Wetlands Ecology and Management (2006) 14:379–399
DOI 10.1007/s11273-005-8827-z

Ecology, disturbance and restoration of coastal saltmarsh in Australia: a review

Pia Laegdsgaard*
*Department of Infrastructure, Planning and Natural Resources, P.O. Box 2185, Dangar, NSW 2309, Australia; *Author for correspondence (e-mail: pia.laegdsgaard@dipnr.nsw.gov.au; phone: +61-2-4960-5029; fax: +61-2-4960-5055)*

Received 10 September 2004; accepted in revised form 12 December 2005

Key words: Conservation, Creation, Disturbance, Rehabilitation, Restoration, Saltmarsh

Abstract

It is clear that saltmarshes are a unique and important component of the coastal biosphere of Australia. Their contribution ranges from stabilisation of fine sediments and providing an excellent protective buffer between land and sea, to their diverse blend of terrestrial and marine fauna. Further, saltmarsh plants are highly specialised and adapted to fill a harsh niche allowing them to act in roles that other vegetation types cannot. Saltmarsh habitats are recognised for their importance to migratory waders under the Ramsar convention, but it is becoming increasingly evident that they are also important to a variety of commercially valuable fish and native mammal species. Activities that are detrimental to saltmarshes continue and need to be addressed in order to conserve remaining saltmarsh areas. In general, urbanisation of the catchment has lead to filling of saltmarshes, tidal restriction, use by recreational vehicles, grazing, trampling and increased sedimentation and nutrient runnoff allowing colonisation and invasion of mangroves. These disturbances have a number of ecological consequences ranging from weed infestation to complete changes in the species composition and ecology. Reversing the disturbance is not always simple and can require extensive groundwork to be successful. Rehabilitation of existing saltmarsh areas has been a successful means to enhance this habitat. In general, it requires relatively little effort to remove weeds and fence off areas to regenerate naturally. Saltmarsh areas have been shown to respond well to this type of manipulation. Restoration and creation require substantial effort and planning to ensure a successful outcome. However, given the right environmental combinations of elevation, tide and salinity, saltmarsh will establish and grow. To speed the process transplantation of saltmarsh plants can be considered either from donor sites or plants propagated in green houses.

Introduction

Coastal saltmarshes around Australia are diminishing. The losses of saltmarsh around the country can be credited to lack of information on the importance of saltmarsh leading to reclamation for industrial, agricultural, port and residential development (Kratochvil et al. 1972; Saenger et al. 1977; Adam 1981; Bucher and Saenger 1991; Zann 1997; Coleman 1998; Davis and froend 1999; Finlayson and Rea 1999). New South Wales in particular has suffered the most alarming losses. Over the past 200 years over 60% of coastal wetlands in NSW have been lost or degraded (Bowen et al. 1995). In response to its demise, saltmarsh has been listed as an Endangered Ecological Community in

New South wales under Part 3, Schedule 1 of the *Threatened Species Conservation Act 1995*.

As the profile of saltmarshes in Australia increases so does the desire to protect, restore and rehabilitate these ecosystems. Streever (1997) identifies ten projects that are specifically aimed at saltmarsh rehabilitation in Australia and it is likely that more are being formulated and instigated now. The future of coastal saltmarshes is linked to knowledge of the general ecology of saltmarsh and its response to disturbance. Many activities remain that are detrimental to coastal saltmarshes and it is important to recognise the types of disturbance and whether recovery is possible before commencing expensive rehabilitation works. The history of the site, cause of problems within a marsh area and the level of perturbation can be the key to effective decision making regarding the management of a particular area. It is important to know how enhancement efforts are going to affect the saltmarsh – i.e. is it going to work? How do saltmarshes recover after disturbance – are they capable of recovery? What is the saltmarsh for – how will it function? Some of these questions can be answered with a thorough understanding of the mechanisms behind recovery and the ecology of saltmarshes and relating these to perturbations and restorative actions. Knowledge of successional patterns, plant physiology, environmental conditions for plant establishment and growth, fauna, amongst other ecological functions is required. In light of this, it seems timely to consider what we know about saltmarsh ecology, disturbance and restoration.

This paper provides an overview of the ecology, threats and restoration efforts on Australian saltmarsh. The information provided is designed to assist in the management of existing saltmarsh areas and the creation of new saltmarshes in coastal areas.

Ecology

The saltmarsh environment

Establishment and development

Saltmarshes generally develop in areas that are protected from the full force of the surf, in locations such as river mouths and sheltered bays and are typically vegetated by a variety of unique low shrubs, herbs and grasses (Clarke and Hannon 1971; Kratochvil et al. 1972; Adam 1981; Bridgewater et al. 1981; Kirkpatrick and Glasby 1981; Wilson 1984; Clarke and Benson 1988; Adam 1993; Latchford 1994; Zedler et al. 1995). They can range from narrow fringes on steep shorelines to nearly flat expanses several kilometres wide.

It was first suggested by Pidgeon (1940), that estuarine wetlands develop when mudflats are colonised by mangroves. As sediment accretes, the mangroves move into the estuary and are replaced on the landward side by saltmarsh. As tides cover the area less frequently, soil salinity increases with evaporation, which in turn limits the distribution of many species including mangroves. Mangrove propagules, although transported into highly saline areas, do not survive (Clarke and Myerscough 1993; Morrisey 1995), which ultimately allows saltmarshes to flourish. Evidence from cores taken in existing saltmarsh areas supports this hypothesis where mangrove root systems dated as 500–1700 years-old were found under the saltmarsh plain (Saintilan and Hashimoto 1999). However, the process may not be the same in every coastal area. Other evidence has shown that mangroves can expand directly onto mudflats without a saltmarsh stage. Also, where there was the opportunity to observe the creation of a new wetland, saltmarshes can be the initial colonists (Mitchell and Adam 1989a).

During the initial stages of saltmarsh formation, pioneer species are the first to establish. Immature saltmarshes are often relatively flat with shallow pools. At this stage, vegetation consists of succulents and small shrubs that are tolerant to the high salinity and regular flooding of the newly created coastal environment. As deposition of sediment continues, the saltmarsh plants trap and bind fluvial and marine sediments that have been transported by tidal currents (Roy 1984), and the surface of the saltmarsh grows higher. In turn, species that are less tolerant of flooding replace earlier pioneer species at upper levels until eventually the system reaches equilibrium.

For colonisation and maintenance of vegetation communities, saltmarsh plants exhibit two modes of reproduction, either: sexually, by flowering and producing seeds for dispersal into bare areas; or vegetatively (asexually), by cloning of individual plants or the extension and spreading of plant parts into new areas (Redfield 1972; Nelson 1994; Allison 1995). Vegetative spread by the means of rhizomes or stolons may produce extensive clones and cover large areas. How large, and how old individual clones can become has not been investigated (Adam 1990); but areas of saltmarsh persist for many years without apparent change, and there is potential for saltmarsh plants to be long-lived, as demonstrated for other clonal plants (Cook 1985). Additionally, most saltmarsh plants flower and set seeds infrequently (Nelson 1994; Huiskes et al. 1995) usually restricted to times when they are less likely to be inundated by the tide or low salinity times to minimise the stress of acquiring water and nutrients. This is particularly important for those species with small inconspicuous flowers that rely on wind for pollination. Other saltmarsh species are capable of holding their inflorescences above the water at high tide, or have pollen that is resistant to tidal inundation. Insect pollination has also been demonstrated for several species, and the most common pollinators are probably bees (e.g. in *Sarcocornia quinqueflora*, Adam and Hutchings 1987) and flies (e.g. in *Suaeda australis*, Adam 1990). Seeds are likely to be dispersed by birds, insects or tides, for example, *S. quinqueflora* is a prolific producer of buoyant seeds that are resistant to desiccation, and are dispersed by tides (Nelson 1994).

The rate of saltmarsh expansion on substrata depends on the incline of the area and topography. That is, saltmarshes will expand more slowly where the incline is steeper. The older marshes of Europe and North America exhibit elaborate systems of drainage creeks and expansive saltpans, but these are notably absent from Australian marshes (Adam 1997). Shallow depressions with poorly defined boundaries may occur; and these are either permanently or temporarily devoid of vegetation, and may become hypersaline (Clarke and Hannon 1967, 1969). Generally, older saltmarshes in Australia exhibit a more diverse plant assemblage with distinct zonation patterns that appear as large flat expanses of low vegetation, much like grass plains. These can however be, visually diverse depending on the dominant plant species.

Temperature and climate

Regional climate is important in determining the location and type of saltmarsh to be expected. In temperate climates, saltmarshes have a vastly different species composition compared to those in tropical latitudes. Temperature and rainfall are the most likely causes of these patterns because of their effect on salinity. Rainfall is significant in salt circulation in communities as it reduces salinity stress. Most saltmarsh species show better growth rates and survivorship in areas where the salinity is lowered, at least for parts of the year. As a result, the distribution of saltmarshes along the coast tends to mimic that of higher average seasonal rainfall (Figure 1). Tropical saltmarshes contain considerably fewer plant species than those in temperate areas (Saenger et al. 1977; Specht 1981). Where temperatures are high, as in northern areas of Australia, the loss of moisture by evaporation is greatest and consequently the salinity increases. This coupled, with low rainfall in these areas is probably the major factor in determining the limited presence of saltmarshes on the northern tip of Australia (Figure 1). The number of species in these areas is restricted to those that are more tolerant of extreme conditions of salinity. On the contrary, saltmarshes are particularly well developed in the southern, temperate areas of Australia, and these areas have a diverse floral component with more than 40 species of plants being recognised (Underwood and Chapman 1993).

Vegetation

Adam et al. (1988) described 25 saltmarsh vegetation communities within NSW, but there is debate about whether saltmarshes should be so highly divided or whether the mid-marsh community (dominated by a few species) should be a single heterogenous community (Zedler et al. 1995). Bridgewater et al. (1981) give descriptions of 13 communities throughout Australia based on the dominant species present in any given zone (high marsh, middle marsh or low marsh). For an approach based on ecology and saltmarsh function, it is beneficial to regard saltmarsh communities as groups of dominant species, especially because fluctuations of species between years (particularly rare and annual species) is a common feature of Australian systems (Adam 1993). Therefore, most of the saltmarshes found in temperate Australia can be considered as a single community complex dominated by one, or a combination of the following species: saltcouch (*Sporobolus virginicus* (L.) Kunth), samphire (*Sarcocornia quinqueflora*

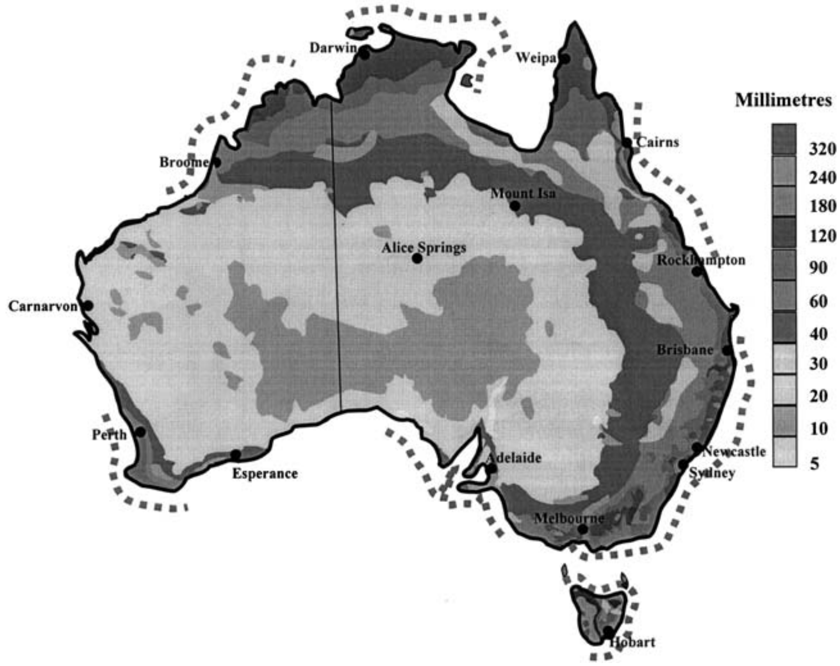

Figure 1. The average rainfall in millimetres (over a 30-year period) shown for Australia on a contour map adapted from data from the Bureau of Meteorology. The main concentrations of saltmarsh along the coast are highlighted with an orange dotted line to show the correlation between saltmarsh and high rainfall.

