3.5 Rehabilitation and management of saltmarsh habitats

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Abstract

Saltmarshes grow in the intertidal zone of estuaries, marine embayments and sheltered coasts, and in Australia find their greatest floristic development in cool temperate climates. On the mainland, saltmarshes grow in sympatric association with mangroves. Mangroves dominate elevations to mean high water restricting saltmarshes to those elevations inundated by spring tides. Saltmarshes play an important and unique role in the ecology of the coastal zone, in the provision of nutrition for estuarine and nearshore fisheries, as a habitat for rare and threatened species of biota, and as a sink for atmospheric carbon dioxide. Since European colonisation of the Australian continent, saltmarshes have been in decline due to reclamation and indirect modifications to the estuarine environment. In this context, saltmarsh restoration is an important initiative, and several successful examples of saltmarsh restoration are presented. Saltmarsh restoration and creation is most successful where due consideration is given to the relationship between marsh surface elevation and the tide, so that natural seeding and growth of saltmarsh is enhanced, and mangrove encroachment minimised. Climate change will provide an additional stress on saltmarsh over coming decades, promoting the further colonisation of saltmarsh by mangrove. Saltmarsh survival will be contingent upon appropriate buffers being set to accommodate landward retreat.

Introduction

Saltmarshes occur on coastlines the world over, though are more developed in temperate coastlines where mangroves are less dominant. The Australia saltmarsh flora has many affinities to saltmarshes on other continents, most notably those linked by a common Gondwanan ancestry, including New Zealand, South Africa and temperate South America, though the majority of saltmarsh species are endemic (Adam 2009). Australian saltmarshes are diverse compared to mangrove communities on the continent: more than 100 species occupy Australian saltmarshes, three times the number of mangrove species. Saltmarsh diversity increases with latitude, as mangrove diversity decreases.

The distribution of saltmarsh species on the Australian continent shows marked regional patterns. The primary demarcation is between a northern (tropical) and southern (subtropical-temperate) saltmarsh flora, separated by the tropic of Capricorn (230° 30'S). These two provinces have only one quarter of species in common. Finer patterns of biogeography are discussed in Saintilan (2009a), which presents a table of saltmarsh flora found in each of 36 coastal bioregions. It is important in conducting restoration programs to carefully consider the flora characteristic of the region.

While diversity may be high, particularly at higher latitudes, saltmarshes are dominated by a few easily recognised species. The grass *Sporobolus virginicus* commonly encountered across most of the continent, often growing in association with the chenopod succulent *Sarcocornia quinqueflora* (Figure 3.5.1). The native rush *Juncus kraussii* is indicative of less saline conditions. These three species dominate the saltmarshes of the east coast. On southern shorelines, larger chenopod shrubs of the genus Tecticornia (incorporating *Halosarcia* and *Sclerostegia*) become more important, dominating the structure of the lower saltmarsh.

Saltmarsh distribution in the coastal zone is an outcome of the interplay of geomorphology, tidal hydrology and competition. On open coasts, saltmarshes develop where wave action is attenuated, as occurs, for example, on the leeward side of sand islands in Southeast Queensland, and in upper intertidal environments on shallow tropical macrotidal coastlines, and on the shores of mesotidal marine embayments in Victoria and South Australia (Saintilan and Rogers 2013). Within estuaries, saltmarsh distribution is determined by the type of estuary and the stage of estuary infill (Roy *et al*. 2001). Estuaries with sand barrier entrances often have restricted tidal range, though their periodic closure may restrict the development of mangroves, allowing saltmarsh to dominate shorelines. Large drowned river valleys often support a range of geomorphic settings occupied by saltmarsh, from marine deltaic sands near the mouth to fluvial brackish silts in the prograding fluvial delta. The saltmarsh species occupying these environments will often differ. For example, in the Hawkesbury estuary, fluvial deltaic saltmarshes are dominated by the rush *Juncus kraussii*, while the deltaic sands support the *Sporobolus virginicus*/*Sarcocornia quinqueflora* association.

Saltmarshes co-exist with mangroves on Australian shorelines with only a few exceptions. Mangroves are absent from Tasmania, may be excluded from estuaries periodically closed and flooded, and from some arid shorelines in Western Australia. Elsewhere mangroves occur where intertidal shorelines are inundated daily or near daily by the tide. Mangroves out-compete saltmarsh in these locations, and so Australian saltmarshes are

Figure 3.5.1. Saltmarsh occupying the upper intertidal zone, with mangrove in the background. Species present are *Sporobolus virginicus* and *Juncus kraussii*.

mostly restricted to upper intertidal environments, inundated during the monthly spring tide cycle. This distinguishes many of the ecological processes of mangrove and saltmarsh in Australia.

