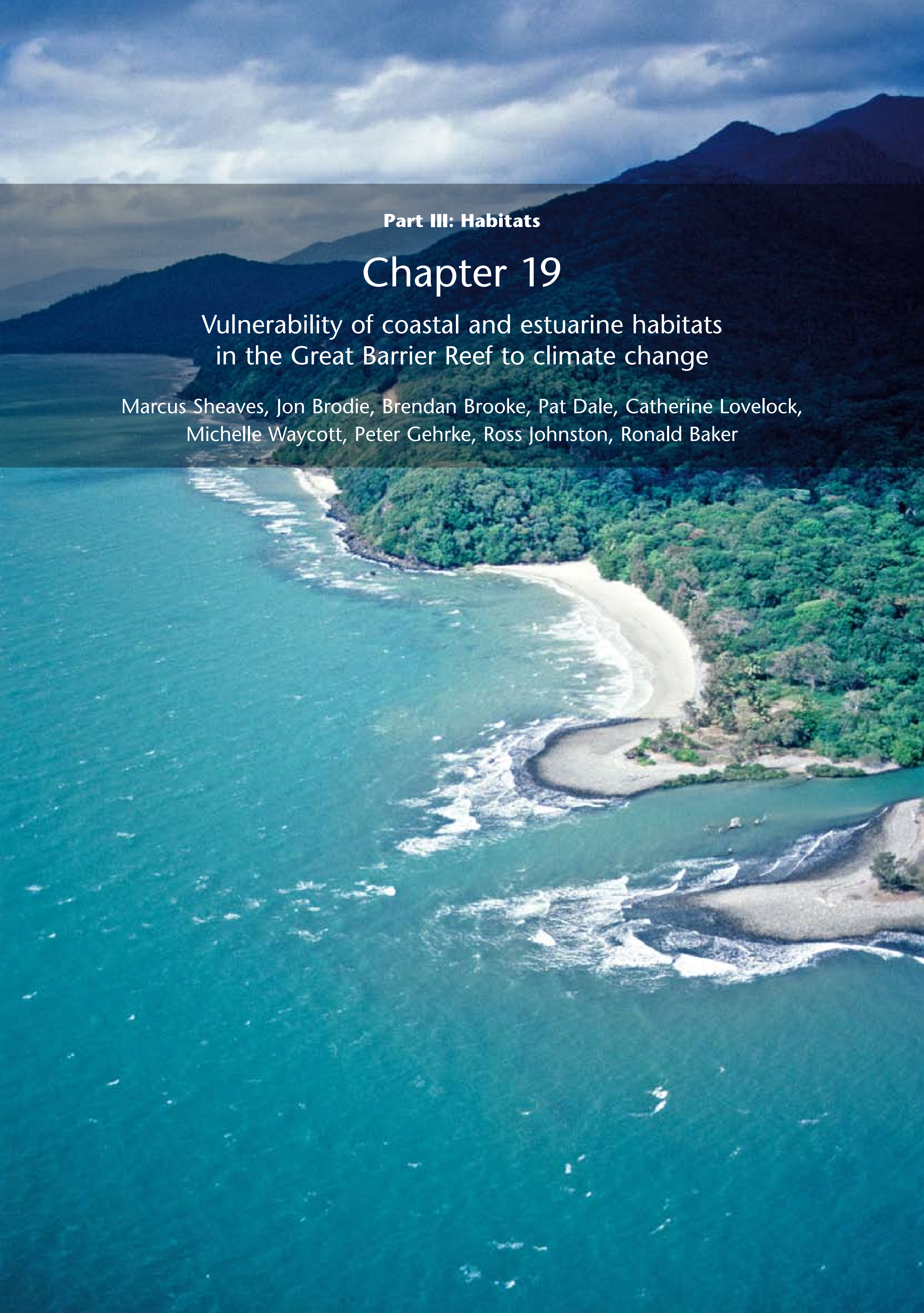
Part III: Habitats

Chapter 19

Vulnerability of coastal and estuarine habitats in the Great Barrier Reef to climate change

Marcus Sheaves, Jon Brodie, Brendan Brooke, Pat Dale, Catherine Lovelock, Michelle Waycott, Peter Gehrke, Ross Johnston, Ronald Baker



19.1 Introduction

Coastal and estuarine habitats occupy a central place in the functioning of tropical marine ecosystems. Their location at the interface between land and sea means they function to modulate the movement of terrestrial materials (eg freshwater, nutrients and pollutants) into the marine environment[160]. Coastal and estuarine habitats also act as a filter, with functional units such as mangrove forests inhibiting trapping and retaining sediments and nutrients[157]. Coastal habitats are also crucial nursery grounds for many species of fish[111] and crustaceans[152], and act as links in the life cycles of species that migrate between marine and freshwater habitats[134]. Beyond this, their close proximity to population and industrial centres makes them the marine habitats most vulnerable to human impacts.

The east coast of tropical Queensland comprises a diversity of habitats, ranging from freshwater and littoral marshes, through estuaries, to nearshore open oceans and reefs. These habitats do not function alone but are an interlinked coastal ecosystem mosaic (CEM), connected at a variety of spatial, temporal, functional and conceptual scales[51]. This complex mix of habitats is inhabited by one of the most diverse faunas on earth[60] with organisms covering the full taxonomic spectrum, from viruses and bacteria to cetaceans. Unfortunately, detailed ecological knowledge is limited to a very small subset of the range of these organisms, with many species unknown, unidentified or unquantified[60,33]. Although it is clear species interact in complex ways, our understanding of this is critically deficient. Moreover, many of the individual components are poorly understood, and details of the links between them largely absent.

This chapter attempts to address the vulnerability of the CEM in the Great Barrier Reef region to global climate change. It does not consider individual habitats (eg reefs or seagrasses) but goes beyond the individual species and habitat assessments, to consider impacts on the whole coastal marine community complex, and the ecological processes that support its functioning.

Due to the diversity of organisms and habitats[60,8], the variety of physical processes involved[165], and their intricate interlacing[93], impacts of global climate change are likely to be complex, pervasive and difficult to predict. Additionally, there are likely to be emergent impacts on ecological processes above and beyond those related to, or predictable from our knowledge of individual taxa or individual habitat and ecosystem components. Unfortunately, at present there is sparse understanding of even the best-researched components on which to base an authoritative vulnerability assessment. Consequently, the major message of this chapter is that more targeted information is needed to make a comprehensive evaluation of the likely impacts of climate change on coastal systems. Although, this chapter addresses the whole CEM, in reality there is little understanding of most of the components of this complex outside of estuaries. Consequently, by necessity much of the discussion will focus on estuaries, and even this discussion draws heavily on understanding from outside of the tropics.

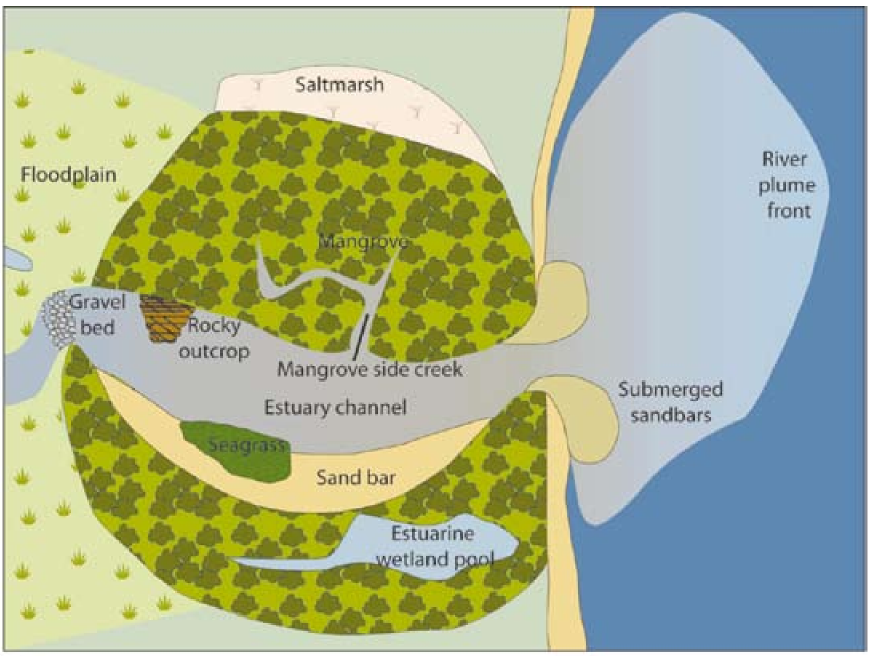
19.1.1 The nature of the coastal ecosystem mosaic

Even at the coarsest level of resolution the diversity of habitats comprising the CEM is obvious (Figure 19.1). Nearshore open ocean, coastal reefs and rocky headlands, beaches, river plumes, estuaries, mangrove forests, salt marshes, estuarine and freshwater wetlands, and freshwater streams are linked by their proximity, the physical transport of material, the movements of organisms, and a variety of physical and ecological processes. Although this resolution is coarse it is still difficult to unambiguously disentangle habitats at different scales[134], with a complete habitat from one point of view being an ecosystem component from another point of view.

Within ecosystems are a range of habitats that occur in various combinations. For example, estuaries (defined as areas where sea water and freshwater mix) comprise a variety of vegetated and non-vegetated habitats (Figure 19.1). Some of these components are peculiar to estuaries, others occur in combination with other habitat types in other parts of the CEM. At this scale there are many components (eg mangrove and seagrass) that are treated in detail in other chapters.

Although the components of CEM are a heterogeneous group, with a variety of properties (eg differing in depth, structure and complexity), they are linked by both the physical movement of materials (physical connectivity), and by the movement and interdependence of organisms and communities[93,51]. Physical connectivity can be seen in the outflow (and inflow) of sediments, nutrients and pollutants through the CEM[162,48,158]. Biological interdependence is obvious in the lack of concordance between the distributions of many organisms and the scale and extent of identifiable habitat or ecosystem units[51] Life history migrations (eg to access nursery grounds)[111,112,131], and shorter-term movements (eg feeding forays)[133], increase this interdependence by linking the mosaic within the lives of organisms and transferring nutrients and energy between various components of the mosaic. This biological connectivity links the components at a diversity of spatial and temporal scales.

Figure 19.1 *The habitats that make up the Coastal Ecosystem Mosaic that comprise coastal and estuarine habitats of the GBR region*



19.2 Exposure and sensitivity to climate change

Due to the complexity of the CEM there are many physical, biological and functional aspects, varying substantially in focus and scale, that are likely to be impacted by global climate change (Table 19.1).

Climate interacts with other physical processes to produce surface characteristics such as topography, soils and water (both surface and subsurface), and to determine the nature of an area's physical environment. This interaction means physical processes are likely to be impacted by most aspects of climate change. The diverse and complex biological processes active in the CEM (Table 19.1) are set within this physical framework. Consequently, their exact natures and the integrity of their functions are closely tied to the environment, meaning climate change has the potential to lead to profound changes. These biological processes are often complex involving a diversity of organisms (eg trophic function) and impinge on every aspect of life. As a result, change to any one component is likely to have far reaching effects, and these effects are likely to be transmitted, and often amplified, throughout the linkages of the CEM. Beyond this, coastal marine habitats fulfil a variety of ecosystem services such as flood control, pollution filtration, nutrient recycling, sediment accretion, groundwater recharge and water supply, erosion control, and plant and wildlife preservation[57]. These pivotal roles mean that climate change is likely to have far-reaching effects that go beyond direct and indirect impacts on biota.