(Bunge ex Ungem-Sternberg) A.J. Scott)), creeping brookweed (*Samolus repens* (Forst & Forst. f) Pers.) and streaked arrowgrass (*Triglochin striatum* Ruiz & Pav.)(Congdon and McComb 1980; Carne 1991; Clarke and Jacoby 1994; Nelson 1994; Krause 1995; Zedler et al. 1995; Turner and Streever 1999).

Rare species should be identified for biodiversity and conservation purposes. In Australia, several saltmarsh species are rare and their distribution is under threat. Of these, the *Wilsonia* species are noteworthy because they are a group that is peculiar to Australia and New Zealand. *Wilsonia backhousei* Hook.f. is a rare species in NSW but is widespread in South Australia. It has been reported in Homebush Bay and Wamberal Lagoon (Adam and Hutchings 1987). A feature of the saltmarsh vegetation of Cararma Inlet in southern NSW is the presence of *Sclerostegia arbuscula* (R.Br.) P.G. Wilson, which is also rare in NSW (Adam and Hutchings 1987). In Western Australia, *Halosarcia* spp. are important successional species that are required for seed stock to colonise bare areas; but *Halosarcia* spp. are threatened in many areas by development (Pen 1983). In South Australia, the perennial blown grass (*Agrostis limitanea* J. Black) is limited to the banks of a river near Spalding in the mid-north. This species lives in semi-saline soils and is associated with emugrass (*Distichlis distichophylla* (Labill.) Fassett.) and samphire (*Sarcocornia quinqueflora*) (Black 1986).

Zonation

Many studies have described the zonation patterns of saltmarshes in Australia (e.g. Clarke and Hannon 1969; Adam and Hutchings 1987; Krause 1995; Zedler et al. 1995; Streever and Genders 1997). Vegetation is usually zoned parallel to the shoreline, and there is a general broad scale zonation from the land to the sea. The zones can be described as lower, mid and upper levels, usually each with a distinct mosaic of species that is often complicated by small-scale patchiness. Succulents dominate the lower marsh (e.g. *Sarcocornia* spp.), while the mid-marsh usually contains species such as *Sporobolus* spp. and *Samolus* spp. The upper marsh is a mosaic of species including *Juncus kraussii* and *Baumea juncea*. The area behind the upper marsh is filled with terrestrial vegetation such as eucalypts, melaleucas and casuarinas. In most saltmarshes a combination of salinity, elevation and inundation is responsible for many of the patterns seen in the distribution of saltmarsh plant species (Adam 1981a, b, 1990; King 1981; Zedler et al. 1995; Streever and Genders 1997). Salinity is especially important in the establishment of new saltmarsh as most saltmarsh plants cannot metabolise well in seawater alone (Web 1966) particularly in terms of germination and early growth. Saltmarshes can range in salinity from brackish to hypersaline, and salinity varies according to rainfall, freshwater inputs, groundwater influx, soil type and extent of tidal flushing (Clarke and Hannon 1969; Vernberg 1993).

Most plants, however, possess mechanisms that allow them to cope with the saline environment so that they can have a competitive advantage over many other terrestrial plant species, and can occupy a specific niche. Hypersaline conditions can lead to the death of saltcouch or the formation of smaller, thicker darker leaves in samphire and seablite communities. Some species avoid having to survive long periods in high soil salinity by growing as ephemerals in high rainfall periods of the year. This is most common in the tropics where seasonal flooding in the wet season decreases salinity and allows species such as *Salsola kali, Sclerolaena* spp. and *Trianthema* spp. to grow (Jacobs 1999).

In many areas *Sporobolus* spp. and *Sarcocornia* spp. co-occur but usually either one or the other genus is dominant (Nelson 1994). This is generally attributed to competition. In general, *Sporobolus* spp. have a competitive advantage on more moist sites, while *Sarcocornia* spp. have an advantage on more saline sites. Biological activity can also influence the zonation of plant species within a saltmarsh. The presence of crab burrows can influence the type and density of vegetation found because of increases in aeration, nutrient availability, and decomposition of below-ground plant detritus, together with decreases in salinity and hydrogen sulphide concentrations (Marsh 1982; Bertness 1985). By excavating sediment to maintain a burrow, crabs transport nutrients within the sediment to the saltmarsh surface where it becomes more available for vegetation (Marsh 1982).

Saltmarsh fauna

Fauna is probably the least studied component of saltmarshes in Australia and information is lacking. Generally, the descriptions available highlight that it consists of several fauna groups ranging from terrestrial to aquatic species with some specialised saltmarsh dwellers.

Aquatic invertebrates

The sediment of saltmarshes generally contain few fauna. Only three groups of fauna (oligochaetes, polychaetes and bivalves), each containing only two or three species, have been identified to be wholly contained within the sediments of saltmarshes in Australia (Warren 1989; Berents 1993; Genders 1997; Laegdsgaard, unpublished data). The hostile nature of the environment no doubt contributes to this lack of fauna with some evidence that the dense impenetrable root systems of saltmarsh can limit burrowing species (Marsh 1982; Laegdsgaard, unpublished data).

Crustaceans and molluscs are the most conspicuous element of the invertebrate fauna characteristic of saltmarshes, and in a comprehensive study of 65 *Sarcocornia quinqueflora* marshes around Tasmania, Richardson et al. (1997) found over 50 species. However, only eight of these species were unique to saltmarshes. Molluscs have received most of the attention in the literature, with studies ranging from species composition and size range to adaptations (Hutchings and Recher 1974; Roach et al. 1989; Berents 1993; CSIRO 1994; Roach 1998; Roach and Lim 2000). *Salinator solida* Von Martens, is the most common gastropod in saltmarsh around Australia (Hutchings and Recher 1974; Hutchings et al. 1977; Roach et al. 1989; CSIRO 1994; Roach 1998; Roach and Lim 2000). *S. solida* burrow into the surface of the mud when the tide covers the saltmarsh surface. When the mud dries out, the snails cluster together at the base of vegetation or in small depressions. In a study at Kooragang Island, *S. solida* was found in areas that were associated with increased flushing (Genders 1997), while it was conspicuously absent from saltmarsh in Homebush Bay (Berents 1993) that have been tidally isolated. This species may therefore provide a useful indicator of healthy tidal exchange.

Differences in zonation of epifaunal snail species in saltmarsh environments have been attributed to their abilities to tolerate physical stress and predation pressures (Roach et al. 1989; CSIRO 1994; Talley and Levin 1999; Roach and Lim 2000). In areas of *Juncus kraussii* occurring high above the shoreline, there is a high proportion of small individuals of *Ophicardelus ornatus* Ferussac. It is suggested that this may relate to these areas providing a stable microhabitat that provides the right temperature and moisture conditions for this species (Roach et al. 1989). *S. solida* has a population size age structure that varies significantly with height above the shoreline. Smaller younger individuals dominate the mangroves, while the *Sarcocornia* habitat supports the larger older individuals (CSIRO 1994; Roach and Lim 2000). Additionally, growth rate and mortality decrease with height above the shoreline. Predation has been suggested as the main mechanism for this trend. Predators limit the size to which *Salinator solida* can grow in the mangroves, while in the saltmarsh they are able to attain a greater size because of decreased predation. Toad fish, yellow-finned bream and eels are identified as the major predators of *S. solida* and it is likely that these fish species may target many of the other mollusc species that are present on the saltmarshes at high tide. However, tides only cover the entire saltmarsh surface on the highest tides (maximum three to four times per year) so that for most of the time fish can only target those molluscs that are closer to the shoreline i.e. in mangroves. Excluding predators at Towra Point actually decreased the mortality of *S. solida* from 82 to 0.7% (Roach and Lim 2000).

Richardson and Mulcahy (1996) identified several species of amphipods as being dominant among Tasmanian saltmarshes, These included both aquatic and terrestrial species of amphipods, and it is hypothesised that saltmarshes may have provided the pathway for amphipods to colonise the land. Saltmarsh vegetation has remained relatively unchanged since the Cretaceous period (Adam 1990), and it is possible that other species utilised saltmarsh as an evolutionary pathway. For example, the gastropods *Ophicardelus* spp. are the most primitive of their family, and they show characteristics similar to those of the primitive ancestors of land snails (Richardson et al. 1997). There are, however, also several amphipods that are found in coastal habitats, including saltmarshes, whose dependence on salt spray has been shown to limit their landward migration (Richardson et al. 2001).

Terrestrial invertebrates

The terrestrial invertebrates of saltmarshes have been studied very little in Australia, with the exception of the saltmarsh mosquito (*Ochlerotatus vigilax* Skuse previously *Aedes vigilax*). Its association with human health risks, such as Ross River Virus (Ryan et al. 2000), has made it a focus for studies on saltmarshes in Australia (Dale et al. 1993; Ritchie 1994; Ritchie and Jennings 1994; Gislason and Russell 1997; Turner and Streever 1997; Chapman et al. 1999; Turner and Streever 1999; Webb and Russell 1999). It is clear, however, that spiders and insects from most of their orders (Homoptera, Hemiptera, Diptera, Coleoptera, Orthoptera, Hymenoptera and Lepidoptera) are common on saltmarshes (Hutchings and Recher 1974; Marsh 1982; Clarke and Miller 1983; Laegdsgaard unpublished data).

Marsh's (1982) research provides an indication that there is seasonal variation in the terrestrial invertebrates that use saltmarshes, despite the lack of spring data. There is a general trend towards a decrease in flying insects in winter because many of these spend winter in the egg state, while other species increase in response to the decrease in predators. Clarke and Miller (1983) provided a glimpse into the spatial distribution of insects by comparing areas within the saltmarsh along with other habitats such as mangrove and pasture. In general, there was an increase in the more terrestrial species (e.g. grasshoppers) in drier saltmarsh, while the diversity of spiders increased in mixed saltmarsh. In comparison with mangroves, saltmarsh has a much greater diversity of insects (a total of 13 species in mangroves compared to 47 in saltmarsh) Clarke and Miller 1983). Since insects are a common component of the saltmarsh fauna, these in turn attract insectivorous animals such as birds and bats. Bats in particular have been identified to be active over saltmarshes of Victoria and NSW with ten species recorded including some listed as rare and threatened (Laegdsgaard et al. 2004).

Vertebrates

Fish

In the past, saltmarshes have not been considered important fisheries habitat in Australia (Connolly et al. 1997). Most saltmarsh areas are only available for fish to use during the highest tides of the year, and therefore their usefulness as a habitat for fish was considered limited. However, the lack of information on fish in saltmarshes is generally related to the difficulties of sampling in this environment (Connolly 1999). Consequently, most studies have centred on creeks because they are easier to sample than saltmarsh flats. Morton et al. (1987) collected samples monthly, over a year, from a large channel draining a saltmarsh; and found 19 species, from 14 families, of fish that regularly used this area. The dominant species were toadfish, yellow-finned bream, yellow perchlets, and flat-tail and fan-tail mullet. Another record of fish from temperate saltmarshes is from Wallis Lake, where poisoning of a small creek resulted in the capture of 11 species (Gibbs 1986).

