Coastal Ecosystems Responses to Climate Change

A synthesis report

NCCARF
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Climate change responses and adaptation pathways in Australian coastal ecosystems: Synthesis Report

Coastal Ecosystems Responses to Climate Change - Synthesis and Integration Project

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The role of NCCARF is to lead the research community in a national interdisciplinary effort to generate the information needed by decision-makers in government and in vulnerable sectors and communities to manage the risk of climate change impacts.

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Executive Summary

Climate change represents a major threat to coastal ecosystems and communities. In many areas around the Australian coast, the combined projected threats of sea level rise, increased temperatures and reduced rainfall will place unprecedented stress on species, ecosystems and human settlements and industries. Given that even the strictest climate change mitigation policies are unlikely to halt or reduce the threat that climate change currently poses to coastal ecosystems, consideration is needed as to how species, ecosystems and human communities might be able to adapt to anticipated changes.

The Coastal Ecosystems Responses to Climate Change Synthesis (CERCCS) Project represents a major Synthesis and Integration project commissioned by the National Climate Change Adaptation Research Facility (NCCARF) and undertaken by staff at Griffith University, the University of the Sunshine Coast, James Cook University and CSIRO. The focus of the project was on conducting a broad-scale assessment of climate change threats to coastal ecosystems of Australia and identifying potential adaptation pathways to inform decision-making and future research.

Australian coastal processes

Australian coastal landforms and ecosystems are strongly influenced by sea level variation, atmospheric, hydrologic and hydrodynamic (mostly marine) processes. Winds, waves and tides represent the major forms of energy in most coastal ecosystems and the influence of these on sediment dynamics plays a particularly important role in shaping coastal landforms. There are considerable regional differences in coastal processes around Australia including a strong north-south temperature gradient, north-south and east-west rainfall gradients (which include magnitude and seasonality), higher waves along the southern coastline and higher tidal ranges along the northern coastline. Dominant coastal sediments also vary around Australia with marine carbonate sediments occurring in the west and fine-grained and muddy terrestrial sediments occurring in the east and north.

Australian coastal ecosystems

There is considerable regional diversity in coastal ecosystems around Australia, both within and between realms. Amongst marine coastal ecosystems, coral reefs fringe the tropical northern coastlines while macroalgal forests dominate much of the southern coastal zone, largely reflecting temperature differences. In contrast, waves and tides largely determine the distribution of estuaries and sandy beaches around the continent with wave-dominated forms occurring in the south and tide-dominated forms in the north. While extensive behind beaches along the southern and eastern coastlines, dune systems are also rare along the lower energy northern coastline. Rocky shores vary around the coast according to geology and geomorphology although headlands are more prevalent along the east coast. Amongst freshwater coastal ecosystems, lakes and lagoons are relatively rare and occur patchily along the east coast while extensive forested wetlands are mostly associated with tidal rivers of northern Australia.

Within Australian coastal ecosystems, ecological structure and function closely reflect dominant physical processes which vary depending on coastal setting with hydrodynamic processes dominating marine and subtidal habitats, atmospheric processes dominating terrestrial subaerial habitats and hydrologic processes shaping estuarine habitats, including the influence of marine hydrodynamic processes within these.

Because of their setting and the range of physical processes shaping their habitats, many coastal ecosystems tend to be highly productive and biologically diverse, supporting a wide range of marine, terrestrial and specialised intertidal organisms. Where physical processes are particularly strong, however, e.g. in coarse-grained, high energy reflective beaches or highly exposed dunes and headlands, only a few hardy species may occur.

There is considerable connectivity (longitudinal, lateral and vertical) within and amongst Australian coastal ecosystems. In particular, primary productivity and food web connections are tightly linked between habitats across all coastal realms. Terrestrially derived sediments and nutrients also play a significant role in all coastal ecosystems considered here. Furthermore, marine inputs (e.g. salts) have considerable influence on estuarine, terrestrial and freshwater coastal ecosystems.

Australian coastal ecosystems provide a wide range of highly valuable services. Many of these, e.g. tourism, recreation, urban development, sand mining and fisheries, contribute directly and significantly to the economy. Other ‘non-use’ values, such as ecosystem services like buffering coastal settlements from storm surges and tsunamis, water and nutrient cycling, and provision of habitat to biodiversity, are also likely to be worth many millions of dollars to the country annually. Many Australian coastal ecosystems, particularly in iconic locations, also have considerable aesthetic, cultural and conservation values.

Australian coastal ecosystems are subject to many non-climatic threats, most of which are associated with human activities. These include changes to hydrological and hydrodynamic processes, as a result of water and land use and infrastructure developments, as well as changes to sediment and nutrient dynamics and fire regimes that have resulted from these catchment alterations. Harvesting of organisms and materials (e.g. sand) has also affected many coastal ecosystems as have disturbances arising from human activities including recreation and tourism. Invasive species also pose a substantial threat to many coastal ecosystems, particularly those in the marine realm. Encroaching development of human settlements on the landward side of much of the Australian coastline, referred to as the ‘coastal squeeze’, is particularly notable as a threatening process to many coastal ecosystems.

Management of Australian coastal ecosystems has tended to shift in recent times from traditional targeted management approaches, e.g. fisheries management, to more holistic, catchment management approaches. Protected areas remain an important element in the management of coastal ecosystems as does the regulation of harvesting and movement of species and materials. Targeted management of direct threats, e.g. urchins, are also important where specific problems can be identified.

Despite their high ecological, economic and cultural values, considerable knowledge gaps exist concerning the structure and function of many Australian coastal ecosystems and how these affect the ecosystem services provided. Whilst some coastal ecosystems have been well studied, e.g. tropical coral reefs, others are very poorly understood. In particular, information about most non-marine coastal ecosystems of northern Australia is lacking. Many terrestrial interface coastal ecosystems and coastal forested wetlands have also received relatively little attention.

Climate change in the Australian coastal zone

All major components of the Australian coastal climate (terrestrial, marine and sea level) have changed over the last century and are projected to change over the next century under the current projected climate change scenarios. These changes vary regionally around the coastline as well as seasonally in many cases.

With respect to the terrestrial climate, mean annual air temperatures have risen by just under 1° C since 1910 with a particular decline in the frequency of extreme cold. The last decade was the warmest on record. Annual rainfall, which is highly variable both temporally and spatially in Australia, has declined since 1950 in eastern and south-western Australia, but increased in the north. No significant trends in the frequency or intensity of tropical cyclones have been detected however a decline in cyclones south of 20°C on the east coast has been observed.

Mean annual air temperature is projected to rise in all Australian coastal regions between 0.8 – 2.1°C by the 2030s and between 1.8 – 6.2°C by the 2070s. A relatively small change in the seasonality of temperatures is projected but warming is likely to be particularly notable in terms of increased minimum temperatures during colder months. Mean annual rainfall is projected to decline in all coastal regions by 4-58%, depending on region, by the 2030s. Rainfall in the wettest period, however, is projected to increase in North Queensland and south-western Western Australia. Solar radiation is also projected to increase throughout the Australian coastal zone, particularly in the east, but is projected to decrease during the warmest quarter in the south-west and south-east, with the exception of Tasmania. Soil moisture is projected to decline in all coastal areas by up to 28% by the 20302. Projections concerning extreme events are highly uncertain but suggest a potential increase in the number of tropical cyclones in categories 3-5 along with an overall decline in the total number as well as a poleward shift in the regions of cyclone genesis and decay. Modelling also suggests a possible increase in coastal winds associated with extreme events as well as in response to increased ocean surface temperatures. A loss of east coast lows may also occur as a result of changes in the East Australian Current.

In the marine climate system, Australian mean annual sea surface temperatures have risen by 0.9°C since 1900 with the greatest rates of warming occurring over the last 50 years, particularly during summer, and in the south-east and south-west. In addition, associated changes have included an increase in ocean salinity resulting in a latitudinal shift in sea surface climate of approximately 3° or 350 km. This is a higher degree of warming than the global average and has been driven by an intensification of the East Australian Current. Ocean pH has also fallen by 0.1 in Australia since 1750 and an increase in the frequency and intensity of large wave events along the southern coast has also been identified.

Projected changes in Australia's marine coastal climate under the scenarios considered here include a warming of sea surface temperatures by 0.2 – 1.2°C by the 2030s and 0.5 – 3.8°C by the 2070s, with the greatest degree of warming projected for the north-west and south-east. Southern and north-eastern coastal waters are also projected to become slightly fresher by the 2030s while western, northern and south-eastern waters are projected to become slightly saltier, patterns which are likely to intensify by the 2070s. Average ocean pH is projected to fall, particularly in the north-east, by 0.3 – 0.4 if atmospheric CO_2 concentrations reach 540 – 979 ppm by the end of this Century making the ocean more acidic than at any time over the last 800 000 years.

Finally, sea level rose by an average of 1.2 mm/yr around Australia between 1920 and 2000 and is projected to increase over the next century, particularly in northern and western tropical coastal areas with low profiles that are not backed by rocky cliffs, e.g. estuarine systems. In the regions with extensive coastal zones considered here, coastal inundation is projected to increase up to 38 – 107 % by 2100.

Climate change impacts in Australian coastal ecosystems

The major drivers of ecological impacts of climate change are similar amongst most Australian coastal ecosystems but vary in their intensity and effects both regionally and between ecosystem types. Overall, the main ecological impacts from these drivers are likely to include reduced population sizes, shifts in species' ranges and changes in the composition, structure and dynamics of biological communities.

Rising temperatures are generally expected to drive species' distributions southwards as well as affecting physiological and behavioural responses in some species and altering ecological processes including primary production. Coral reefs are particularly sensitive to temperature and extreme ocean temperatures lead to bleaching events which can result in mass coral mortality and significant shifts in community composition, including the replacement of corals by algae.

Sea level rise will redistribute shallow marine and intertidal habitats around the coastal zone, lead to saltwater intrusion into estuarine and freshwater coastal ecosystems and result in a loss of area of some habitats, particularly those experiencing coastal 'squeeze' as a result of human developments. Dominant coastal processes including wind, waves, tides, currents and hydrology are also likely to change and drive ecological impacts in all coastal ecosystems by altering the distribution, movement and processing of water, materials (i.e. sediments and nutrients) and biota.

Changes in the frequency and intensity of extreme events will further affect coastal ecosystems in all realms both directly, e.g. via mechanical damage to organisms or effects on sediment dynamics, and indirectly, e.g. by influencing the quantity and quality of terrestrial runoff entering coastal ecosystems. Increased levels of coastal erosion are also widely predicted.

In the coastal marine environment and intertidal and subtidal coastal habitats, ocean acidification is likely to result in further ecological impacts by reducing the growth and survival of the many organisms which rely on dissolved carbonate to build their shells or skeletons, with significant ramifications for the food webs which rely on them. Ocean acidification may also directly affect the development and metabolism of non-calcifying marine organisms.

In terrestrial coastal ecosystems, e.g. dunes and headlands, CO_2 fertilisation may lead to vegetation thickening and encroachment of grasslands by shrubs. Altered fire regimes resulting from rising temperatures and reduced precipitation are also likely to affect vegetation communities in these coastal ecosystems and the habitat they provide to fauna. Some fauna, e.g. penguins, may be affected directly by changed burning patterns as well.

Numerous ecological impacts of climate change have already been observed in coastal ecosystems in Australia and around the world. In the marine realm, these include severe, large-scale episodes of coral bleaching related to increased sea surface temperatures resulting in significant changes in community composition, although Australian reefs appeared to have been more resilient to these than reefs elsewhere in the world. Observed changes in the distribution and abundance of macroalgae herbivores, e.g. the black sea urchin, along Australia's east coast, linked to dramatic losses of giant kelp and the formation of 'urchin barrens', are also directly related to increased temperatures as well as strengthening of the East Australian Current. With respect to intertidal species of rocky shores, considerable range expansions of warm water species and range contractions of cold water species have been recorded in the northern hemisphere. Furthermore, Australian arrival and departure dates of migratory birds, including shorebirds, have shifted in line with temperature changes.

Certainty surrounding predictions of ecological impacts of climate change varies considerably between ecosystems and regions. Specific studies of climate change impacts in Australian coastal ecosystems are relatively limited with most work having been conducted on coral reefs, particularly the Great Barrier Reef, and mangroves. Climate change studies on sandy beach and coastal dune ecosystems as well as freshwater coastal habitats appear to be particularly lacking.

Adaptation pathways

Pathways for climate change adaptation can be autonomous (ecological or human), or managed (human only). Autonomous ecological adaptation at a species level may occur via:

- acclimatisation: changes in physiology or life history toward phenotypes which can persist under changed conditions;
- adaptation: natural selection of genotypes which can persist under changed conditions;
- epigenetic interactions: changes in the function and expression of genes that are not explained at the level of DNA but which enable organisms to persist under changed conditions; or
- geographic range shifts: migration into areas with appropriate conditions

Shifts in community composition towards hardier species that are more tolerant of changed conditions may also be perceived as autonomous ecological adaptation at the community level.

Most research into autonomous ecological adaptation in coastal ecosystems has been conducted in the marine realm, particularly in relation to coral reefs. There is limited evidence to suggest that some coral species have the potential to acclimatise, adapt and migrate in response to climate change and those changes in communities composition may also occur. With respect to estuarine ecosystems, mangroves are considered to be particularly plastic with a high ability to adapt to changed conditions and migrate landward with sea level rise, provided appropriate habitats are not already occupied by human developments.

The adaptive capacity of coastal terrestrial and freshwater species and ecosystems is largely unknown although it is likely some species will tolerate changed conditions in situ, some will adapt life histories or behaviours, e.g. altered microhabitats for egg-laying amongst turtles, and other, more mobile or easily dispersed organisms, will migrate, e.g. shorebirds. In all coastal ecosystems, the potential for autonomous ecological adaptation pathways to ‘keep up’ with rates of climate change is largely unknown.

With respect to managed adaptation pathways in the coastal zone, four broad responses to climate change, particularly sea level rise, can be identified: 1. managed retreat, 2. limited intervention or accommodation, 3. hold the line and 4. do nothing. Each of these can entail a range of on-ground adaptation options which include:

- minimisation of existing non-climatic threats, e.g. invasive species;
- hard-engineering approaches, e.g. sea walls, groynes, armouring etc.;
- soft-engineering approaches, e.g. removing hard-engineering structures, revegetation, beach nourishment and drainage;
- ecological engineering, i.e. retrofitting hard engineering structures or introducing new structures to create artificial habitats; and
- ecosystem engineering, i.e. introduction of species which play a key role in shaping ecosystems structure and function, e.g. oysters, corals and dune grasses.

These adaptation approaches target a wide range of adaptation objectives and certainties surrounding the efficacy of each approach in achieving specific objectives vary considerably, both between approaches and with respect to different ecosystems and regions. All of these approaches are also likely to incur a range of unintended consequences, both ecological, e.g. effects on food webs, and socio-economic or cultural, e.g. impacts on human activities or loss of income, which, given the high level of connectivity amongst coastal ecosystems, can be far-reaching. Furthermore, these adaptation options entail varying costs, both in terms of time and resources involved in their implementation and maintenance as well as with respect to the risks involved. Selection of adaptation action is likely to be further limited by socio-economic and cultural context, e.g. recognition of high value of ecosystem services.

Many existing strategies of relevance to climate change adaptation for Australian coastal ecosystems can be identified amongst global, national, state and local conventions, legislation and policy. For the most part, these do not address climate change specifically but, by addressing non-climatic threats, can be perceived as adaptation strategies since they aim to enhance ecosystem resilience. With respect to specific climate change adaptation strategies, those at state and local levels tend to offer the greatest degree of practical advice concerning on-ground adaptation options, though these tend to be quite limited. Local strategies are also significantly constrained by state and federal legislation.

Common themes emerging from consideration of current approaches to climate change adaptation for Australian coastal ecosystems, particularly with respect to the three case study areas examined here (i.e. Kakadu National Park, the Hunter River estuary and the Cairns region) include:

- climate change impacts tend to be common amongst coastal regions but issues associated with their impacts may differ;
- current management strategies share an overarching aim to build resilience in threatened ecosystems by targeting non-climatic threats;
- current on-ground climate change adaptation actions are limited;
- adaptation decision-making is hampered by a lack of certainty and availability of information and funding;
- adaptation is also impeded by existing legislation and the timeframes involved;
- unintended consequences of adaptation actions require greater consideration.

Key recommendations for policy and management

- Climate change adaptation approaches and actions require clearly stated (and debated) goals and objectives to reduce the risk of establishing unrealistic expectations and implementing maladaptive strategies. Climate change adaptation planning should therefore include the setting of broad goals, e.g. 'keeping the system as it is' versus 'moving the system to a new state' as well specific, targeted objectives concerning the desired ecological consequences of adaptation actions, e.g. conserving species, ecosystem function or ecosystem services.

- Climate change adaptation planning and decision-making requires involvement from a wide range of stakeholders across environmental, social, economic and cultural sectors. Such integration is critical to developing appropriate goals and objectives for adaptation as well as identifying strategies which are likely to be successfully implemented and maintained and that involve minimal risks across sectors.

- Climate change adaptation planning requires information to be made easily available and shared. This includes information regarding climate projections, physical, chemical and ecological parameters and social, economic and cultural components of the area of concern. Issues of data availability also highlight the need for monitoring across all sectors to provide information to underpin adaptation decision-making. Improved mechanisms of data collation, storage and delivery are also urgently required.

- Climate change adaptation for the Australian coastal zone requires more integrated, flexible and dynamic legislative, policy and institutional frameworks which adequately reflect the temporal and spatial scales required by adaptation decision-making as well as allowing for adaptive management cycles.