Table 19.1 *Summary of features and processes likely to be influenced by climate change*

Feature or process	Climate change process with greatest potential impact	Aspects likely to change
Physical processes relevant to ecosystems	sea level change rainfall patterns severe weather events acidification temperature	coastal/estuarine geomorphology estuarine flushing sediment loads nutrient transport salinity profiles ecosystem-specific chemistry
Habitats and ecosystems	sea level change rainfall patterns severe weather events temperature	extent of particular habitats/ecosystem components relative proportions of habitats habitat interspersion, patch size, pattern, connectivity habitat boundaries habitat availability
Species and species-level ecological functions	sea level change rainfall patterns severe weather events acidification secondary outcomes from effects on habitats and species temperature	abundance distribution spawning supply of recruits or propagules temporal and spatial matching with prey/ nutrients

Feature or process	Climate change process with greatest potential impact	Aspects likely to change
Trophic function	secondary outcomes from effects on habitats, species and diversity	food web structure and integrity physically mediated nutrient flows biologically mediated nutrient transfers balance of export/import dominant trophic processes
Connectivity	sea level change rainfall patterns severe weather events secondary outcomes from effects on habitats and species	physical connectivity biological connectivity overall ecosystem linkages
Higher level ecological functions	temperature sea level change rainfall patterns severe weather events acidification secondary outcomes from effects on habitats, species and diversity	nursery ground function ecosystem/habitat dependence regularity/periodicity of ecosystem structuring events (eg cyclones) changes in complex ecosystem interactions changes in structure of production models impacts on key ecosystem components fisheries production
Diversity	temperature sea level change rainfall patterns severe weather events acidification	taxonomic diversity functional diversity
Interactions with anthropogenic factors	sea level change rainfall patterns severe weather events acidification secondary outcomes from effects on habitats, species and diversity	interactions with anthropogenic stressors interactions with human response to climate change

19.3 Vulnerability to climate change

A common theme of the previous individual species and habitat chapters is a general uncertainty about the details, magnitude and even the direction of effects of global climate change. These uncertainties are magnified when extrapolated to the scales of individual habitats, the CEM and high-level ecological functions.

19.3.1 Physical processes

The Great Barrier Reef (GBR) coast comprises 42 percent sandy beaches, 39 percent muddy shoreline and 19 percent rocky exposures[49]. Each type of coast has distinctive assemblages of habitats and types of vulnerability to climate change. The nature of any climate-induced change is likely to be region specific[163]. In general terms, sandy coasts are susceptible to recession and erosion due to sea level rise and increased frequency of storms[75]. Habitats associated with muddy coasts (eg mangroves and salt marsh) and adjacent low-lying freshwater swamps are vulnerable to shoreline erosion, the landward incursion of saltwater and changes in rainfall (eg Nicholls et al.[92], Rogers et al.[114]). Rocky coasts are less prone to erosion, depending on rock type, than the sedimentary coasts. However, associated marine biota, such as intertidal attaching organisms, will likewise be affected by changes in sea level and wave exposure associated with climate change.

The particular spatial pattern of physical environments found on the GBR influence the extent to which various components of the CEM are vulnerable to climate change. Although the coast is largely protected from ocean swell by the outer reefs, there is significant variability in the local and regional sea surface temperature, wind, wave and tidal regimes. For example, large tides on the central and southern coast are a major control on coastal processes, and sea surface temperatures are significantly lower in the southern GBR (mean annual range 22 to 27°C) compared to the north (mean annual range 25 to 29°C[80]). The coast is also characterised by strong gradients in rainfall, with a marked decline in the average annual rainfall from Cairns (3200 mm) towards both the far northern (1600 mm) and southern (1000 mm) margins of the GBR coasta. Similarly, the frequency of cyclones declines to the south from approximately 0.4 cyclones per year on the Cape York coast (30 year annual average) to 0.1 at the southern margin of the GBR[a85]. The set of climatic and oceanographic conditions each region experiences results in a distinctive set of landforms and geomorphic processes. For example, estuary type ranges from river-dominated deltas in the wetter areas, with relatively low tidal and wave energy, to tide-dominated estuaries on the drier, macro-tidal coasts[61].

Changes in climate, and particularly in sea level, at a rate greater than that previously experienced over geological time[52], will cause far-reaching impacts on processes of erosion and sedimentation. An increased incidence of extreme events may lead to acute episodes of high erosion in upper catchments and then to high rates of deposition in CEM areas. Rates of sedimentation are critically important in determining responses to sea level change. Additionally, if erosion increases in the CEM then there will be a high risk of acidification as much of the coastal area below 10 metres Astronomical High Datum is underlain by acid sulphate soils[31]. Oxidation occurs when acid sulphate soils are exposed to air and subsequent wetting leads to runoff of sulphuric acid. This is highly detrimental to organisms because acid can mobilise aluminium and cause death of fish and other organisms, or render them susceptible to disease[143,122]. Effects of estuarine acidification can impact all trophic levels resulting in both short- and long-term damage[121].

Of all the possible impacts of climate change, variation in rainfall patterns is likely to have the most far-reaching influences on estuarine ecology because freshwater flow is generally the largest source of physical variability in estuaries[139,68]. Variation in freshwater inflow determines inundation of floodplains and supra-littoral habitats, nutrient loadings, advective transport of materials and organisms,

a Bureau of Meteorology 2006, Climate averages: http://www.bom.gov.au/ climate/ averages/

the location, intensity and nature of estuarine salinity profiles and density gradients[68]. It also affects community structure, faunal distribution[157] and community function[139]. In fact, changes in the severity and periodicity of episodic events are, in themselves, a problem because these are part of the normal cycle that maintains estuarine productivity[160].

Changes in the timing, magnitude and variability of rainfall influence five fundamental characteristics of inflow to estuaries[108]: i) the *magnitude* of conditions (eg salinity, depth and available habitat area), ii) the *timing* of occurrence of conditions, iii) the *frequency* of occurrence of conditions, iv) the *duration* of conditions and v) the *rate* of change of conditions. The extent to which environmental needs, and life-history needs and timings, match with this combination of factors determines the ability of organisms to continue to use and thrive in estuarine habitats[108]. In turn these influences flow-on to affect other dependent organisms and processes. Importantly, such effects are often complex and indirect[97], and impose their influences across a spectrum of time scales, with effects often lagged by a year or more[24].

As well as direct consequences for ecological functioning, freshwater flows influence other factors, such as salinity, temperature, turbidity, dissolved oxygen and nutrient supply, which in turn impact ecological functioning[132,105]. For example, changes in the rate and timing of freshwater inflow can cause shifts in water quality parameters in estuaries, bays and tidal marshes that ultimately affect distributions of fauna[64,128]. In fact, changes in inflow can completely alter the nature of an estuary, with 'reverse estuaries' developing, where salinity increases upstream[98], as a response to high evaporation coupled with low freshwater inflow[88], or shorter hydroperiods[79]. Such effects are likely to be particularly severe in dry tropics estuaries where hypersaline conditions develop rapidly following the end of the wet season[109]. In some locations the estuary becomes a fully reverse estuary, that is, the salinity increases monotonically from the mouth to the head. In other locations, a salinity maximum zone separates the sea from low salinity water that persists at the head of the estuary throughout the dry season[109]. Even under present conditions freshwater flows can be reduced to insignificant levels for periods of five years or more[135].

Coupled with other influences of global climate change, the effects of changes in the pattern of freshwater inflow to estuaries on salinity, temperature, sediment delivery and movement and nutrient supply has far reaching ecological implications. These implications extend to communities and ecosystems, the distribution, abundance and diversity of plants and animals, migration and nursery ground function, habitats and habitat availability, primary production, nutrient cycling and food webs, overall estuarine health, and the resilience of estuarine habitats to human impacts. Moreover, these effects are likely to have interactive, and not necessarily linear or simple additive effects.

Despite the range of likely detrimental effects, physical change in itself is not necessarily bad. Physical instability (eg flow variation) is important in maintaining stable biological functioning of estuaries[78]. In reality, a major danger in climate change is that the normal cycle of variability will be disrupted, modifying the periodicity and extent of the 'resetting' of estuaries by episodic events that are essential in maintaining estuarine productivity, trophic structure and habitat diversity[160].

19.3.2 Habitats and ecosystems

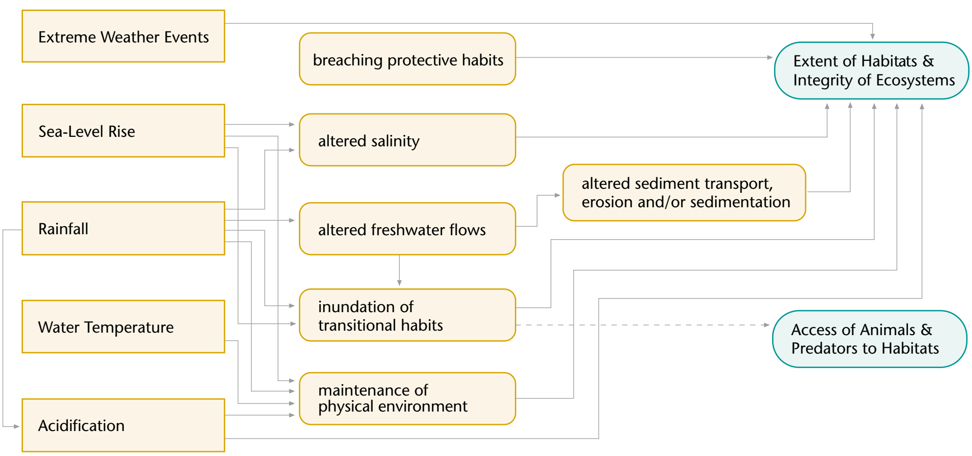
There are likely to be many changes to the extent of individual habitats and ecosystems, however, there is little certainty about the direction or extent of change, and the direction and extent of change is likely to vary spatially across a multitude of scales. Although our understanding is far from complete, there is considerable GBR specific detail for seagrass (Waycott et al. chapter 8), mangrove (Lovelock and Ellison chapter 9) and coral reef habitats (Fabricius et al. chapter 7). Unfortunately, this is not the case for many other habitats (eg estuaries, inshore benthic soft bottoms, coastal sandy intertidal, littoral wetlands) and habitat components (eg beaches, rocky intertidal, large woody debris (snags), salt marsh) comprising the CEM, although their location at the interface of land and sea makes them particularly vulnerable[43].

Impacts on habitats will be complex (Figure 19.2). The extent of vegetated habitats is likely to be impacted by interactions between changes in water temperature, sea level, rainfall, acidification and the frequency and intensity of severe weather events. The effects may also be indirect. For instance, tidal[39] and coastal wetlands that lie behind mangroves[45] and beaches[54] are particularly at risk if sea level rise leads to increased groundwater salinities[45] or if more frequent severe weather events[144] increases the breaching of protective habitats (eg mangroves or beach dunes).

The integrity of estuarine ecosystems depends largely on maintaining patterns of salinity distribution, including spatio-temporal profiles of hydroperiods, salinity gradients, and the position of the freshwater/estuarine interface[35]. These factors are functions of all aspects of flow; magnitude (volume), timing, frequency, duration of conditions, and rate of change of condition[24], and the interaction of these parameters with sea level rise[35] and tidal patterns.