More recently, investigators have overcome some of the difficulties of sampling on saltmarsh flats to discover that these environments in Australia are used by fish during flood tides (Connolly et al. 1997; Thomas and Connolly 2001; Crinall and Hindell 2004; Mazumder et al. 2005). The number of fish caught on the flats is lower than in creeks (Connolly et al. 1997) but still provide a habitat that is utilised by many fish species most likely for feeding. The abundance of insects, spiders, crustaceans and mollusc provide ample food resources (adults, nymphs and larval stages) to be targetted by fish (Morton et al. 1988; Mazumder unpublished data). Small resident species such as perchlets and gobies dominated catches, but commercial species such as whiting, bream and mullet were also caught in significant numbers in Queensland and NSW (Thomas and Connolly 2001; Mazumder unpublished data). It is not only the edges of the saltmarsh flats that are used either, some fish venture to the farthest reaches of a saltmarsh during the tidal cycle (Connolly and Bass 1996; Thomas and Connolly 2001).

Semi-permanent and permanent ponds in saltmarsh areas have been investigated as a suitable habitat for a nursery for juvenile fish, despite being a relatively harsh environment that is only flushed by extreme high tides. Gibbs (1986) sampled several pools in saltmarshes around Wallis Lake in NSW, and found juveniles of several species, including silver biddy and yellow-finned bream. Smaller ponds within saltmarshes have been found to contain species such as the introduced mosquito fish along with the native blue-eyes and gobies (Davis 1988; Morton et al. 1988; Lincoln-Smith et al. 1994).

Birds

In the available literature, there are several good descriptions of birds that utilise saltmarshes, but the information available on reptiles and mammals is more rare, with only two studies mentioning them (Latchford 1994; Morrisey 1995). Many terrestrial birds frequent the saltmarshes, and use them as breeding grounds (e.g. bronze cuckoos). They feed on the variety of insects found on the saltmarsh or on the seeds of the saltmarsh plants (e.g. galahs). All these smaller birds and mammals on the saltmarsh form ideal prey for the hunting birds such as brahminy kite, whistling kite and marsh harriers, which are considered to be the top predators in the structure of the saltmarsh food web (Figure 2). Saltmarsh provides summer feeding and roosting grounds for migratory waders of international significance (Gosper 1981; Clarke and van Gessel 1983; Maddock 1983; Day et al. 1989; Smith 1991; Latchford 1994). Bird species that utilise saltmarshes as a roosting site do not tend to use wooded areas (including mangroves) because these areas can hide land-based predators and, more importantly, restrict landing and take off areas for birds (Clarke and van Gessel 1983; Saintilan 2003). Many wading birds feed primarily on mudflats, and it is important that roosting places are close to feeding areas, to minimise energy expended on flights during their overwintering period. This makes large expanses of saltmarsh ideal roosting sites, and indeed 18 of the 42 sites throughout Australia recognised as wetlands of international importance, under the Ramsar convention, contain large expanses of saltmarsh that are considered vital for several species of migratory wading birds. Additionally, saltmarshes have associated ponds of water that are flooded by the occasional high tide. These ponds contain fish that remain after the tide has receded, and several invertebrates which attract waterbirds such as sharp-tailed sandpipers, curlew sandpipers, greenshanks and marsh sandpipers (Straw 1996).

Saltmarsh habitats in south-eastern Australia support the endangered bird species, the orange-bellied parrot (*Neophema chrysogaster* Latham) which has a single breeding population containing less than 200 mature adults in the wild. These rare parrots are confined to coastal habitats within 10 km of the coastline in south-eastern Australia. The parrots spend the winter around saltmarshes in Victoria, South Australia and Tasmania where they feed on the seeds of saltmarsh plants such as *Frankenia, Sarcocornia, Sclerostegia* and *Suaeda*.

Saltmarsh productivity

There are very few data on productivity, and no detailed measurements of fluxes into and out of Australian marshes. The characteristics of saltmarshes in Australia make them different from those that are found in North America and other parts of the world, which are dominated by tall robust grasses and are generally considered highly productive. From the small amount of data available it is clear that Australian marshes record lower productivity figures than those reported for many USA marshes (Table 1). Additionally, high variability precludes consistent spatial or temporal trends were associated with above-ground biomass of the dominant saltmarsh species (*Sporobolus virginicus* or *Sarcocornia quinqueflora*) (Smith-White 1981; Clarke 1986; Clarke and Jacoby 1994; Seliskar 1998), This may be attributed to natural variation, fluctuations in soil salinity (Smith-White 1981) or disturbance. It has been shown that above-ground biomass can be lower in sites that have been affected by urban development (Laegdsgaard unpublished data).

Although saltmarsh plants utilise nutrients for growth, nitrogen concentration within the tissue of plants such as *Sarcocornia quniqueflora* is only around 2% (Clarke 1983; van der Valk and Attiwill 1983; Dick 1999), and phosphorus is less than 1% (van der Valk and Attiwill 1983; Dick 1999). This means very little of the nutrients brought into the saltmarsh system are actually incorporated into the plant material at any one time (estimated at around 15%), so the plants themselves do not act as a nitrogen source (Clarke 1986). It has been suggested that nitrogen and phosphorus are balanced in saltmarshes with no net import or export to adjacent areas. For most of the time, saltmarshes in Australia are not covered by the tide, facilitating exchanges with the atmosphere, rather than exporting nutrients and plant matter to the estuary. Therefore, a relatively large proportion of the macrophyte production is consumed on the saltmarsh by respiratory or burial processes. In addition, denitrification (and thereby loss of available nitrogen) is likely to be limited because this process is generally enhanced in waterlogged anoxic soils that are typical of habitats constantly inundated by the tides. The soils of saltmarshes in Australia are typically drier than those of nearby mangroves (Saintilan and Williams 1999b), thereby reducing the potential for nitrogen loss to the atmosphere. Furthermore, saltmarsh vegetation actively transfers oxygen to the roots and consequently to the soil (Kaplan and Valiela 1979). This forms the basis for nitrification processes whereby nitrogenous compounds are converted to biologically available ammonium and nitrate that is exported to coastal waters and used in active plant growth (Boon and Cain 1988). In addition, during decomposition, nutrients in the plant tissue are released and recycled into new plant growth, Decomposition rates of most plants in Australian marshes are high (61–67% in the first year, van der Valk and Attiwill 1983) compared to the USA (50% in the first year, de la Cruz and Hackney 1977) which probably relates to the succulent nature of most Australian saltmarsh plants. Decomposition of more woody saltmarsh plants such as *Juncus Kraussii* is very slow (approximately 20% in the first year) (van der Valk and Attiwill 1983). Additionally, above ground litter decomposes faster than below-ground litter (Dick 1999). Therefore, very little litter is left on the surface of the marsh to be exported with the rare full tidal inundation.

The litter decomposed by microorganisms provides energy to invertebrates and higher trophic levels in the foodweb. A great number of animals found in the saltmarsh can be classified as detritivorous or decomposers (e.g. protozoans and nematodes). These fauna convert the wealth of plant matter in saltmarshes to detrital food sources. Such food sources are utilised by a rich and diverse invertebrate community that may in turn support other marine and terrestrial species in a foodweb that climaxes with hunting birds as the top predators (Figure 2). In Australia, Boon et al. (1997) found that the saltmarsh plant *Sarcocornia quinqueflora* did not contribute as a food source for two intertidal callinassid shrimps in Western Port southern Australia. However, Irving (2001) found that *Sporobolus virginicus* was a basis of the foodweb of the common gastropod of saltmarshes (*Salinator solida*), the semaphore crab (*Heleocius cordiformis*) and several fish species (e.g. mullet and stingrays). In addition, bream were found to derive nutrition from *Sarcocornia quinqueflora*. Many fish species feed on amphipods such as *Orchestia* spp., which are common in (Berents 1993; Richardson et al. 1997) throughout Australia, and are primary consumers of halophytes (Lefeuvre et al. 2000). It has also been demonstrated that fish feeding in saltmarshes at high tide targeted mainly saltmarsh crabs (Morton et al. 1987).

Response of saltmarsh to disturbance

Saltmarsh have to cope with a variety of natural and anthropogenic disturbances (Laegdsgaard 2001) to which they are particularly susceptible. It is important to understand the ecological consequences of disturbance in order to reverse or halt it.

Changes to hydrology

Alterations to drainage and hydrology can have devastating effects on saltmarsh communities. These range from habitat destruction to modification of the ecology. When estuaries are closed or tidally blocked, water levels rise as a result of localised freshwater run-off, leading to the inundation of saltmarshes for extended periods. Many succulent saltmarsh plants such as *Sarcocornia* spp. can only withstand short periods of inundation before the plants quickly rot and decompose (Adams and Bate 1994). Naturally occurring flood events cause a similar effect; however, the water does not remain to cause permanent damage. Some plants may appear to die because of prolonged submergence; but if the stems of the plant remain alive, despite leaf decomposition, it is possible that the plant will survive and regenerate once water levels drop and the tidal influence is restored. If the tidal movement is not restored, the water table is substantially lowered, and there is a relative drop in the surface level of the saltmarsh. This favours the establishment and spread of such species as common reed (*Phragmites australis* [Cav.] Trin ex Steud), water couch (*Paspalum vaginatum*) and river clubrush *Schoenoplectus validus* [Vahl] A & D Löve), and the loss of saltmarsh species (Roman et al. 1984). The common reed (*Phragmites australis*) is tenacious and recruits easily to areas that have become tidally isolated. If allowed to persist, it can form extensive stands that restrict the movement of aquatic life and alter the ecology and function of the entire saltmarsh (Adams and Bate 1994; Windham 1995; Weinstein and Balletto 1999). Dense monotypic *Phragmites* stands generally provide unsuitable or less preferred habitat and food for wildlife and waterfowl (Roman et al. 1984).

Agricultural practices

In areas that are adjacent to wetlands and have been reclaimed for agriculture, pasture species exclude saltmarsh plants to a point where the pasture species can no longer cope with the salinity. Saltmarsh plants cannot compete with pasture species, and therefore their expansion is limited by competition (Genders 1996) in these altered environments.

In addition to being replaced, many saltmarsh areas in Australia occur on private land and are used as pasture for livestock. Grazing and trampling are particularly detrimental to saltmarsh plants. Where trampling is high saltmarsh plants are unable to regenerate or re-establish. Fauna that is native to Australia is unique and does not posses hard hooves; therefore, constant trampling by hard hoofed farm animals can easily disrupt a saltmarsh area. Hoofed animals in saltmarsh habitats disrupt the dense vegetation and root system, often destroying delicate succulent chenopods, such as *Sarcocornia* spp. and *Suaeda* spp., and allowing tidal water to pool. Such pools form excellent habitat for biting insects (mosquitoes and midges) or other plant species (e.g. *Triglochin striata*) which are more tolerant of waterlogging and lowered salinity (Zedler et al. 1995). Trampling also introduces gaps where weeds can establish (Bridgewater 1982), which can affect the dynamics of saltmarsh communities. In areas where trampling is high, regeneration of the saltmarsh plants is generally slow. Alterations in typical saltmarsh species distributions can occur because some plants are grazed selectively in preference to unpalatable species. For example, the reduction of cover of rare species (e.g., *Sclerostegia arbuscula*) has been linked to selective grazing (Kirkpatrick and Glasby 1981; Bridgewater 1982) in saltmarsh areas.