- Climate change adaptation in the Australian coastal zone requires a greater understanding and appreciation of connectivity within and amongst coastal ecosystems as well as between ecological and human systems, e.g. the high value of ecosystem services provided to human communities by coastal ecosystems.

- Climate change adaptation actions will be implemented at local or regional scales, since these will determine which adaptation approaches are appropriate to address adaptation goals and objectives and possible given the physical, ecological, social, economic and cultural features of the area of concern. However, larger scales require consideration since adaptation actions may have consequences for connectivity with ecological and human systems beyond this area, e.g. migrating species.

- Climate change adaptation in the Australian coastal zone cannot be considered in isolation of existing non-climatic threats. Climate change adaptation should focus on coastal zone sustainability so explicit consideration of non-climatic threats is essential, particularly as the impacts of many are likely to be exacerbated by climate change. As with other adaptation approaches, management of non-climatic threats should take into account the risks associated with their cost, efficacy and unintended ecological and human consequences.

Key recommendations for future research

- Improved projections of future climate change for the Australian coastal zone would be aided by the development of a coastal climate model which integrates existing terrestrial, marine and sea level models and considers the interactions amongst these. In particular, improved information is required with respect to climate change impacts on winds and hydrodynamics (i.e. waves, tides and currents) around the Australian coastline.

- There is a need for much basic ecological information for many Australian coastal ecosystems to contribute to an improved understanding of ecosystem structure, function and connectivity. In particular, research is needed on sandy beach and dune ecosystems and coastal forested wetlands around the country as well as most coastal ecosystems in northern Australia.

- Ecological monitoring is lacking for many Australian coastal ecosystems and regions. Research is needed to identify robust indicators and appropriate methods for collecting and analysing ecological data with respect to assessing climate change impacts and the efficacy of adaptation actions in the Australian coastal zone.

- Research is needed to assess the efficacy and potential unintended ecological consequences of different proposed adaptation actions. This work needs to be done at the regional scale, as it is likely that consequences will vary according to the local setting and in response to interactions with each other and regional non-climatic stressors.

- Research is needed to support the development of robust decision-making approaches which can integrate ecological, social, economic and cultural objectives and information. This should include an assessment of information needs across stakeholder groups as well as an examination of constraints and barriers to adaptation and how these might be overcome.

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Steering Committee

Special thanks to the constructive comments and feedback provided by the members of the project Steering Committee.

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Expert Panel

Expert panel members were invited to participate in a wide variety of project activities, including the project workshops and the tasks associated with evaluating climate change impacts and adaptation options across the realms of their experience. Expert panel workshop participants and their affiliations are as follows:

Dr Melanie Bishop	Macquarie University
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1. INTRODUCTION

1.1. Background

Climate change represents a major threat to coastal ecosystems and communities. In many areas around the Australian coast, the combined projected threats of sea level rise, increased temperatures and reduced rainfall will place unprecedented stress on species, ecosystems and human settlements and industries. Given that even the strictest climate change mitigation policies are unlikely to halt or reduce the threat that climate change currently poses to coastal ecosystems, consideration is needed as to how species, ecosystems and human communities might be able to adapt to anticipated changes.

The Coastal Ecosystems Responses to Climate Change Synthesis (CERCCS) Project represents a major Synthesis and Integration project commissioned by the National Climate Change Adaptation Research Facility (NCCARF) and undertaken by staff at Griffith University, the University of the Sunshine Coast, James Cook University and CSIRO. The focus of this project was on conducting a broad-scale assessment of climate change threats to coastal ecosystems of Australia and identifying potential adaptation pathways to inform decision-making and future research.

1.2. Project objectives

The CERCCS project was developed "*to synthesise knowledge of climate change impacts on Australian coastal ecosystems and integrate understanding of potential adaptive pathways, both ecological and human, to identify priorities for management and future research*".

To achieve this goal, the project's major objectives were to:

- integrate knowledge of historical and projected climatic changes in Australian coastal ecosystems
- synthesise knowledge of historical and predicted ecological impacts of climate change in Australian coastal ecosystems
- identify ecological and socio-economic pathways for adaptation to climate change in Australian coastal ecosystems
- identify priorities for management and future research

1.3. Project approach

The CERCCS Project comprised four broad work packages, as follows:

Work Package 1 sought to identify, catalogue and review sources of knowledge concerning historic and projected climate change in Australian coastal ecosystems and synthesise understanding of documented and predicted ecological impacts of climatic changes. Whilst consideration was given for impacts at multiple scales, the work predominantly focused on a set of priority ecosystems, species and processes.

Work Package 2 revolved around a review of existing knowledge of ecological adaptive pathways in coastal ecosystems.

Work Package 3 reviewed existing and proposed human adaptation strategies to climate change in coastal zones and assessed their impacts on priority ecosystems, species and processes. Non-climatic threats to Australian coastal ecosystems and approaches to their management were also reviewed, as potential interactions between these and human climate adaptation strategies need to be understood during the adaptation decision making process. An expert panel workshop was conducted to examine realm and habitat-based adaptation strategies and in addition, three in-depth regional case studies were also considered to investigate interactions amongst a range of ecological and human systems and to evaluate the possible adaptation actions in real-world settings.

Work Package 4 involved the development of synthesis products, in forms appropriate for potential end-users, from the results of Work packages 1 to 3, including the development of this Synthesis Report.

1.4. Structure of this report

This report provides a synthesis of the results of the CERCCS project. Section 1 provides background information on Australia's coastal zone: Chapter 2 provides a review of physical processes shaping Australian coastal landforms and ecosystems, including atmospheric, hydrologic and hydrodynamic processes while Chapter 3 summarises information concerning the distribution, ecological structure and function, ecosystem services, non-climatic threats and approaches to management of key coastal ecosystems of Australia within four realms: marine, estuarine, terrestrial interface and freshwater.

Section 2 examines climate change and its potential impacts for selected Australian coastal ecosystems. Climate change projections for the Australian coastal zone are presented in Chapter 4. Observed and predicted ecological impacts of climate change within key coastal ecosystems of Australia are discussed in Chapter 5.

Section 3 explores adaptation pathways, including autonomous ecological adaptation pathways and managed human adaptation pathways, reviewed in Chapter 6. Practical on-ground approaches to managed adaptation are presented in this chapter along with a review of existing strategies of relevance to climate change adaptation for Australian coastal ecosystems. Chapter 7 provides a summary of the key findings of three case studies conducted during this project (i.e. Kakadu National Park, the Hunter River estuary and the Cairns region).

Finally, Section 4 presents a synthesis of the preceding sections. Chapter 8 discusses knowledge gaps and priorities for future research while Chapter 9 presents key communication and education messages. Chapter 10 presents a summary of the key findings of this project and presents major recommendations for policy and management as well as future research.

SECTION 1. BACKGROUND

2. AUSTRALIAN COASTAL PROCESSES

Coastal landforms are shaped by a wide range of geological, atmospheric, terrestrial and marine processes which have a significant influence on the structure and function of coastal ecosystems. The Australian coast is exposed to a broad spectrum of climates, from temperate to tropical, and consequently atmospheric, marine and hydrologic processes vary around the coastline. This chapter provides an overview of the key physical processes in the coastal zone and their general influence on Australian coastal landforms and ecosystems with major regional variations noted where relevant.

2.1. Sea level variation

Following the end of the last glacial period, about 18 000 years ago, sea level was around 150 m below current mean levels and the Australian mainland was connected to Tasmania and Papua New Guinea as one continent (Douglas et al. 2000, Short and Woodroffe 2009). As temperatures increased, ice melted and sea level rose rapidly to reach present levels about 5 000 years ago. Such changes in sea level have occurred repeatedly in the past in association with climatic variability and those which have occurred over the past few million years have exerted a major influence on the evolution of the Australian coastline (Douglas 2000, Woodroffe 2001, Short and Woodroffe 2009).

Sea level variation in the short-term is strongly associated with coastal processes such as tides, winds, waves and storm surges and depends on atmospheric and marine processes. Local changes in coastal sea level therefore tend to be more variable in comparison with variation in global sea level (Church et al. 2006). Furthermore, long-term coastal sea level changes are also related to coastal landforms and tectonic activities (i.e. land uplift and subsidence). The Australian coast, however, has been tectonically stable for the past 5 000 years and changes in coastal geomorphology have mostly been due to atmospheric and marine processes. The long stretches of sandy coastline in Australia are a result of this tectonic stability and a relatively low energy coastal environment.

2.2. Atmospheric processes

Atmospheric processes influence the coastal zone both directly and through their interaction with terrestrial and marine processes including river hydrology, waves and ocean currents.

2.2.1. Air temperature

Air temperatures across Australia vary in relation to latitude, proximity to the coast and elevation (Short and Woodroffe 2009) with a general trend for lower temperatures towards the poles and higher temperatures in the tropics. Air temperatures are also moderated along the coast, particularly in the east, where cooler humid easterlies move landward from the sea reducing coastal temperatures by several degrees (Short and Woodroffe 2009).

2.2.2. Rainfall

Rainfall is highly variable over the Australian continent, both spatially and temporally. Strong north-south and east-west rainfall gradients are present with higher rainfall occurring in the north and east of the continent and lower rainfall in the south and west. In the north of the continent, rainfall is typically associated with northwest monsoons and southeast trade winds during summer while westerlies bring cold fronts and associated rain to the south during winter. Occasional tropical cyclones also bring torrential rain to the northern coastline, especially in the Northern Territory and Queensland. Rainfall varies over longer time scales as well due to climatic patterns such as El Niño and La Niña as well as other climatic fluctuations, e.g. the Southern Annual Mode (SAM; CSIRO-BOM 2007, Hendon et al. 2007, Ladson 2008, Shi et al. 2010). Rainfall tends to be high during La Niña phases and lower during El Niño events as air in the western Pacific Ocean is covered with high pressure (i.e. dry air).

2.2.3. Wind

Winds are one of the most important influences on coastal processes and landforms, both directly and indirectly through their role in generating waves and currents. Simply put, winds are the result of horizontal differences in air pressure. The distribution of air pressure systems, along with the Coriolis effect (a result of the Earth's rotation), create major wind patterns over Australia including polar easterlies, strong westerly winds associated with sub-polar lows and trade winds that blow between the subtropical high and equatorial low which produce winds blowing from the south-east (Short and Woodroffe 2009).

Winds are highly variable in the coastal zone due to the frictional and topographical influences of coastal landforms (Laughlin 1997, Struyman and Tapper 2006). As well as major regional wind patterns, coastal areas are subject to sea breezes (i.e. onshore winds that blow inland from the ocean) and land breezes (i.e. offshore winds that blow from the land) which result from pressure differences between the land and ocean related to temperature variation. In general, sea breezes occur at night, when sea temperatures are higher than land temperatures, while land breezes occur during the day (Abbs and Physick 1992).

2.2.4. Tropical and mid-latitude cyclones

Tropical cyclones are very intensive low pressure systems that originate over the tropical ocean in the ITCZ (Inter Tropical Convergence Zone) in response to warm sea surface temperatures (> 27°C), atmospheric instability, high humidity in the low to mid-troposphere, a pre-existing low level disturbance and low vertical wind shear (NOAA 2011). Tropical cyclones are typically accompanied by very gale force winds, high storm surges, high surface waves and heavy rainfall, all of which may have significant impacts on coastal ecosystems. Cyclones are fuelled by warm water so tend to lose energy and disintegrate quickly upon landfall.

Mid-latitude (or frontal) cyclones are low pressure systems of up to 2 000 km diameter and much less intensity than their tropical counterparts. An intense low pressure system, the 'East Coast lows', develops several times a year during Autumn and Winter off the east coast of Australia and may be associated with gale winds, heavy rainfall and high waves along coasts of south-east Queensland, New South Wales and eastern Victoria. Mid-latitude cyclones that propagate from the west at around 30°S can also influence the southern coast of Australia and a further low pressure system also develops over south-eastern Australia, influencing rainfall in Victoria (Sturman and Tapper 2006).

2.3. Hydrological processes

Hydrology is a critical component of coastal ecosystems, all of which are influenced to some degree by the provision of fresh water. Hydrology in Australia is highly variable compared with other continents and is characterised by cycles of drought and occasional heavy rains and flooding (Ladson 2008). Average annual rainfall on the Australian mainland is approximately 456 mm with about 9% of this discharged from rivers to the ocean (Ladson 2008).

2.3.1. Flooding

Most floods in Australia are caused by heavy rainfall and associated failure of dams, operation of dams, stream blockages and interaction with high flows, tides, storm surges and tsunamis (Ladson 2008). In coastal areas, storm surges and spring tides are particularly important as extreme sea level changes can exacerbate floods (Watson and Frazer 2009). Floods have a wide range of impacts on coastal ecosystems, including delivery of pollutants and excess nutrients from upland areas (e.g. Rabarais et al. 2002), and severe floods pose a disturbance that can wipe out coastal habitats. Floods are also associated with many ecological benefits, however, including the provision of triggers for breeding amongst waterbirds and opportunities for seedling recruitment amongst plants (Ladson 2008). Floods also recharge groundwater.

2.3.2. Groundwater

Groundwater is that water held in saturated soils below the water table and provides a vital water source for coastal ecosystems and their vegetation in particular (Ladson 2008). In Australia, groundwater occurs primarily in the east of the continent but is also significant along the south-west coast and in parts of the north and north-west.

2.4. Hydrodynamic processes

Coastal dynamics of waves, currents, tides and sediment transport are driven by several physical forces, including winds, the Earth's rotation (i.e. the Coriolis force), gravity due to the Moon and Sun, and water density.

2.4.1. Waves

In most coastal ecosystems, the main source of energy comes from surface waves of the ocean. Waves are a periodic vertical movement of water due primarily to gravity generated by the action of wind over water, but also due to movement of boats and ships (Dean and Darlymple 1984, Hothuijsen 2007). Two forms of waves are generated by winds: swell and seas (Woodroffe 2001). Seas are waves that are still being generated by blowing wind while swell refers to waves that have left the area of wave generation and are travelling under their own energy, i.e. gravity (Holthuijsen 2007). Wave height depends on wind speed, wind duration, fetch and ocean currents (Laughlin 1997). The highest waves are generated by strong winds which blow in a constant direction over a long distance (i.e. fetch) for a long duration in deep oceans (Short and Woodroffe 2009). In Australia, high waves occur off the southern coast as a result of strong winds, long fetches and duration. In contrast, waves are generally low in northern Australia except during passages of tropical cyclones.

When waves approach a coastline, they 'feel' the bottom and change direction (i.e. refraction), tending to be parallel to the coastline by the time they reach it. When they reach the surf zone, waves cannot retain a linear shape and increase in height to conserve energy despite bottom friction, eventually breaking. Breaking waves have several forms, i.e. collapsing, spilling, plunging and surging, and collectively form a current that moves parallel to the coastline, called the 'longshore current', which is very influential in coastal sediment transport (Woodroffe 2001). Infragravity waves, with a period of 20 to 200 seconds, are another important wave type in the surf zone that cause significant variations in water level and are associated with the generation of rips, crecentic bars and other longshore bars (Aagaard and Masseline 1999, Woodroffe 2001).

Waves can also occur underwater as a result of differences in water density (e.g. a thermocline). These 'internal waves' typically occur in response to a disturbance, e.g. strong wind blowing over the sea surface, and can significantly influence marine coastal environments.

2.4.2. Tides

Tides, i.e. the vertical movement of water level caused mainly by the gravity of the Moon and Sun, are the second major source of marine energy shaping coastal landforms (Woodroffe 2011). This vertical movement of water level causes horizontal currents, or tidal currents, which are mostly uniform from the bottom to the surface over most of Australia's continental shelves due to the long wave length of tides. Tide ranges, however, exhibit a north-south trend in Australia with a higher tidal range in the north. In north-western Australia, the tidal range can reach 10 m in some places while tidal ranges of around 2-3 m are common in the south-west, south and south-east (Laughlin 1997). Coastal tides are influenced by topography, particularly in estuaries and bays (Dyer 1997).

Tides play an important role in the coastal zone by influencing material transport, e.g. sediments and nutrients, particularly where tidal range is high, i.e. north-west Australia, as well as in estuaries. Tides also affect salt water intrusion and mixing in brackish water, with implications for estuarine ecosystem function (Dyer 1997).

2.4.3. Ocean currents

Ocean currents are generated primarily by winds and gravitational forces of the Moon and Sun but are also influenced by the Earth's rotation, coastal landforms and topography (Allen et al. 1983, Nittrouer and Wright 1994, Wolanski 1994, Laughlin 1997, Short 1999, Woodroffe 2001, Dean 2004). Global wind patterns generate persistent ocean circulation over the Pacific, Atlantic and Indian Oceans (Pinet 2006, Sturman and Tapper 2006) and the East Australian Current, which flows from the Coral Sea toward the South Pole off Australia's east coast, is a part of the circulation of the south Pacific (Pinet 2006). The Leeuwin Current is part of the circulation of the Indian Ocean.

Current patterns become quite complicated in shallow coastal waters due to bottom friction and complex coastal bathymetry. When winds blow near the coast parallel to the land on the right side in the southern hemisphere, surface water is pushed offshore due to the Coriolis force creating an onshore bottom current that compensates for the offshore flow, i.e. the Ekman Current. This is called 'upwelling'. 'Downwelling', i.e. offshore bottom flow, is caused by winds blowing in the opposite direction. Upwelling and downwelling are common near coasts where winds blow parallel to nutrient-rich water from the bottom to the surface (Schahinger 1987, Nittrouer and Wright 1994, Roughan and Middleton 2002, Condie and Harris 2006, Mann and Lazier 2006). Downwelling is particularly important in lowland coastal areas as water piles up towards the land and can contribute to flooding. Other significant coastal currents include longshore currents and tidal currents (see above) as well as rip current, an offshore current which occurs as a result of interactions between waves breaking in the surf zone and beach morphology. Currents in the surf and swash zones are highly influential on beach morphology and ecology (Short 1999, Woodroffe 2001).