Changes in timing and magnitude of flows alter sediment transport[10,11]. Altered river flows can lead to erosion or extensive sedimentation of estuaries[103,104], changing the nature and distribution of habitats. Modified flows can also reduce access to complex habitats in freshwater[21] and upper estuary

Figure 19.2 *Major likely impacts of climate change on coastal and estuarine habitats in the GBR region*



reaches[74], and reduce the erosion production of large woody debris, important as habitats for invertebrates and fish[131,136]. Consequently, populations of organisms relying on such habitats may decline and be replaced by ecological generalists[7]. On the other hand, sedimentation can lead to accretion that may allow many salt marshes to keep up with sea level rise[119]. Although this is only likely to occur where conditions are optimal for growth of salt marsh plants[5] and is dependent on the specifics of subsurface processes[25] and interactions with biotic factors[99].

Changes in sea level will directly affect the extent and periodicity of inundation of intertidal and estuarine wetland habitats of all types[134]. This will alter the nature of flora and fauna in areas that are presently intertidal, both because of physical tolerances to altered inundation levels[5], and because of changes in the prey, predators and competitors that can access intertidal habitats[16]. Other transitional habitats, such as those at the freshwater/estuary interface will be similarly affected, although in this case changes in rainfall patterns, as well as sea level changes, are likely to be important drivers[134].

From a general perspective, the effects of climate change on habitats may not be immediately obvious. Habitats are likely to be identifiable over time, although their locations and extents may have changed considerably. However, there is evidence from other climatic zones that although habitats and plant communities affected by sea level rise may appear similar, their underlying ecological functioning may be quite different to that before sea level rise[22].

19.3.3 Species and species-level ecological functions

There is considerable understanding of the likely effects of change on the distribution, growth and abundance of particular species and species groups (chapter 5 to 16). However, this information is lacking for the majority of species, and specific information on many species-level ecological functions is often not available. Additionally, most available information relates largely to estuaries, so prediction of likely impacts for other parts of the CEM can only be by extrapolation. Prediction is further complicated because, with such a diversity of species, habitats and physical conditions, any impact of climate change is likely to have different outcomes depending on the specific situation.

Flora

Freshwater flow and salinity are likely to have a variety of effects on plants (Figure 19.3). Variations in freshwater discharge have the potential to control the distribution and abundance of marine plants from phytoplankton[26] to macrophytes[6]. Change in salinity conditions can affect the growth and distribution of salt marsh plants[2] and even lead to the extinction of species[6], because different species have their own particular salinity requirements[5]. In fact, regular freshwater flooding is often needed to maintain salt marsh growth, reproduction and health[20]. At high topographic levels of the intertidal zone elevated salinities can lead to the accumulation of salt, restricting the distribution of macrophytes[6] including mangroves[41]. Even lower intertidal and subtidal plants, like seagrasses, have growth salinity optima[3], meaning salinity is important in determining their distributions[6]. Exacerbating the effects of flow on salinity, many salt marsh plants rely on freshwater seepage to maintain favourable salinity conditions[5]. Additionally, reduced flooding can limit the dispersal of mangrove propagules[115]. Where a lack of river flow prevents the opening of river mouths[156] tidal flooding, essential for some marsh plants[4], is reduced and exposure time of plants to desiccation increased[3].

Freshwater wetlands are already in a severely reduced state along the GBR coast with an estimated 80 percent reduction in area south of Cooktown since 1850[47]. Salinisation due to sea level rise will stress the remainder, although the extent of mangroves may increase if they can migrate landward. However, in general mangroves are in relatively good condition and under far less pressure than freshwater and estuarine wetlands. Sea level rise is thus likely to place extra stress on the most vulnerable component of the coastal wetland mosaic.

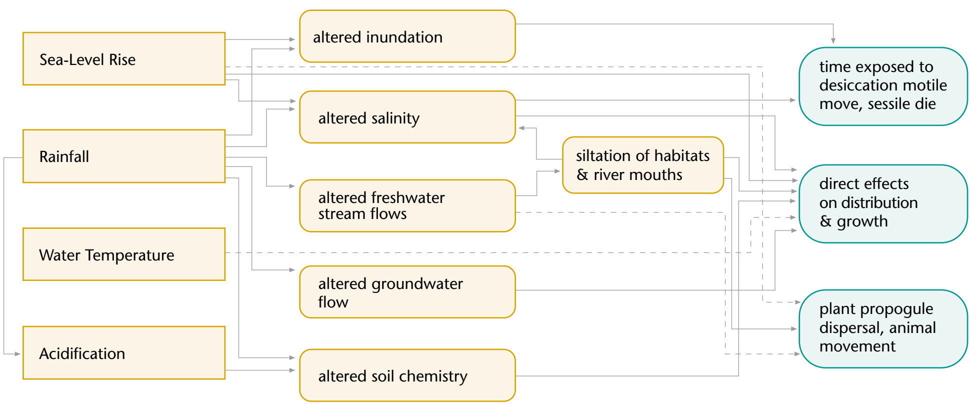
Fauna

Effects of flow, and flow regulated salinity on fauna are more diverse and complex (Figure 19.3). Motile animals can move to accommodate changes in salinity, however, sedentary or sessile organisms may experience rapid changes in salinity levels or altered salinity conditions leading to metabolic stress, increased oxygen consumption and altered density of red blood cells[34,90,101,55,102]. In many cases organisms can make metabolic adjustments, but these come at the cost of degraded condition, reduced growth, greater vulnerability to other stressors[89,159] or impaired reproduction and recruitment[86].

Fish and pelagic and benthic invertebrates form distinct species assemblages along the longitudinal salinity gradients of estuaries[14,164,18], reflecting different salinity tolerances. These salinity tolerances may also be temperature dependent[23], presenting the possibility of interaction between the effects of altered rainfall and temperature change.

Changes in flow and salinity profiles can lead to substantial alterations in species distribution and abundance[77,130], or changes in patterns of habitat use[127]. However, the exact effects vary in space and time. In some situations high freshwater inflow to estuaries can enhance macrofaunal productivity[87] or fish abundance[68]. While in others, freshwater flows can lead to depressed abundances[161], produce population changes and even lead to the disappearance of some estuarine species[145,130]. These differences relate to such factors as the extent of connectivity to marine environments[145,134], the location of communities along the estuarine salinity gradient[130] and the type of estuary[18].

Figure 19.3 *Major likely impacts of climate change on plants and animals of coastal and estuarine habitats in the GBR region*



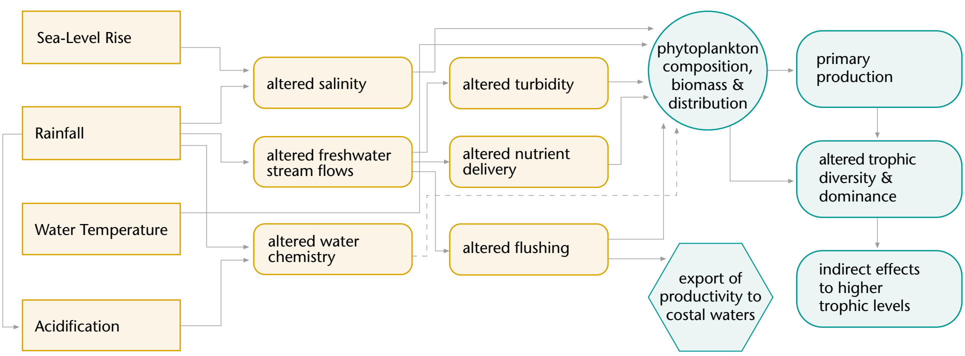
Additionally, responses tend to be species-specific with freshwater necessary to induce recruitment of low salinity species, while other species require more marine conditions[66]. Where hypersaline conditions omit species with low salinity tolerance, diversity and abundance may decline sharply[160]. In contrast, where constant high salinities result in estuaries becoming 'arms of the sea'[78] diversity may increase due to colonisation by stenohaline marine species[135]. This is likely to be at the expense of estuarine dependent species less tolerant of higher salinities[160]. Additionally, while changes to overall salinity levels may benefit some organisms, any advantage may be counteracted by other changes, such as increases in salinity variability[40].

19.3.4 Trophic function

Trophic function is likely to be affected by climate change both directly and secondarily through impacts on habitats, species distribution, abundance and connectivity (Figure 19.4). The direction and extent of change will depend on interactions at a range of scales. This uncertainty in outcomes is complicated because our understanding of trophic function of the CEM, and indeed of its individual components, is generally deficient. This lack of empirical understanding leads to a poor understanding of theoretical implications of change.

Effects of altered flow on estuarine food webs operate principally through stimulation of primary production, with effects then propagating upwards through food webs[67]. Changes in rainfall and freshwater flow have considerable implications for nutrient cycling and primary productivity in estuaries[84], with the biomass, productivity and community composition of estuarine phytoplankton extensively impacted by freshwater flows[30,84]. Variations in flow influence the supply of nutrients to estuaries[28], controlling inputs of phosphate, ammonium, nitrate and dissolved silicate[146]. For example, low flows during dry seasons or due to El Niño-Southern Oscillation (ENSO) driven disruptions of seasonal rainfall patterns both alter salinity patterns and reduce inputs of phosphorus to Everglade (USA) estuaries leading to alterations in nutrient processing[29]. The pattern of nutrient supply influences phytoplankton species composition because any reduction in dissolved silicate supply is likely to advantage flagellates (nonsiliceous and potentially harmful) while disadvantaging diatoms

Figure 19.4 *Major likely impacts of climate change on trophic function in coastal and estuarine habitats in the GBR region*



(siliceous and mostly benign)[56]. Additionally, silicate is potentially limiting to algal biomass in many ecosystems[70] with the potential to lead to low densities of diatoms and low algal productivity even in the face of adequate nitrogen and phosphorus. Any adverse impact on microalgae is likely to have far reaching impacts on estuarine productivity because microalgae are now recognised as among the most important primary producers in tropical estuaries[32]. The duration of flow events is also crucial because short-term freshwater flow events may not produce the lasting increases in inorganic dissolved nutrients[125] needed to benefit the productivity of phytoplankton communities[124].

As well as effecting nutrient supply, freshwater discharge affects residence time[26,46,29]. In high flow, residence time is short and most nutrients are washed through the estuary[46] but when residence time increases nutrients are retained in the estuary as biomass accumulates[46]. Additionally, changes in freshwater flows can modify the location and nature of salinity gradients[106] and alter the extent of intrusion of marine water into estuaries[26], altering the distribution of phytoplankton species and changing the succession between marine, estuarine and freshwater taxa. Alterations to the spatial distribution of phytoplankton can also impact productivity by modifying the spatial matching of the highly productive suspended particulate organic matter maximum to highly productive areas of the estuary (eg shallow bays[30]). Changes in turbidity or water colour due to altered freshwater flow can influence light attenuation[78,36], further impacting phytoplankton biomass and primary productivity. The combined effects of flows on nutrient supply and recycling, and the retention of phytoplankton mean that the pattern of freshwater flows both influences estuarine water column productivity and controls the delivery of nutrients to coastal waters[141].

Since effects of flow on estuarine food webs operate principally through stimulation of primary production[67] changes in freshwater flows that alter patterns of primary production can lead to substantial changes in trophic organisation[78,160]. For example, prolonged drought can lead to reduced abundance in particular trophic groups[134] and reduced trophic diversity (ie food webs are simplified), due to differential mortality and changing predation effects[134] and/or changes in nutrient cycling[77].