Urban encroachment

Where saltmarsh is adjacent to urban development it can be subject to mowing which can disrupt the flowering of grasses while destroying succulent species. Watering of lawns adjacent to saltmarsh also reduces their competitive advantage and leads to terrestrial grass species eradicating saltmarsh species (Genders 1996). Halophytes are not competitive in non-saline conditions (Zedler et al. 1990; Genders 1996; Wilson et al. 1996). So, fresher conditions allow exotic species to invade and conquer the otherwise harsh saltmarsh environment. The competition between saltmarsh plants and terrestrial vegetation is not restricted to above-ground; root competition is just as important. In a study on the ability of *Sarcocornia quinqueflora* seedlings to invade areas where pasture species had been removed, Genders (1996) found that *S. quinqueflora* were only successful in plots that had been weeded to remove above- and below-ground vegetation. Plots that were simply mown, remained free of saltmarsh plants.

Proximity to urban development has also precipitated the need for increased mosquito management. The saltmarsh mosquito is associated with various diseases and is therefore a priority for control. This is achieved either through pesticide application, which may be harmful to non-target insect populations, or habitat modification. Runnelling is a type of habitat modification using shallow channels in the saltmarsh to increase the tidal flushing of the area to reduce mosquito breeding and is likely to affect the plant species distribution and faunal communities in the saltmarsh (Connolly and Bass 1996). Runnelling was not found to have any significant impacts on the wetland environment over a 6.5-year study period by Dale et al. (1993). However, its effect on saltmarsh crabs was the subject of a study in Queensland, where it was concluded that although runneling did not affect the total number of crabs it did have an effect on the species distribution of crabs (Chapman et al. 1998). Significantly greater numbers of *Parasesarma erythodactyla* Hess. were found at the runnelled site while *Helograpsus haswellianus* Whit. was more abundant at the unrunnelled site (Chapman et al. 1998). Additionally, it has been found that the overall effect of runnelling appears to be a reduction in the abundances of nekton in the immediate vicinity of runnels thereby adversely affecting the saltmarsh environment (Connolly 2005). The tidal penetration also increases the chance of mangrove incursion with propagules transported high into the marsh by runnels (Breitfuss et al. 2003). The increased flushing may also decrease the high salinity in the marsh and allow mangroves seedlings to establish and grow (Clarke and Myerscough 1993; Morrisey 1995).

Table 1. Published values of above-ground productivity levels for dominant, wide-spread saltmarsh species in south eastern Australia compared to species that dominate the marshes of the USA.

Species	Location	Above-ground production (g $m^{-}2$)	Reference
Sprobolus virginicus	South-eastern Australia	148–852	Clarke and Jacoby (1994)
		172–1600	Laegdsgaard, unpub. data
Juncus Kraussii	South-eastern Australia	1116	Clarke and Jacoby (1994)
		300–1300	Congdon and McComb (1980)
		210–3300	Congdon and McComb (1981)
Sarcocornia quinqueflora	South-eastern Australia	800	Congdon and McComb (1981)
		317	Clarke and Jacoby (1994)
		88–2411	Laegdsgaaerd, unpub. data
Samolus repens	South-eastern Australia	400	Congdon and McComb (1981)
Scirpus maritimus	South-eastern Australia	1100	Congdon and McComb (1981)
Salicornia virginica	USA	600–1000	Mahall and park (1976)
Spartina alterniflora	USA	500–2500	Taylor and Allanson (1995)

The proximity of saltmarshes to urban settlements increases their attractiveness to drivers of recreational vehicles. Off-road vehicles (e.g. mountain bicycles, 4-wheel drive vehicles, trail motorbikes) traversing saltmarsh vegetation can cause localised and widespread damage. Decrease of saltmarsh in areas of NSW and Tasmania has been directly attributed to recreational vehicle use (Kirkpatrick and Glasby 1981; Clarke 1993; Kelleway in press). The type of disturbance to the saltmarsh depends greatly on the nature and purpose of the driving. Effects like stein-height reductions and stem breakage are common with light traversing (restricted to a set of wheel ruts) of saltmarsh areas. However, continuous, heavy usage can cause a complete removal of vegetation, soil compaction and removal of mollusc and crab populations (Kelleway in press).

Mangrove incursion

An imminent threat to saltmarshes around Australia is mangrove incursion. Over the last few decades colonisation and invasion of mangroves into south-eastern Australian saltmarsh areas has been documented (Buckney 1987; Mitchell and Adam 1989a, b; Morton 1993; West 1993; Fenech 1994; Coleman 1998; Saintilan and Hashimoto 1999; Saintilan and Williams 1999; Saintilan and Wilton 1999). There are a number of hypotheses that have been put forward to explain this phenomenon. These include sea level rise, increased rainfall, increased freshwater inputs into saltmarsh or altered tidal regimes most of which need to be tested. Wilton (2002) was unable to find a correlation between the degree of mangrove encroachment with sea level rise or degree of urbanisation, which suggests that other physical factors within the environment may be driving the changes being observed. Salinity is a major driving factor in maintaining wetland communities. Normally, saltmarshes flourish because soil salinity increases with evaporation, which in turn may limit the distribution of many species including mangroves, Mangrove propagules, although transported into highly saline areas, do not survive (Clarke and Myerscough 1993; Morrisey 1995). Nevertheless, during a succession of wetter years soil salinity may fall to an extent where mangroves can establish and grow, but in subsequent dry periods the salinity would increase thereby eliminating the mangroves again (Outhred and Buckney 1983). The view that salinity is the driving force for maintaining mangrove distribution remains a hypothesis. Clarke and Allaway (1993) suggest that upslope delimitation of the grey mangrove (*Avicennia marina*) is related to desiccation that may suggest that inundation frequency is the critical factor. The fact that mangroves are threatening to over run many saltmarsh areas, suggests there is a mechanism operating to allow mangroves to flourish where they would normally be stressed or absent.

Fragmentation

Fragmentation is another major contributing factor for saltmarsh habitat decline, however, it is not clear what the ecological consequences might be. Fragmentation in other habitats such as forests and grasslands has been shown to cause degradation of habitat quality and decreases in biodiversity (Collinge 1996; Harrison and Bruna 1999; Mazluff and Ewing 2001; Tschantke et al. 2002). Rare or specialised species and species with lower dispersal capabilities are most affected (Tscharntke et al. 2002). Although it has not been tested, fragmentation is likely to affect the foodweb structure of saltmarsh significantly. Many of the predators require space for prey capture, particularly those that feed on the wing such as bats and hunting birds. Large saltmarsh habitats with a diverse array of molluscs and crabs produce a large amount of plankton that is exported with the tide when the saltmarsh is inundated which is an important food source for fish (Mazumder, unpublished data). In this way, saltmarshes are important in sustaining other estuarine species, many of which may be of commercial significance. Many of the crabs and molluscs are generally absent from small fragmented saltmarsh habitats and these do not have the capacity to supply larval zooplankton to estuarine fish species. It is predicted that with increasing fragmentation and reduced Patch size of saltmarsh habitat the foodweb will become limited to small predators and few insects as shown in Figure 3. This would be particularly true if the saltmarsh patch also becomes tidally isolated (Figure 3b). In grassland, fragments can become too small even to maintain

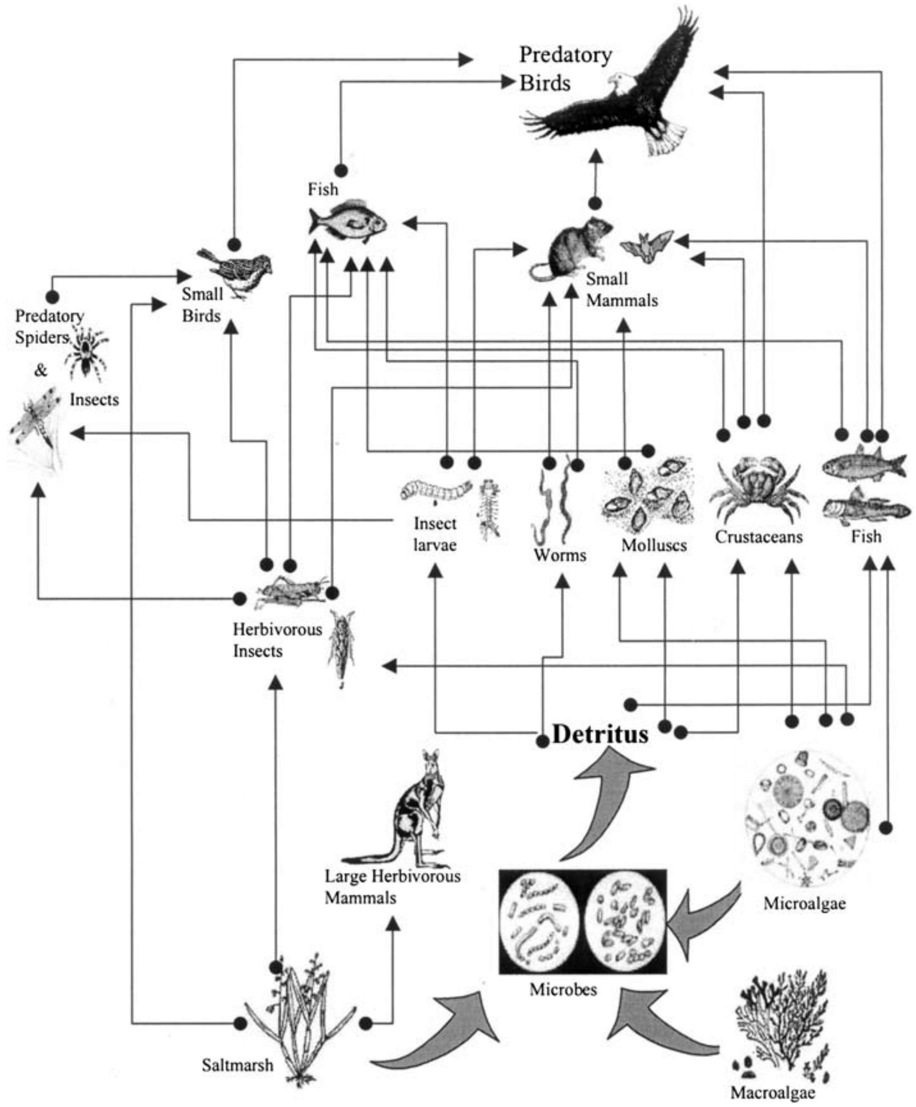

Figure 2. Representation of the foodweb of a typical coastal saltmarsh in Australia. Arrows represent the direction of the links in the foodweb with respect to consumers.

viable populations of small birds (Johnson 2001). This could also be true for saltmarshes, which would reduce the top predators to spiders and insects of a very small fragment (Figure 3d). Urbanisation of many coastal areas has seen the reduction of saltmarsh areas to minute patches that are likely to be utilised only by insects.

Migratory birds are generally attracted to larger areas of saltmarsh to give better visual protection from predators (Straw 1996; Saintilan 2003). The size of breeding colonies of egrets has been positively correlated to the area of saltmarsh within 20 km radius of the breeding colony (Baxter 1998).

Where saltmarshes are fragmented by the presence of roads, contamination is also likely to affect biodiversity. Contaminants may cause physiological stress in some plants and make them more susceptible to pest attack, Saltmarshes contain a high number of insects that may be reduced by the lead in combustion gases in cars (Spellerberg 1998).

