marine and estuarine communities. Typically, initial impacts during the construction phase are apparent (arrival of new habitat, disappearance of other habitats, disturbance to mobile species such as fish, birds), but apart from habitat changes most are temporary. Intermittent impacts due to maintenance may be more subtle in their effects on ecological parameters such as the numbers of species present and the structure of the community. Construction impacts such as changes in habitat type are generally considered negative and long-term while intermittent impacts are considered negative but temporary (Govarets and Lauwerts 2009). However, some aspects of the change in habitat can have differential impacts on different members of marine and estuarine communities. For example, construction of training walls at the entrance of embayments that replace sand habitat required for nesting in bird species such as Little terns can lead to local reductions in population size, while increasing roosting habitats for other shorebirds. Loss of subtidal soft-sediment benthic habitat reduces food for bottom-feeding fish, but increases the populations of invertebrates that live on hard substrata, providing food for a different suit of reef-associated fish species.

The following section outlines the possible ecological impacts of the most common coastal protection works.

2.1 Loose Armour Seawalls/Revetments

Seawalls are a common form of foreshore protection and are used in estuaries and on open ocean shores to protect against erosion or as retaining walls for reclaimed land. Loose armour seawalls are made of rubble (e.g. basalt, sandstone, granite) or concrete in the form of loose units (blocks) or dolosse (double t-shaped concrete structures weighing around 20-30 tonnes). The impacts of seawalls vary depending on their location. For example, in estuaries, seawalls can alter the nature of the sediment and increase deposition of floating wrack, resulting in loss of habitat such as seagrass through smothering and creating areas of anoxic sediment (Cummins *et al*. 2004). On beaches, seawalls built to protect coastal assets often have the effect of exacerbating coastal erosion, not only in the vicinity of the structure (placement loss), but also at varying distances along the shore (Richmond *et al*. 1997, Castelle *et al*. 2008, Dugan *et al*. 2008, Lucrezi *et al*. 2010) and can result in total loss of beach habitat (Richmond *et al*. 1997). Sea walls also cause loss of habitat on the high shore which adversely affects a range of animals including invertebrates, turtles and shore birds (Dugan *et al*. 2008).

Revetments are sloping structures used to armour shorelines against erosion. They are commonly used in rivers and estuaries and may consist of natural rock or concrete arranged in steps. Although their relatively gentle slopes provide a greater area of intertidal habitat than vertical walls, they can cause a similar range of impacts to those associated with seawalls. Furthermore, if they are constructed of smooth concrete blocks or dressed stone, they also have limited potential to provide habitat for marine organisms.

2.2 Geotextile Sand Containers

Sand-containing polypropylene or polyethylene bags are usually used as temporary structures to protect coastal facilities against erosion or flooding. They have similar impacts to those of seawalls (e.g. erosion, loss of high shore habitat, etc.) and these impacts will be exacerbated the longer the sand bags are in place. Unlike solid structures, they can break apart and have very limited capacity to create habitat for marine organisms. An additional impact arises from the slow rate of degradation of the plastics, which may remain in the environment for long periods of time.

2.3 Sand Nourishment

Beach nourishment is the process by which the effects of beach erosion are countered by the periodic placement of sand from elsewhere such as offshore sand deposits or material dredged from river mouths. While sea level rise is becoming a major driver for beach nourishment works, much of the existing nourishment is necessitated by other coastal defence works, such as seawalls, groynes or breakwaters which have caused downdrift erosion (Richmond *et al*. 1997, Ruol and Tondello 2008, Lucrezi *et al*. 2010). The ecological impacts of beach nourishment include disturbance to benthic assemblages at the borrow area, smothering of beach fauna by the new material, changes in local hydrology and grain size and changes in the composition and abundance of beach fauna (Greene 2002).

2.4 Vertical or Stepped Rigid Seawalls

Many seawalls are constructed from concrete cast as blocks to form a continuous wall. Like loose armour seawalls, they replace natural habitats with structures that differ in the nature of the substratum, in particular surface texture (smooth concrete vs. sediment or complex rocky topography) and slope (vertical vs. near-horizontal) and also have less capacity to act as a buffer between aquatic and terrestrial environments. Some of these effects can be mitigated if the walls are constructed in a stepped fashion which increases the surface area available for growth of marine organisms (see Section 3).