Even outside the estuary freshwater flows can have important effects. Floods export pulses of organic matter to near-coastal waters, leading to high abundances of detritus feeding invertebrates, such as polychaetes, and ultimately to increased abundances of predatory fish and enhanced fisheries productivity[120]. Consequently, the timing of flood pulses is likely to be important in supporting crucial life history stages in these habitats[120].

From an overall perspective, specific effects on food webs are diverse, complex and often difficult to predict. Trophic responses vary among groups. Since different trophic groups are often composed principally of particular taxonomic groups (eg herbivores and omnivores are often invertebrates while carnivores are often fish) they often respond to different factors (eg for invertebrates; physicio-chemical variables, for fish; biological factors)[77] However, although fish may not respond directly to flows, they are often impacted indirectly via food web interactions[77]. For example, in the Apalachicola Bay system, Florida, prolonged drought led to reduced fish richness, specific-abundances and trophic diversity principally through flow-on effects from alterations to nutrient cycling[77]. Additionally, effects can be contradictory. Increased light penetration due to reduced turbidity, resulting from reduced flow, can increase productivity and affect herbivore/omnivore abundance in coastal bays[78]. At the same time, low flows lead to lower nutrient loadings in estuaries resulting in severely reduced productivity[78]. In essence, under reduced flows, highly productive river-estuarine systems that previously had distinct salinity gradients can become merely extensions of the sea[78,17,160]. Although the presence of marine species often leads to high species richness, productivity is often substantially impaired[78], abundances reduced[161], and ultimately fisheries production degraded[106].

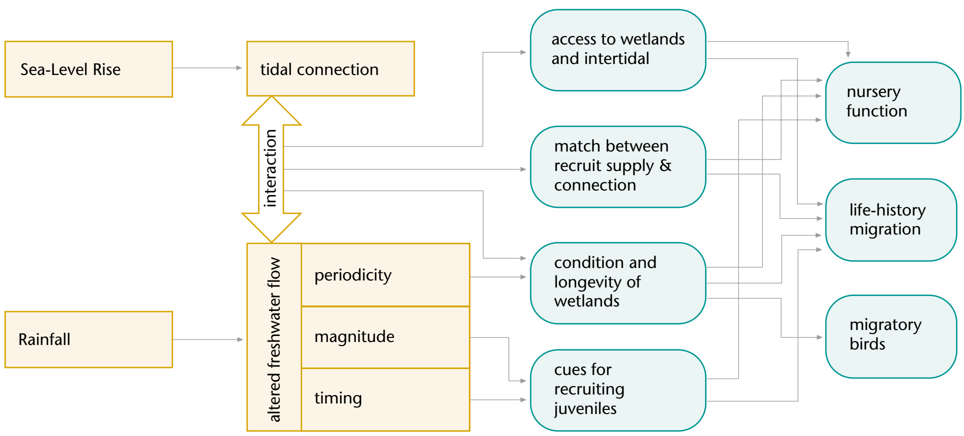
19.3.5 Connectivity

While the impacts of climate change on many aspects of the CEM are uncertain, potential effects on connectivity are much easier to evaluate. Depending on the scale and nature of the particular connection, sea level change, altered rainfall patterns, extreme weather events and secondary consequences arising from effects on habitats and species are likely to be influential (Figure 19.5).

Animals using wetlands need tidal and/or freshwater connections at specific times (eg when larvae are ready to recruit)[134]. Consequently, changes to base tidal levels or the magnitude or regularity of freshwater flows will be a major factor in determining the future success of wetland connectivity[134]. This effect is complex. For instance, the extent to which tidal connections penetrate salt marshes to replenish wetland pools depends on the pre-existing condition of the salt marsh surface. Tidal connections will occur more often and more extensively if the salt marsh surface is already wet from rainfall[134]. Any reduction in connectivity due to less regular rainfall will diminish the value of wetland nurseries to marine species, both because connectivity occurs less often, and because a reduced frequency of connection leads to pools drying out more often[134].

At a different temporal and spatial scale, change in sea level will alter the accessibility of intertidal regions to marine fauna. Rising sea levels will extend the time animals can spend in current intertidal habitats and the distance they can penetrate into them[152,153]. Although this will be offset because the intertidal zone will move as sea levels change, in many cases the effect is likely to be asymmetric.

Figure 19.5 *Major likely impacts of climate change on connectivity, migration and nursery ground function in coastal and estuarine habitats in the GBR region*



For example, rapidly rising sea level may allow mangrove forests to extend landwards (Lovelock and Ellison chapter 9), but while rising sea levels will eventually drown mangroves at the most seaward edges of mangrove forests[15], many plants will persist in the short term by extending pneumatophores vertically to continue to access oxygen when the roots are submerged[149]. Mangroves provide structurally complex habitat thought to be used as a refuge for fish[73]. Any landward progression of mangrove forests will be likely to enhance this refuge effect in the short term, with recently dead mangroves on the seaward edges of forests continuing to provide refuge habitat for some time.

In addition, there is likely to be a range of indirect effects on connectivity, as changes in the extent and proximity of habitats alter the nature and extent of connecting corridors[134]. For instance, major losses of intertidal seagrasses may adversely affect connectivity in areas where seagrass beds provide connecting habitats between coastal reefs and mangroves[91].

19.3.6 Migration

As is the case around the world[81,142], the volume, timing and duration of freshwater flows are crucial factors determining the ability of tropical estuarine fish to undertake migrations that are critical parts of their life histories (Figure 19.5). In the GBR region, this is the case for recreationally and commercially important species like barramundi, *Lates calcarifer*, and mangrove jacks, *Lutjanus argentimaculatus*,[117,118,50,134] as well as many other species of ecological importance[134]. Changes to climate patterns are likely to modify the biological usefulness of connectivity. A second factor that controls migration between estuaries and many wetland areas is the extent of tidal inundation of connecting channels[117,118,134], a factor that can be extensively modified by even small alterations in tidal level[117,118,134]. To complicate the problem, in many cases the extent to which tidal peaks connect estuaries and wetlands is greatly modified by sediment moisture levels of connecting channels[134], with rainfall prior to peak tides greatly enhancing connections. Consequently, alterations in rainfall patterns interact strongly with altered sea level to greatly affect the ability of fish to migrate between estuaries and estuarine wetlands[134]. Although, in some situations, it may appear superficially that increasing tidal levels will offset any effects of reduced or more periodic rainfall, this is unlikely to occur in most cases. The majority of Queensland coastal streams are already blocked by dams, weirs and other impoundments that impede fish migration[63,134], and the major human response to increased sea level is likely to be the construction of even more barriers.

Beyond the effects on fish, GBR estuarine wetlands are nursery grounds for important crustacean species, such as commercial penaeid prawns[138], which have the same requirements for effective connectivity. In addition, freshwater flows have species-specific impacts on abundance of migrating water birds on estuarine mudflats, with both high and low flows potentially problematic depending on the particular estuary and species involved[107]. Furthermore, altered rainfall patterns modify salinity profiles and the persistence of wetland pools, affecting both their viability as fish habitats[134] and as feeding grounds for migrating water birds[69,134].

19.3.7 Nursery grounds

Estuarine wetland and connected freshwater areas are crucial juvenile nurseries for many species[13,94,147,95]. In the GBR region this includes commercially and recreationally important species like barramundi[117,118,63,134] and mangrove jack[131]. Climate change, particularly through altered freshwater flows, is likely to profoundly influence nursery ground function because it directly affects assemblage composition, abundance, growth of juveniles[117,13,71,134], the viability (persistence before drying out, salinity levels and temperature) of the habitats as effective nurseries[134] and the ability of juveniles to enter and leave nursery grounds (Figure 19.5).

Implications of climate change for nursery grounds go far beyond this however. Too little flow may alter the strength and position of the estuarine turbidity maximum, an area where larval fish aggregate[94,148], particularly those requiring reduced salinities. Reduced flow may also fail to provide sufficient cues to marine larvae using salinity or other signals transmitted through flows to find and enter estuaries[147,160]. In contrast, too much flow can flush estuary-resident species from the upper reaches of the estuary[148] and render conditions unsuitable for species requiring higher salinities. The timing and extent of freshwater inflow is also important in the provision of appropriate shallow water nursery habitat[72], ensuring the supply of nutrients to estuarine and wetland nurseries[110], and in supporting the complex productivity patterns that support species-specific feeding patterns crucial to nursery ground utilisation[77]. In addition, the recruitment success of marine species is likely to be strongly influenced by the timing of freshwater flow events[132], with the potential for recruitment failure if the occurrence of flows fails to match the availability of recruiting larvae[155].

19.3.8 Higher-level ecological functions

Again, effects of climate change on higher-level ecological functions are likely to result from complex interactions of effects at lower levels[77,67], making detailed prediction impossible at this time. However, in a general sense, major climate change is likely to alter the nature of communities and community interactions in pervasive ways. For example, the small amount of research available from quite diverse taxonomic groups[76,137,130] indicates considerable differences in composition and function of Queensland's wet and dry tropical estuarine fauna. Consequently, a reduction in the amount or regularity of rainfall in the wet tropics could move those ecosystems towards dry tropics composition and functioning, with obvious flow-on effects for other components of the CEM. Similarly, the dry tropics would probably move towards wet tropics functioning with increases in the amount or regularity of rainfall. Therefore, while a functioning habitat would be maintained, it could be quite different to that operating pre-climate change. Such changes would probably extend across most higher-level functions (Table 19.1), although at present there is no knowledge base that would allow the implications of changes to these functions to be quantified. Additionally, while switches between dry and wet tropical climates would be likely to produce fairly predictable outcomes, there is no way of predicting the outcomes for dry tropics of lower, less regular rainfall, or for wet tropics of higher, more regular rainfall.

At a different scale, dominant patterns of coastal production are likely to change substantially. These depend on interactions between biological components and a suite of environmental factors such as rainfall, river flow, tidal action and turbidity[51]. Consequently, through changes to these factors and effects on diversity and species composition, major changes in weather patterns have great potential to alter patterns of habitat productivity. While the outcomes of such changes would still be functioning habitats, the natures of the resulting habitats are likely to be quite different to those prior to climate change.

19.3.9 Diversity

The strong relationships between species and their habitats[19] means changes to the presence, extent, boundaries or connectivity of habitats and ecosystems are likely to directly impact the range of species able to use them. Additionally, changes in the extent of habitats will be likely to directly influence species richness because the number of species is highly correlated with habitat area (the well-known species-area relationship[83]). Changes to environmental conditions (eg temperature, salinity, rainfall patterns and environmental stability) will also lead to changes in diversity because these factors are major determinants of the distribution of species[44]. Resulting changes in the presence and abundance of predators, prey and competitors will further modify species richness[38]. Additionally, any change in the frequency or intensity of extreme weather events (cyclones or major floods) is also likely to directly impact species richness because the nature of the species present (eg opportunistic versus persistent[151]) and the number of species[82] is correlated with disturbance frequency.

Changes in habitat availability, extent, proportion and/or connectivity are also likely to affect the diversity of ecological function. Diversity of function is probably even more important than species diversity, because diversity of function feeds back to determine the identity and number of species present, as well as influencing ecosystem stability[62].