Invasive species

Several invasive species have the potential to completely overrun a natural saltmarsh. These species form a priority for rehabilitation efforts. Of particular note are the common cordgrass and spiny rush. The invasive common cordgrass (*Spartina anglica*) was introduced into Tasmania and Victoria specifically for reclamation of land and stabilisation of mudflats. In Tasmania, it has completely taken over the Tamar Estuary (Adam 1981). Despite attempts to establish it in NSW it has not become a problem in this State (Adam and Hutchings 1987). The common cordgrass can have several detrimental effects on natural environments in Australia. These effects include invading mudflats that are rich in invertebrates and producing dense monotypic stands that replace more diverse plant communities. Species such as *Sarcocornia quinqueflora* and *Samolus repens* are particularly prone to competitive exclusion by *Spartina anglica* (Simpson 1995; Hedge and Kriwoken 2000). Birds have been observed to avoid *S. anglica* (Simpson 1995; Hedge and Kriwoken 2000), and species richness and total abundance of fauna are greater in saltmarshes dominated by native plants, compared to those dominated by *S. anglica* (Hedge and Kriwoken 2000).

Spiny rush (*Juncus acutus*) is another introduced species, from the Mediterranean, that has become widespread throughout saltmarshes and on saline-affected pasturelands in southeastern Australia (Milford and Simons 2002; Zedler and Adam 2002). It has been so successful at invasion that it has been listed as a noxious weed for Australia (NAWC 2003). This species occupies the same niche as the native rush, *Juncus krausii* but is tougher and more resilient and easily out-competes the native species. The introduction of *J. acutus* into saltmarshes has altered the structure and complexity of these environments. Once *J. acutus* becomes established, its sharp tough cylindrical leaves form dense impenetrable thickets so that the native rush is displaced or unable to establish. Many gastropods and other invertebrate fauna are believed to depend on *J. krausii* for completion of their lifecycle and the same function is not afforded by *J. acutus* due to its harsher habit. Therefore, the ecosystem may be severely impacted by the invasion of *J. acutus* as it displaces *J. krausii* in many saltmarsh ecosystems of coastal Australia.

Restoration efforts

Restoration of saltmarsh in Australia is a relatively new concept. As the profile of saltmarshes increases so do restoration efforts. Unfortunately, rehabilitation efforts generally go undocumented and there is little measure of their success. Nevertheless, examples do exist that allow confidence in rehabilitation efforts.

Actions such as fencing to remove cattle from saltmarsh areas, diversion of stormwater away from saltmarsh and weed removal are the most common rehabilitation methods for saltmarsh. A good example of a saltmarsh restoration project, where these have been employed, is the Kooragang Wetland Rehabilitation Project on the central coast of NSW. The project was initiated in 1993 to compensate for the loss of estuarine habitat due to 200 years of clearing and filling (Buckney 1987). The project covers three sites, Tomago, Ash Island and Stockton and it is one of the major environmental projects in NSW. The main area for rehabilitating estuarine habitats has been Ash Island where tidal flushing is being restored through the removal of culverts. In areas where tidal restriction has been removed there has been an observed reversal of the habitat degradation brought about by the tidal restriction and reclamation for agriculture (Streever et al. 1996), with a return and expansion of native saltmarsh and mangrove species. Additionally, evidence from a large area impacted by cattle grazing at Kooragang Island in NSW, where cattle had been excluded to allow rehabilitation, suggests that *Sarcocornia quinqueflora* is able recover naturally in around five years once the disturbance is removed (Kooragang Wetland Rehabilitation Project unpublished data).

Weed removal is particularly important in the rehabilitation of many saltmarsh habitats as there are several introduced species that plague saltmarshes around Australia, and the way in which most have arrived is unknown. Common introduced species include buck's horn plantain (*Plantago coronopus*), rock sea-lavender (*Limonium binervosurn*), grasses (*Polypogon monspeliensis.*) and daisy (*Aster subulatus*). All these species have been introduced from the Northern Hemisphere, and the majority have the ability to out-compete native saltmarsh species (Callaway and Zedler 1998). Generally, these are simple to eradicate from saltmarsh areas. The removal of spiny rush (*Juncus*

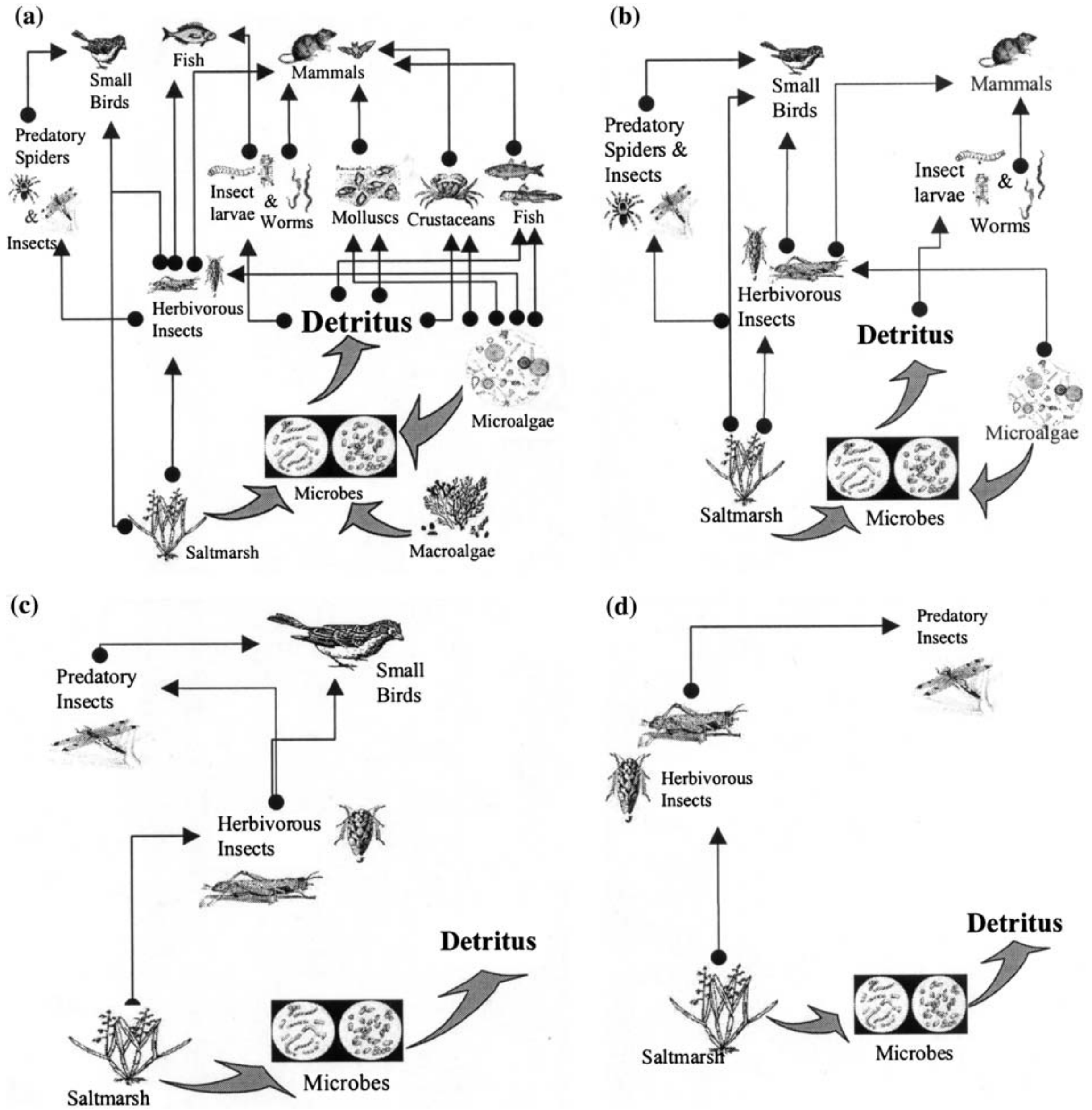

Figure 3. Predicted changes to the typical saltmarsh foodweb with disturbance and fragmentation. (a) Reduction in size of the saltmarsh limits the ability of birds of prey to feed thereby eliminating them from the foodweb. Top predators become small birds, fish and small mammals. (b) Tidal restriction coupled with decreased habitat size eliminates fish, crustaceans and molluscs from the saltmarsh foodweb. (c) A fragment of saltmarsh approximately the size of a house block are likely to support only small ground feeding birds and insects. (d) Minute fragments of saltmarsh ($1-2$ m^2) can only support arthropods. Predatory insects and spiders take on the role of top predators in this scenario.

acutus) however has become a focus for management in some areas but it is proving particularly difficult to eradicate. More information is required on the general biology and physiology of this species in order to formulate effective and permanent eradication methods.

Where land needs reshaping in order to restore tidal inundation for saltmarshes to grow and flourish, it is important to understand that saltmarsh species can be sensitive to changes of a few centimetres in elevation and tidal inundation. Zonation of saltmarsh plants requires a specific combination of land gradients (to ensure inundation) and soil salinity (Clarke and Hannon 1970; Adam 1990; Zedler et al. 1995). This may be particularly difficult to achieve. Callaway et al. (1997) established that hydrology and substratum are the key elements in restoration. Porous substratum drains and dries too quickly to be conducive to the growth of dominant saltmarsh species. Additionally, saltmarsh areas planted with *Salicornia virginica* (a species similar to *Sarcocornia quinqueflora*) did not thrive in areas that were infrequently tidally flooded but retained water (Callaway et al. 1997). Where this has been trialled and access to tidal water restored through excavation and relevelling, saltmarsh has establish naturally. Several sites in Sydney have been reverted from parks to saltmarsh that is floristically mature and attracting bird species (Eckstein 2004; Sainty and Roberts 2004) and areas of Kooragang Island in NSW have been successfully converted from pasture back to saltmarsh in this way (Personal Observation).

It is usually assumed that if hydrology is restored that vegetation, soil and animals will come naturally. In many areas, this is true but may not always be the case and may require assistance. If the site is excavated and the surface soils removed it may take longer for organic carbon levels at depth (where it is needed) to return to similar levels to natural marshes (Havens et al. 2002). It may be necessary to add organic substrate back to the marsh surface at the time of construction when re-levelling is complete to speed the development of a sediment profile similar to natural marshes. In addition, soil salinity is a major factor determining seed germination and the ability of plants to mature in saltmarshes so the right balance of tide and freshwater are essential. Table 2 provides tolerances for the most common species associated with Australian saltmarsh.

Natural recovery of saltmarsh communities occurs after disturbance via establishment of seedlings. The degree of isolation from natural habitats will affect recolonisation. *Sarcocornia quinqueflora*,

Table 2. Dominant saltmarsh species and their requirements for growth in early and mature stages.

Species	Appearance	Germination and early growth	Mature conditions
Sarcocornia quinqueflora	A small erect leafless herb with succulent jointed stems. Can vary in colour from green to red and purple.	Requires conditions of low salinity to trigger germination (Chapman 1960).	Flowering in late summer is triggered by high salinity conditions (Clarke and Hannon 1970). Die back in winter
Sporobolus virginicus	Grass like Narrow imrolled leaves are stiff, erect and green.	Low salinity periods are required for establishment. Responds well to increased nutrients Waterlogging can hasten the onset of flowering (Clarke and Hannon 1970)	Can tolerate periods of high salinity (Gallagher 1979), flooding and hypoxic soils (Donovan and Gallagher 1984; Donovan and Gallagher 1985). However, hypersaline and constant inundation leads to little or no growth (Clarke and Hannon 1970).
Suaeda australis	Low growing herb Newly produced foliage is soft green and may become pink or purple	High mortality and retarded growth in seedlings is common in well-drained areas suggesting wet conditions are necessary for germination and early growth (Clarke and Hannon 1970).	Plants in full sun become pink or purple while those in shaded positions remain green (Cribb and Cribb 1985). With age and maturity, it can tolerate drier conditions.
Triglochin striata	Non-tuberous annual plant with succulent leaves rounded in cross section	Opportunistic and will invade areas that become waterlogged. Waterlogging hastens the onset of flowering (Clarke and Hannon 1970).	Plants die down to underground rhizomes in dry conditions and will only flower once they are flooded.
Samolus repens	A herb with creeping lower stems and erect upper stems to 30 cm tall. White star flowers.	Can be planted in most soils but grows best with some moisture.	Occurs in saline conditions on the edge of estuaries

is a prolific producer of buoyant seeds dispersed by the tide (Nelson 1994). If an entire saltmarsh field is removed and no saltmarsh habitats are nearby, then it is likely that the saltmarsh will be very slow to recover. Seeds would need to be transported from areas further afield.