2.4.4. Ocean temperature

Oceans cover approximately 71% of the Earth's surface and therefore absorb much of the solar radiation reaching the planet. Most of this heat is received by oceans in the tropics and this is then transported toward higher latitudes via atmospheric and ocean circulations with ocean boundary currents transporting heat to polar regions (Sturman and Tapper 2006). Ocean temperature regulates the function of coastal ecosystems by influencing photosynthesis, respiration, growth, reproduction, metabolism and mobility of marine organisms (OzEstuaries 2003) as well as influencing coastal processes such as tropical storms, internal waves and some currents (Tomlinson and Cox 1993, Mann and Lazier 2006).

2.4.5. Storm surges

A storm surge is a rise in sea surface above normal water level as a result of strong winds blowing toward land and/or reduced atmospheric pressure. Storm surges accompany low pressure systems (e.g. tropical and mid-latitude cyclones) and their height is influenced by local topography, coastline angle, and the size and track of the cyclones, tending to be highest on the side of onshore wind and the side consistent with the forward direction of the cyclone (Laughlin 1997). When a cyclone approaches northeast Queensland from the north-east, for example, storm surge is highest on the southern side because the maximum onshore gale wind blows on the south side of the storm's eye, which is also consistent with the direction of the cyclone movement. Storm surge also tends to be higher on wide shallow continental shelves.

Since tropical cyclones are generally accompanied by extremely high waves, gale winds and heavy rains as well as surges, sea surface levels can become higher than the storm surge itself, particularly when a storm approach is consistent with high or spring tides. The combination of storm surge and tide is called storm tide and can result in significant coastal inundation (Abbs 2008).

2.4.6. Sediment dynamics

Coastal habitats are characterised to a large degree by the sediments which comprise their landforms. Carbonate sediments, which are marine in origin, occur along the west coast of Australia where there is little sediment input from rivers. In contrast, Australia's eastern and northern coastlines are dominated by fine-grained terrestrial sediments, e.g. quartz sand, delivered via rivers to estuaries and coasts (McLachlan and Brown 2006, Sturman and Tapper 200, Short and Woodroffe 2009). Muddy sediments, i.e. silt and clay) commonly occur in the southern Great Barrier Reef, Gulf of Carpentaria, south-eastern Australia and Bass Strait (Condie and Harris 2006, Short and Woodroffe 2009).

Coastal landforms are shaped by the accretion (deposition) and erosion of sediments via various marine and fluvial processes, particularly sediment transport processes driven by near-shore waves and currents (Komar 1997, Short 1999, Woodroffe 2001). Sediment transport usually happens in shallow water (i.e. the surf zone, inner shelf etc.) when waves and currents 'feel' the bottom and disturb sediments, initially by traction then by siltation and eventually as suspended load (Bagnold 1940, Komar 1997, Short 1999, Woodroffe 2001, Masselink and Hughes 2003, Dean 2004). The degree to which sediments are suspended depends on the energy of a force near the bottom and therefore tends to be particularly significant in the surf zone and during storms in coastal areas (Nielsen 1992, Short 1999, Masselink and Hughes 2003).

Longshore transport, controlled by near-shore waves, prevails along most Australian coasts though cross-shore transport can also occur around the continent (Chapman 1980, Tomlinson and Cos 1993, Short and Woodroffe 2009). On the east coast, the trade wind prevails most of the year and therefore the direction of waves and the transport of sediments, supplemented by river sediments, is from south to north (Short 2010). For the west coast, south-westerly winds prevail and sediment transport is also northward (Short 2010). There are a few regimes where large volumes of transported sediments are deposited, i.e. 'sinks', including south-east Queensland near Fraser Island, the Murravian Gulf, Zuytdopr Cliffs and the Torres Strait tidal delta (Short and Woodroffe 2009).

2.5. Summary

Australian coastal landforms and ecosystems are strongly influenced by sea level variation, atmospheric, hydrologic and hydrodynamic (mostly marine) processes. Winds, waves and tides represent the major forms of energy in most coastal ecosystems and the influence of these on sediment dynamics plays a particularly important role in shaping coastal landforms. There are considerable regional differences in coastal processes around Australia including a strong north-south temperature gradient, north-south and east-west rainfall gradients (which include magnitude and seasonality), higher waves along the southern coastline and higher tidal ranges along the northern coastline. Dominant coastal sediments also vary around Australia with marine carbonate sediments occurring in the west and fine-grained and muddy terrestrial sediments occurring in the east and north.

3. AUSTRALIAN COASTAL ECOSYSTEMS

This chapter provides an overview of the ecological structure and function of major Australian coastal ecosystems. For the purposes of this project, coastal environments have been separated into four realms – a) marine, b) estuarine, c) terrestrial interface, and d) freshwater. The following section presents the key values, non-climatic stressors and existing approaches to management of each of these coastal realms.

3.1. Marine coastal ecosystems

The two distinct ecosystems considered here are tropical coral reefs and macroalgal forests.

3.1.1. Coral reefs

Distribution and extent

Coral reefs occur throughout shallow tropical habitats of northern Australia and occupy virtually all areas with hard substrates and low sediment and nutrient concentrations. Fringing reefs along the coast are discontinuous but can be well developed as in the case for Ningaloo Reef which extends 230 km in length (Spalding et al. 2001).

Physical and chemical processes

Coral reefs form under conditions of warm water (> 18°C), stable full salinity, high aragonite sea water saturation, high light intensity and low dissolved nutrient concentrations (McClanahan et al. 2008). Coral reefs also develop where wave energy is high and are better developed on exposed, windward shores than sheltered, leeward shores. Reefs favour clear waters, where light can penetrate deeply, and require a suitable substrate on which to develop, often reoccupying former reef positions (Short and Woodroffe 2009). Sea level therefore has a critical influence on the development of reefs by determining the area available for coral to colonise (McClanahan et al. 2008).

Water temperature is a particularly significant determinant of reef condition and coral reefs are highly sensitive to temperature with small increases in sea surface temperature of around 1-2°C having the potential to lead to substantial reef damage via coral bleaching and mass mortality (Poloczanska et al. 2009). Declines in the condition of coral reefs may also result from high levels of sediments, nutrients and pollutants delivered by terrestrial runoff during floods (Furnas 2003, Johnson and Marshall 2007).

Ecology

Coral reefs ecosystems are renowned for their high biodiversity (Connell 1978) and comprise geomorphologic structures constructed through the accretion of calcium carbonate by reef-building corals, as well as coralline algae and many other organisms that are associated with these habitats, e.g. fish (Spalding et al. 2001, Hopley 2009). Corals, especially reef-building scleractinian corals, are fundamental to the ecological functioning of these ecosystems and contribute to primary production, nutrient recycling and reef growth (Hoegh-Guldberg 2004, Wild et al. 2004) as well as providing a range of habitats which support an exceptional diversity of reef animals (Connell et al. 1997). Coral cover, for instance, influences the presence of specialist fishes that rely on corals for food or shelter (Williams 1986, Syms 1998, Pratchett et al. 2006) while the habitat complexity of reefs is an important determinant of fish diversity (Lindah et al. 2001, Gratwicke and Speight 2005, Graham et al. 2006).

Ecosystem services and values

Coral reef ecosystems provide social and economic benefits of considerable significance in Australia. Tourism and commercial fishing are amongst the most significant uses of coral reefs by people, in terms of income and employment generated (Wachenfeld et al. 2007). Coral reefs can also have substantial non-use values associated with maintaining their 'near-pristine' status, e.g. in the Great Barrier Reef (Oxford Economics 2009).

Non-climatic pressures

Current non-climatic pressures on coral reefs in Australia include exposure to high sediment loads, excess nutrients and pollutants via flood plumes, the levels of which are linked to catchment management practices, e.g. agriculture (McCulloch et al. 2003, Daley et al. 2008). Large-scale outbreaks of the invasive crown-of-thorns starfish, *Acanthaster planci*, are also closely associated with declines in reef condition and cover (Osborne et al. 2011, Pratchett et al. 2011). Coral loss may also occur as a result of coral diseases, e.g. white syndrome, black-band and brown-band diseases.

Management

Management of coral reef ecosystems in Australia has tended to move away from traditional fisheries management, focused on maintaining populations of target species, toward more integrated strategies that aim to maintain ecosystem function and maximise ecological resilience (e.g. Marshall and Schuttenberg 2006). Targeted management of specific threats at local and regional scales is also increasingly important (Bryant et al. 1998, Osborne et al. 2011). Protecting areas of representative habitats remains an important spatial approach to conservation (Margules et al. 2002, Fernandes et al. 2005) in addition to conventional non-spatial management approaches, e.g. regulation of species harvests and quarantine arrangements to limit species invasions.

3.1.2. Macroalgal forests

Distribution and extent

Dense macroalgal forests are a defining feature along much of Australia's southern coastline where sloping rocks, up to 25 m deep, provide ideal habitat for large canopy-forming macroalgae from the orders Laminariales (kelp) and Fucales (littoral seaweeds) (Connell 2007). The greatest diversity of giant kelps occurs in cool and relatively nutrient-rich southern waters. Macroalgal forests cover around 80-90% of Coral systems shallow subtidal habitats along the temperate Western Australian and South Australian coastlines (Connell 2007) which are amongst the world's most pristine temperate coasts (Wernberg et al. 2009). Brown algae, or kelps, are probably the most widely recognised macroalgae in Australia but are limited to Tasmania and particular areas in the south-east and south-west of Australia (DCC 2009). In south-eastern Australia, however, increasing urbanisation of major population centres is increasingly linked with the replacement of macroalgal forests by urchin barrens, devoid of large macroalgae and dominated by small encrusting coralline algae (Connell et al. 2008).

The cover and composition of macroalgal forests vary considerably across Australia's temperate marine habitats (Connell 2007). Kelp, for instance, especially giant kelp (*Macrocystis* spp.), tends to be limited to mid-latitudes of 40-60° (Steneck et al. 2002). Macroalgal forests in Western Australia typically comprise dense forests of short, flexible plants (e.g. *Eklonia radiata*). In contrast, eastern Australian macroalgal forests tend to have taller, more rigid plants (e.g. *Macrocystis pyrifera*). The composition and structure of biological communities inhabiting the understoreys of these macroalgal forests vary as a result of these differences in habitat structure (Connell 2006).

Physical and chemical processes

Macroalgae occur wherever persistent hard substrates receive sufficient light (DCC 2009) and their distributions are strongly controlled by ocean temperature (Werberg et al. 2009). Marine algae with ranges centred in temperate Australia are mostly cold-water specialists and cannot survive in warmer waters (Werberg et al. 2009). Other important factors influencing the growth of macroalgae include water quality (nutrients and turbidity), light penetration, wave action and topography (DCC 2009). Light is particularly important since this controls photosynthesis amongst macroalgae. Increased turbidity due to high river discharge or sediment suspension can therefore negatively affect macroalgal forest habitats. Additionally, high wave energy can scour substrates and further increase turbidity (Hemer et al. 2008).

Ecology

Australia's temperate marine flora is highly diverse with many unique, endemic species (e.g. Kerswell 2006). Canopy-forming macroalgae comprise the key habitat-forming species of Australia's temperate rocky reefs and their physical structure provides a three dimensional habitat that supports high diversity of fish and invertebrates as well as mammals (Mann 1973). Light is reduced under dense macroalgal canopies, providing important habitat to species adapted to low light intensity and inhibiting the growth of understorey algae which could otherwise limit recruitment of larger, slow-growing macroalgae (Steneck et al. 2002).

Macroalgal forests contribute greatly to coastal productivity, magnifying secondary production and thereby supporting complex coastal food webs. Macroalgal canopies also dampen waves and therefore influence coastal hydrodynamics, sediment dynamics, benthic productivity and recruitment (Duggins et al. 1990).

Ecosystem services and values

Macroalgal forests are critical to the productivity and biodiversity of temperate marine habitats, contributing directly to primary production and increasing habitat and topographic complexity (Steneck et al. 2002). Macroalgal forests therefore support many temperate fish species and the extensive recreational and commercial fishing industries that rely on these (Booth et al. 2008). Abalone (*Haliotis rubra*) and rock lobster fisheries, worth over $150 million per annum, are also dependent on intact macroalgal forests (Connell 2007).

Non-climatic pressures

Losses of macroalgal forests globally are attributed to increased disease, herbivory, physiological stress and interactions amongst these (Steneck et al. 2002). At lower latitudes, rising nutrients and salinity are amongst the non-climatic factors that may result in deforestations or disease while herbivory by sea urchins is the most significant agent of deforestation at higher latitudes (40-60°) (Steneck et al. 2002). In Australia, declines in the resilience and cover of giant kelp are strongly associated with reduced water quality, as well as altered herbivore abundance (Wernberg et al. 2010).

Management

Reducing the extent of urchin infestations is a key objective for the management of temperature rocky reefs and is approached using marine protected areas and reducing harvesting of specific predators such as lobsters (Guidetti 2006). Effective urchin control is expected to have significant ecological benefits, particularly along Tasmania's east coast. Targeted management of localised sources of pollutants as well as broad scale catchment management to reduce sediment and nutrient loads are the key management approaches to declining water quality linked to loss of macroalgal forests.

3.1.3. Connectivity

Coral reefs only account for a small proportion of coastal waters (e.g. 7% of GBRMP) and therefore do not exist in isolation. Tidal wetlands, including mangroves and saltmarsh, intercept land-based nitrates and therefore protect marine coastal habitats from excessive eutrophication (Valiela et al. 2009). These intertidal habitats similarly retain many industrial contaminants (e.g. heavy metals) which would otherwise affect marine coastal ecosystems (Twilley 1995). Tidal habitats are fundamental to sustaining coastal fisheries by providing nursery, feeding and shelter areas (Laegdsgaard and Johnson 1995). In turn, macroalgal forests and coral reefs influence tidal ecosystems by supporting high primary productivity and influencing sedimentation and recruitment as well as coastal erosion through their effects on waves and currents (Duggins et al. 1990)

3.2. Estuarine coastal ecosystems

Estuaries are semi-enclosed coastal aquatic ecosystems situated at the interface of the freshwater, marine and terrestrial realms. Because of their location, estuaries are spatially and temporally dynamic and highly productive ecosystems, with a wide variety of critical habitats and species. Seven broad classes of Australian estuaries are recognised by OzCoasts (www.ozcoasts.org.au) on the basis of geomorphological differences and the significance of wave, river and tide energy in determining estuary structure and function. Here, coastal lagoons and strandplains are considered together since they share many similar characteristics.

3.2.1. Wave dominated estuaries

Distribution and extent

Wave dominated estuaries occur mainly along exposed coastlines with limited tidal influence in south-eastern and south-western Australia. 'Positive' wave dominated estuaries occur in high rainfall areas, where freshwater flows exceed marine inflows, while arid areas tend to have 'negative' wave dominated estuaries where the reverse occurs.

Physical and chemical processes

Wave dominated estuaries form when coastal embayments, often flanked by bedrock, become enclosed by sediments of both marine and catchment origin. Sand barriers at the mouth periodically open and close the entrance, enclosing a central basin that resembles the underlying topography. Tidal flushing is restricted by the narrow entrance but high river discharges may periodically flush sediments and marine water. Wave and tidal energy are high at the entrance, and river energy at the fluvial delta, but all three forms of energy are low in the mid-estuary (Bazairi et al. 2003). In positive wave dominated estuaries, river flows and wave energy are important and, given sufficient energy, water in the central basin may be well mixed. If river and wave energy are low, however, due to a large water volume, a gradient from fresh to marine water may occur. In negative wave dominated estuaries, low freshwater flows typically prevent similar stratification, except during floods, and evaporation is significant, often driving the development of hypersaline water in the central basin. Wind and, to a lesser extent, tides, may drive internal circulation of water in the central basin in both types of wave dominated estuary, interrupted periodically by high river flows.

Catchment derived sediments tend to be deposited and retained in wave dominated estuaries rather than being exported to marine habitats. Coarse sediments (e.g. sand and gravel) are deposited on the fluvial delta and, during flood events, in fringing habitats, e.g. mangroves, while finer materials (e.g. clay and silt) are deposited in the central basin. Wave action resuspends fine sediments and can increase turbidity. During storm surges, marine sediments may also be deposited on the barrier, closing the entrance, and finer sediments transported into the central basin via wind or hydrological processes.

Nutrients in wave dominated estuaries derive mainly form catchment sources although atmospheric nitrogen (e.g. ash) may also be important, particularly in negative systems.

Ecology

Estuaries are amongst the world's most productive natural ecosystems (McLusky 1981) and have high abundances of resident biota, typically orders of magnitude greater than those of marine or freshwater environments. Due to this high productivity, estuaries are important nursery grounds for juvenile fish and crustaceans (Condie et al. 1999, Baker and Sheaves 2009). Estuaries comprise a diverse range of habitats, including mangroves, saltmarsh, seagrass beds and tidal flats, and this habitat diversity enhances the capacity of estuaries to support large numbers of juvenile fish by supplying food and habitat in which to avoid predators (Loneragan et al. 1997, Valesini et al. 1997, Adam et al. 2002).