19.3.10 Estuary health and resilience

Effects of climate change, such as alterations to freshwater inflow to estuaries, are likely to influence overall estuarine health, and the resilience of estuarine habitats to human impacts. Water quality (flow, chlorination, temperature, dissolved oxygen, pH and suspended solids) is affected by drought[12], and freshwater flows can be important in diluting pollutants and maintaining oxygen levels[100]. Reduced freshwater inputs can enhance eutrophication in polluted estuaries due to decreased flushing potential of the estuary[126], and the interaction of flow-induced changes in the nutrient environment, elevated nutrient levels due to anthropogenic pollution, and alterations in phytoplankton composition. One potential consequence of this is increased likelihood of cyanobacteria blooms[28,113,37].

19.3.11 Interactions with anthropogenic factors

Complicating the potential for impact on the diversity of physical, biological and functional aspects of the CEM is the problem of interactions between the effects of climate change and anthropogenic factors. These take two forms. Firstly, the heavy pressure from human activities on many habitats (eg estuaries[65]), habitat components (eg mangroves[96]) and at-risk species (eg dugongs[59]). Secondly, the inevitable changes produced by human responses to the effects of climate change such as the construction of dams and walls to prevent tidal incursion into wetlands[63,134] and croplands. Existing bunds are a major factor in the disruption of estuarine connectivity in areas of the lower Fitzroy catchment[63,134]. These interactions between climate change and human responses have the potential to impact the CEM as profoundly as climate change itself[57]. As well as reducing connectivity between estuaries and coastal wetlands, the construction of barriers to prevent inundation from sea level rise is likely to greatly reduce connectivity, and prevent the landward advance of mangroves, salt marshes and seagrass meadows that would compensate for seaward losses[42]. Similarly, dams built to increase the storage of water under drying conditions, or control flooding under conditions of increasing rainfall, would hamper connectivity and impede the delivery of nutrients to estuaries and other coastal habitats[53,140]. Many estuaries on the southern and central GBR coast have already been significantly modified by agricultural and urban development. While fundamental understanding of estuarine ecosystems is quite limited[134], it is clear that their ability to respond to the impacts of climate change will be constrained by these human modifications, for example channel structures and hard boundaries with agricultural and urban land[92].

The Fitzroy estuary in the southern GBR catchment provides examples of these types of modifications and the pressures they place on the resilience of estuaries in relation to climate change. The Fitzroy estuary is a large tide-dominated estuary characterised by mangrove-lined tidal creeks backed by extensive salt marsh and salt flats that merge with the freshwater reaches of the lower floodplain. In the north of the estuary, tidal creeks have been dammed to provide freshwater pasture (ponded pasture) for cattle grazing (Figure 19.6). In the south, extensive areas of salt marsh, salt flat and adjacent floodplain have been converted to evaporation ponds for the production of salt (Figure 19.6), and the landward limit of tidal influence has been reduced by a tidal barrage on the Fitzroy River at Rockhampton. These structures have obviously reduced the area of wetland and form hard boundaries with estuarine habitats (Figure 19.7). They will constrain the potential responses of the estuary to climate change because:

i) they limit the ability of habitats to shift in response to the predicted rapid rise in sea level, for example the back stepping of intertidal habitats such as salt marsh and mangroves[166],

ii) they effectively sequester large areas of floodplain that could be colonized by intertidal species in response to sea level rise,

iii) they will result in additional changes in the areal proportions of estuarine habitats as the estuary adjusts to sea level rise, and

iv) they may further influence the hydrodynamics of the estuary under a rising sea level.

Even without human responses to climate change, interactions with human development are likely to complicate and magnify impacts on coastal habitats. For example, land clearing alters drainage patterns and interacts strongly with changes in rainfall to influence downstream flows and sediment loads[26,9,27,116]. Similarly, because of their proximity to human population centres and ports, coastal ecosystems and habitats are under heavy developmental pressure. Areas of habitats such as mangroves and salt marshes[123], and seagrass beds[42] continue to diminish as intertidal and supra-tidal wetlands are reclaimed for ports, marinas, housing developments and aquaculture ventures to name a few. Altered hydrologic regimes due to climate change could further exacerbate encroachment of agricultural land-use into wetlands[57]. Freshwater wetlands are likely to be squeezed between fixed (and protected by bunds from salt water intrusion) coastal cropping lands (sugarcane in particular) and encroaching marine wetland systems (mangroves and salt marsh). This will impinge on species such as barramundi given the importance of the complete range of coastal wetlands for such species.

These human pressures are likely to work in the same direction as the effects of climate change, both amplifying any adverse effects and reducing the ability of habitats to respond positively.

Figure 19.6 *Landsat image (2003) of the Fitzroy estuary, southern GBR coast, showing the location of dams across tidal creeks to provide ponded pasture (P) and inter and supra tidal areas converted to evaporation ponds (E)*

Figure 19.7 *Aerial photograph (2003) showing one of the ponded pasture dams (P) indicated in Figure 19.6. The dam forms a hard boundary between mangroves (green) and pasture (brown)*

19.4 Adaptive capacity

In a general sense, coastal habitats have a demonstrated capacity to respond to climatic change as there have been many changes in the past and the habitats have persisted[58]. Over geological times coastal systems have adapted to sea level changes, as evidenced in the pollen record. However, changes due to human activities in these ecosystems have led to ecological changes that appear to be beyond the adaptive capacity of the ecosystems[1,154]. Additionally, substantial adaptation to large-scale change is likely to mean substantial habitat change, in most cases to unknown or at least unpredictable states. While there is probably little that can be done to prevent ecosystem-scale change, it will be important to do everything possible to prevent interactions with anthropogenic factors that lead to degraded habitats and impaired ecosystem function.

At a more specific level, a lack of a sufficiently detailed knowledge base means it is difficult to predict the adaptive capacity of individual components of the CEM in the face of forces of climate change that can impact at a variety of conceptual scales. An example, will illustrate this point. The barramundi, *Lates calcarifer*, is an iconic component of GBR coastal habitats. Barramundi have formidable abilities to thrive across a very wide range of environmental conditions, from freshwater to hypersaline conditions[150]. At face value barramundi should be well equipped to deal with climate change, they should be able to utilise alternative habitats if usual habitats become unavailable in a particular area. It is even possible that the ability to utilise a diversity of habitats will greatly reduce the likely impacts of reduced connectivity[134]. However, we also know that barramundi exist as a number of distinct stocks along Queensland's east coast, with each tending to be confined to a particular climatic region[129]. The implications of this stock structure are not yet understood. For instance, different stocks appear to use nursery grounds differently. Since we do not know the extent to which populations can adapt to different nursery ground availability, we can not be sure if the ability to use a variety of habitats, which is obvious at the species level, translates to a similar ability at the population level; the level where adaptation to climate change will be necessary. What is alarming about this is that barramundi are probably by far the best understood coastal marine species in the GBR region.

19.5 Summary and recommendations

19.5.1 Major vulnerabilities to climate change

There is little doubt that coastal and estuarine habitats and ecosystems in the GBR region will be severely impacted by climate change. They are particularly vulnerable to four aspects of climate change: i) alterations in the magnitude, timing and frequency of rainfall, ii) sea level rise, iii) altered frequency and severity of extreme weather events, and iv) major changes in water temperature. Changes to rainfall patterns are likely to have the most diverse and far reaching effects because it is the mixing of fresh and marine waters that give estuaries their unique characters, and because freshwater delivers nutrients from the land that supports estuarine and coastal productivity.

Altered rainfall is likely to profoundly affect individual species and their distributions, the habitats they rely on, the trophic webs that support them and ecological processes like migration and nursery ground function. Changes in rainfall will manifest its effects through impacts on salinity, nutrient delivery and export, flushing, sediment transport, inundation, habitat availability and the cuing of recruits to enter estuarine nurseries (Figures 19.2 to 19.5). Rainfall will also interact strongly with sea level rise to determine crucial connectivity, wetland health and persistence, and nursery ground availability and value, as well as impacting inundation levels and salinity to affect the very nature of estuaries (eg shifts between dry and wet tropics estuarine conditions). Changes to the timing and frequency of extreme weather events is likely to disrupt the normal cycle of variability and resetting (essential in maintaining estuarine productivity, trophic structure and habitat diversity), alter patterns of diversity through time, influence the rate of habitat destruction, and change the extent of opening of estuary mouths.

19.5.2 Potential management responses

While impacts of climate change on coastal and estuarine habitats seem inevitable, effects can be ameliorated by careful management of human responses to climate change. In this regard much can be done. It is of primary importance that dams and weirs used to impound freshwater, and bunds and other barriers built to prevent the ingress of marine waters, are constructed sparingly. Where they must be constructed every effort should be made to maximise normal biological connectivity (not just the movement of organisms but all aspects of biological connectivity), and ensure that flows into estuaries are sufficient and correctly timed, to meet the ecological needs of estuaries and coastal waters (eg nutrient and sediment supply, maintain recruitment to nurseries). In addition, current barriers that are not essential should be identified, and where possible removed. This is particularly important where hard barriers limit the landward progress of wetlands and intertidal habitats (eg mangroves and seagrass) able to respond to sea level rise by moving landwards to occupy newly available niches. Even given the most stringent management, human response to climate change will inevitably lead to some loss of connectivity and reduction of current wetland area. This makes careful management of future development of wetlands for agricultural, commercial and urban development crucial, and means that current developments need to be reviewed to determine ways in which their present and future impacts can be minimised. Finally, it will be crucial to carefully control human activities (eg land clearing and coastal development) that impact the delivery of sediment, nutrients and pollutants to estuaries and coastal ecosystems.

19.5.3 Critical knowledge gaps and future research

Compared to knowledge of coral reefs or freshwater streams, understanding of coastal ecosystems of tropical Australia is deficient. Some individual habitat components (eg mangrove and seagrass) have received some attention but are still poorly understood. For many other habitat components (eg salt marshes, fresh and salt water coastal wetlands, soft bottom communities, inshore pelagic communities) there is little region-specific understanding. Ecosystem-level understanding is even more limited, even for estuaries that occupy a vital, central position between land and sea, while understanding of the complex interlinking of habitats and ecosystem components is almost non-existent. Consequently, there is a broad spectrum of knowledge gaps. Some of the most basic and most likely knowledge gaps that will impair responses to the threat of climate change are discussed below.

Connectivity

Even though coastal habitats are extensively interlinked, and crucial processes like nursery ground provision are underpinned by connectivity, there is a poor and simplistic understanding of connectivity. In fact we have not even documented the full extent of connectivity or the processes they facilitate and depend on.

Effects of flow on tropical coastal systems

Among the most likely consequences of climate change are alterations in rainfall intensity, duration and variability, all likely to modify the pattern of freshwater inflow and delivery of nutrients and other materials to coastal habitats, and greatly impact connectivity. We have little understanding of the ecological importance of freshwater to tropical marine ecosystems, let alone knowledge of the likely effects of change.

Diversity and function

At a very basic level, understanding of the diversity of life and the diversity of ecological function of tropical coastal ecosystems is data limited, even for the better studied components. Many groups are poorly characterised and their distributions little understood at any scale.

Habitats

Similarly, there are many gaps in understanding of habitats, inter-habitat relationships and organism-habitat relationships, so little understanding of how changes to these will impact organisms and ecosystem function.

Life-cycles

The life cycles of most species are poorly understood. For instance, a lack of knowledge of the juvenile habitats or environmental requirements of a majority of species translates to a poor understanding of potential impacts of climate change on this crucial life-history stage.