Several studies in Australia have examined the active transplantation of saltmarsh plants cultivated in greenhouses or taken from donor populations (Table 3). In short, several species of saltmarsh plants can be propagated and grown for transplantation purposes (Burchett et al. 1998). Saltmarsh plants that are transplanted from donor sites into rehabilitation areas survive and spread, although often slowly (Nelson 1996; Dick 1999). The best results from restoration are generally achieved where the environment has been prepared for the natural recolonisation or regeneration of saltmarsh plants (Nelson 1996; Burchett et al. 1998; Dick 1999). Plants that appear spontaneously in areas tend to grow better than transplanted individuals (Burchett and Pulkownik 1995).

In transplantation from natural sites, it is important to consider the impacts to the donor sites and that the effects of harvesting may take some time to recover also. It has been found that the time required for saltmarsh plants to recover to their natural densities in small plots varies with species and location within the saltmarsh. In a study using small, denuded, plots of *Sporobolus virginicus* and *Sarcocornia quinqueflora*. NSW, it was found that access to tidal inundation was important for recovery of *S. quinqueflora*. It took longer (estimated 4–5.5 years) at higher elevations than at lower positions (14–17 months) (Laegdsgaard 2002). *S. virginicus*, it is estimated at 4–5 years regardless of position (Laegdsgaard 2002).

Saltmarsh areas that are restored using transplants from donor sites may establish a compliment of fauna faster as some may be transported in with the transplant. This is effectively inoculating the site with fauna. This has been shown to be an effective way to speed up the faunation of sites in the USA (Brady et al. 2002). It may also be possible to stock the site with some of the invertebrates known to occur in natural saltmarshes. This requires collection of fauna from nearby natural sites, which may not be appropriate in many cases. It may be useful where a created or restored saltmarsh area is far removed from other natural areas and therefore the recruitment capacity of fauna may be limited. Direct stocking of target taxa has been successful and can allow

Table 3. Propagation and replanting trials from the literature with different species of saltmarshes.

Saltmarsh species	Methods	Reference
Sporobolus virginicus	Propagated in a greenhouse. Transplanted into restoration site and growth recorded	Burchett et al. (1998), Seliskar (1998)
	Removed from donor site and transplanted onto varying substrata and spread to cover sites	Nelson (1994), Burchett and Pulkownik (1995)
	Seeding no shoots emerged	Burchett and Pulkownik (1995)
Sarcocornia quinqueflora	Propagated in a greenhouse and transplanted onto bare natural sites or onto slag deposited in natural sites and spread to cover sites	Burchett and Pulkownik (1995), Dick (1999)
	Transplants from donor site onto prepared levelled and cleared pasture site. but did not expand	Nelson (1994)
	Seeding no shoots emerged	Burchett and Pulkownik (1995)
	Transplants of 8 cm cores from donor sites. Some fertilised. Some planted in topsoil with 50–100% survival. Survival poor in unreplaced soil and where tidal influence reduced	Kay (2004)
Suaeda australis, Halosarcia sp., *Wilsonia baekhousei, Lampranthus tegens*	Propagated in a greenhouse and transplanted but did not expand	Burchett and Pulkownik (1995)
Triglochin striata	Transplants from donor site onto prepared levelled and cleared pasture site Did not survive transplanting	Nelson (1994)
Juncus krausii	Transplanting of clumps of Juncus. After 10 months were expanding and setting seed	Pen (1983)

restored areas to function like natural systems more quickly by facilitating the establishment of key species (Bradshaw 1996).

Acknowledgments

Thanks go to Dr. Kylee Wilton and Dr. Nicole Hacking for comments on an earlier draft of this manuscript. I am grateful to Peggy Svoboda for involving me in the Kooragang Wetland Rehabilitation Project where gained first hand experience of saltmarsh rehabilitation and creation.

References

Adam P. 1981a. Australian saltmarshes. Wetlands (Australia) 1: 8–10.

Adam P. 1981b. Saltmarsh plants of NSW. Wetlands (Australia) 1(1): 11–19.

Adam P. 1990. Saltmarsh Ecology. Cambridge University Press, Cambridge.

Adam P. 1993. Saltmarsh Vegetation Study. Homebush Bay Ecological Studies 1993–1995. 2. CSIRO Publishing.

Adam P. 1997. Absence of creeks and pans in temperate Australian salt marshes. Mangrove Salt Marsh 1: 239–241.

Adam P. and Hutchings P. 1987. The saltmarshes and mangroves of Jervis Bay. Wetlands (Australia) 6(2): 58–64.

Adam P., Wilson N.C. and Huntley B. 1988. The phytosociology of coastal saltmarsh vegetation in New South Wales. Wetlands (Australia) 7: 35–57.

Adams J.B. and Bate G.C. 1994. The effect of salinity and inundation on the estuarine macrophyte *Sarcocornia perennis* (Mill.) A. J. Scott. Aquat. Bot. 47: 341–348.

Allison S.K. 1995. Recovery from small-scale anthropogenic disturbances by northern California salt marsh plant assemblages. Ecol. Appl. 5: 693–702.

Baxter G.S. and Fairweather P.G. 1998. Does available foraging area, location or colony character control the size of multispecies egret colonies? Wildlife Res. 25: 23–32.

Berents P.B. 1993. Wetlands and Benthos. Homebush Bay Ecological Studies 1993–1995. 2. CSIRO Publishing.

Bertness M.D. 1985. Fiddler crab regulation of Spartina alterniflora production in a New England salt marsh. Ecology 66: 1042–1055.

Black J.M. 1986. Flora of South Australia. South Australian Government Printer, Adelaide.

Boon P.I., Bird F.L. and Bunn S.E. 1997. Diet of the intertidal Callianassid shrimps *Biffarius arenosus* and *Trypea australiensis* (Decapoda, Thaladdinidea) in Western Port (Southern Australia), determined with multiple stable isotope analyses. Marine Freshw. Res. 48(6): 503–511.

Boon P.I. and Cain S. 1988. Nitrogen cycling in salt marsh and mangrove sediments in Western Port, Victoria. Austr. J. Marine Freshw. Res. 39: 607–23.

Bowen R., Stephens N. and Donnelly P. 1995. SEPP-14 wetland protection and the role of mitigation. Wetlands (Australia) 14: 6–12.

Bradshaw A. 1996. Underlying principles of restoration. Can. J. Fish. Aquat. Sci. 53(Suppl. 1): 3–9.

Brady V., Cardinale B., Gathman J. and Burton T. 2002. Does facilitation of faunal recruitment benefit ecosystem restoration? An experimental study of invertebrate assemblages in wetland mesocosms Restor. Ecol. 10(4): 617–626.

Breitfuss M.J., Connolly R.M. and Dale P.E.R. 2003. Mangrove distribution and mosquito control: transport of Avicennia marina propagules by mosquito-control runnels in southeast Queensland saltmarshes. Estuar. Coast. Shelf Sci. 56(3–4): 573–579.

Bridgewater P.B. 1982. Phytosociology of coastal salt-marshes in the mediterranean climatic region of Australia. Phytocoenologia 10(3): 257–296.

Bridgewater P.B., Rosser C. and de Corona A. 1981. The saltmarsh plants of southern Australia, Botany Department, Monash University Report.

Bucher D. and Saenger P. 1991. An inventory of Australian estuaries and enclosed marine waters: an overview of results. Austr. Geogr. Stud. 29: 370–381.

Buckney R.T. 1987. Three decades of habitat change: Kooragang Island New South Wales. In: Saunders A., Arnold G.W., Burbidge A.A. and Hopkins A.J.M. (eds), Nature Conservation: The Role of Remnants of Native Vegetation. Surrey Beatty and Sons Pty Ltd in association with CSIRO and CALM, Chipping Norton.

Burchett M.D., Allen C., Pulkownik A. and MacFarlane G. 1998. Rehabilitation of saline wetland, Olympic 2000 site, Sydney (Australia). II: Saltmarsh transplantation trials and application. Marine Pollut. Bull. 37(8–12): 526–534.

Burchett M.D. and Pulkownik A. 1995. Wetlands study. Homebush Bay Ecological Studies 1993–1995. 1. CSIRO Publishing.

Callaway J.C. and Zedler J.B. 1998. Interactions between a salt marsh native perennial (*Salicornia virginica*) and an exotic annual (*Polypogon monspeliensis*) under varied salinity and hydroperiod. Wetlands Ecol. Manag. 5: 179–194.

Callaway J.C., Zedler J.B. and Ross D.L. 1997. Using tidal salt marsh mesocosm to aid wetland restoration. Restor. Ecol. 5: 135–146.

Carne R.J. 1991. Landform vegetation relationships in the Minamurra estuary NSW. Department of Geography and Oceanography, NSW University Report.

Chapman H.F., Dale P.E.R. and Kay B.H. 1998. A method for assessing the effects of runneling on salt marsh grapsid crab populations. J. Amer. Mosq. Contr. Assoc. 14(1): 61–68.

Chapman H.F., M H.J., Jennings C., Kay B.H. and Ritchie S.A. 1999. Population structures and dispersal of the saltmarsh mosquito Aedes vigilax in Queensland, Australia. Med. Vetinary Entomol. 13(4): 423–430.

Chapman V.J. 1960. Saltmarshes and Saltdeserts of the World. London.

Clarke C. and Miller P. 1983. Habitat evaluation – invertebrates. In: Moss J. (ed.), An Investigation of Natural Areas of Kooragang Island, Hunter River. Department of Environment and Planning, Sydney.