2.5 Groynes

Groynes are used in areas where beach erosion is a problem and are specifically designed to disrupt longshore currents and trap sediment. Apart from loss of the beach habitat directly under the groyne, other impacts may include disruption of sediment supply to downstream sections of coastline and increased erosion (Ruol and Tondello 2008) and alteration of local hydrodynamics and sediment grain size which may adversely affect the abundance, distribution and diversity of beach fauna (Walker *et al*. 2008). Groynes, which may be constructed from concrete or simply piles of rocks, introduce islands of hard substrata into what would otherwise be continuous areas of intertidal sand. By removing isolating barriers, these structures provide stepping stones for the dispersal of marine biota (including invasive species) normally associated with rocky reefs (Airoldi *et al*. 2005).

2.6 Offshore Reefs and Breakwaters

Breakwaters are used to protect the entrances to harbours and in this application extend from the shoreline out to sea. They may also be constructed offshore to reduce wave attack on beaches, for example. In this case they are referred to as “detached” breakwaters and may either be submerged or emergent. These structures may be made of concrete blocks, rock piles or dolosse. Ironically, one major effect of these structures, whether attached or detached, is the creation of currents that can cause downdrift coastal erosion, often at some considerable distance from the structure. Detached breakwaters can also cause updrift erosion due to induced longshore currents. The ecological consequences include altered hydrology, which influences the dispersion of marine organisms, changes in granulometry which affects abundance and composition of fauna and loss of habitat through erosion (Ruol and Tondello 2008), and alteration of habitat by replacing soft substrata with hard structures.

3 Mitigation of Impacts

One of the most common consequences of the construction of artificial structures for coastal protection is a reduction of biodiversity. Apart from the loss of the original habitat (usually soft sediment), the nature of the materials and construction methods used produce homogeneous structures characterised by smooth surfaces with few features. Such structures have little potential to support a diversity of marine biota. Research shows, however, that biodiversity is greater on structures that provide a variety of habitats, such as crevices, holes and slopes ranging from vertical to horizontal (Chapman and Bulleri 2003). In view of this, mitigation usually involves engineering modifications that provide greater surface complexity to encourage marine growth (Chapman and Blockley 2009, DECC 2009).

When alternatives to coastal armouring, such as planting vegetation or planned retreat, have been eliminated and construction of protection works is considered the only viable option, it is essential that design criteria should incorporate measures to reduce environmental impacts as much as possible. Given the unintended ecological impacts that often result from coastal protection works, it is surprising that, until fairly recently, little consideration has been given to improving the environmental performance of coastal armouring structures. As is evident from the above, the unintended consequences of coastal protection works comprise physical effects, including disturbance during construction and subsequent erosion, and ecological effects, such as loss of habitat and displacement of fauna. The focus of this report is on the ecological effects of protection works, although it is widely acknowledged that a good understanding of local hydrology and predictions based on hydrological modelling are essential prerequisites for the approval of such works.

Ideally, coastal defence structures should comply with the following principles (Ruol and Tondello 2008):

- They should not affect (directly or indirectly) vulnerable environmental assets,
- They should not be harmful to people or marine organisms,
- They should enhance biodiversity,
- They should use environmentally friendly materials.

Most of the research on improving the environmental performance of coastal protection structures relates to relatively sheltered locations in estuaries and has focussed on increasing the biodiversity that these structures can support. Traditional construction methods have favoured smooth structures of concrete or dressed and mortared stone blocks which offer little scope for providing habitat for marine organisms. Relatively simple modifications to the design of these structures have, however, been shown to greatly enhance their capacity to provide habitat for biota (Chapman and Bulleri 2003, Chapman and Blockley 2009).