Ecological Function and Utility of Saltmarsh

Saltmarshes provide a diverse array of ecological goods and services to the coastal zone, including the support of fisheries, contributions to biodiversity, and carbon sequestration. Recent research in Australia has begun to quantify these benefits, and provide some indications of how these vary between geomorphic and geographic settings.

Saltmarshes are flooded by the spring tide, and fish visiting saltmarsh are therefore itinerant, spending most of their time in other parts of the estuary. The saltmarsh fish community is dominated by small fish of the families Ambassidae, Atherinidae and Gobiidae (Connolly 2009), though several species of commercial significance are also found in the saltmarsh (Mazumder *et al*. 2006a; Connolly 2009). There is some evidence to suggest that most of the smaller fish and crustaceans may move into the mangrove and saltmarsh from adjacent environments, including seagrasses occupying shallow permanently inundated estuarine waters (Saintilan *et al*. 2007; Jelbart *et al*. 2007). An important implication of these observations is that the maximum benefit of a saltmarsh to fish occurs as a result of its position within a mosaic of vegetated estuarine habitats. The restoration of saltmarsh might achieve the greatest fisheries benefit where located near seagrass, or if conducted in association with seagrass restoration where appropriate.

One of the distinguishing characteristics of saltmarsh is the periodic high density of crab larvae made available during the spring tides, especially the highest astronomical tides of winter. Crabs release larvae on mass (Mazumder *et al*. 2006a; 2009), contributing to the highest density of zooplankton found within the estuary (Figure 3.5.2), and this provides a unique feeding environment for fish (Mazumder *et al*. 2006a; Hollingsworth and Connolly 2006). The most intensively studied saltmarsh in NSW is located at Towra Point, within Botany Bay. Within the Towra Point saltmarsh, the saltmarsh crab fauna is dominated by *Helgrapsis haswellianus*, and this species should be considered foundational to the restoration of fisheries values associated with saltmarsh. Opportunities for crab re-establishment can occur simultaneously with saltmarsh vegetation re-establishment, as the vegetation only forms a minor part of their diet (Alderson *et al*. in press).

In addition to the role played by saltmarsh in providing nutrition to fish within the estuary, saltmarshes provide a unique habitat for many plants and animals. These include threatened species of plants (e.g. *Wilsonia backhouseii*), the

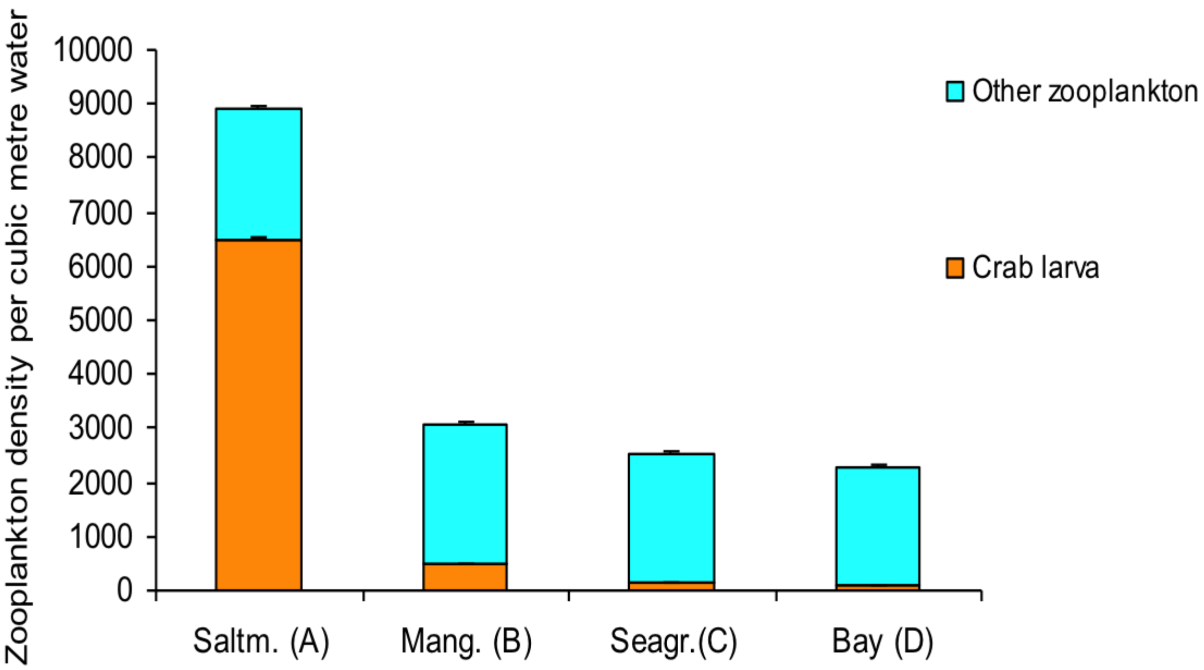

Figure 3.5.2. Density of zooplankton in estuary waters, from the saltmarsh to the bay on the Spring tide, Towra Point. Adapted from Mazumder *et al*. 2009.