Clarke C.J. and van Gessel F.W.C. 1983. Habitat evaluation – birds. In: Moss J. (ed.), An Investigation of Natural Areas of

Kooragang Island, Hunter River. Department of Environment and Planning, Sydney.
Clarke L.D. and Hannon N.J. 1967. The mangrove swamp and salt marsh communities of the Sydney district I Vegetation, soils and climate. J. Ecol. 55: 753–771.
Clarke L.D. and Hannon N.J. 1969. The mangrove swamp and salt marsh communities of the Sydney district II The holocoenotic complex with particular reference to physiography. J. Ecol. 57: 213–234.
Clarke L.D. and Hannon N.J. 1970. The mangrove swamp and salt marsh communities of the Sydney district III Plant growth in relation to salinity and waterlogging. J. Ecol. 56: 351–369.
Clarke L.D. and Hannon N.J. 1971. The mangrove swamp and salt marsh comminities of the Sydney district IV The significance of species interaction. J. Ecol. 59: 535–553.
Clarke P. and Benson D. 1988. The natural vegetation of Homebush Bay – two hundred years of changes. Wetlands (Australia) 8: 3–15.
Clarke P.J. 1983. Nitrogen pools in a mangrove-saltmarsh system. Wetlands 3: 85–93.
Clarke P.J. 1986. Nitrogen pools and soil characteristics of a temperate estuarine wetland in eastern Australia. Aquat. Bot. 23: 275–290.
Clarke P.J. 1993. Mangrove, saltmarsh and peripheral vegetation of Jervis Bay. Cunnighamia 3(1): 231–253.
Clarke P.J. and Allaway W.G. 1993. The regeneration niche of the grey mangrove (*Avicennia marina*): effects of salinity, light and sediment factors on establishment, growth and survival in the field. Oecologia 93: 548–556.
Clarke P.J. and Jacoby C.A. 1994. Biomass and above-ground productivity of salt marsh plants in south-eastern Australia. Australian Journal of Marine and Freshwater Research 45: 1521–1528.
Clarke P.J. and Myerscough P.J. 1993. The intertidal distribution of the grey mangrove (Avicennia marina) in southeastern Australia - The effects of physical conditions, interspecific competition, and predation on propagule establishment and survival. Austr. J. Ecol. 18(3): 307–315.
Coleman P.S.J. 1998. Changes in a mangrove/samphire community, North Arm Creek, South Australia. Trans. Roy. Soc. S Austr. 122(4): 173–178.
Collinge S.K. 1996. Ecological consequences of habitat fragmentation: Implications for landscape architecture and planning. Landscape Urban Plan 36(1): 59–77.
Congdon R.A. and McComb A.J. 1980. Productivity and nutrient content of Juncus krausii in an estuarine marsh in south-western Autralia. Austr. J. Ecol. 5: 221–234.
Congdon R.A. and McComb A.J. 1981. The vegetation of the Blackwood River estuary, South-west Australia. J. Ecol. 69: 1–16.
Connolly R.M. 1999. Saltmarsh as habitat for fish and nektonic crustaceans: challenges in sampling designs and methods. Austr. J. Ecol. 24: 422–430.
Connolly R.M. 2005. Modification of saltmarsh for mosquito control in Australia alters habitat use by nekton. Wetlands Ecol. Manag. 13(2): 149–161.
Connolly R.M. and Bass D.A. 1996. Do fish actually use salt marsh flats? Proceedings of the Coastal Management Conference, Glenelg, South Australia April, 1996, pp. 273–276.
Connolly R.M., Dalton A. and Bass D.A. 1997. Fish use of a inundated saltmarsh flat in a temperate Australian estuary. Austr. J. Ecol. 22: 222–226.
Cook R.E. 1985. Growth and development in clonal organisms. In: Jackson J.B.C., Buss L.W. and Cook R.E. (eds), Population Biology and Evolution of Clonal Organisms. Yale University Press, New Haven.
Cribb A.B. and Cribb J.W. 1985. Plant Life of the Great Barrier Reef and Adjacent Shores. University of Queensland Press, Australia.
Crinall S.M. and Hindell J.S. 2004. Assessing the use of saltmarsh flats by fish in a temperate Australian embayment. Estuaries 27: 728–739.
CSIRO 1994. Epifauna of mangroves and saltmarshes. Perth, CSIRO Division of Fisheries: Final report 619–653.
Dale P.E.R., Dale P.T., Hulsman K. and Kay B.H. 1993. Runnelling to control saltmarsh mosquitoes – long-tern efficacy and environmental impacts. J. Amer. Mosquito Contr. Assoc. 9(2): 174–181.
Davis J.A. and Froend R. 1999. Loss and degradation of wetlands in southwestern Australia: underlying causes, consequences and solutions. Wetlands Ecol. Manag. 7: 13–23.
Davis T.L.O. 1988. Temporal changes in the fish fauna entering a tidal swamp system in tropical Australia. Environ. Biol. Fish 21: 161–172.
Day J.W., Hall C.A.S., Kemp M.W. and Yanez-Arancibia A. 1989. Estuarine Ecology. John Wiley And Sons.
de la Cruz A.A. and Hackney C.T. 1977. Energy value, elemental composition and productivity of below ground biomass of Juncus tidal marsh. Ecology 58: 1165–1170.
Dick T.M. 1999. Decomposition of saltmarsh and mangrove vegetation on and around Kooragang Island, Master of Science Thesis, University of Newcastle.
Donovan L.A. and Gallagher J.L. 1984. Anaerobic substrate tolerance in *Sporobolus virginicus* (L.) Kunth. Amer. J. Bot. 71(10): 1424–1431.
Donovan L.A. and Gallagher J.L. 1985. Morphological responses of a marsh grass, *Sporobolus virginicus* (L) Kunth to saline and anaerobic stresses. Wetlands 5: 1–13.
Eckstein D. 2004. Leichardt Council Federal Park Wetland Project. Final report for Encironmental Trust, Restoration and Rehabilitation Trust Grant 1995/RR/G0021.
Fenech H. 1994. An assessment of the estuarine wetland status within the Sutherland Shire. Bachelor of Environmental Science Thesis, Faculty of Science, University of Woolongong.
Finlayson C.M. and Rea N. 1999. Reasons for the loss and degradation of Australian wetlands. Wetlands Ecol. Manag. 7: 1–11.
Gallagher J.L. 1979. Growth and elemental compositional responses of Sporobolus virginicus (L) Kunth to substrate salinity and nitrogen. Amer. Midland Nat. 102: 68–75.
Genders A. 1997. Creek 3 Benthic Invertebrate Study, University of Newcastle Report.
Genders A.J. 1996. Interaction of marsh and pasture species on Kooragang Island, Graduate Diploma of Science Thesis, University of Newcastle.
Gibbs P.J. 1986. The fauna and fishery of Wallis Lake. Wallis Lake: Present and Future. Australian Marine Science Association, Sydney Report.

Gislason G.M. and Russell R.C. 1997. Oviposition sites of the saltmarsh mosquito, *Aedes vigilax* (Skuse) (Diptera, Culicidae), at Homebush Bay, Sydney NSW – A preliminary investigation. Austr. J. Entomol. 36(Part 1): 97–100.

Gosper D.G. 1981. Survey of birds on floodplain-estuarine wetlands on the Hunter and Richmond Rivers in northern NSW. Corella 5: 1–18.

Harrison S. and Bruna E. 1999. Habitat fragmentation and large-scale conservation: what do we know for sure? Ecography 22(5): 225–232.

Havens K.J., Varnell L.M. and Watts B.D. 2002. Maturation of a constructed tidal marsh relative to two natural reference tidal marshes over 12 years. Ecol. Eng. 18: 305–315.

Hedge P. and Kriwoken L.K. 2000. Evidence for effects of *Spartina anglica* invasion on benthic macrofauna in Little Swanport estuary, Tasmania. Austral Ecol. 25: 150–159.

Huiskes A.H.L., Koutstaal B.P., Herman P.M.J., Beeftink W.G., Markusse M.M. and de Munck W. 1995. Seed dispersal of halophytes in tidal salt marshes. J. Ecol. 83: 559–567.

Hutchings P.A., Pickard J., Recker H.F. and Weate P.B. 1977. A survey of the mangroves at Brooklyn, Hawkesbuly River, NSW. Operculum 5(3): 105–112.

Hutchings P.A. and Recher H.F. 1974. The fauna of Careel Bay with comments on the ecology of mangroves and seagrass communities. Austr. Zool. 18: 99–127.

Irving L. 2001. An investigation of the structure and primary food sources of the intertidal macrofauna of Coombabah Lake, southeast Queensland. Honours Thesis, School of Environmental and Applied Science. Gold Coast, Griffith University.

Jacobs S.W.L. 1999. Terrestrial wetlands and waterplants. In: Orchard A.E. and Thompson H.S. (eds), Flora of Australia, Vol. 1. CSIRO Publishing, Collingwood, VIC.

Johnson D.H. 2001. Habitat fragmentation effects on birds in grasslands and wetlands: a critique of our knowledge. Great Plains Res. 11(2): 211–231.

Kaplan W. and Valiela I. 1979. Denitrification in a salt marsh ecosystem. Limnol. Oceanogr. 24(4): 726–734.

Kay S. 2004. Experimental re-establishment of *Sarcocornia quinqueflora* in Haslams Creek flats. Proceedings of the Wetland an Education Training Program: Recent Techniques in Protection, Creation and Rehabilitation of Coastal Saltmarshes, Homebush 3–4 June 2004.

Kelleway J. in press. Ecological impacts of recreational vehicle use on saltmarshes of the Georges River, Sydney. Wetlands, Australia.

King R.J. 1981. Mangroves and saltmarsh plants. In: Clayton M.N. and King R.J. (eds), Marine Botany: An Australasian Perspective. Longman Cheshire, Melbourne.

Kirkpatrick J.B. and Glasby J. 1981. Salt marshes in Tasmania: distribution, community composition and conservation. Tasmania, Department of Geography, University of Tasmania Report.

Kratochvil M., Hannon N.J. and Clarke L.D. 1972. Mangrove swamp and saltmarsh communities in southeastern Australia. Proc. Linnaen Soc. NSW 97: 262–274.

Krause A. 1995. Factors determining the spatial distribution of vegetation in a Tomago saltmarsh, University of Newcastle, Bachelor of Environmental Science Thesis.

Laegdsgaard P. 2001. Conservation of coastal saltmarshes and management implications. Proceedings of the 11th Coastal Management Conference, Newcastle, November 2001.

Laegdsgaard P. 2002. Recovery of small denuded patches of the dominant NSW coastal saltmarsh species (*Sporobolus virginicus* and *Sarcocornia quinqueflora*) and implications for restoration using donor sites. Ecol. Manag. Restor. 3(3): 202–206.

Laegdsgaard P. in prep. The Lack of Burrowing Macrofauna in Coastal Saltmarshes of New South Wales, Australia.

Laegdsgaard P., Monamy V. and Saintilan N. 2004. Investigating the presence of threatened insectivourous bats on coastal NSW saltmarsh habitat. Wetlands (Australia) 22(1): 29–41.

Latchford J. 1994. Samphire flats of the Peel-Harvey Estuary – A community asset, Peel Preservation Group Inc. Report.

Lefeuvre J., Bouchard V., Feunteun E., Grare S., Laffaille P. and Radureau A. 2000. European salt marshes diversity and functioning: The case study of the Mont Saint-Michel bay, France. Wetlands Ecol. Manag. 8: 147–161.

Lincoln-Smith M., White G.A. and Hawes P.M.H. 1994. Fish Study. Homebush Bay Ecological Studies 1993–1995. 1. CSIRO Publishing.

Maddock M. 1983. Hunter Valley wetland birds raise conservation issues. Wetlands (Australia) 3(2): 58–70.

Mahall B.E. and Park R.B. 1976. The ecotone between *Spartina foliosa* Trin. and *Salicornia virginica* L. in saltmarshes of northern San Francisco Bay. I. Biomass and production. J. Ecol. 64: 421–433.

Marsh J.A. 1982. Aspects of the ecology of three saltmarshes of the Derwent region, and an investigation into the role of the burrowing crab Helograpsus haswellianus (Whitelegge 1889). Honours Thesis, Department of Zoology. Hobart, University of Tasmania.

Mazluff J.M. and Ewing K. 2001. Restoration of fragmented landscapes for the conservation of birds: A general framework and specific recommendations for urbanizing landscapes. Restor. Ecol. 9(3): 280–292.

Mazumder D., Saintilan N. and Williams R.J. 2005. Temporal variations in fish catch using pop nets in mangrove and saltmarsh flats at Towra Point, NSW, Australia. J. Wetland Ecol. Manag. 13(4): 457–467.

Milford H.B. and Simons N. 2002. The Salinity Soil Data Care. Supplement 1 to the 3rd edition of the soil data entry handbook, Department of Land and Water Conservation Report.