Wet versus dry tropics

At a more specific focus, there is little understanding of the differences in composition and function of wet and dry tropical habitats, although climate change is very likely to cause shifts between these states, and even see individual systems fluctuate between these extremes.

Interaction with anthropogenic responses

From a management perspective, there is a need for detailed investigation of ways to minimise the impacts of anthropogenic responses to climate change on coastal ecosystems. Overall, although there are many and diverse specific gaps in understanding, the major deficiencies are in 'big picture' understanding. While more encompassing studies, focussing at this conceptual level, are obvious priorities, well-directed studies of specific aspects will also be required to underpin them.

References

1 Aube CI, Locke A and Klassen GJ (2005) Zooplankton communities of a dammed estuary in the Bay of Fundy, Canada. *Hydrobiologia* 548, 127–139.

2 Adams JB and Bate GC (1994a) The effect of salinity and inundation on the estuarine macrophyte *Sarcocornia perennis* (Mill.) A.J. Scott. *Aquatic Botany* 47, 341–348.

3 Adams JB and Bate GC (1994b) The tolerance to desiccation of the submerged macrophytes *Ruppia cirrhosa* (Petagna) Grande and *Zostera capensis* Setchell. *Journal of Experimental Marine Biology and Ecology* 183, 53–62.

4 Adams JB and Bate GC (1995) Ecological implications of tolerance of salinity and inundation by *Spartina maritima. Aquatic Botany* 52, 183–191.

5 Adams JB and Bate GC (1999) Growth and photosynthetic performance of *Phragmites australis* in estuarine waters: a field and experimental evaluation. *Aquatic Botany* 64, 359–367.

6 Adams JB, Knoop WT and Bate GC (1992) The distribution of estuarine macrophytes in relation to freshwater. *Botanica Marina* 35, 215–226.

7 Albanese B, Angermeier PL and Dorai-Raj S (2004) Ecological correlates of fish movement in a network of Virginia streams. *Canadian Journal of Fisheries and Aquatic Sciences* 61, 857–869.

8 Alongi DM and Sasekumar A (1992) Benthic Communities. In: AI Robertson and DM Alongi (eds) *Tropical Mangrove Ecosystems*. American Geophysical Union, Washington, pp. 137–171.

9 Archer D and Newson M (2002) The use of indices of flow variability in assessing the hydrological and instream habitat impacts of upland afforestation and drainage. *Journal of Hydrology* 268, 244–258.

10 Assani AA, Buffin-Belanger T and Roy AG (2002) Impacts of a dam on the hydrologic regime of the Matawin river (Quebec, Canada). *Revue des Sciences de l'Eau/Journal of Water Science* 15, 557–574.

11 Assani AA, Gravel E, Buffin-Belanger T and Roy AG (2005) Impacts of dams on the annual minimum discharges according to artificialised hydrologic regimes in Quebec (Canada). *Revue des Sciences de l'Eau/Journal of Water Science* 18, 103–126.

12 Attrill MJ and Power M (2000) Modelling the effect of drought on estuarine water quality. *Water Research* 34, 1584-1594.

13 Attrill MJ and Power M (2002) Climatic influence on a marine fish assemblage. *Nature* 417, 275–278.

14 Attrill MJ, Power M and Thomas RM (1999) Modelling estuarine Crustacea population fluctuations in response to physico-chemical trends. *Marine Ecology Progress Series* 178, 89–99.

15 Bacon PR (1994) Template for evaluation of impacts of sea level rise on Caribbean coastal wetlands. *Ecological Engineering* 3, 171–186.

16 Baker R and Sheaves M (2005) Redefining the piscivore assemblage of shallow estuarine nursery habitats. *Marine Ecology Progress Series* 291, 197–213.

17 Bate GC and Adams JB (2000) The effects of a single freshwater release into the Kromme Estuary. 5. Overview and interpretation for the future. *Water SA* 26, 329–332.

18 Bate GC, Whitfield AK, Adams JB, Huizinga P and Wooldridge TH (2002) The importance of the river-estuary interface (REI) zone in estuaries. *Water SA* 28, 271–279.

19 Begon M, Harper JL and Townsend CR (1990) *Ecology: Individuals, populations and communities*. Blackwell Scientific Publications, Cambridge, Massachusetts.

20 Bornman TG, Adams JB and Bate GC (2002) Freshwater requirements of a semi-arid supratidal and floodplain salt marsh. *Estuaries* 25, 1394–1405.

21 Bowen ZH, Bovee KD and Waddle TJ (2003) Effects of flow regulation on shallow-water habitat dynamics and floodplain connectivity. *Transactions of the American Fisheries Society* 132, 809–823.

22 Brinson MM (2006) *Response of coastal wetlands to rising sea level: comparison of tidal and nontidal estuarine environments*. Catchments to Coast Conference, Australian Marine Sciences Association and Society of Wetland Scientists, Brisbane.

23 Browder JA, Zein-Eldin Z, Criales MM, Robblee MB, Wong S, Jackson TL and Johnson D (2002) Dynamics of pink shrimp (*Farfantepenaeus duorarum*) recruitment potential in relation to salinity and temperature in Florida Bay. *Estuaries* 25, 1355–1371.

24 Brown LR and Ford T (2002) Effects of flow on the fish communities of a regulated California river: implications for managing native fishes. *River Research and Applications* 18, 331–342.

25 Cahoon DR (2006) *Patterns and processes of surface elevation response to sea level rise in mangrove forests*. Catchments to Coast Conference, Australian Marine Sciences Association and Society of Wetland Scientists, Brisbane.

26 Chan TU and Hamilton DP (2001) Effect of freshwater flow on the succession and biomass of phytoplankton in a seasonal estuary. *Marine and Freshwater Research* 52, 869–884.

27 Chan TU, Hamilton DP, Robson BJ, Hodges BR and Dallimore C (2002) Impacts of hydrological changes on phytoplankton succession in the Swan River, Western Australia. *Estuaries* 25, 1406–1415.

28 Chicharo MA, Chicharo LM, Galvao H, Barbosa A, Marques MH, Andrade JP, Esteves E, Miguel C and Gouveia I (2001) Status of the Guadiana Estuary (south Portugal) during 1996-1998: An ecohydrological approach. *Aquatic Ecosystem Health and Management* 4, 73–89.

29 Childers DL, Boyer JN, Davis SE, Madden CJ, Rudnick DT and Sklar FH (2006) Relating precipitation and water management to nutrient concentrations in the oligotrophic "upside-down" estuaries of the Florida Everglades. *Limnology and Oceanography* 51, 602–616.

30 Cloern JE, Alpine AE, Cole BE, Wong RLJ, Arthur JF and Ball MD (1983) River discharge controls phytoplankton dynamics in the northern San Francisco Bay Estuary. *Estuarine, Coastal and Shelf Science* 16, 415–429.

31 Cook FJ, Hicks W, Gardner EA, Carlin GD and Froggatt DW (2000) Export of acidity in drainage water from acid sulphate soils. *Marine Pollution Bulletin* 41, 319–326.

32 Cook PLM, Revill AT, Clementson LA and Volkman JK (2004) Carbon and nitrogen cycling on intertidal mudflats of a temperate Australian estuary. III. Sources of organic matter. *Marine Ecology Progress Series* 280, 55–72.

33 Currie DR and Small KJ (2005) Macrobenthic community responses to long-term environmental change in an east Australian sub-tropical estuary. *Estuarine, Coastal and Shelf Science* 63, 315–331.

34 Davenport J and Vahl O (1979) Responses of the fish *Blennius pholis* to fluctuating salinities. *Marine Ecology Progress Series* 1, 101–107.

35 Davis SM, Childers DL, Lorenz JJ, Wanless HR and Hopkins TE (2005) A conceptual model of ecological interactions in the mangrove estuaries of the Florida Everglades. *Wetlands* 25, 832–842.

36 Doering PH and Chamberlain RH (1999) Water quality and source of freshwater discharge to the Caloosahatchee Estuary, Florida. *Journal of the American Water Resources Association* 35, 793–806.

37 Domingues RB, Barbosa A and Galvao H (2005) Nutrients, light and phytoplankton succession in a temperate estuary (the Guadiana, south-western Iberia). *Estuarine, Coastal and Shelf Science* 64, 249–260.

38 Downing AL (2005) Relative effects of species composition and richness on ecosystem properties in ponds. *Ecology* 86, 701–715.

39 Doyle TW, Conner WH and Krauss KW (2006) *The vulnerability of tidal freshwater forests of southern United States to changing climate and rising sea level*. Catchments to Coast Conference, Australian Marine Sciences Association and Society of Wetland Scientists, Brisbane.

40 Drake P, Arias AM, Baldo F, Cuesta JA, Rodriguez A, Silva-Garcia A, Sobrino I, Garcia-Gonzalez D and Fernandez-Delgado C (2002) Spatial and temporal variation of the nekton and hyperbenthos from a temperate European estuary with regulated freshwater inflow. *Estuaries* 25, 451–468.

41 Drexler JZ and De Carlo EW (2002) Source water partitioning as a means of characterizing hydrologic function in mangroves. *Wetlands Ecology and Management* 10, 103–113.

42 Duarte CM (2002) The future of seagrass meadows. *Environmental Conservation* 29, 192–206.

43 Edgar GJ, Barrett NS, Graddon DJ and Last PR (2000) The conservation significance of estuaries: a classification of Tasmanian estuaries using ecological, physical and demographic attributes as a case study. *Biological Conservation* 92, 383–397.

44 Ewanchuk PJ and Bertness MD (2004) The role of waterlogging in maintaining Forb Pannes in northern New England salt marshes. *Ecology* 85, 1568–1574.

45 Ewel KC (2006) *Indirect effects of sea level rise on tropical coastal wetlands*. Catchments to Coast Conference, Australian Marine Sciences Association and Society of Wetland Scientists, Brisbane.

46 Ferguson A, Eyre B and Gay J (2004) Nutrient Cycling in the Sub-tropical Brunswick Estuary, Australia. *Estuaries* 27, 1–17.

47 Finlayson CM and Lukacs G (2003) The status of wetlands in northern Australia. In: *Proceedings of the 2nd National Conference on aquatic environments*. Queensland Department of Natural Resources and Mines, Brisbane.

48 Ford P, Tillman P, Robson B and Webster IT (2005) Organic carbon deliveries and their flow related dynamics in the Fitzroy estuary. *Marine Pollution Bulletin* 51, 119–127.

49 Galloway RW, Story R, Cooper R and Yapp GA (1984) Coastal Lands of Australia, *Natural Resources* Series 1. Commonwealth Scientific and Industrial Research Organisation, Canberra.

50 Garrett RN (1987) Reproduction in Queensland barramundi (*Lates calcarifer*). In: JW Copland and DL Grey (eds) *International Workshop on Management of Wild and Cultured Sea Bass/Barramundi (Lates calcarifer)*, Darwin.

51 Gehrke P and Sheaves MJ (2006) *Research priorities to sustain coastal fisheries resources in the Great Barrier Reef region: A scoping study for the Tully-Murray catchment.* Commonwealth Scientific and Industrial Research Organisation: Water for a Healthy Country National Research Flagship, Canberra.

52 Gehrels RW (1999) Middle and late Holocene sea level changes in Eastern Maine reconstructed from foraminiferal saltmarsh stratigraphy and AMS ^{14}C dates on basal peat. *Quaternary Research* 52, 350–359.