eastern grey kangaroo (*Macropus giganteus*) and swamp wallabies (*Wallabia bicolour*) which most probably graze on the grass *Sporobolus virginicus*. Laegdsgaard *et al*. (2004) detected eight bat species within saltmarsh including three threatened species, and bats demonstrate a higher proportion of feeding buzzes in saltmarsh compared to other habitats (Gonsalves *et al*. 2013). Saltmarshes also provide habitat for endemic threatened species of birds, such as the white-fronted chat (*Epthianura albinfrons*) and the orange-bellied parrot (*Neophema chrysogaster*) and a drought refuge for colonially nesting shorebirds (Spencer *et al*. 2009). However, probably the most important role of saltmarsh, given Australia's international treaty commitments, is the provision of habitat for migratory shorebirds. Many of these species roost in saltmarsh, particularly at night, taking advantage of shallow pools for protection and supplementary feeding environments (Spencer *et al*. 2009). Thought should be given to the preservation of these habitats in the face of climate change and estuary development.

Recent attention has focussed on the contribution of saltmarshes to carbon sequestration. "Blue Carbon" is a term given to the contribution of coastal and marine ecosystems, primarily mangrove, saltmarsh and seagrass, to carbon capture and storage. Taking measures from saltmarshes across several sites in SE Australia, Saintilan *et al*. (2013) demonstrated a high carbon store in saltmarshes, particularly those dominated by *Juncus kraussii*, where the carbon it the top metre of sediment was approximately 300 tonnes per hectare. Most of this carbon is lost to the atmosphere if the wetland is drained. Left in their natural state, these saltmarshes continue to accumulate 2 tonnes per hectare per year. Saltmarshes dominated by *Sarcocornia quinqueflora* and *Sporobolus virginicus* typically have lower carbon stores and accumulation rates (about one third that of *Juncus kraussii*), though still higher than most terrestrial ecosystems. Blue Carbon represents an important incentive for wetland preservation, and with the further development of carbon markets could become a tradable commodity.

In light of the important ecosystem services provided by saltmarsh, it is concerning that saltmarsh extent has declined across Australia since European colonisation. Historical accounts of early shoreline flora at the time of first settlement suggest shorelines were dominated by saltmarshes (McLoughlin 2000). The gradual replacement of saltmarsh by mangroves therefore has a long history, at least on the east coast. A century or more of tidal flat reclamation up until the 1970s saw many saltmarshes reclaimed for sporting fields, residential and industrial development. The area lost has never been quantified, though estimates have been as high as 74 percent (Finlayson *et al*. 1999). The pattern of saltmarsh decline to mangrove demonstrated from the analysis of aerial photography, perhaps has high as 30 per cent saltmarsh decline since 1940, therefore occurs against a backdrop of saltmarsh reclamation and loss from the end of the eighteenth century. Our current saltmarshes, particularly on developed coastlines, are small remnants of the original extent. The focus should therefore be on protection and restoration.

Figure 3.5.3. Off road vehicle damage, caused by a single pass of a four-wheel drive (Jervis Bay).

Several threats to saltmarsh remain in the 21st century. Several species of invasive weeds are slowly gaining ground in Australia. Spartina anglica was introduced in southern Victoria and Tasmania to promote shoreline stabalisation, in that the species can occupy lower elevations than native saltmarshes. It has established on some shorelines, such as the Tamar estuary in Tasmania, though its expansion to estuaries other than those to which it was introduced had been slow. A more aggressive coloniser has been the introduced rush *Juncus acutus*. *Juncus acutus* forms thick, nearly impenetrable stands with pungent tips, crowding out the native Juncus and any other species of saltmarsh. It has quickly spread in many developed estuaries taking advantage of disturbed conditions. Techniques for the eradication or control of Juncus acutus are described below.