Life in wave dominated estuaries is strongly influenced by the status of estuary entrances (Roy et al. 2001). When entrances are open and there are high levels of surface water connectivity with marine habitats, wave dominated estuaries support life across many habitats including mangroves, saltmarsh, seagrass and tidal flats, although the extent of tidal habitats (i.e. mangroves, saltmarsh and tidal flats) is typically lower than in tide dominated systems due to lower tidal ranges. Seagrass and macroalgal communities are supported at estuary entrances where high wave energy ensures clear water and sub-tidal sandy substrates. When entrances are closed, habitat distributions can be significantly altered and the absence of marine flushing can lead to loss of mangrove, saltmarsh and seagrass habitats. With long periods of closure, wave dominated estuaries may support more freshwater habitats and species, e.g. frogs (Hadwen and Arthington 2007).

3.2.2. Wave dominated deltas

Distribution and extent

Wave dominated deltas are most common in north-eastern, south-eastern and south-western Australia although, on a global scale, there are relatively few of this estuary type in Australia because catchment-derived sediment supply is comparatively low.

Physical and chemical processes

Wave dominated deltas form when rivers connect directly with the sea via one or more channels meandering through lowland floodplains and associated wetlands. These are mature systems that succeed wave dominated estuaries when a central basin is completely in-filled by sediment and are shaped by physical energy rather than the underlying topography. Entrances may be flanked by sand bars but rarely close because strong river flows ensure flushing of sediments. Physical energy is high throughout these estuaries but particularly at the entrance due to waves. River energy dominates these estuaries' interiors. Consequently, freshwater flows have an important influence on water chemistry, connectivity and sediment dynamics in these systems and flooding of low-lying floodplains and salt flats is especially significant. Sediments and nutrients are catchment derived in these systems but tend to be rapidly exported to marine habitats rather than retained.

Ecology

As in wave dominated estuaries, the presence, distribution and productivity of intertidal and subtidal habitats within wave dominated deltas is strongly determined by whether or not estuary entrances are open or closed (see above).

3.2.3. Coastal lagoons and strandplain creeks

Distribution and extent

Coastal lagoons and strandplain creeks occur most commonly in south-eastern and south-western Australia as well as in the Gulf of Carpentaria along wave-dominated coastlines.

Physical and chemical processes

Coastal lagoons are small basins with small catchment areas and almost no fluvial inputs but varying marine inputs. Otherwise morphologically similar to wave dominated estuaries, coastal lagoons lack fluvial delta heads and have significantly lower habitat diversity. Strandplain creeks are narrow, shallow systems that form between beach ridges and dune systems parallel to wave-dominated coastlines and have limited water inputs from either fluvial or marine sources. Both of these estuary types have low levels of river, wave and tidal energy throughout and sediments therefore accumulate at entrances which can close for long periods or, in the case of some strandplain creeks, permanently.

Due to their low hydrologic and sediment inputs, these estuaries may have high salinity due to frequency wash of marine water and percolation of seawater at high tide (Roy et al. 2001). Freshwater inputs may be limited to floods and groundwater can also be significant. Some water circulation may be facilitated by wind. With respect to nutrients, catchment sources are only important during flood events and groundwater and atmospheric sources may be more significant in some regions. As closed systems, these estuaries are vulnerable to eutrophication.

Ecology

Coastal lagoons and strandplain creeks can support species with strong freshwater affinities during long periods of lost connectivity with the ocean. Following entrance opening events, however, freshwater biota is quickly replaced by marine and brackish species (Hadwen et al. 2007, Hadwen and Arthington 2007). Submerged habitats in these estuaries are usually dominated by macroalgae with seagrasses occurring in some systems. Mangroves and saltmarsh may also be present but are usually limited and can be completely absent following long periods of entrance closure.

3.2.4. Tide dominated estuaries

Distribution and extent

Tide dominated estuaries are typical in northern Australia where tidal ranges are large. As for wave dominated estuaries, ‘positive’ and ‘negative’ tide dominated estuaries occur in high rainfall areas and arid zones respectively.

Physical and chemical processes

Tide dominated estuaries form along low-gradient coastlines where bedrock embayments become partly in-filled with both catchment and marine sediments. Tidal sandbanks and sub-tidal channels form near entrances while fluvial deltas are poorly developed. Tide energy is high throughout these estuaries while river energy is high only in the very upper estuary. These systems often have wide, unconstricted entrances with high rates of marine water exchange. Catchment derived sediments tend to be deposited where river flows and tidal currents meet and are generally retained in inter-tidal flats and fringing mangroves. Tidal currents often cause the resuspension of sediments leading to high turbidity. Variable nutrient loads derive from catchment sources and atmospheric nitrogen may also be important in negative systems. Tidal flushing exports moderate amounts of nutrients to marine habitats.

Ecology

Tide dominated estuaries (and deltas) are generally the most complex and ecologically diverse estuary types. Conditions in these estuaries favour the colonisation and maintenance of extensive areas of mangroves (depending on latitude), saltmarsh and tidal flat communities. Large seagrass beds are also typically found close to estuary entrances but can be present throughout.

3.2.5. Tide dominated deltas

Distribution and extent

Tide dominated deltas are relatively restricted in Australia and are most common in north-eastern Australia. These estuaries are relatively rare in Australia, largely due to the continent's aridity and low relief.

Physical and chemical processes

Tide dominated deltas form when a river connects directly to the sea via one or more funnel-shaped distributary channels which may be widely spaced throughout coastal floodplains and wetlands. As geomorphically mature systems, the shape of these channels is determined by the balance of river, wave and tide energy rather than the underlying topography. Entrances tend to be wide with tidal sand bars and adjacent deep channels with strong tidal currents. These sand bars dissipate wave energy at the entrance and physical energy tends to lowest here and highest in the mid-estuary where tidal energy dominates. River energy is high in the upper estuary. The dominance of tidal and river energy in these systems results in high turbidity and high levels of exchange and mixing of marine and fresh water. Depending on river flows, stratification may occur. Evaporation can be important in inter-tidal areas. Whilst considerable processing of water, sediments and nutrients occurs in tide dominated deltas, these tend to be rapidly exported to marine habitats.

Ecology

As for tide dominated estuaries, tide dominated deltas tend to be highly diverse and complex ecologically, supporting extensive areas of mangroves, salt marsh, tidal flats and seagrass (see above).

3.2.6. Tidal flat and tidal creek

Distribution and extent

This is the most common estuary type in Australia and is particularly widespread in north-western Australian and the Gulf of Carpentaria along macro-tidal, low-gradient coastal plains.

Physical and chemical processes

Tidal creeks are waterways with wide and open marine entrances and channels that taper relatively short distances landward through tidal flats and mangrove forests. These channels can form reticulated, interconnected networks but do not have tidal sand bars or deep channels characteristic of other tide dominated estuaries. Freshwater inputs are virtually absent and marine water is contained within channels, inundating adjacent mudflats during spring tides. These systems are dominated by high levels of tidal energy and, except in monsoonal regions of northern Australia, river and wave energy are low to absent. Large open entrances promote tidal flushing of marine water and export of fine sediments to sea. Since water within these estuaries can be relatively turbulent, turbidity is often high with no stratification of salinity. Salt crusts often form on adjacent salt flats since inundation is infrequent and groundwater may become hypersaline. Evaporation is therefore significant, particularly in large systems.

Catchment derived sediments and nutrients are limited in tidal flats and creeks, with fine material only delivered by sheet runoff during rain events and coarser material during extreme storms. Marine sediments and nutrients dominate and are deposited in inter-tidal habitats, although strong tidal energy leads to erosion of finer sediments in sub-tidal habitats.

Ecology

Given their generally small size, tidal creeks do not tend to support large areas of mangrove, saltmarsh, seagrass or tidal flat habitats. In areas where multiple tidal creeks exist, however, very large and highly connected mangrove and saltmarsh areas can form, supporting a wide range of estuarine and terrestrial life. Seagrasses are uncommon in sub-tidal habitats of tidal creeks due to high turbidity and high canopy cover limited light in benthic habitats.

3.2.7. Ecosystem services and values

Estuarine ecosystems of all types provide significant ecological, cultural and socioeconomic benefits to human society. Maintenance of fish stocks and buffering of coastal habitats from storm surges, for instance, are ecosystem services provided by estuaries that are worth many millions of dollars annually (e.g. Steffen et al. 2009). Other services include provision of navigation and shipping, erosion and water quality control, recreation and tourism, spiritual and aesthetic values, soil formation and nutrient and water cycling (Millennium Ecosystem Assessment 2005, Steffen et al 2006, Wallace 2007).

3.2.8. Non-climatic pressures

Estuaries are vulnerable to a wide range of non-climatic threats with human activities in terrestrial, freshwater and marine realms having flow-on effects into estuaries (Cardosos et al. 2008). The main non-climatic threats to Australian estuaries include: hydrological impacts (including dredging and modification of channels and entrances), land use change and associated sediment and nutrient impacts, pollution, invasive species, tourism and extractive industries, e.g. fishing.

3.2.9. Management

Traditionally, management of estuaries has revolved around protection from overfishing, maintenance of habitats and estuarine function and engineered solutions to manage entrances with key management approaches including: protection of nursery grounds, habitat restoration and land reclamation, maintenance of ports and harbours (including engineering works to maintain entrances) and environmental monitoring of water quality and other ecological indicators. Recently, a more holistic approach has been promoted which incorporates consideration of catchment and freshwater influences on estuarine ecology (Abal et al. 2001, Bunn et al. 2007).

3.2.10. Connectivity

Connectivity is important both within and between estuaries as well as between estuaries and ecosystems within freshwater, marine and terrestrial realms. Connectivity can be longitudinal, lateral or vertical. Longitudinal connectivity includes the transfer of materials from rivers to estuaries and then to the sea (or vice versa) and is therefore influenced, in estuaries, by tide, wave and river energy as well as human modifications to flow regimes or estuary entrances. Longitudinal connectivity in estuaries can be important for sediment and nutrient movement and processing as well as the passive or active movement of biota.

Lateral connectivity is also very important and refers to the transfer of material from the main stem of the estuary into adjacent fringing habitats (and vice versa). In estuaries, lateral sediment movements can influence the survival and recruitment of mangrove and salt marsh species. Lateral connectivity also influences movement of mobile species into foraging areas (Grant 2002). The estuarine crocodile (*Crocodylus porosus*) for instance, nests above the high tide level in habitats adjacent to estuaries in northern Australia (Kay 2004, Read et al 2004). Lateral connectivity in estuaries is largely driven by tidal fluctuations. Consequently, tide-dominated estuaries tend to have greater lateral connectivity between intertidal habitats than do wave dominated systems. Finally, vertical connectivity refers to connectivity between the water column and the substrate or sediments and includes processes such as sediment deposition and mixing of waters with differing salinities.

3.3. Terrestrial interface coastal ecosystems

The terrestrial interface coastal realm encompasses those coastal habitats which occur along the shoreline of the Australian landmass, excluding estuarine habitats. The three major ecosystem types considered here are: i) sandy beaches, ii) dune systems and iii) rocky shores (including headlands).

3.3.1. Sandy beaches

Distribution and extent

Sandy beaches account for around 49% of the Australian coastline, occurring in both tropical and temperate regions (Short and Woodroffe 2009). In southern Australia, where there is a low tidal range and constant exposure to the Southern Ocean swell, wave-dominated beaches occur (Short 2006, 2011). Tide-modified and tide-dominated beaches are more common along the northern coast where the tidal range is high and there are lower seas. Reflective beaches, which are narrow and steep with coarse particles are accretional systems that dominate tropical locations while erosional dissipative beaches occur in temperate regions (Schlacher et al. 2008).

Physical and chemical processes

Sandy beaches are the accumulation of sediments, mostly sand, via wave action, and their habitat structure depends on interactions between waves, tides and sediments, which vary in their relative influence depending on beach type and location (McLachlan and Brown 2006). Near-shore currents also influence the morphology, sediment and water movement of beaches. Beaches are inherently unstable, dynamic habitats with regular water movement and a high potential for erosion (Aagaard and Masselink 1999). They are also shallow habitats and therefore tend to have good light exposure (Short and Woodroffe 2009).

Ecology

Sandy beaches are unique ecosystems, typically comprising three main latitudinal habitats: i) the subtidal zone, ii) the surf zone and iii) the subaerial zone. Three vertical habitats are also present in each of these zones: i) pelagic, ii) benthic and iii) interstitial, i.e. surfaces and spaces between sand particles and accounting for up to 40% of beach volumes (Short and Woodroffe 2009). Marine species tend to dominate the subtidal zone and terrestrial species the upper, subaerial zone, with many specialised species occurring in intertidal habitats (Schlacher et al. 2008). Attached plants are generally absent from sandy beaches but many microscopic plants exist in interstitial habitats and support complex and diverse food webs comprising bacteria, fungi and a wide range of invertebrates as well as fish (Schlacher et al. 2008, Short and Woodroffe 2009). Subtidal and surf zones of sandy beaches are particularly important as nursery areas for juvenile fish while subaerial zones provide important breeding and feeding habitats for a wide range of birds and turtles (Schlacher et al. 2008, Short and Woodroffe 2009).

Reflective beaches tend to be dominated by robust crustaceans that can tolerate coarser grain structure while dissipative beaches usually have higher species diversity with more soft-bodied species (Jones et al. 2008) amongst which biological interactions tend to be more important in determining community structure (Defeo and McLachlan 2005).

Ecosystem services and values

Sandy beaches offer many unique ecological, physical, economic and biological ecosystem services including stabilisation of the shoreline, flood protection, recreational facilities and sand for mining and other human needs (Short and Woodroffe 2009). In particular, sandy beaches provide a buffer between significant coastal assets, e.g. human settlements, and the ocean, protecting against waves, storm surges and tsunamis and responding dynamically to sea level variation (Defeo et al. 2009). Other major ecosystem services include the breakdown of organic materials and pollutants, water filtration and purification, nutrient cycling and provision of bait and food (Defeo et al. 2009). Furthermore, sandy beaches provide resources (bait) and opportunities for recreational and some commercial fisheries.

Non-climatic pressures

Sandy beaches represent major sites for human recreation and tourism in Australia and many of the activities associated with these pursuits threaten beach ecosystems. Beach nourishment, grooming and armouring, pollution, overfishing, trampling and clearing are amongst these key threats (Defeo et al. 2009). Sandy beaches are particularly susceptible to the impacts of major engineering structures that affect sand storage and transport (Brown and McLachlan 2002). Furthermore, as coastal settlements expand, beaches are increasingly being ‘squeezed’ between rising sea level on the marine side and human development on the landward side (Schlacher et al. 2008). Sand mining and biological invasions are also major threats to beach ecosystems (Defeo et al. 2009).

Management

Sandy beaches that are heavily used by people are often intensively managed via practices including beach grooming (i.e. removal of wrack, litter and debris) and beach nourishment (i.e. replenishment of sands) (Defeo et al. 2009). Shore protection structures, e.g. sea walls and armouring, also have a long history of use to protect sandy coastlines from erosion. While sandy beach management often prioritises human uses, the need for consideration of environmental issues and multi-faceted approaches to management has recently been highlighted (Jones et al. 2008, Schlacher et al. 2008). Some management practices that target environmental concerns in sandy beaches include pollution control measures, both event based (e.g. oil spills) and catchment management, managed harvesting (e.g. of bait species) and restoration. Protected areas also represent a major management approach in coastal areas, with approximately 27% of the Australian coastline protected by national parks and state reserves (Short and Woodroffe 2009). Restriction of access to significant breeding areas during breeding seasons also occurs both within and beyond such protected areas.

3.3.2. Dune systems

Distribution and extent

Dune systems are associated with most sandy beaches in Australia and occur around approximately 85% of the sandy coastline (Short and Woodroffe 2009). Australia's coastal dune systems are amongst the largest and most extensive in the world with an average length of 10 km and average width of 2 km (Short and Woodroffe 2009). Dune systems tend to be rare behind very low-energy, small and embayed beaches and are therefore limited in northern Australia.

Physical and chemical processes

Dune formation depends primarily on the presence of sufficiently strong on-shore winds that transport sand inland from beach systems and waves and storm surges further influence dune structure and sediment dynamics (Short and Woodroffe 2009). Vegetation colonisation and development plays a major role in stabilising and shaping coastal dunes (Short and Woodroffe 2009) and groundwater availability has an important influence on dune vegetation, as does precipitation. Fire regimes may also structure dune habitats and vegetation (Keith 2006, McLachlan and Brown 2006).

Ecology

Dune systems are considered inhospitable habitats because of their infertile sandy substrates, exposure to strong winds and salt spray and their susceptibility to erosion by waves (Short and Woodroffe 2009). A limited range of specialised plants colonise dunes and these vary somewhat predictably within dune systems between the unstable frontal dune (usually dominated by a few grasses and herbs), the semi-stable foredune (supporting grasses and shrubs) and the stable hind-dune (which may support forests and woodlands) (Short and Woodroffe 2009). Although these major growth forms are common, considerable regional zonation of dune vegetation around Australia, particularly from north to south and in semi-arid to arid areas (e.g. South Australian coastline). On the east coast, for example, typical hind-dune areas support Eucalypt woodlands and forests while in southern Australia, dunes tend to be dominated by shrublands and sedgelands with trees only sparsely present (Short and Woodroffe 2009).

Birds, e.g. penguins, reptiles and other fauna, also for a significant component of coastal dune ecosystems (e.g. Chambers 2004). Many species are likely to play important ecological roles, e.g. dispersal of seeds of dune and headland plants by seabirds (Keith 2006).

Ecosystem services and values

Coastal dune systems provide similar ecosystem services to sandy beaches and have substantial socio-economic values for recreation and tourism (Schlacher et al. 2008, Defeo et al. 2009). Additionally, dunes are highly valued for their provision of minerals and their proximity to the coast in terms of providing sites for urban development (Short and Woodroffe 2009). With their neighbouring beaches, coastal dunes also afford the land behind them considerable protection from cyclones, strong oceanic winds and other climate events.