53 Gillanders BM and Kingsford MJ (2002) Impact of changes in flow of freshwater on estuarine and open coastal habitats and the associated ecosystems. *Oceanography and marine biology: An Annual Review* 40, 233–309.

54 Gornitz V, Couch S and Hartig EK (2001) Impacts of sea level rise in the New York City metropolitan area. *Global and Planetary Change* 32, 61–88.

55 Haney DC, Nordlie FG and Binello J (1999) Influence of simulated tidal changes in ambient salinity on routine metabolic rate in *Cyprinodon variegatus. Copeia* 1999, 509–514.

56 Harashima A, Kimoto T, Wakabayashi T and Toshiyasu T (2006) Verification of the silica deficiency hypothesis based on biogeochemical trends in the aquatic continuum of Lake Biwa- Yodo River-Seto Inland Sea, Japan. *Ambio* 35, 36–42.

57 Hartig EK, Grozev O and Rosenzweig C (1997) Climate change, agriculture and wetlands in Eastern Europe: vulnerability, adaptation and policy. *Climate Change* 36, 107–121.

58 Harvey N, Barnett EJ, Bourman RP and Belperio AP (1999) Holocene Sea level change at Port Pirie, South Australia: A contribution to global sea level rise estimates from tide gauges. *Journal of Coastal Research* 15, 607–615.

59 Harwood J (2001) Marine mammals and their environment in the twenty-first century. *Journal of Mammalogy* 82, 630–640.

60 Hatcher BG, Johannes RE and Robertson AI (1989) Review of research relevant to the conservation of shallow tropical marine ecosystems. *Oceanography and Marine Biology: An Annual Review* 27, 337–414.

61 Heap AD, Bryce S and Ryan DA (2004) Facies evolution of Holocene estuaries and deltas: a large-sample statistical study from Australia. *Sedimentary Geology* 168, 1–17.

62 Huston MA (1994) *Biological Diversity: The Coexistence of Species on Changing Landscapes.* Cambridge University Press, Cambridge.

63 Hyland SJ (2002) *An investigation of the impacts of ponded pastures on barramundi and other finfish populations in tropical coastal wetlands*. Final Report to Queensland Department of primary Industries and Fisheries, Brisbane.

64 Irlandi E, Macia S and Serafy J (1997) Salinity reduction from freshwater canal discharge: Effects on mortality and feeding of an urchin (*Lytechinus variegatus*) and a gastropod (*Lithopoma tectum*). *Bulletin of Marine Science* 61, 869–879.

65 Jickells T (2005) External inputs as a contributor to eutrophication problems. *Journal of Sea Research* 54, 58–69.

66 Kalke RD anad Montagna PA (1991) The effect of freshwater inflow on macrobenthos in the Lavaca River delta and upper Lavaca Bay, Texas. *Contributions in Marine Science* 32, 49–71.

67 Kimmerer WJ (2002a) Effects of freshwater flow on abundance of estuarine organisms: Physical effects or trophic linkages? *Marine Ecology Progress Series* 243, 39–55.

68 Kimmerer WJ (2002b) Physical, biological, and management responses to variable freshwater flow into the San Francisco Estuary. *Estuaries* 25, 1275–1290.

69 Kingsford RT and Norman FI (2002) Australian waterbirds: Products of the continent's ecology. *Emu* 102, 47–69.

70 Kocum E, Nedwell DB and Underwood GJC (2002) Regulation of phytoplankton primary production along a hypernutrified estuary. *Marine Ecology Progress Series* 231, 13–22.

71 Kraus RT and Secor DH (2005) Connectivity in estuarine white perch populations of Chesapeake Bay: evidence from historical fisheries data. *Estuarine, Coastal and Shelf Science* 64, 108–118.

72 Kukulka T and Jay DA (2003) Impacts of Columbia River discharge on salmonid habitat: 2. Changes in shallow-water habitat. *Journal of Geophysical Research*. C. Oceans 108.

73 Laegdsgaard P and Johnson CR (1995) Mangrove habitats as nurseries: Unique assemblages of juvenile fish in subtropical mangroves in eastern Australia. *Marine Ecology Progress Series* 126, 67–81.

74 Lafaille P, Thieulle L, Feunteun E and Lefeuvre JC (2001) Composition of fish community in small anthropic estuary (the Couesnon, France). *Bulletin Francais de la Peche et de la Pisciculture* Paris,191–208

75 Leatherman SP, Zhang K and Douglas BC (2000) Sea level rise shown to drive coastal erosion. *Eos* 81, 55–57.

76 Ley JA (2005) Linking fish assemblages and attributes of mangrove estuaries in tropical Australia: criteria for regional marine reserves. *Marine Ecology Progress Series* 305, 41–57.

77 Livingston RJ (1997) Trophic response of estuarine fishes to long-term changes of river runoff. *Bulletin of Marine Science* 60, 984–1004.

78 Livingston RJ, Niu X, Lewis FG, III and Woodsum GC (1997) Freshwater input to a gulf estuary: Long-term control of trophic organization. *Ecological Applications* 7, 277–299.

79 Lorenz JJ (1999) The response of fishes to physicochemical changes in the mangroves of northeast Florida Bay. *Estuaries* 22, 500–517.

80 Lough JM (2001) Climate variability and change on the Great Barrier Reef. In: E Wolanski (ed) *Oceanographic Processes on Coral Reefs: Physics-Biology Links in the Great Barrier Reef.* CRC Press, Boca Raton, pp. 269–300.

81 McCormick SD, Hansen LP, Quinn TP and Saunders RL (1998) Movement, migration, and smolting of Atlantic salmon (*Salmo salar*). *Canadian Journal of Fisheries and Aquatic Sciences* 55, supplement 1, 77–92.

82 McKenna JE Jr (1997) Influence of physical disturbance on the structure of coral reef fish assemblages in the Dry Tortugas. *Carribean Journal of Science* 33, 82–97.

83 MacArthur RH and Wilson EO (1967) *The Theory of Island Biogeography*. Princeton University Press, Princeton.

84 Mallin MA, Paerl HW, Rudek J and Bates PW (1993) Regulation of estuarine primary production by watershed rainfall and river flow. *Marine Ecology Progress Series* 93, 199–203.

85 Massell SR and Done TJ (1993) Effects of cyclone waves on massive coral assemblages on the GBR: meteorology, hydrodynamics and demography. *Coral Reefs* 12, 153–166.

86 Melancon EJ, Addison CD and Duke RW (2005) Understanding how oyster metapopulations respond to salinity in the Barataria estuary. J*ournal of Shellfish Research* 24, 667.

87 Montagna PA and Kalke RD (1992) The effect of freshwater inflow on meiofaunal and macrofaunal populations in the Guadalupe and Nueces estuaries, Texas. *Estuaries* 15, 307–326.

88 Montagna PA, Kalke RD and Ritter C (2002) Effect of restored freshwater inflow on macrofauna and meiofauna in upper Rincon Bayou, Texas, USA. *Estuaries* 25, 1436–1447.

89 Moore HB (1972) Aspects of stress in the marine environment. *Advances in Marine Biology* 10, 217-269.

90 Moser ML and Hettler WF (1989) Routine metabolism of juvenile spot, *Leiostomus xanthurus* (Lacepede), as a function of temperature, salinity and weight. *Journal of Fish Biology* 35, 703–707.

91 Mumby PJ, Edwards AJ, Arias-Gonzalez JE, Lindeman KC, Blackwell PG, Gall A, Gorczynska MI, Harborne AR, Pescod CL, Renken H, Wabnitz CCC and Llewellyn G (2004) Mangroves enhance the biomass of coral reef fish communities in the Caribbean. *Nature* 427, 533–536.

92 Nicholls RJ, Hoozemans E and Marchand M (1999) Increasing flood risk and wetland loss due to global sea level rise: regional and global analyses. *Global Environmental Change* 9, S69–S88.

93 Norberg J (2004) Biodiversity and ecosystem functioning: A complex adaptive systems approach. *Limnology and Oceanography* 49, 1269–1277.

94 North EW, Hood RR, Chao SY and Sanford LP (2002) *Retention of fish early-life stages and copepod prey in an estuarine nursery area: The influence of environmental variability*. Report No. ICES CM 2002/N:04.

95 North EW, Hood RR, Chao SY and Sanford LP (2005) The influence of episodic events on transport of striped bass eggs to the estuarine turbidity maximum nursery area. *Estuaries* 28, 108–123.

96 Ong JE (1995) The ecology of mangrove conservation and management. *Hydrobiologia* 295, 343-351.

97 Osmundson DB, Ryel RJ, Lamarra VL and Pitlick J (2002) Flow-sediment-biota relations: implications for river regulation effects on native fish abundance. *Ecological Applications* 12, 1719–1739.

98 Palmer TA, Montagna PA and Kalke RD (2002) Downstream effects of restored freshwater inflow to Rincon Bayou, Nueces Delta, Texas, USA. *Estuaries* 25, 1448–1456.

99 Paramor OA and Hughes RG (2004) The effects of bioturbation and herbivory by the polychaete *Nereis diversicolo*r on loss of saltmarsh in south-east England. *Journal of Applied Ecology* 41, 449–463.

100 Peirson G and Frear PA (2003) Fixed location hydroacoustic monitoring of fish populations in the tidal River Hull, north-east England, in relation to water quality. *Fisheries Management and Ecology* 10, 1–12.

101 Plaut I (1998) Comparison of salinity tolerance and osmoregulation in two closely related species of blennies from different habitats. *Fish Physiology and Biochemistry* 19, 181–188.

102 Plaut I (1999) Effects of salinity on survival, osmoregulation and oxygen consumption in the intertidal blenny, *Parablennius sanguinolentus. Copeia* 1999, 775–779.

103 Poff NL and Allan JD (1995) Functional organization of stream fish assemblages in relation to hydrological variability. *Ecology* 76, 606–627.

104 Pontee NI, Whitehead PA and Hayes CM (2004) The effect of freshwater flow on siltation in the Humber Estuary, north east UK. *Estuarine, Coastal and Shelf Science* 60, 241–249.

105 Power M, Attrill MJ and Thomas RM (2002) Environmental influences on the long-term fluctuations in the abundance of gadoid species during estuarine residence. *Journal of Sea Research* 47, 185–194.

106 Prat N and Ibanez C (1995) Effects of water transfers projected in the Spanish National Hydrological Plan on the ecology of the lower River Ebro (N.E. Spain) and its delta. *Water Science and Technology* 31, 79–86.

107 Ravenscroft NOM and Beardall CH (2003) The importance of freshwater flows over estuarine mudflats for wintering waders and wildfowl. *Biological Conservation* 113, 89–97.

108 Richter BD, Baumgartner JV, Powell J and Braun DP (1996) A method for assessing hydrologic alteration within ecosystems. *Conservation Biology* 10, 1163–1174.

109 Ridd PV and Stieglitz T (2002) Dry season salinity changes in arid estuaries fringed by mangroves and saltflats. *Estuarine, Coastal and Shelf Science* 54, 1039–1049.

110 Riera P, Montagna PA, Kalke RD and Richard P (2000) Utilization of estuarine organic matter during growth and migration by juvenile brown shrimp Penaeus aztecus in a South Texas estuary. *Marine Ecology Progress Series* 199, 205–216.