More local impacts on saltmarshes include off-road vehicle use and fire. Kelleway (2006) reviewed the ecological impacts of off-road bikes on saltmarshes in the Georges River catchment demonstrating the denudation of the saltmarsh over 21 hectares and alterations to hydrology promoting the breeding of mosquitoes and mangrove encroachment. Saltmarsh rushes are highly flammable, and inappropriate fire regimes have the potential to permanently damage the landward fringe of the saltmarsh. There are examples of extensive estuarine shorelines in NSW being damaged through inappropriate application of control burning, the southern shore of Batemans Bay being a recent example.

Saltmarsh restoration: recent success stories

While the long-term trend for saltmarsh in NSW has been one of decline, it is heartening to consider the success of several saltmarsh restoration programs conducted in urban and peri-urban environments in Australia over recent years. The largest of these in terms of area of saltmarsh reclaimed have been tidal reintroduction programs in NSW estuaries, including the Hunter and the Macleay. In the 1950s and 1960s large-scale flood control works were installed in several estuaries on the Australian east coast, designed to minimise the disruption caused by lowland flooding. A consequence of these levees was the conversion of wetlands from saltmarsh and mangrove to freshwater reed-swamp or marginal agricultural land (Winning and Saintilan 2010). This conversion led to many deleterious environmental outcomes, including the production of acid sulphate soils, the development of wetlands characterised by high methane emissions, and the loss of biodiversity and fisheries benefits associated with healthy mangrove and saltmarsh.

Saltmarsh restoration can be as simple as re-landscaping estuarine foreshores to facilitate tidal inundation. Recent examples include the establishment of saltmarsh on the banks of Wolli Creek and the Cooks River at Steel Park, Marrickville, and Turella Creek under the Cooks River Urban Water Initiative. The Steel Park saltmarsh restoration involved the removal of a section of the seawall and lowering of the adjacent park surface to allow tidal flow during spring tides. The aim was to allow inundation from only those tides required by saltmarsh, thereby limiting opportunities for mangrove colonisation.

A further step towards restoration may involve the removal of concrete storm water drains and their replacement with a more natural creek-line, with the associated restoration of ecological function. Case Study 1 presents some of the lessons learnt in the restoration of tidal creeks at Sydney Olympic Park. Modifications to a tidal channel was also required in the restoration of the Eve Street saltmarsh near the mouth of the Cooks River, Sydney. Here, a tidal channel connecting the saltmarsh and mudflats to the Cooks River silted up over time, impeding tidal exchange and causing the conversion of saline tidal wetland to freshwater pools. This reduced the suitability of the habitat for several species of migratory shorebird that utilised the site. The tidal channel was re-contoured and a blocked pipe was cleared of sediment using a water cannon. These simple measures have allowed the re-introduction of the tide and improved foraging habitat for Eastern Curlew (*Numenius Madagascariensis*) and the Broad-Billed Sandpiper (*Limicola falcinellus*).

On a larger scale, restoration may extend to entire estuarine floodplains previously isolated from the tide by levee banks. Examples include the Yarrahapinni wetland on the Macleay, and the Tomago, Hexham Swamp and Kooragang wetlands on the Hunter River. In each of these environments, staged tidal reintroduction has commenced. This process has typically involved (i) the purchase and incorporation of additional lands into the reserve system (ii) the installation of regulators to control tidal flow, (iii) improvements of levees surrounding the wetland to avoid inadvertent flood damage, and (iv) hydrodynamic modelling of inundation extent. Tidal reintroduction is often staged to reduce private property flood risk and calibrate hydrodynamic modelling. Case Study 2 features the Smart-gate technology used in the rehabilitation of the Tomago Wetlands.

The experience at Yarrahapinni, Kooragang, Tomago and Hexham is that flooding extent can be predicted and controlled through staged tidal reintroduction, and that over time freshwater wetlands convert back into saltmarsh and mangrove through natural seeding. Manual planting is not required. However, tidal levels need

Case Study 1: Regeneration of coastal saltmarsh at Sydney Olympic Park—the importance of soil conditions

Swapan Paul, Sydney Olympic Park Authority

Over the past decade or so, several hectares of Coastal Saltmarsh have been regenerated within Sydney Olympic Park. Recently, more than two hectares of coastal saltmarsh has been re-established on the banks of Haslams Creek, giving the chance of further viability of this Endangered Ecological Community in Homebush Bay region. In the late 1990s, a concrete-lined stormwater channel was removed and a new creek bed constructed in its place. It was edged with terraces built at elevations designed to suit saltmarsh. Saltmarsh established well on the western side of the new creek, but large parts of the eastern embankment remained bare. This was primarily because the topsoil that was chosen for saltmarsh to establish, was very poor in its suitability for saltmarsh. The eastern bank largely contained rocks and rubbles, and sand-dominated but organic-matter deficient soil. As a result, the water-holding capacity, nutrient-contents and porosity of the soil was unsuitable for saltmarsh.