Non-climatic pressures

Non-climatic threats to coastal dune systems are comparable to those for sandy beaches, i.e. activities associated with recreation, clearing, pollution, exploitation and biological invasions (Defeo et al. 2009). Coastal development on dune systems is particularly significant since many urban settlements are constructed directly on hind-dunes.

Management

Management of coastal dune systems generally corresponds to that applied to adjacent sandy beaches. Protected areas, limiting access, pollution control, managed harvesting and restoration (including revegetation and weed control) represent some of the major management approaches.

3.3.3. Rocky shores and headlands

Distribution and extent

Rocky coasts comprise around half of Australia's mainland coastline, i.e. that portion not occupied by sandy coasts, and occur in both temperate and tropical regions wherever the coastal terrestrial interface comprises hard, stable surfaces (Short and Woodroffe 2009). Rocky coasts comprising sedimentary rocks are most common and occur around the country while the next most prevalent type, those composed of metamorphic rocks, dominate coastal areas where fold belts occur. Granite headlands and rocky coasts are also widespread, except along the northern coast, and basalt rocky coasts and headlands are mostly distributed along the east coast in association with the Great Dividing Range (Short and Woodroffe 2009). Rocky headlands partition beaches and rocky shores around the continent but are particularly prevalent on the east coast (Rule 2007).

Physical and chemical processes

The morphology of rocky coasts depends primarily on the characteristics of the rocks of which these landforms are comprised, including rock type, strength, permeability, height and slope (Short and Woodroffe 2009). As in estuarine and sandy coastal ecosystems, wind, wave and tidal processes are amongst the key physical processes in these systems but, due to their hard, stable surfaces, rocky shores and headlands respond at different time scales (Short and Woodroffe 2009). Geochemical interactions between rocks and marine processes are also important, as are the tidal range and orientation of the coastline (Short and Woodroffe 2009).

Atmospheric processes, i.e. temperature variation, rainfall and wind, dominate subaerial zones of rocky coasts which are influenced by salt spray but not waves. Intertidal zones are also subject to these processes as well as breaking waves, tides and currents which promote erosion and export materials from rocky coasts. In the subtidal zone, wave action is the dominant physical process (Short and Woodroffe 2009).

On headlands, habitat and vegetation structure is also influenced by rock type, exposure to salt-bearing winds and fire (Keith 2006).

Ecology

Due to their hard, stable surface, rocky shore habitats differ significantly from sandy beach and dune systems. They are also far more exposed than beaches, as well as subject to waves breaking more heavily, though some sheltered microhabitats, e.g. tidal pools, can also be present (Short and Woodroffe 2009). Ecosystem structure and function tends to vary somewhat predictably in relation to the influence of tides, waves and currents along a gradient form subaerial to subtidal zones on rocky shores. In temperate Australia, rock surfaces of the subaerial zone often support small blue periwinkles (*Littorina* spp.) and limpets which are gradually replaced by barnacles at lower elevations in the intertidal zone (Short and Woodroffe 2009). A zone of white tube-worms typically occurs below the high-tide line, where there is heavy surf, while subtidal areas, that are rarely or never exposed to the air, are often covered by macroalgae and support diverse assemblages of sessile and mobile invertebrates (Short and Woodroffe 2009). In southern Australia, rocky shores also provide important breeding habitats for pinnipeds including the Australian sea lion and New Zealand fur seal (DSEWPAC 2011). The ecology of Australia's tropical rocky shores is poorly known (Short and Woodroffe 2009).

Australian headlands support a range of vegetation types including littoral rainforests, coastal vine thickets, heathlands and grasslands, which vary locally and regionally mainly with respect to degrees of exposure (Keith 2006). As with dune ecosystems, a range of mammals, birds and reptiles inhabit headlands with habitat diversity and community structure strongly influenced by fire (Keith 2006).

Ecosystem services and values

As with other coastal terrestrial interface ecosystems, rocky shores and headlands are highly valued as sites for recreation, tourism, urban development as well as the provision of habitat for biodiversity and protection from storm surges. Rocky shores and headlands also afford embayed beaches protection from sediment loss (Short and Masselink 1999).

Non-climatic pressures

Major threats to Australia's rocky coasts are largely similar to those faced by sandy coasts. Human infrastructure development, for instance, has both direct impacts on rocky shores (i.e. habitat loss) and indirect effects, e.g. by altering patterns of erosion and sedimentation (Walker and Kendrick 1998) or fire regimes. Pollution and invasive species also pose major threats to rocky shore ecosystems (Walker and Kendrick 1998). Furthermore, harvesting of subtidal and intertidal organisms, e.g. algae and invertebrates, can significantly disturb rocky shores.

Management

Major approaches to the management of rocky shores and headlands in Australia are comparable to those for sandy coasts. While nourishment and grooming practices do not tend to occur in these systems, some engineering approaches, e.g. armouring, may be implemented on rocky coasts, e.g. to limit threats posed by falling rocks. Pollution control, managed harvesting, restoration (including control of invasive species), limiting access and protected areas comprise some of the key management strategies relevant to rocky coasts. Managed fire regimes may also be used in some cases, particularly in National Parks and State reserves.

3.4. Freshwater coastal ecosystems

The freshwater coastal realm encompasses the coastal freshwater habitats that occur along the shoreline of the Australian landmass. This does not include riverine habitats, which fall beyond the scope of the project, but rather the significant freshwater habitat types that support unique flora and fauna in the coastal zone. The two major ecosystem types considered here are i) lakes and lagoons and ii) forested wetlands.

3.4.1. Lakes and lagoons

Distribution and extent

On a global scale, lakes and lagoons are relatively uncommon features around the Australian coastline. However, there are regions where they occur in relatively high densities, including south-east Queensland (especially on the dune islands in the region) and northern Queensland (Cape Flattery), although small numbers of freshwater lakes are also found along the coasts of New South Wales and Victoria (Timms 1980).

Physical and chemical processes

The vast majority of coastal freshwater lakes and lagoons occur in extensive dune systems. Whilst most sit in dune depressions, which intersect the local groundwater, perched dune lakes, which are not hydrologically linked to the groundwater table, are common in south-east Queensland. Perched dune lakes form in dune depressions that are sealed when decaying plant material forms an impervious boundary layer of soil. These systems typically have no inflow or outflow streams and, as a result, they are essentially basins of rainwater, with low nutrient concentrations. Water chemistry is strongly influenced by the coastal setting, with higher concentrations of sodium and chloride in lakes that are closer to the ocean, reflecting the atmospheric deposition of these ions.

Ecology

The unique mode of origin of perched dune lakes makes colonisation by truly aquatic organisms difficult (Timms 1986a). The acidic sodium and chloride dominated water of perched dune lakes is also thought to play a strong role in determining the species composition of these coastal ecosystems (Bayly 1964, Bayly 1966). Only acid tolerant species thrive in these systems, as testified by significant populations of the rare fish honey blue-eye *Pseudomugil mellis* and the Oxleyan pygmy perch *Nannoperca oxleyana* (Arthington 1984, Arthington et al. 1986, UNESCO 2001) and the geographically rare and restricted “acid frogs” such as the Wallum froglet *Crinia tinnula*, the Cooloola sedgefrog *Litoria cooloolensis*, the Wallum rocketfrog *L. freycineti* and the Wallum sedgefrog *L. olongburensis* (UNESCO 2001). Despite the presence of these acid lake specialists, some of the aquatic beetle species found in these systems are comparatively widespread taxa, presumably due to their wide tolerances to acidity and generalist diet requirements (Timms and Watts 1981).

Ecosystem services and values

Lakes and lagoons are highly valued ecosystems in the coastal zone. Not only do they provide habitat for a wide range of endemic, unique, sensitive and vulnerable taxa (Arthington and Watson 1982, Arthington 1984), they also represent significant ‘hot spots’ for tourism and recreation (Hadwen and Arthington 2003, Hadwen et al. 2003, Hadwen et al. 2005). In some areas, coastal lakes and lagoons are also highly valued habitats for migratory and local populations of waterbirds (Kingsford 2011).

Non-climatic pressures

Australian freshwater ecosystems have been significantly altered by human actions. These alterations predominantly fall into the following categories: a) hydrological impacts, including flow regulation and water extraction, b) land use change and diffuse sediment and nutrient impacts, c) point-source nutrient impacts, d) extractive industries – recreational and commercial fishing, and e) tourism. Depending on the local context (including whether the lake is perched or connected to the groundwater table and adjacent land uses), the relative strength of each of these non-climatic pressures is highly variable.

Management

Many coastal lakes and lagoons sit in low-lying areas that are not always suitable for development. To this end, there are pockets of coastal freshwater lakes that are not currently significantly threatened by non-climatic drivers. Management in these areas largely focuses on conservation and preservation of these unique habitats and their biota. The most threatening non-climatic stressor in these relatively pristine settings tends to be tourism and some control over the access and activities of visitors may be required in the future to ensure that the ecology of these dune lake ecosystems is not compromised.

3.4.2. Forested wetlands

Distribution and extent

In contrast to dune lakes, which sit in dune depressions, forested wetlands are typically associated with the floodplains of coastal draining rivers and streams (Short and Woodroffe 2009). They may be billabong oxbows that have become disconnected from the main channel of the river system, or they may be depressions in the floodplain which flood and fill on the basis of seasonal or annual cycles of rainfall, flow and groundwater contributions. The most extensive coastal freshwater wetlands in Australia occur in Kakadu National Park in the Northern Territory. Similar wetlands occur along tidal rivers of northern Australia (Short and Woodroffe 2009). There are freshwater wetlands in southern Australia, however they tend to be restricted to waterlogged areas between beach ridges and back-barrier depressions and lagoons (Short and Woodroffe 2009).

Physical and chemical processes

Forested wetlands occur throughout coastal Australia, but are most abundant in low-lying coastal floodplains. Their proximity to riverine and estuarine floodplains determines their hydrology and ecological character, with wetting and drying cycles largely driven by overbank flows and local rainfall, although some become inundated under high tides (Salter et al. 2008). Forested wetlands at the upper margins of floodplains are typically less often inundated than those lower on the floodplain and the vegetation and faunal communities reflects both the type and nature of inundation. During dry spells forested wetlands appear more like terrestrial habitats than aquatic habitats, but the frequency and history of re-wetting ensures that the biodiversity and functioning of these systems is quite different from terrestrial woodlands (Jin 2008, Lamontagne et al. 2009).

Ecology

Forested wetlands sit at the interface between estuarine and terrestrial environments and as such, they represent a gradient of species and habitats that range from occasionally saline environments (sharing elements of saltmarsh communities) to occasionally freshwater environments (sharing elements of terrestrial communities). The presence of these systems, which are often small in terms of areal extent, between terrestrial and estuarine habitats and the gradient of species within them makes classification difficult (Arthington and Hegerl 1988) and generalisable conclusions regarding their ecology are almost impossible to make given that local conditions, revolving around frequency of inundation and salinity, not only drive the ecology of the systems but can also fundamentally change their character over relatively short time frames. Arthington and Hegerl (1988) also note that although coastal freshwater wetlands support a wide range of diverse and endemic species and can represent important habitats that support migratory waterbirds, surprisingly little is known of the ecology of these ecosystems. Furthermore, these environments have, to date, largely been surveyed and classified according to their vegetation communities, with dominant taxa from *Eucalyptus*, *Melaleuca* and in some low lying peaty areas *Sphagnum* (Arthington and Hegerl 1988). Significantly more work is required to classify and understand the complex ecology of forested wetlands in coastal Australia, particularly as these systems are vulnerable to climate change impacts resulting from reduced rainfall, increased temperatures and sea level rise and saltwater intrusion.

Ecosystem services and values

Forested wetlands contain many endemic species and represent significant biodiversity hotspots in the coastal zone (Kingsford 2011). In particular, they are known to support unique vegetation, frog and bird assemblages (Finlayson et al. 2006, Kingsford 2011). In addition to their biodiversity values, forested wetlands also show some promise as carbon sinks in floodplain environments (Dalal et al. 2008) and recent calls for wetland conservation have highlighted their utility as useful climate change mitigating environments (Howe et al. 2009).

Non-climatic pressures

Non-climatic pressures on Australian forested coastal wetlands are largely similar to those threatening coastal lakes and lagoons (see above).

Management

Management of freshwater wetlands requires commitment on several levels, federal and state government policy, local government planning controls and community understanding and support. In addition, and particularly in northern Australia, freshwater wetland management can benefit greatly from the input of indigenous knowledge (Finlayson 2005). At present little is really understood of the ecology of the northern freshwater systems (Finlayson 2005, Hamilton and Gehrke 2005).

One of the major limiting factors around the management of coastal freshwater environments is the lack of ecological knowledge and understanding of these systems. For example, more research is required on plant growth and the environmental factors that drive seasonal and annual changes in vegetation distribution and productivity to help manage changes due to increasing invasive species and changes in fire regimes (Finlayson 2005).

3.5. Summary

There is considerable regional diversity in coastal ecosystems around Australia, both within and between realms. Amongst marine coastal ecosystems, coral reefs fringe the tropical northern coastlines while macroalgal forests dominate much of the southern coastal zone, largely reflecting temperature differences. In contrast, waves and tides largely determine the distribution of estuaries and sandy beaches around the continent with wave-dominated forms occurring in the south and tide-dominated forms in the north. While extensive behind beaches along the southern and eastern coastlines, dune systems are also rare along the lower energy northern coastline. Rocky shores vary around the coast according to geology and geomorphology although headlands are more prevalent along the east coast. Amongst freshwater coastal ecosystems, lakes and lagoons are relatively rare and occur patchily along the east coast while extensive forested wetlands are mostly associated with tidal rivers of northern Australia.

Within Australian coastal ecosystems, ecological structure and function closely reflect dominant physical processes which vary depending on coastal setting with hydrodynamic processes dominating marine and subtidal habitats, atmospheric processes dominating terrestrial subaerial habitats and hydrologic processes shaping estuarine habitats, including the influence of marine hydrodynamic processes within these.

Because of their setting and the range of physical processes shaping their habitats, many coastal ecosystems tend to be highly productive and biologically diverse, supporting a wide range of marine, terrestrial and specialised intertidal organisms. Where physical processes are particularly strong, however, e.g. in coarse-grained, high energy reflective beaches or highly exposed dunes and headlands, only a few hardy species may occur.

There is considerable connectivity (longitudinal, lateral and vertical) within and amongst Australian coastal ecosystems. In particular, primary productivity and food web connections are tightly linked between habitats across all coastal realms. Terrestrially derived sediments and nutrients also play a significant role in all coastal ecosystems considered here. Furthermore, marine inputs (e.g. salts) have considerable influence on estuarine, terrestrial and freshwater coastal ecosystems.

Australian coastal ecosystems provide a wide range of highly valuable ecosystem services. Many of these, e.g. tourism, recreation, urban development, sand mining and fisheries, contribute directly and significantly to the economy. Other 'non-use' values, such as buffering coastal settlements from storm surges and tsunamis, water and nutrient cycling, and provision of habitat to biodiversity, are also likely to be worth many millions of dollars to the country annually. Many Australian coastal ecosystems, particularly in iconic locations, also have considerable aesthetic, cultural and conservation values.

Australian coastal ecosystems are subject to many non-climatic threats, most of which are associated with human activities. These include changes to hydrological and hydrodynamic processes, as a result of water and land use and infrastructure developments, as well as changes to sediment and nutrient dynamics and fire regimes that have resulted from these catchment alterations. Harvesting of organisms and materials (e.g. sand) has also affected many coastal ecosystems as have disturbances arising from human activities including recreation and tourism. Invasive species also pose a substantial threat to many coastal ecosystems, particularly those in the marine realm. Encroaching development of human settlements on the landward side of much of the Australian coastline, referred to as the 'coastal squeeze', is particularly notable as a threatening process to many coastal ecosystems.

Management of Australian coastal ecosystems has tended to shift in recent times from traditional targeted management approaches, e.g. fisheries management, to more holistic, catchment management approaches. Protected areas remain an important element in the management of coastal ecosystems as does the regulation of harvesting and movement of species and materials. Targeted management of direct threats, e.g. urchins, are also important where specific problems can be identified.

Despite their high ecological, economic and cultural values, considerable knowledge gaps exist concerning the structure and function of many Australian coastal ecosystems and how these affect the ecosystem services provided. Whilst some coastal ecosystems have been well studied, e.g. tropical coral reefs, others are very poorly understood. In particular, information about most non-marine coastal ecosystems of northern Australia is lacking. Many terrestrial interface coastal ecosystems and coastal forested wetlands have also received relatively little attention.

SECTION 2. CLIMATE CHANGE IMPACTS

4. CLIMATE CHANGE IN THE AUSTRALIAN COASTAL ZONE

There is considerable evidence that the Earth's climate has warmed over the past century (IPCC 2007). Global average temperatures have risen in line with recent climate model projections and global average sea temperatures are warming at the upper end of climate model projections. Since 1950, the Australian climate has warmed by around 0.7°C with more heatwaves, fewer frosts and more rain in north-west Australia and less rain in southern and eastern Australia (Hennessy et al. 2007). Sea levels have also risen by about 70 mm during this period (Hennessy et al. 2007).

In this chapter, an overview is provided of observed and projected climate change of relevance to the Australian coastal zone, including key elements of terrestrial and marine coastal climate systems as well as sea level rise.

4.1. Terrestrial coastal climate

4.1.1. Observed climate

Temperature

Climate records indicate that terrestrial surface temperatures in Australia rose by just under 1°C between 1910 to 2009 (Brazanga and Church 2011). The last decade (i.e. 2000 – 2009) was Australia's warmest on record and 2010 was one of the hottest years ever recorded (Brazanga and Church 2011). The frequency of extreme cold weather has declined across most of the country with cold days (i.e. ≦15°C) decreasing by 0.14 days/yr and cold nights (i.e. ≦5°C) by 0.15 nights/yr (Hennessy et al. 2007). Average temperatures are lower in the coastal zone than in inland Australia, however, the trend for rising terrestrial temperatures is consistent.