Mitchell M.L. and Adam P. 1989a. The decline of saltmarsh in Botany Bay. Wetlands (Australia) 8(2): 55–60.

Mitchell M.L. and Adam P. 1989b. The relationship between mangrove and saltmarsh communities in the Sydney region. Wetlands (Australia) 8(2): 37–46.

Morrisey D. 1995. Saltmarshes. In: Underwood A.J. and Chapman M.G. (eds), Coastal Marine Ecology of Temperate Australia. UNSW Press, Sydney.

Morton R.M. 1993. Fluctuations in wetland extent in southern Moreton Bay. In: Greenwood J.G. and Hall N.J. (eds), Future of Marine Science in Moreton Bay. School of Marine Science, University of Queensland, Brisbane.

Morton R.M., Beumer J.P. and Pollock B.R. 1988. Fishes of a subtropical Australian saltmarsh and their predation upon mosquitoes. Environ. Biol. Fish. 21: 185–194.

Morton R.M., Pollock B.R. and Beumer J.P. 1987. The occurrence and diet of fishes in a tidal inlet to a saltmarsh in southern Moreton Bay, Queensland. Austr. J. Ecol. 12: 217–237.

NAWC 2003. Noxios weed list for Australian States and Territories, National Australian Weeds Commitee.

Nelson P.J. 1994. Aspects of the ecology of vascular halophytes which determine their distribution in a Kooragang Island saltmarsh community, Honours Thesis, University of Newcastle.

Nelson P.J. 1996. The ecology of saltmarsh restoration on Kooragang Island. Newcastle, University of Newcastle, Department of Biological Sciences Report.

Outhred R.K. and Buckney R.T. 1983. The vegetation of Kooragang Island, New South Wales. Wetlands (Australia) 3(2): 58–70.

Pen L.J. 1983. Peripheral vegetation of the Swan and Canning estuaries 1981. Department of Conservation and Environment Western Australia Report.

Pidgeon I.M. 1940. The ecology of the central coastal area of New South Wales II Types of primary succession. Proc. Linnaean Soc. 65: 221–249.

Redfield A.C. 1972. Development of a New England salt marsh. Ecol. Monogr. 42: 201–237.

Richardson A.M.M. and Mulcahy M.E. 1996. The distribution of Talitrid amphipods (Crustacea) on a salt marsh in southern Tasmania, in relation to vegetation and substratum. Estuar. Coast. Shelf Sci. 43: 801–817.

Richardson A.M.M., Swain R. and McCoull C.J. 2001. Salt spray limits the inland penetration of a coastally restricted invertebrate: a field experiment using landhoppers (Crustacea: Amphipoda: Talitridae). Funct. Ecol. 15(4): 435–442.

Richardson A.M.M., Swain R. and Wong V. 1997. The crustacean and molluscan fauna of Tasmanian saltmarshes. Proc. Roy. Soc. Tasmania 131: 21–30.

Ritchie S.A. 1994. Spatial stability of *Aedes vigilax* (Diptera, Culicidae) eggshells in southeastern Queensland salt marshes. J. Med. Entomol. 31(6): 920–922.

Ritchie S.A. and Jennings C.D. 1994. Dispersion and sampling of *Aedes vigilax* eggshells in southeastern Queensland, Australia. J. Amer. Mosq. Contr. Assoc. 10(2 part 1): 181–185.

Roach A.C. 1998. Effects of predation on the size structure of the gastropod *Salinator solida* (Martens) populations at Towra Point, NSW, Australia. Marine Freshw. Res. 49: 779–784.

Roach A.C., Hunt A.M. and Ward C.J.A. 1989. Factors related to the intra- and interspecific zonation of two pulmonate gastropods *Salinator solida* (Lamarck and *Ophicardelus ornatus*(Ferussac). J. Malacol. Soc. Austr. 10: 59–67.

Roach A.C. and Lim R.P. 2000. Variation in the population dynamics of the intertidal pulmonate gastropod *Salinator solida* Martens (Gastropoda: Amphibolidae) at Towra Point, NSW, Australia. Wetlands Ecol. Manag. 8: 53–69.

Roman C.T., Niering W.A. and Warren R.S. 1984. Salt marsh vegetation change in response to tidal restriction. Environ. Manag. 8(2): 141–150.

Roy P.S. 1984. New South Wales Estuaries: Their origin and Evolution. Coastal Geomorphology in Australia. Academic Press, Australia.

Ryan P.A., Do K.A. and Kay B.H. 2000. Definition of Ross River virus vectors at Maroochy Shire, Australia. J. Med. Entomol. 37(1): 146–152.

Saenger P., Specht M.M., Specht R.L. and Chapman V.J. 1977. Mangal and coastal saltmarsh communities in Australasia. In: Chapman V.J. (ed.), Ecosystems of the World: Wet Coastal Ecosystems. Elsevier Scientific Publishing Company.

Saintilan N. 2003. The less obvious impacts of human settlement. In: Straw P. (ed.), Status and Management of Migratory Shorebirds in Sydney. Sydney Olympic Park Authority, Sydney.

Saintilan N. and Hashimoto T.R. 1999. Mangrove-saltmarsh dynamics on a bay-head delta in the Hawkesbury River estuary, New South Wales, Australia. Hydrobiologia 413: 95–102.

Saintilan N. and Williams R.J. 1999. Mangrove transgression into saltmarsh environments in south-east Australia. Global Ecol. Biogeogr. 8: 117–124.

Saintilan N. and Wilton K. 1999. Changes in the distribution of mangroves and saltmarshes in Jervis Bay, Australian Catholic University, Report prepared for the Shoalhaven Catchment Management Committee.

Sainty G. and Roberts D. 2004. Saltmarsh restoration and construction. *Proceedings of the Wetland an Education Training Program: Recent Techniques in Protection, Creation and Rehabilitation of Coastal Saltmarshes*, Homebush 3–4 June 2004.

Seliskar D.M. 1998. Natural and tissue culture-generated variation in the salt marsh grass *Sporobolus virginicus*: Potential selections for marsh creation and restoration. Hortscience 33(4): 622–625.

Simpson J. 1995. Wading birds of Anderson Inlet and the work of the Victorian Wader Study Group. In: Rash J.E., Williamson J.S. and Taylor J.S. (eds), Proceedings of the Australasian Conference on Spartina Control. Victorian Government, Melbourne.

Smith P. 1991. The biology and management of waders (suborder Charadrii) in NSW, National Parks and Wildlife Service Report.

Smith-White A.R. 1981. Physiological differentiation in a saltmarsh grass. Wetlands (Australia) 1: 20–21.

Specht R.L. 1981. Biogeography of halophytic angiosperms (salt-marshes, mangrove and sea-grass). In: Keast A. (Ed.), Ecological Biogeography of Australia. Dr Junk, The Hague.

Spellerberg I. 1998. Ecological effects of roads and traffic: A literature review. Global Ecol. Biogeogr. Letts 7: 317–333.

Straw P. 1996. Waterbirds. Homebush Bay Ecological Studies 1993–1995. 2. CSIRO Publishing.

Streever W.J. 1997. Trends in Australian wetland rehabilitation. Wetlands Ecol. Manag. 5: 5–18.

Streever W.J. and Genders A.J. 1997. Effect of improved tidal flushing and competitive interactions at the boundary between salt marsh and pasture. Estuaries 20(4): 807–818.

Streever W.J., Wiseman L., Turner P. and Nelson P. 1996. Short term changes in flushing of tidal creeks following culvert removal. Wetlands (Australia) 15(1): 22–30.

Talley T.S. and Levin L.A. 1999. Macrofaunal succession and community structure in *Salicornia* marshes of southern California. Estuar. Coast. Shelf Sci. 49(5): 713–731.

Taylor D.I. and Allanson B.R. 1995. Organic carbon fluxes between a high marsh and estuary, and the inapplicability of the outwelling hypothesis. Marine Ecol. Progr. Ser. 120: 263–270.

Thomas B.E. and Connolly R.M. 2001. Fish use of subtropical saltmarshes in Queensland, Australia: relationships with vegetation, water depth and distance onto the marsh. Marine Ecol. Progr. Ser. 209: 275–288.

Tscharntke T., Steffan-Dewenter I., Kruess A. and Thies C. 2002. Characteristics of insect populations of habitat fragments: a mini review. Ecol. Res. 17: 229–239.

Turner P.A. and Streever W.J. 1997. The relationship between the density of *Aedes vigilax* (Diptera, Culicidae) eggshells and environmental factors on Kooragang Island, New South Wales, Australia. J. Amer. Mosq. Contr. Assoc. 13(4): 361–367.

Turner P.A. and Streever W.J. 1999. Changes in productivity of the saltmarsh mosquito, *Aedes vigilax* (Diptera: Culicidae), and vegetation cover following culvert removal. Austr. J. Ecol. 24: 240–248.

Underwood A.J. and Chapman M.G. 1993. Seashores A Beachcomber's guide. NSW University Press, Australia.

van der Valk A.G. and Attiwill P.M. 1983. Above- and belowground litter decomposition in an Australian salt marsh. Austr. J. Ecol. 18: 441–447.

Vernberg F.J. 1993. Salt-marsh processes: a review. Environ. Toxicol. Chem. 12: 2167–2195.

Warren J. 1989. The status and production of mangrove and saltmarsh ecosystems in the Parramatta River Basin. Sydney, University of Technology, Masters Thesis.

Web K.L. 1966. NaCl effects on growth and transpiration in *Salicornia bigelovii* salt marsh halophyte. Pl. Soil 24: 261–268.

Webb C.E. and Russell R.C. 1999. Towards management of mosquitoes at Homebush Bay, Sydney, Australia. I. Seasonal activity and relative abundance of adults of Aedes vigilax, Culex sitiens, and other salt-marsh species, 1993–94 through 1997–98. J. Amer. Mosq. Contr. Assoc. 15(2): 242–249.

Weinstein M.P. and Balletto J.H. 1999. Does the common reed, *Phragmites australis*, affect essential fish habitat? Estuaries 22(3B): 793–802.

West R.J. 1993. Estuarine fisheries resources of two south eastern Australian rivers, University of New South Wales, PhD Thesis.

Wilson J.B., King W.M., Sykes M.T. and Partridge T.R. 1996. Vegetation zonation as related to the salt tolerance of species of brackish riverbanks. Can. J. Bot. 74: 1079–1085.

Wilson N.C. 1984. The plant communities of saltmarshes of the Sydney region. Honours Thesis, University of New South Wales, Sydney.

Wilton K.M. 2002. Coastal wetland habitat dynamics in selected New South Wales Estuaries. PhD thesis, Faculty of Arts and Sciences. Australian Catholic University.

Windham L. 1995. Effects of *phragmites australis* invasion on above-ground biomass and soil properties in brackish tidal marsh of the Mullica River, New Jersey. New Brunswick, New Jersey, Rutgers University, Masters Thesis.

Zann L.P. 1997. Our Sea, Our Future, Major findings of the State of the Marine Environment Report for Australia. Department of Environment, Sport and Territories, Canberra.

Zedler J.B. and Adam P. 2002. Saltmarshes. In: Perrow M.R. and Davy A.J. (eds), Handbook of Ecological Restoration. Cambridge University Press.

Zedler J.B., Nelson P. and Adam P. 1995. Plant community organization in New South Wales saltmarshes: Species mosaics and potential causes. Wetlands (Australia) 14: 1–18.

Zedler J.B., Paling E. and McComb A. 1990. Differential responses to salinity help explain the replacement of native Juncus krausii by *Typha orientalis* in Western Australia salt marshes. Austr. J. Ecol. 15: 57–72.