111 Robertson AI and Duke NC (1987) Mangroves as nursery sites: Comparisons of the abundance and species composition of fish and crustaceans in mangroves and other nearshore habitats in tropical Australia. *Marine Biology* 96, 193–205.

112 Robertson AI and Duke NC (1990) Recruitment, growth and residence time of fishes in a tropical Australian mangrove system. *Estuarine, Coastal and Shelf Science* 31, 723–743.

113 Rocha C, Galvao H and Barbosa A (2002) Role of transient silicon limitation in the development of cyanobacteria blooms in the Guadiana Estuary, south-western Iberia. *Marine Ecology Progress Series* 228, 35–45.

114 Rogers K, Saintilan N and Heijnis H (1995) Mangrove encroachment of salt marsh in Western Port Bay, Victoria: the role of sedimentation, subsidence and sea level rise. *Estuaries* 28, 551–559.

115 Rubin JA, Gordon C and Amatekpor JK (1998) Causes and consequences of mangrove deforestation in the Volta Estuary, Ghana: Some recommendations for ecosystem rehabilitation. *Marine Pollution Bulletin* 37, 441–449.

116 Rudnick DT, Ortner PB, Browder JA and Davis SM (2005) A conceptual ecological model of Florida Bay. *Wetlands* 25, 870–883.

117 Russell DJ and Garrett RN (1983) Use by juvenile barramundi, *Lates calcarifer* (Bloch), and other fishes of temporary supralittoral habitats in a tropical estuary in northern Australia. *Australian Journal of Marine and Freshwater Research* 34, 805–811.

118 Russell DJ and Garrett RN (1985) Early life history of barramundi, *Lates calcarifer* (Bloch), in north-eastern Queensland. *Australian Journal of Marine and Freshwater Research* 36,191–201

119 Rybczyk JM and Cahoon DR (2002) Estimating the potential for submergence for two wetlands in the Mississippi River Delta. *Estuaries* 25, 985–998.

120 Salen Picard C, Darnaude AI, Arlhac D and Harmelin Vivien MI (2002) Fluctuations of macrobenthic populations: a link between climate-driven river run-off and sole fishery yields in the Gulf of Lions. *Oecologia* 133, 380–388.

121 Sammut J (1998). *Associations between acid sulfate soils, estuarine acidification, and gill and skin lesions in estuarine and freshwater fish*. PhD Thesis. University of New South Wales, Sydney.

122 Sammut J, Callinan R and Dove R (1999) *A brief review of the aquatic impacts of acid sulfate soils. Acid sulfate soils and their management in coastal Queensland.* Forum and Technical Papers, Brisbane 21–23 April, Department of Natural Resources, Canberra.

123 Schaffelke B, Mellors J and Duke NC (2005) Water quality in the Great Barrier Reef region: responses of mangrove, seagrass and macroalgal communities. *Marine Pollution Bulletin* 51, 279–296.

124 Scharler UM and Baird D (2000a) The effect of a single freshwater release on the physico-chemical properties of the freshwater-starved Kromme Estuary, St. Francis Bay, South Africa. *African Journal of Aquatic Sciences* 25, 227–228.

125 Scharler UM and Baird D (2000b) The effects of a single freshwater release into the Kromme Estuary 1: General description of the study area and physico-chemical responses. *Water SA* 26, 291–300.

126 Scharler UM and Baird D (2003) The nutrient status of the agriculturally impacted Gamtoos Estuary, South Africa, with special reference to the river-estuarine interface region (REI). *Aquatic Conservation: Marine and Freshwater Ecosystems* 13, 99–119.

127 Schofield PJ (2003) Salinity tolerance of two gobies (*Microgobius gulosus, Gobiosoma robustum*) from Florida Bay (USA). *Gulf of Mexico Science* 21, 86–91.

128 Serafy JE, Lindeman KC, Hopkins TE and Ault JS (1997) Effects of freshwater canal discharge on fish assemblages in a subtropical bay: Field and laboratory observations. *Marine Ecology Progress Series* 160, 161–172.

129 Shaklee JB, Salini J and Garrett RN (1993) Electrophoretic characterization of multiple genetic stocks of barramundi perch in Queensland, Australia. *Transactions of the American Fisheries Society* 122, 685–701.

130 Sheaves J (in prep) Spatial and temporal patterns in the abundance and distribution of estuarine benthos at multiple spatial scales. PhD Thesis, James Cook University, Townsville.

131 Sheaves M (1995) Large lutjanid and serranid fishes in tropical estuaries: Are they adults or juveniles? *Marine Ecology Progress Series*. 129, 31–40.

132 Sheaves M (1996a) Do spatial differences in the abundance of two serranid fishes in estuaries of tropical Australia reflect long-term salinity patterns? *Marine Ecology Progress Series* 137, 39–49.

133 Sheaves M (2005) Nature and consequences of biological connectivity in mangroves systems. *Marine Ecology Progress Series* 302, 293–305.

134 Sheaves M, Collins J, Houston W, Dale P, Revill A, Johnston R and Abrantes K (2006) *Contribution of floodplain wetland pools to the ecological functioning of the Fitzroy River Estuary.* Cooperative Research Center for Coastal Zone, Estuarine and Waterway Management.

135 Sheaves M, Johnston R, Molony B and Shepard G (2007) The effect of impoundments on the structure and function of fish fauna in a highly regulated dry tropics estuary. *Estuaries* 30, 507-517.

136 Sheaves MJ (1996b) Habitat-specific distributions of some fishes in a tropical estuary. *Marine and Freshwater Research* 47, 827–830.

137 Sheaves MJ (2006) Scale dependent variation in composition of fish fauna among tropical estuarine sandy embayments. *Marine Ecology Progress Series* 310, 173–184.

138 Sheaves MJ, Abrantes KGS and Johnston RW (2007) Nursery ground value of an endangered wetland to juvenile shrimps. *Wetlands Ecology and Management* 15, 311-327.

139 Sklar FH and Browder JA (1998) Coastal environmental impacts brought about by alterations to freshwater flow in the Gulf of Mexico. *Environmental Management* 22, 547–562.

140 Snow GC and Adams JB (2006) Response of micro-algae in the Kromme Estuary to managed freshwater inputs. *Water SA* 32, 71–80.

141 Snow GC, Adams JB and Bate GC (2000) Effect of river flow on estuarine microalgal biomass and distribution. *Estuarine, Coastal and Shelf Science* 51, 255–266.

142 Solomon DJ and Sambrook HT (2004) Effects of hot dry summers on the loss of Atlantic salmon, *Salmo salar*, from estuaries in South West England. *Fisheries Management and Ecology* 11, 353–363.

143 Soukup MA and Portnoy JW (1986). Impacts from mosquito control-induced sulfur mobilisation in a Cape Cod Estuary. *Environmental Conserv*ation 13, 47–50.

144 Street MW (2006) *Management of North Carolina's coastal fish habitats and fisheries as sea level rises.* Catchments to Coast Conference, Australian Marine Sciences Association and Society of Wetland Scientists, Brisbane.

145 Stora G, Arnoux A and Galas M (1995) Time and spatial dynamics of Mediterranean lagoon macrobenthos during an exceptionally prolonged interruption of freshwater inputs. *Hydrobiologia* 300/301, 123–132.

146 Struyf E, Van Damme S and Meire P (2004) Possible effects of climate change on estuarine nutrient fluxes: a case study in the highly nutrified Schelde estuary (Belgium, The Netherlands). *Estuarine, Coastal and Shelf Science* 60, 649–661.

147 Strydom NA and Whitfield AK (2000) The effects of a single freshwater release into the Kromme Estuary. 4: Larval fish response. *Water SA* 26, 319–328.

148 Strydom NA, Whitfield AK and Paterson AW (2002) Influence of altered freshwater flow regimes on abundance of larval and juvenile *Gilchristella aestuaria* (Pisces: Clupeidae) in the upper reaches of two South African estuaries. *Marine and Freshwater Research* 53, 431–438.

149 Toma T, Nakamura K, Patanaponpaiboon P and Ogino K (1991) Effect of flooding water level and plant density on growth of pneumatophore of Avicennia marina. *Tropics* 1, 75–82.

150 Tucker JW Jr, Russell DJand Rimmer MA (2005) Barramundi Culture. *American Fisheries Society Symposium* 46, 273–295.

151 Valdivia N, Heidemann A, Thiel M, Molis M and Wahl M (2005) Effects of disturbance on the diversity of hard-bottom macrobenthic communities on the coast of Chile. *Marine Ecology Progress Series* 299, 45–54.

152 Vance DJ, Haywood MDE, Heales DS, Kenyon RA, Loneragan NR and Pendrey RC (1996) How far do prawns and fish move into mangroves? Distribution of juvenile banana prawns *Penaeus merguiensis* and fish in a tropical mangrove forest in northern Australia. *Marine Ecology Progress Series* 131, 115–124.

153 Vance DJ, Haywood MDE, Heales DS, Kenyon RA, Loneragan NR, Pendrey RC (2002) Distribution of juvenile penaeid prawns in mangrove forests in a tropical Australian estuary, with particular reference to *Penaeus merguiensis. Marine Ecology Progress Series* 228, 165–177.

154 Verspagen JMH, Passarge J, Joehnk KD, Visser PM, Peperzak L, Boers P, Laanbroek HJ and Huisman J (2006) Water management strategies against toxic Microcystis blooms in the Dutch Delta. *Ecological Applications* 16, 313–327.

155 Vidy G, Darboe FS and Mbye EM (2004) Juvenile fish assemblages in the creeks of the Gambia Estuary. *Aquatic Living Resources* 17, 56–64.

156 Walker DJ (2003) Assessing environmental flow requirements for a river-dominated tidal inlet. *Journal of Coastal Research* 19, 171–179.

157 Walker KF (1985) A review of the ecological effects of river regulation in Australia. *Hydrobiologia* 125, 111–129.

158 Webster IT, Ford PW and Tillman P (2005) Estimating nutrient budgets in tropical estuaries subject to episodic flows. *Marine Pollution Bulletin* 51, 165–173.

159 Wedemeyer GA, Barton BA and McLeay DJ (1990) Stress and acclimation. *In:* CB Schreck and PB Moyle (eds) *Methods for Fish Biology*. American Fisheries Society, Bethesda, pp. 451–489.

160 Whitfield AK (2005) Fishes and freshwater in southern African estuaries - A review. *Aquatic Living Resources* 18, 275–289.

161 Whitfield AK and Harrison TD (2003) River flow and fish abundance in a South African estuary. *Journal of Fish Biology* 62, 1467–1472.

162 Wolanski E (1992) Hydrodynamics of mangrove swamps and their coastal waters. *Hydrobiologia* 247, 141–161.

163 Wolanski E and Chappell J (1996) The response of tropical Australian estuaries to a sea level rise. *Journal of Marine Systems* 7, 267–279.

164 Wooldridge TH, Callahan R (2000) The effects of a single freshwater release into the Kromme Estuary. 3: Estuarine zooplankton response. *Water SA* 26, 311–318.

165 Woodroffe C (1992) Mangrove Sediments and Geomorphology. In: AI Robertson and DM Alongi (eds) *Tropical Mangrove Ecosystems*. American Geophysical Union, Washington, pp. 137–171.

166 Woodroffe CD (1995) Response of tide-dominated mangrove shorelines in northern Australia to anticipated sea level rise. *Earth Surface Processes and Landforms* 20, 65–85.