Rainfall

With the exception of the recent year, most of eastern and south-western Australia has experienced substantial declines in rainfall since 1950 while rainfall in northern Australia has increased. Characterising long-term trends in Australian rainfall is challenging, however, due the continent's extreme rainfall variability, driven by large-scale atmospheric and oceanic circulation patterns, such as El Nino-Southern Oscillation (Braganza and Church 2011).

Tropical cyclones and lows

No significant trends in the total numbers of cyclones or the proportion of intense cyclones in the Australian region have been found in the period between 1981 – 2007 (Kuleshov et al. 2010). Cyclone frequency and intensity south of 20°C on the east coast have significantly declined since the early 1980s, corresponding with a shift to the positive phase of the Interdecadal Pacific Oscillation and an increased frequency of ENSO events (Levin 2011).

4.1.2. Projected climate

Simulations of future climate are available for a range of greenhouse gas emission scenarios. Confidence in near-term projections has been strengthened following comparisons between projections in the IPCC First Assessment Report (i.e. 0.15-0.3°C per decade average global temperature, IPCC 1990) and observed global warming of

0.2°C decade over 1990-2005 (IPCC 2007). Global warming is currently tracking the higher end of IPCC projections (Fig. 4.1). Consequently, higher end scenario projections are considered here, i.e. A1B and A1FI (IPCC 2007). The A1FI emissions scenario is a high impact scenario with high climate sensitivity while A1B is a medium impact scenario with medium climate sensitivity.

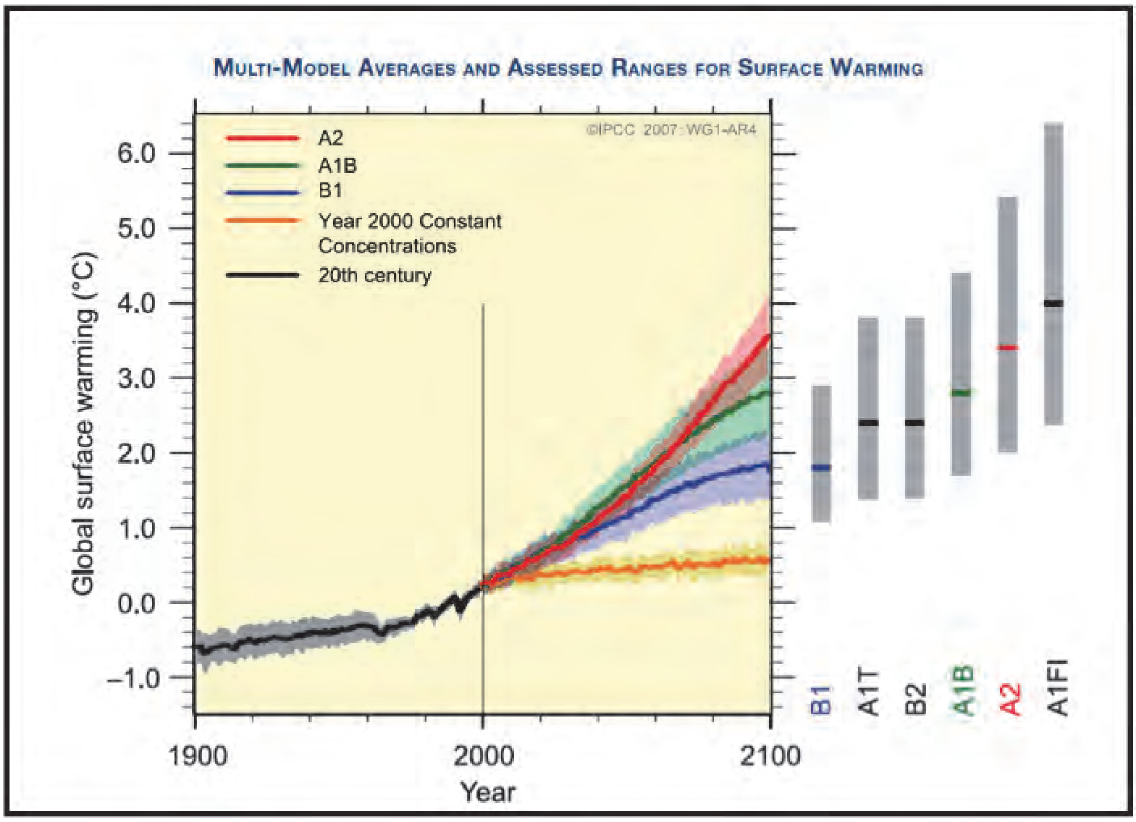

Figure 4.1 Simulations of future climate under different greenhouse gas emissions. Solid lines are multi-model global averages of surface warming (relative to 1980-1999) for the scenarios A2, A1B and B1, shown as continuations of the 20th century simulations. Shading denotes the ± standard deviation range of individual model annual averages. The orange line is for the experiment where concentrations were held constant at year 2000 values. The grey bars at right indicate the best estimate (solid line within each bar) and the likely range assessed for the six SRES marker scenarios. The assessment of the best estimate and likely ranges in the grey bars includes AOGCMS in the left part of the figure as well as results from a hierarchy of independent models and observational constraints. (Source: IPCC 2007).

Projections presented here were calculated using the CSIRO Mk3.5 General Circulation Model (GCM) downloaded from OzClim (www.csiro.au/ozclim). Thirty-five climate variables (11 temperature, 8 precipitation, 8 solar radiation and 8 soil moisture variables) were computed at 1 km^2 resolution for two future dates: 2030 (near term: i.e. 2025 – 2035) and 2070 (long term: i.e. 2065 – 2075), unless otherwise specified, with baseline time slices in the range of 1970-2005 depending on the variable. Description of the thirty-five climate variables and their utility in this study are presented in Appendix 1.

Regional climate projections were analysed and mapped with respect to the Interim Biogeographic Regionalisation for Australia (IBRA) which categorises the continent into 85 regions based on dominant climate, lithology, geology, landforms and vegetation (Fig 4.2; Thacway and Cresswell 1995). The focus was on results projected in the 43 bioregions with some coastline. The names, area and length of coastline in each of these bioregions is presented in Appendix 2. Results for temperature, rainfall, solar radiation and soil moisture are summarised here as well as a brief discussion of projected changes to extreme events.

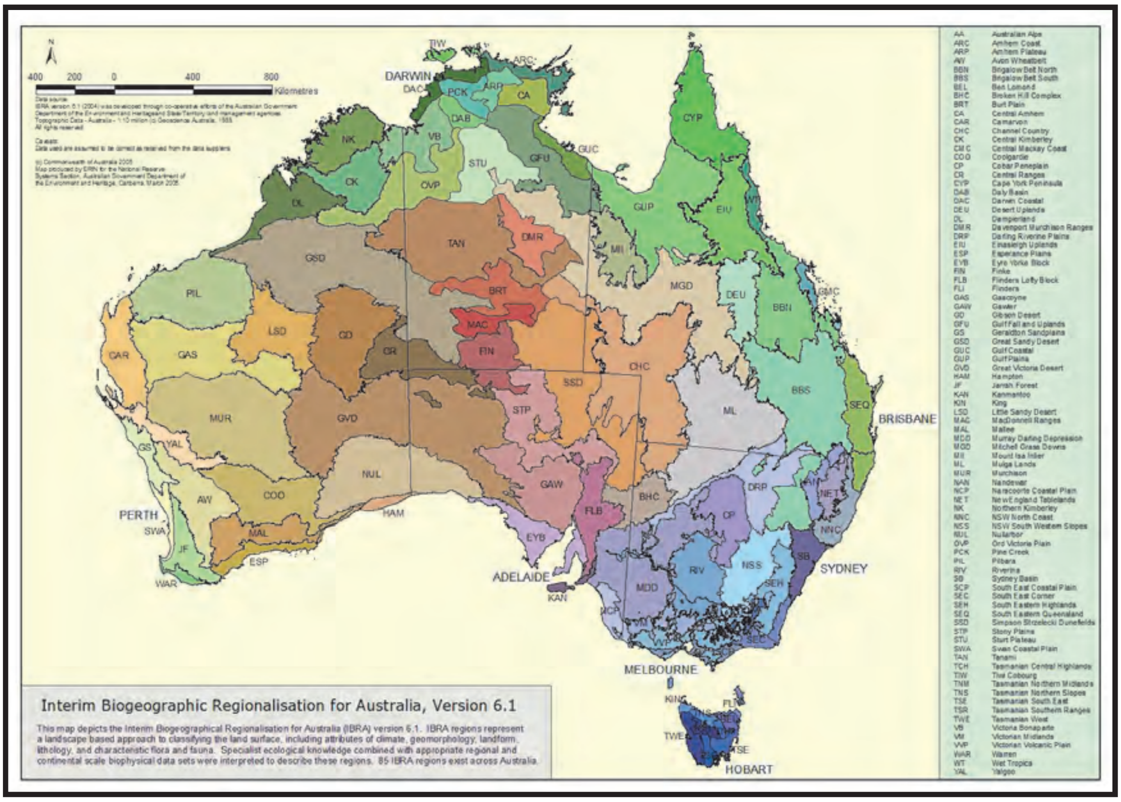

Figure 4.2 Interim Biogeographic Regionalisation of Australia (IBRA)
Source:
http://www.environment.gov.au/parks/nrs/science/pubs/regions.pdf

Temperature

Mean annual temperatures are projected to warm across all coastal IBRA regions under both the A1B and A1FI scenarios for both time periods (Fig 4.3) For both scenarios, mean annual temperature is projected to warm between 0.8-2.1°C by the 2030s and between 1.8-3.9°C under the A1B scenario and between 3.2-6.2°C under the A1FI scenario by the 2070s. The warmest quarter of the year is projected to increase by 0.8°C by the 2030s under A1B to 6.3°C by the 2070s under A1FI.

Maximum temperatures of the warmest week of the year and minimum temperatures of the coldest week of the year are also projected to warm under both scenarios for both dates. However, a greater rate of warming of minimum temperatures of coldest weeks than of the maximum temperatures of warmest weeks results in a decrease in the annual temperature range in the west, while the reverse results in an increase in annual temperature range in the south and east. There is a relatively small change in the seasonality of temperatures.

Rainfall

Annual mean precipitation is projected to decline across all IBRA regions under both the A1B and A1FI climate scenarios and time periods 2030 and 2070 (see Appendix 3). Annual precipitation (mm) is the sum of all the monthly precipitation estimates.

Mean annual rainfall is projected to decline, by the 2030s, by a minimum of 4% under A1B and 5% under scenario A1FI (both in IBRA 62 Warren and 43 Central Mackay Coast) and a maximum of 37% and 58% (both in IBRA 54 Carnarvon) under A1B and A1FI respectively.

The wettest period (precipitation in the wettest week) is projected to increase in North Queensland and SW Western Australia. Precipitation of the driest period (week) decreased by 100% in almost all regions by the 2070s under A1FI, however baseline rainfall during the driest period ranged from 0 in northern WA and NT to 23mm in IBRA 14 (Tasmanian West). Considering precipitation in the warmest quarters, declines are projected across most IBRA regions apart from the south east (excluding Tasmania) (Table 4.1).

Table 4.1 IBRA regions with baseline mean rainfall projections (mm) during warmest quarter and projected increases (%).

IBRA region	Region Name	Baseline 1990s (mm)	2030: A1B	2030: A1FI	2070: A1B	2070: A1FI
5 South	Eastern Highlands	189	1.4 1.7 3.3			5.7
10 South	East Corner	216	2.5 3.1 5.6			9.4
20	Sydney Basin	282	1.1 1.3 2.6			4.6
42	Wet Tropics	941	2.1 2.6 4.6			7.7
43 Central	Mackay Coast	671	2.0 2.5 5.2			8.3

Solar radiation

Solar radiation is a measure of the total amount of radiation emitted from the sun. Radiation quantities are generally expressed in terms of either irradiance or radiant exposure. Irradiance is a measure of the rate of energy received per unit area, and has units of Watts per square metre (W/m2), where 1 Watt (W) is equal to 1 Joule (J) per second. Radiant exposure is a time integral (or sum) of irradiance. Thus a 1 minute radiant exposure is a measure of the energy received per square metre over a period of 1 minute. Therefore a 1-minute radiant exposure = mean irradiance (W/m2) x 60(s), and has units of joule(s) per square metre (J/m2). The outputs of the BIOCLIM solar radiation layers represent measures of irradiance, with units of megajoule(s) per square metre (Busby 1986), where the min r is the lowest weekly radiation estimate and max r is the largest weekly radiation estimate.

Solar exposure estimates are important for a wide range of applications, particularly in the agricultural, engineering and scientific research sectors. Examples of use include:

- monitoring plant growth and disease control;
- evaporation and irrigation;
- calculation of water requirements for crops;
- architecture and building design;
- power generation;
- solar heating system design and use;
- skin cancer research;
- research into coral growth;
- weather and climate prediction models;

For all future climate scenarios, annual mean solar radiation is expected to increase by 0.1 – 0.3 J/m^2 by 2030s under A1B and A1FI scenarios and by 0.2 to 1.0 a maximum of 1 J/m^2 by 2070s under A1B and A1FI scenarios. Increases are larger in the east than the west. During the warmest quarter of the year, increases in mean solar radiation are projected for the south-east (Table 3.4) with little change (<6%) or declines of up to 16% (IBRA 13 Tasmanian South East) by 2030s and 80% (IBRA 13 Tasmanian South East) by the 2070s in the other coastal regions. The mean radiation of the warmest quarter is projected to increase in the north and north-east but decrease in the south west and south east, with the exception of Tasmania where mean radiation is projected to increase. Mean radiation of the coldest quarter is projected in increase, with the strongest increases in the south.

Table 4.2 IBRA regions with baseline solar radiation projections ($J.m^2$) during warmest quarter and projected increases (%).

IBRA region	Region Name	Baseline 1990s (J/m^2)	2030: A1B	2030: A1FI	2070: A1B	2070: A1FI
1 Murray	Darling Depression	14.5	17 19		25 28	
5 South	Eastern Highlands	15.5	8 9		8 13	
10 South	East Corner	17.9 8		9	13	18
31 Gawl	er	23.1	6	7	10	13
36 Flinde	rs Lofty Block	19.6 9		11	15	20

Soil moisture

Soil moisture influences factors such as the rate of runoff from land, soil stability and ecosystem productivity. The moisture index ranges from 0 (dry) to 1.0 (saturated) and can be perceived as the water held in the spaces between soil particles. Amongst the coastal IBRA regions, the annual mean soil moisture index is projected to decline by the 2030s up to 25% under the A!B scenario and up to 28% under the A1FI scenario and, by the 2070s, up to 29% under A1B and 58% under A1FI. During the warmest and coldest quarters, soil moisture is also projected to decrease across all coastal IBRA regions.

Extreme events

Projections of tropical cyclones throughout Australia are uncertain. Studies suggest that there may be an increase in the number and magnitude of tropical cyclones in categories 3-5, but a potential decline in the total number (Church et al. 2008). However, a regional model for the Queensland coastline suggests a decline in cyclonic activity (Fuentes and Abbs 2011). Studies also suggest a poleward shift of between 0.7 and 2° latitude in the genesis of region of the cyclone and 3° in the decay location of cyclones on the east coast (Abbs et al. 2006).

Only a handful of studies examine projected changes in wind using climate models. Of these, a number suggest extreme winds associated with tropical cyclones and mid-latitude lows may increase. Short bursts of locally high winds and rainfall may also result from water temperatures which lead to an increased activity of small-scale convective systems within coastal regions (Commonwealth Australia 2009). The southward extension of the warm East Australian Current could also lead to an extinction of east coast lows and extreme wave conditions (McInnes et al. 2007).