Before attempting to replace this unsuitable topsoil, experimental field trials were conducted between 2003 and 2007 to determine the most cost-effective but sensible way to establish saltmarsh across this large area. Trials concluded that poor soil quality was inhibiting saltmarsh establishment and that soil would need to be either replaced or ameliorated for saltmarsh to grow. Replacement of the top soil would have been effective but no doubt a very expensive exercise. One of the experiments has proven that application of mulch (in this instance mangrove mulch) was suitable to improve soil quality and permit self-germination (Paul and Farran 2009).

Following this experimental outcome, the area was progressively ameliorated in three batches over three years. The bare areas of the embankment were ploughed, rock-rubbles larger than tennis ball size were removed and mangrove mulch was mixed into the top 100mm of the soil. In the first year, local seeds were collected and spread over certain areas; however, in the next years natural colonisation by tidal-borne seeds provided the greatest source of regeneration. Coastal Saltmarsh germinated across the rehabilitated area in spring 2008 and by the following two consecutive years, a dense Coastal Saltmarsh cover has established. In addition to the vegetation re-establishment, the areas are now colonised with saltmarsh crabs, as evidenced by the presence of live crab holes.

In terms of cost-effectiveness, compared with topsoil replacement for re-establishing saltmarsh in nearly 20,000m^2 areas, the soil amelioration expense was less than 2%, marking a tremendous win-win for saltmarsh regeneration.

Figure 1a. Before regeneration.

Figure 1b. After regeneration.

Case Study 2: Tidal reinstatement at the Tomago Wetland, Lower Hunter River estuary

The Tomago wetland is situated on the northern shore of the lower Hunter River estuary, covering an area of some 450 hectares. Between 1968 and 1980 a series of levee banks and drains were used to isolate the wetland from tidal inundation, with the purpose of agricultural protection and flood mitigation for the city of Newcastle (Russell *et al*. 2012). Over time the original mangrove and saltmarsh was replaced by freshwater wetlands including *Phragmites australis* and *Casuarina glauca* forest, along with saline pasture grasses. In 1983, the Tomago Wetland was gazetted as a component of the Koorgang Nature Reserve, and a decade later, in 1993, work commenced to rehabilitate the tidal wetlands (Russell *et al*. 2012). Restoration sought to achieve several ecological outcomes, including the provision of night roosting habitat for shorebirds, improvement of fish passage, and the restoration of a mosaic of estuarine ecosystems, though encouraging saltmarsh colonisation over that of mangrove.

Hydrodynamic modelling in the nearby Kooragang Island by Howe (2008) has suggested that saltmarsh is prone to mangrove colonisation if inundation depth exceeds 0.3 metres on the spring tide. With this threshold in mind, the Water Research Laboratory at UNSW developed hydrodynamic models to determine the optimal flood tide flow to achieve saltmarsh restoration without mangrove colonisation. For the initial (western floodplain) tidal re-introduction, a one-dimensional hydrodynamic model was used, and calibrated using trial openings of the floodgates. With the provision of Lidar-derived elevation models in 2010, a two-dimensional model was constructed in the Mike Flood software environment to guide the further restoration (Stage 2 and 3) of the eastern floodplain (Raynor and Glamore 2011).

These models demonstrated the viability of saltmarsh re-establishment using carefully controlled floodgates. For the western floodplain (stage 1), SmartGates were installed to regulate flow. The SmartGate monitors hydrological conditions in real-time using a data-logger, and is able to open or close when pre-determined conditions are reached. Thresholds and trigger points can be changed using remote telemetry. For Stages 2 and 3, a novel SwingGate was designed to passively close at a threshold flood tidal level, and open for the ebb tide. The SwingGate maintained flow at levels beneficial to fish passage at low turbulence (Russell *et al*. 2012).