These include:

- Sloping walls (on the leeward side in the case of breakwaters) with a stepped profile which increases the intertidal area and provides horizontal as well as vertical surfaces,
- Including cavities and sills to increase surface complexity and provide a variety of habitats, some of which remain wet or full of water during low tide,
- Retaining crevices by not cementing between stone blocks,
- Utilizing natural building materials,
- Utilizing irregularly shaped blocks,
- Placing boulders or reef balls at the foot of the structure,
- In sheltered environments such as estuaries, revetments can be constructed with wide shelves on which salt marsh or mangrove trees can be established.

While the above applies to new construction, many of these measures can be implemented on existing structures during maintenance or rehabilitation work (DECC 2009).

There is less scope for mitigating the impacts of armouring placed in exposed locations such as ocean beaches. This is because these structures inevitably cause loss of habitat and enhanced erosion, not only at the point of placement, but also further along the beach. Erosion is a major problem because it necessitates additional measures such as beach nourishment and the construction of groynes or detached breakwaters (Roul and Tondelli 2008), each of which comes with their own suite of ecological impacts. Furthermore, since there is no viable way of preventing the colonisation of these hard structures by marine biota normally associated with rocky reefs (and thus exotic to beaches), the guiding principle should be to avoid such interventions as far as possible (Moschella *et al*. 2005).

Where sand containers are used, damaged bags should be periodically removed as the plastics persist in the environment.

4 Assessment of Proposed Coastal Protection Works

4.1 Information Requirements

In order to adequately assess proposed coastal protection works, the following minimum information is required:

- Location and nature of shoreline where construction is to be undertaken. This would include information on the nature of the land immediately behind and adjacent to the proposed construction (i.e. urban structures, previously reclaimed land, etc.),
- Type and extent of structure/works to be built and justification for this,
- Characteristics of the hydrology of the location (i.e. currents, tides, depth, exposure, etc.) and the probable cause(s) of erosion,
- Proximity of sensitive or threatened habitats/communities/species. The spatial scale over which sensitive ecological receptors should be identified should encompass the spatial scale over which altered physical processes have been identified, including both the source and fate of sediments,
- Assessment of the impacts of predicted alteration in hydrology including altered patterns of erosion on aquatic habitats such as seagrass, algal beds, unvegetated sediments and rocky reefs,
- Assessment of possible ecological impacts on the coastal environment during and post-construction.

4.2 Monitoring Requirements

As discussed, the emphasis in mitigating the impacts of shoreline defences in sheltered locations such as estuaries has been on increasing habitat diversity and complexity in order to support greater biodiversity. Post-construction monitoring in this context therefore entails regular assessments of abundance and diversity of marine biota colonising new structures in order to evaluate the performance of habitat enhancements.

If it is determined that construction of hard structures such as groynes is the only feasible option for armouring ocean beaches, then appropriate monitoring of the beach fauna and fauna colonising the structures should be undertaken to assess the extent of impacts on coastal biodiversity. It has been shown, for example, that invertebrates such as polychaete worms and amphipod crustaceans are good indicators of changes in hydrology and sediment characteristics following construction of low crested coastal defence structures such as groynes (Moschella *et al*. 2005, Martin *et al*. 2005).

Whether the coastal protection works are in sheltered or exposed locations, an assessment of the impacts of artificial structures requires comparisons of post-construction faunal assemblages with baseline conditions prior to construction. If ecological monitoring is considered necessary (it should be noted that this may not be required for temporary structures), this should include surveys at the construction site and at remote reference locations (Underwood 1994). Details of the design (frequency of sampling, number of locations, etc.) will depend on local conditions and management objectives and should be established on a case by case basis.

4.3 Heads of Consideration for Consent Authorities

In assessing project proposals, responsible authorities should seek answers to the following questions:

- Has adequate consideration been given to alternative solutions? This should include a risk analysis of the consequences of various options, including “do nothing”.
- Is the type of construction/intervention justified? In answering this question, proponents should consider various options such as rigid/soft intervention or innovative structures (e.g. reef balls or other habitat enhancing marine structures).
- Does the design comply with best environmental practice ? (as discussed in Section 3). For example, do the designs incorporate a variety of microhabitats such as crevices and pools? Do they slope gently rather than being vertical?

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