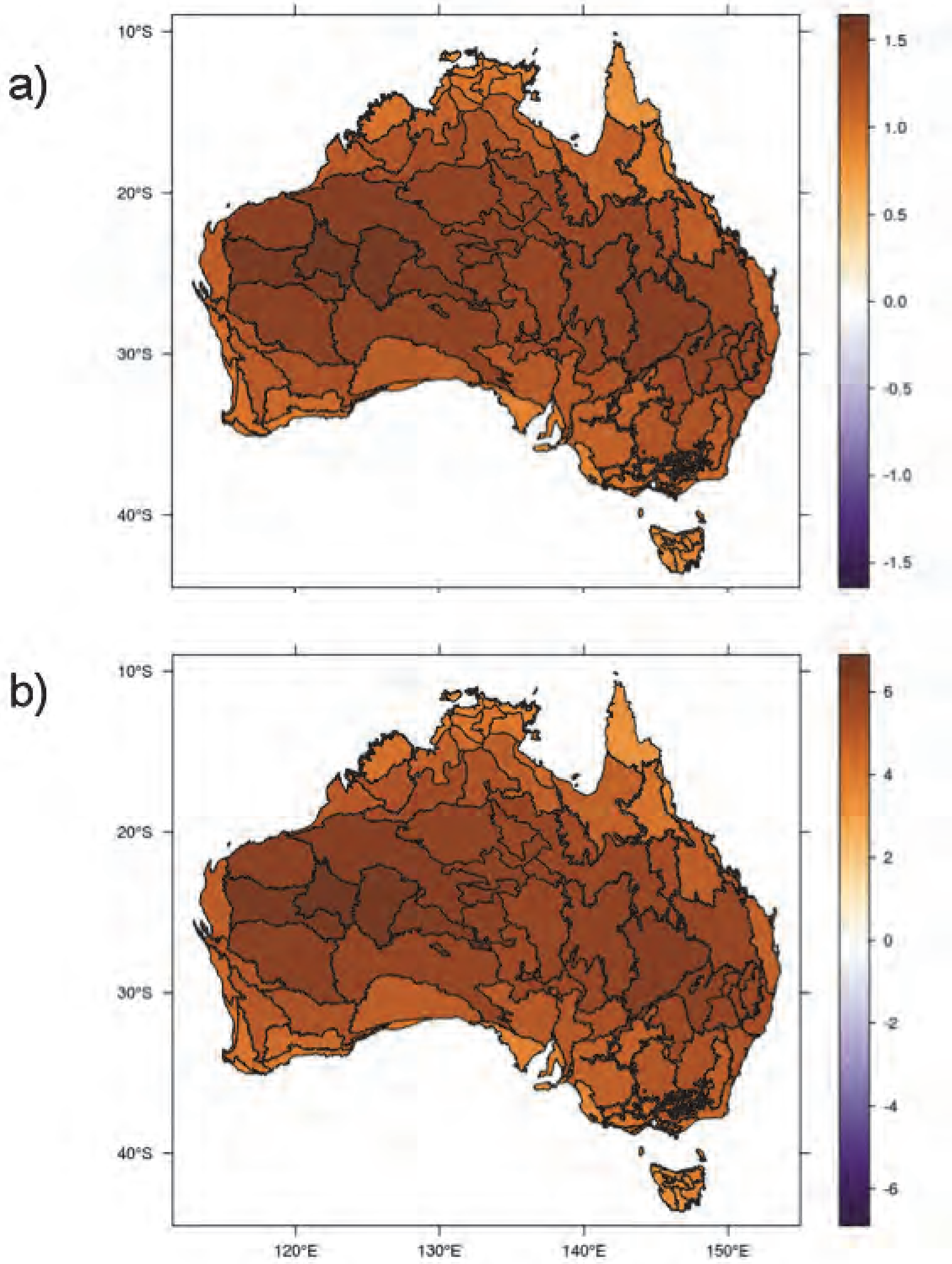

Figure 4.3 The change in annual mean temperature from the baseline to scenario a) A1B 2030 b) A1FI 2070. Note scales differ between figures.

4.2. Marine coastal climate

4.2.1. Observed climate

Ocean temperature

Since 1900, global average sea surface temperatures have increased by about 0.7°C while surface waters surrounding Australia have warmed by about 0.9°C with about 0.4°C of this warming occurring in the last 50 years (Braganza and Church 2011). The warmest year for Australian average sea surface temperatures was 1998 and 6 out of the 10 warmest years since 1910 have occurred in the most recent decade (Lough 2009). The greatest rates of warming over the past 50 years have occurred off the south-east (0.23°C per decade, Hill et al. 2008) and south-west (0.20°C per decade, Pearce and Feng 2007) coasts of Australia with greater warming during summer and winter in the south-east and in the autumn and winter in the south-west (Lough 2009).

Changes in south-eastern Australian waters have also included increasing salinity, with a mean trend in the Tasman Sea of 0.036 psu/decade between 1944-2002 (Hill et al. 2008) which, in combination with a trend of sea surface temperature warming of 0.23°C/decade, correspond to a shift in sea surface climate of around three degrees in latitude or 350 km (Ridgway and Hill 2009). This high rate of warming, greater that the global average over the 20th Century (Ridgway 2007), is driven by an intensification of the East Australian Current, which transports warm water of tropical origin southwards, due to stratospheric ozone depletion and increases in atmospheric CO_2 (Cai et al. 2005, Cai 2006).

Warming in south-western Australian coastal waters, of around 0.6-1°C over the past 50 years, may be driven by air-sea heat flux into the south-eastern Indian Ocean (Pearce and Feng 2007). In tropical Australia, rates of warming of around 0.11-0.12°C/decade, suggest southward shifts in annual mean sea surface temperature climate of > 200km in the north-east and > 100km in the north-west between 1950-2007 (Lough 2008).

Ocean acidification

Ocean surface pH around Australia has fallen by 0.1 since around 1750 (Feely et al. 2004) and an increasing trend towards ocean acidification is evident from studies in the Southern Ocean and Great Barrier Reef region (McNeil et al. 2001, Matear and Lenton 2008, Wei et al. 2009). Changes in pH are a function of temperature, salinity, alkalinity and dissolved inorganic carbon concentrations. Elevated CO_2 in the ocean alters the carbon system and decreases the carbonate saturation state of seawater. Hydrogen ions are also generated making the water more acidic.

Wave climate

A positive trend in the frequency and intensity of large wave events has been indentified along Australia’s southern coastline (Hemer et al. 2008).

4.2.2. Projected climate

Marine climate datasets were downloaded from ozclim (www.csiro.au/ozclim). The marine climate projections considered are sea surface temperature (SST) and sea surface salinity (SSS). Projections for increases in SST were available for 11 general circulation models (CGCM3.1(T47); CGCM3.1(T63); MIROC-H; CSIRO Mk 3.0; CSIRO Mk 3.5; HadGEM1; INM CM3.0; MRI-CGCM2.3.2; GISS AOM; GISS E-H; GISS E-R) and 3 models for sea surface salinity (MIROC-H; MIROC-M; GISS E-R). Projections were selected for two time periods, 2030 and 2070, and two emission scenarios, A1B and A1FI to correspond with the terrestrial climate projections. Projections are scaled to a 0.25° grid. Some of the figures showing projections are presented here in the body of the report – others are provided in Appendix 4.

Sea surface temperature

Sea surface temperature is projected to warm by 0.2-1.2°C by 2030 under both scenarios and 0.5-2.8°C by 2070 under the A1B scenario and y 0.6-3.8°C under the A1FI scenario (Figs 4.4. and 4.5). Ocean regions with the greatest projected warming are the north-west and south-east. There is little difference in the projected warming pattern seasonally under each scenario by 2030 but by 2070 warming is projected to be slightly higher in autumn and winter compared to spring and summer, particularly in south-eastern waters.

Sea surface salinity

Generally, southern and north-eastern Australian marine waters are projected to become slightly fresher by the 2030s (by -0.1g/l) while the west, north-west and south-east waters are projected to become slightly saltier (by +0.1 g/l) under both scenarios (Figs 4.6 and 4.7). By 2070, these projections are more intense, particularly in south-eastern waters probably due to increased incursion of warm, saltier water transported by the East Australian Current.

Ocean acidification

Atmospheric carbon dioxide (CO_2) concentrations have increased from approximately 280 ppm in pre-industrial times to approximately 380 ppm (IPCC 2007b) causing global ocean pH to decline from 8.2 to 8.1. Depending on emission scenarios, CO_2 concentrations are predicted to reach 540-979 ppm by the end of the century (IPCC 2007b) which will cause the average ocean pH to drop a further 0.3 to 0.4 units (Royal Society 2005), making the ocean more acidic than at any time in the past 800 000 years (Luthi et al. 2008). The greatest declines in pH in surface waters around Australia are projected for the north-east (Fig. 4.8).

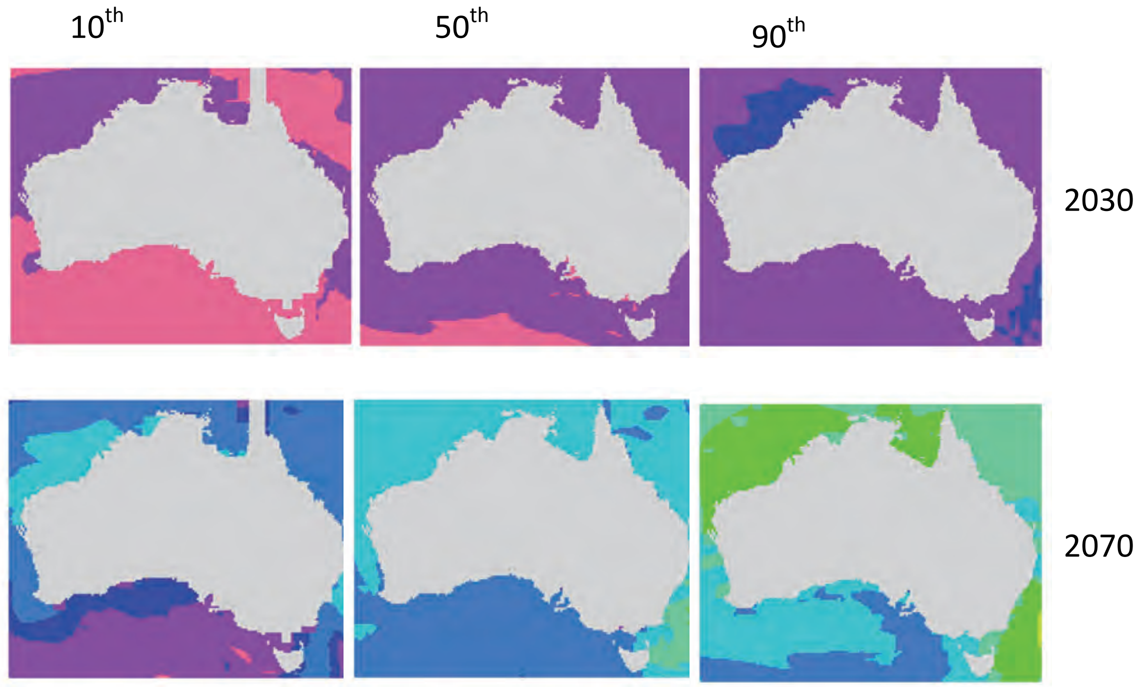

Figure 4.4 Warming of SST (°C) from baseline 1990 projected by 2030 (top row) and 2070 (bottom row) from 11 GCMs under scenario A1B, moderate global warming. 10th, 50th and 90th percentile plotted for each time slice.

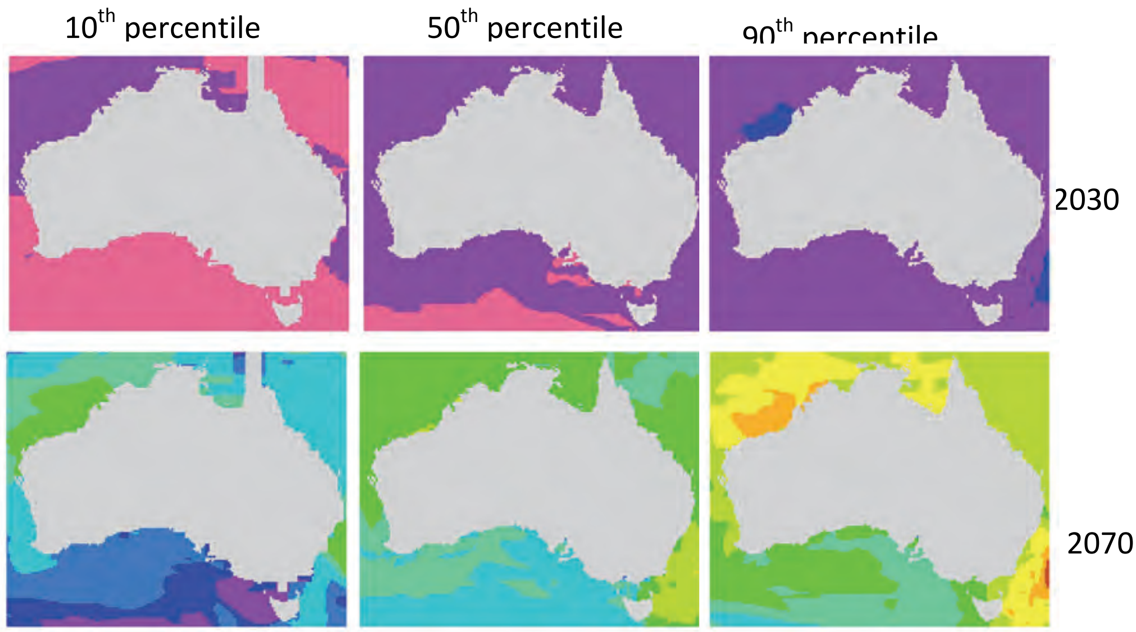

Figure 4.5 Warming of SST from baseline 1990 projected by 2030 (top row) and 2070 (bottom row) from 11 GCMs under scenario A1FI, moderate global warming. 10th, 50th and 90th percentile plotted for each time slice.

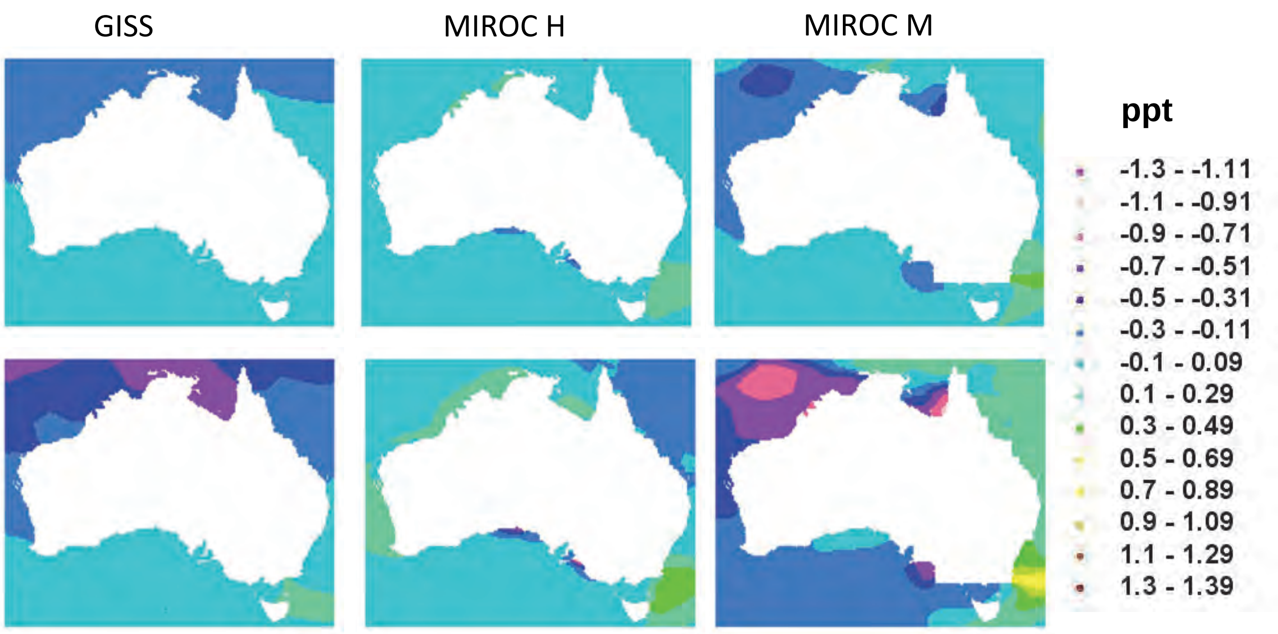

Figure 4.6 Change in annual mean Sea Surface Salinity (in g/l) from 1990 baseline under scenario A1B by 2030 (top row) and 2070 (bottom row) projected by three GCMs (GISS; MIROC-H and MIROC-M)

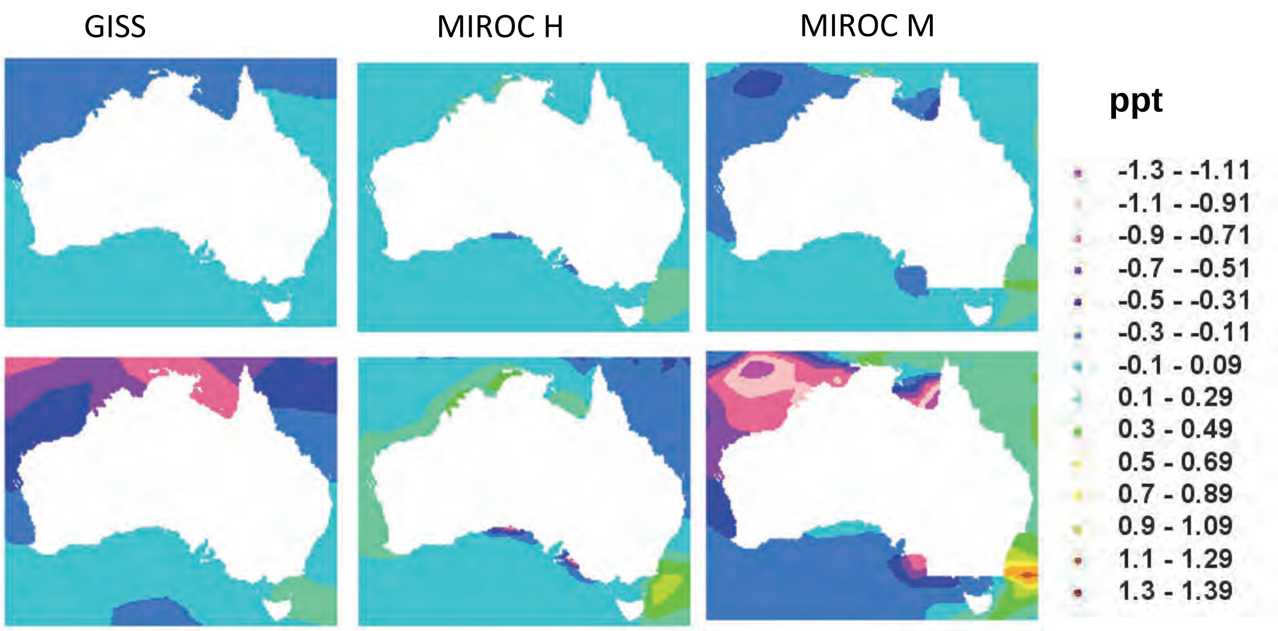

Figure 4.7 Change in annual mean Sea Surface Salinity (g/l) from 1990 baseline under scenario A1FI by 2030 (top row) and 2070 (bottom row) projected by three GCMs (GISS; MIROC-H and MIROC-M)