Monitoring is being led by staff of the NSW Parks and Wildlife Service, and consists of water quality measures, assessment of inundation extent and periodic surveys of biotic response. An innovative component of the monitoring is a fixed camera situated on top of an 18m pole, taking images 5 times each day, and suitable for the interpretation of tidal inundation, geomorphic evolution and bird counts in the vicinity. Images are available from the website: www.wrl.unsw.edu.au/site/projects/tomago-wetland-remote-monitoring

Even in the early stages of restoration ecological outcomes have been achieved, including the return of migratory birds to the site (Russell *et al*. 2012). Observations by the Hunter Bird Observers Club have identified roosting and/or feeding by Black-winged stilt (*Himantopus himantopus*), Sharp-tailed sandpipers (*Calidris acuminate*), Black-fronted Dotterels (*Elseyornis melanops*) and Red-kneed Dotterels (*Erythrogonys cinctus*).

to be carefully controlled if the restoration goal is the creation of saltmarsh rather than mangrove. Several other wetlands on coastal floodplains show potential for conversion back to saltmarsh and mangrove, though some impediments remain. In some locations, the passage of time has led to the creation of freshwater wetlands of ecological significance, such as the Coastal Swamp Oak Floodplain Forest Endangered Ecological Community, or habitat for threatened species of frog, such as the Green and Golden Bell Frog (*Litoria aurea*). Decisions concerning tidal reintroduction in these settings need to occur in the context of estuary-wide management targets for the range of ecological services provided by coastal and freshwater ecosystems.

In many urban estuaries, saltmarshes have been created by local councils and management authorities to promote environmental and recreational amenity. Sydney Olympic Park Authority has long been a proponent of saltmarsh restoration, with several created saltmarshes providing ecological benefits in the Powells Creek, Haslams Creek and Newington Nature Reserve wetlands. Monitoring at these sites have demonstrated that fish visit these wetlands, and derive nutrition from saltmarsh infauna (Saintilan and Mazumder 2005; Mazumder *et al*. 2006b). The implication is that saltmarsh creation at the site has led to the restoration of ecosystem function within 15 years of establishment. Other created saltmarshes in the Sydney region include several projects under the Cooks River Urban Water Initiative, compensatory habitat relating to the Port Botany expansion, and the restoration of saltmarsh on the Kurnell Peninsula.

A significant challenge in many created saltmarshes has been the management of exotic weeds, principally the invasive rush *Juncus acutus*. Sydney Olympic Park Authority experimented on the efficacy of control methods (Paul 2006; Paul and Young 2006). Physical removal of the whole plant was the most effective treatment, but labour intensive. Glyphosate (50:1) was effective in killing *Juncus acutus*, but only when applied to the whole plant. Cutting the plant at the base did not prevent resprouting. Once removed, mulch was found to be effective in reducing the rate of seedling regrowth. They found that native species of saltmarsh were able to naturally seed into environments previously occupied by *Juncus acutus*, but that ongoing maintenance and seedling removal were required over several years to prevent reinfestation.

Lessons Learnt in Saltmarsh Restoration

After several decades of saltmarsh restoration effort, important lessons have been learned. These may be summarised as follows:

- The key to success is managing inundation frequency. Saltmarsh will flourish if the flat is inundated by spring tides. If inundated daily, mangroves will over time replace saltmarsh, and if inundated too infrequently terrestrial glycophytes will invade.
- Manual seeding of saltmarsh is generally not required, given the speed with which native saltmarsh plants will colonise areas of suitable tidal hydrology. Substrate is not an issue, as saltmarshes will colonise surfaces ranging from pure sand to estuarine muds, and from hypersaline to brackish salinities. Manual plantings are of varying success, and add an expense to projects which may not be justified in most cases.
- Where saltmarsh flora has been restored or created, the ecological services provided by saltmarsh have generally followed, for example, in the provision of bird habitat or the restoration of fisheries values.
- Created saltmarshes should be situated where landward retreat is possible. Creating saltmarshes against hard barriers will condemn them to drowning within the next 100 years, unless the intention is to provide supplementary sediment on an ongoing basis.

Management of Saltmarsh

While the recent successes in the restoration of saltmarsh have provided grounds for optimism, by far the most effective means of preserving the benefits provided by saltmarsh is protection in legislation and policy. Important progress has been made in recent decades and most Australian states and territories have measures in place to control the reclamation and loss of saltmarsh. In NSW, State Environment Planning Policy 14 (Coastal Wetlands) has effectively slowed the rate of reclamation since the early 1980s. More recently, coastal saltmarsh was declared an Endangered Ecological Community under the *Threatened Species and Conservation Act* 1995. In Queensland, the *Fisheries Management Act* 1994 provides protection for all marine plants, irrespective of tenure, below the highest astronomical tide. In South Australia, Victoria, Western Australia and Tasmania saltmarshes are protected on Crown Land, and in local and regional planning instruments, though without the legislative protection afforded in NSW and Queensland. This may soon be rectified under a proposal to list coastal saltmarsh south of the Tropic of Capricorn as a Threatened Ecological Community under the *Commonwealth Environment Protection and Biodiversity Conservation Act* 1999.

Risk Factors

However, listing under threatened species legislation does not protect saltmarshes from several key threats. Saltmarshes in urban settings still require protection from off-road vehicle access. This may involve a co-ordinated program of signage, community education, gating and the provision of alternative venues for trail bike riding. Education may also be required to protect saltmarsh from inappropriate control burning, given the extent of damage in recent years in several estuaries near urban centres.

A more profound and intractable threat is posed by anthropogenic emissions of CO_2 and associated climate change. There are several mechanisms by which we have altered the environment to the benefit of mangroves and at the expense of saltmarsh (McKee *et al*. 2012). Elevated levels of CO_2 in the atmosphere are likely to make mangroves better able to survive in the water limited environment of the saltmarsh flat (Saintilan and Rogers 2013). Higher temperatures favour mangroves over saltmarsh, several species of which may be intolerant of higher temperatures (Saintilan 2009b). Higher sea-levels and coastal rainfall are likely to be contributing to mangrove encroachment in SE Australia and Queensland respectively (Rogers *et al*. 2006; Eslami-Andargoli 2009). The transition from saltmarsh to mangrove in temperate and subtropical settings is a global trend (Saintilan *et al*. in press), likely to continue through the coming centuries.

An effective response to the pressure of climate change requires a long-term view and a whole-of-landscape approach. Unfortunately, our static planning mechanism, in which wetlands are defined in perpetuity as polygons on a map which are afforded special protection, is singularly ill-suited to wetland conservation in the face of climate change. Wetlands are four dimensional entities, changing their position over time in response to external stressors (Rogers *et al*. in press). Their long-term survival in the face of sea-level rise will require the development of appropriate buffers into which they can migrate. We now have tools that allow us to more accurately predict the redistribution of mangrove and saltmarsh over the coming century (Rogers *et al*. 2012), and these need to be applied more broadly to inform coastal planning for critically important coastal ecosystems.

Figure 3.5.4. Mangrove encroachment on saltmarsh, Tweed River NSW.

In some places the control of mangrove may be warranted, for example in the protection of important, fixed rookery sites within estuaries. The removal of mangroves from the Stockton Sand Spit on the Hunter is an example of relatively inexpensive mangrove control for an important ecological outcome for migratory waterbirds. However, in most cases the physical removal of mangroves for the protection of saltmarsh is expansive and unsustainable. Mangrove encroachment is a natural phenomenon, and may provide benefits in shoreline protection and carbon sequestration that could in the long-term be of significance to adaptation and mitigation. As previously argued, the most effective means of adaptation for wetlands is to allow natural retreat, a program that demands appropriate and informed coastal planning at the earliest opportunity.

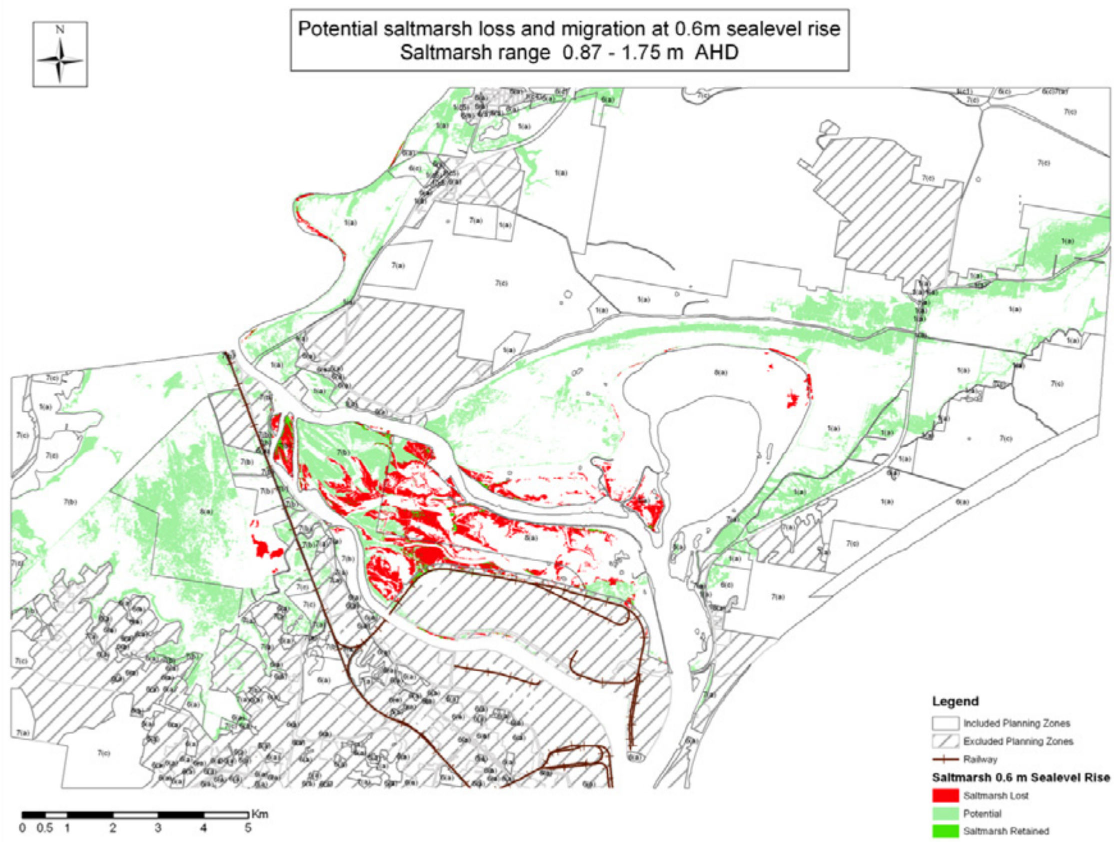

Figure 3.5.5. Projected distribution of saltmarsh in the lower Hunter estuary under a scenario of 0.75 metre sea-level rise to 2100. Based on Rogers *et al.* (2012).

Monitoring and Assessment

There are several reasons to monitoring saltmarsh condition and extent as a guide to management. At the broadest level, saltmarsh extent can be an important indicator of estuary condition, and for this reason saltmarshes have been incorporated into the estuarine Monitoring Evaluation and Reporting (MER) strategy in NSW. At a project scale, wetland restoration will require vigilance for the identification and removal of invasive weeds, most notably *Juncus acutus*. Early detection and removal of this species more than justifies the cost of project-scale monitoring. Monitoring has been an important component of staged tidal reintroduction, ensuring that private assets are protected and improving the accuracy of hydrodynamic models predicting inundation extent.

The monitoring of ecosystem services in selected locations provides important information informing management priorities. One of the as yet unquantified benefits of reinstatement of tidal flows is the carbon sequestration and emissions benefit of conversion from reedswamp to mangrove/saltmarsh. Methanogenic bacteria are more prevalent and freshwater and brackish settings, and the artificial freshwater wetlands created behind levee banks on coastal floodplains are likely to be strong emitters of methane, given their high organic content and suitable geochemical/bacteriological conditions. Saltwater wetlands are net carbon sinks, but the real benefit of tidal reinstatement to carbon budgets is likely to be the combination of reducing methane emission and the sequestration of carbon by saline wetlands. A demonstration site would be of international relevance in determining emissions factors associated with the conversion of freshwater to saline wetland. With the further development of carbon markets, tidal reintroduction projects would provide an income based on quantifiable carbon emissions offsets, providing an additional incentive for wetland restoration in Australia and internationally.

Summary/Conclusion

Saltmarshes provide important ecosystem services in the coastal zone of Australian estuaries and embayments. Their inundation characteristics contribute to the provision of services to estuarine and nearshore fisheries. They provide a net export of carbon on the spring tide through the production of crab larvae, relayed by zooplanktivorous fish to estuarine and marine ecosystems. They provide an important habitat for a range of fauna including threatened species of microbats, migratory and endemic birds, and rodents. They are efficient carbon sinks, sequestering carbon at a rate greater than attained by any terrestrial ecosystem.

Given the importance of these ecological services, the rate of saltmarsh loss in Australia since European colonisation has been alarming. After two centuries of saltmarsh reclamation and degradation, we are left with a remnant of the original extent, particularly on urban coastlines. In recent decades, several projects have demonstrated the success of saltmarsh restoration and creation. Tidal reintroduction has converted degraded freshwater wetland into saltmarsh and mangrove on several east coast estuaries. In urban settings in the Sydney region, several saltmarshes have been created, resulting and the natural colonisation of saltmarsh species and associated saltmarsh fauna and ecosystem processes.

Long-term protection and restoration of saltmarsh will require a combination of saltmarsh restoration and creation, legislative protection and coastal landuse planning. Legislation alone is not sufficient to protect saltmarsh in the face of climate change, given the dynamic nature of wetland boundaries under this stressor. The availability of Lidar in coastal environments, and modelling tools that allow prediction of habitat extent with sea-level rise, should be informing coastal planning so that options for natural retreat are not eliminated.

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