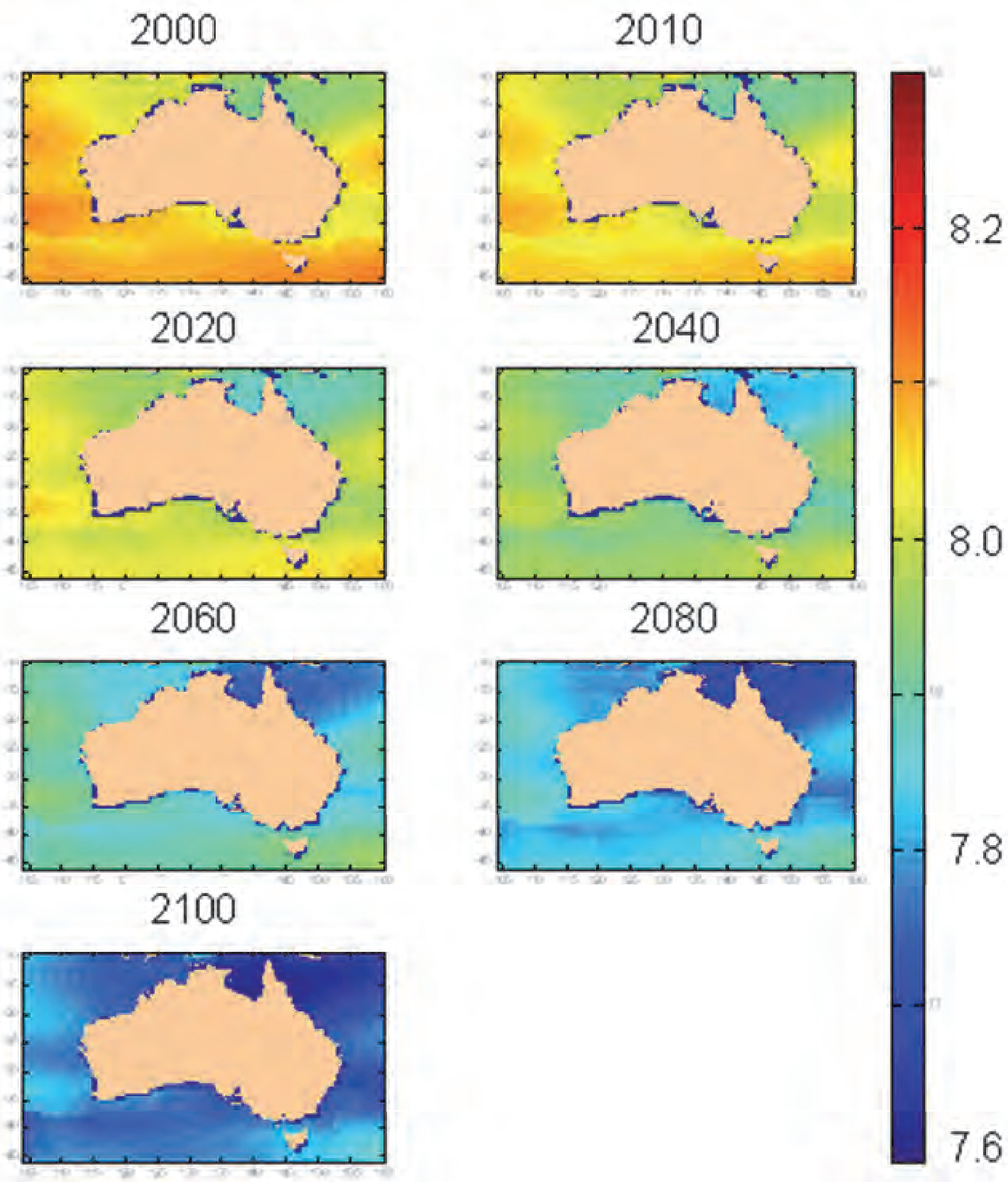

Figure 4.8 Projected progression of ocean acidification around Australia under emission scenario A2.

4.3. Sea level rise

4.3.1. Observed sea level rise

There is considerable variability in the rate of sea level rise during the 20th Century (Church and White 2011). The average rate of sea level rise around the Australian coastline between 1920 and 2000 is 1.2 mm/yr (Church et al. 2006). The two longest records of sea level in Australia, from Sydney and Fremantle, show relative sea level rise of 0.9±0.2 mm/yr over 1914-2007 and 1.4±0.2 mm/yr over 1897-2007 respectively (Church et al. 2009).

4.3.2. Projected sea level rise and coastal inundation

Sea-level rise and changes in extreme events such as storm surges increase the risk of inundation of the terrestrial and estuarine regions of Australia's coastal zone by seawater. The coastal inundation dataset produced by Geosciences Australia was supplied by Department of Climate change and Energy Efficiency. The inundation model uses a relatively simple 'bucket fill' approach where the water height is projected inland and all land areas below this elevation are classed as inundated (for further details see DCC 2009).

The inundation datasets (DCC 2009) are on a 100 m^2 grid and three future scenarios are explored: 2030 max, 2100 min and 2100 max. Previously, the intersection between these datasets and a 100 km^2 grid covering Australia's coastal region, were plotted (Fig. 4.9-11; Taranto 2009). The regions with the highest proportion of inundation tend to occur on northern Australia, particularly in the gulf and estuarine systems.

Coastal Inundation - 2030max

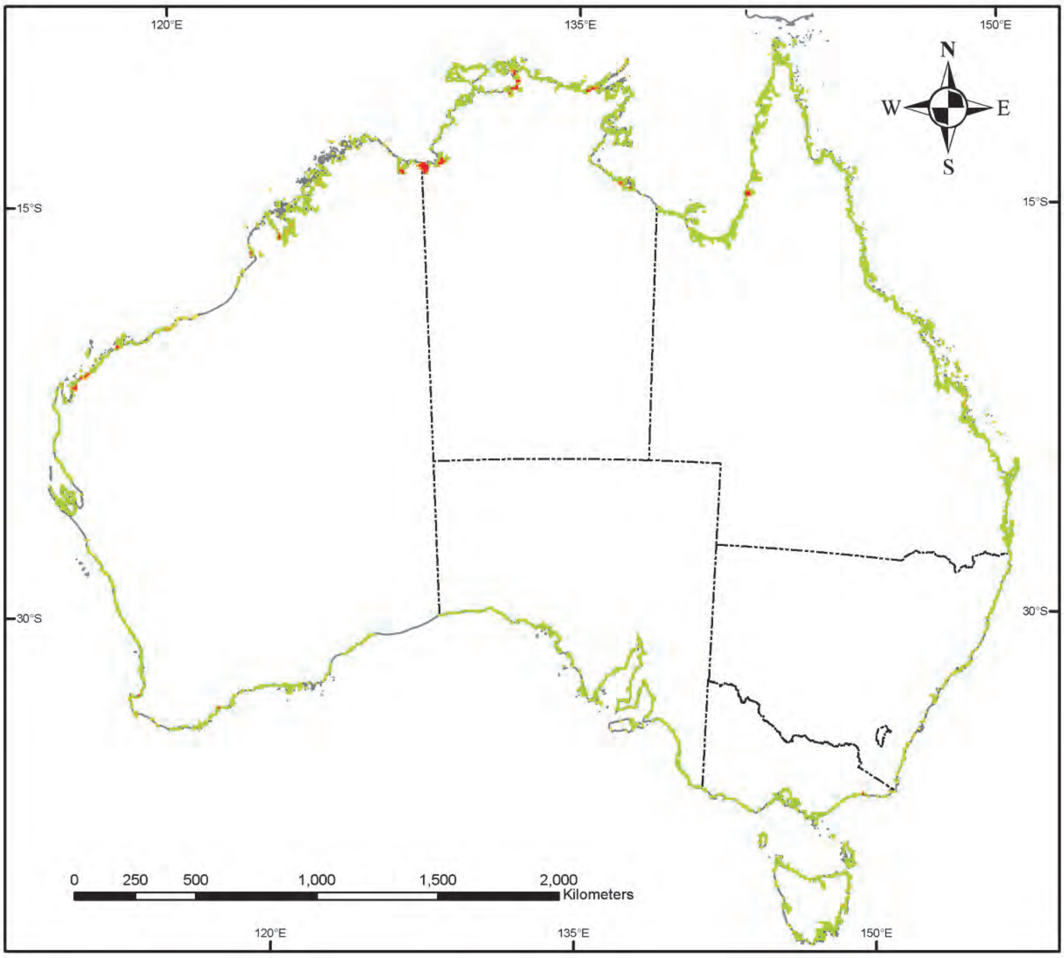

Figure 4.9 Area inundated (%) in each 10 x 10km grid cell covering Australia's coastal region under future scenario 2030max. Green cells = < 2% of cell inundated, orange cells = 2-5 % of cell inundated, red cells = >5% of cell inundated.

Coastal Inundation - 2100min

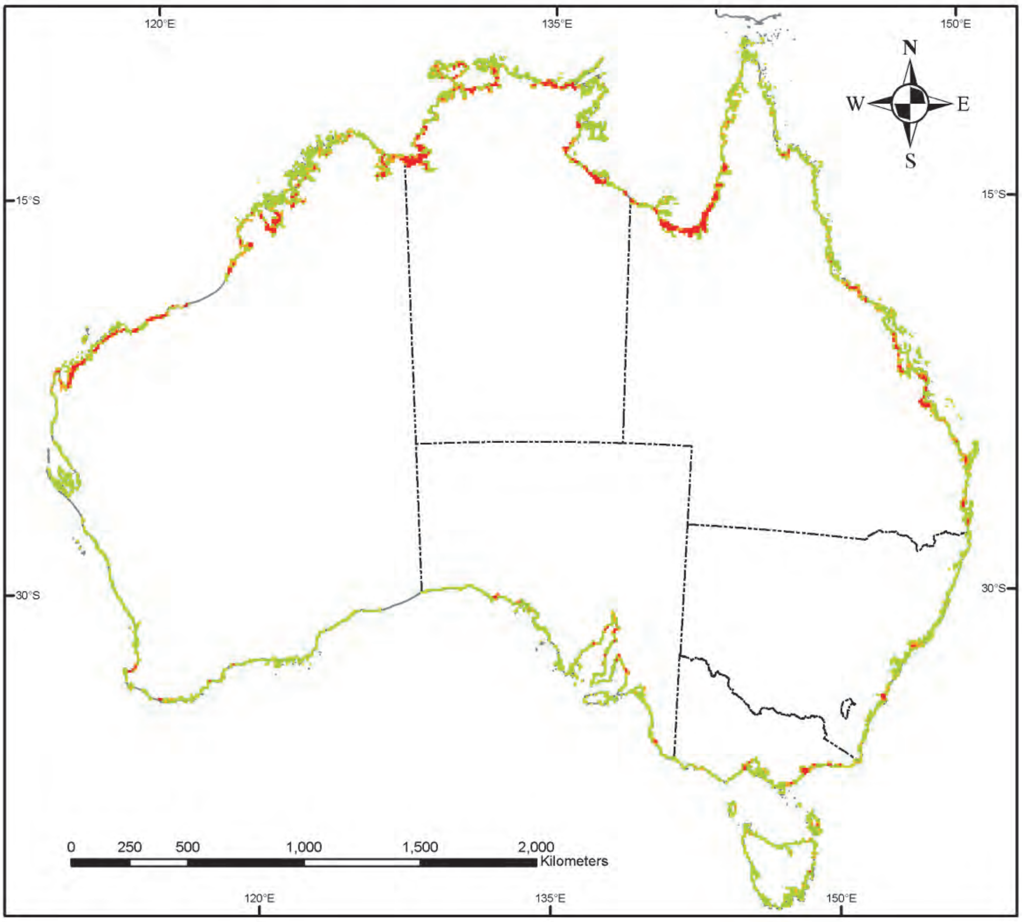

Figure 4.10 Area inundated (%) in each 10 x 10km grid cell covering Australia's coastal region under future scenario 2100min. Green cells = < 2% of cell inundated, orange cells = 2-5 % of cell inundated, red cells = >5% of cell inundated.

Coastal Inundation - 2100max

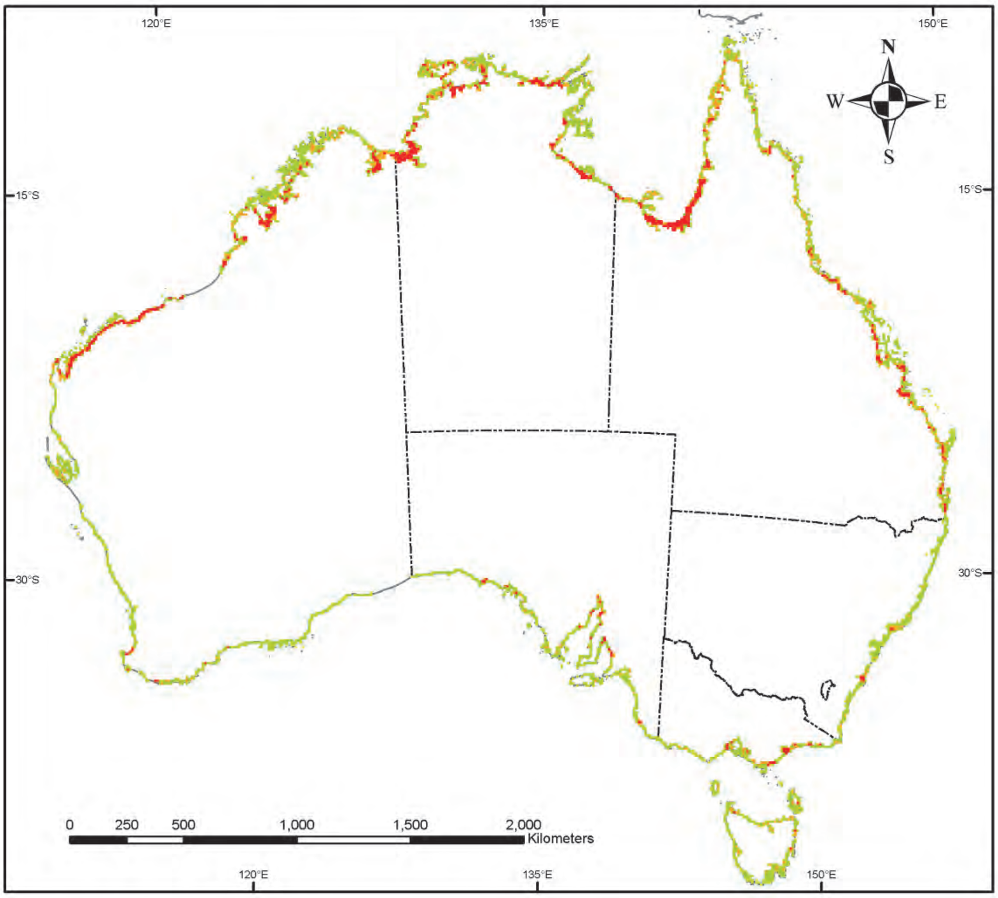

Figure 4.11 Area inundated (%) in each 10 x 10km grid cell covering Australia's coastal region under future scenario 2100max. Green cells = < 2% of cell inundated, orange cells = 2-5 % of cell inundated, red cells = >5% of cell inundated.

Regional inundation patterns

Projected inundation was analysed using the IBRA bioregionalisation. For each IBRA region, *coastline length* (km), *bioregion area* (km^2) and the *coastal area,* defined as area within 14km of the coast (km^2), were determined. A distance of 14km was chosen to define the inland coastal limit as 90% of the area inundated under the 2009 baseline is within this boundary. IBRA regions were intersected with the inundation datasets to determined the total *area inundated* (km^2) per IBRA region under baseline (2009) conditions and for the projected scenarios (Table 4.3). From these statistics, two further indices were determined (Table 4.4). First, *average retreat* of the coastline landwards in m (*area inundated/coastline length* x 1000), in other words, the average distance of inundation landwards. Second, the percentage of the coastal area inundated *coastal inundation* (*area inundated/coastal area* x 100). The statistics are presented as averages for each IBRA region, however users should be aware that coastlines are complex with a range of land formation including estuaries and headlands. As a result of these formations, the inundated areas of each coastline may be fragmented. Inundation also penetrates river systems.

Coastline length is extremely variable among IBRA regions ranging from 51km (IBRA 36: Flinders Lofty Block) to 4,744km (IBRA 81: Arnhem Coast). Discussion will focus on the IBRA regions with larger coastlines (>800km). Of these, most regions had relatively low levels of inundation of the coastal areas in 2009 (<400km^2). Five regions (IBRA 39: Gulf Plains, 52: Victoria Bonaparte, 54: Carnarvon, 58: Dampierland, 68: Pilbara) had extensive coastal regions (>7000km^2) and extensive baseline inundation (>700km^2 and >7% of coastal area). Under the 2100max scenario, the inundation of the coastal areas of these regions is projected to increase by 38 - 107% with the exception of IBRA 39 (Gulf Plains) where the inundated area increases from 769km^2 to 3647km^2 (Table 8). All of these are northern and western tropical shores that are low profile and not backed by rocky cliffs. 46% of the Northern Territory coastline and 20% of Western Australia coastline are muddy shores backed by soft sediments (mainly tidal mud flats) and low profile soft rock shores (DCCEE 2009). In Western Australia, rocky coastline is found in the Kimberley and south coast with the remainder, which include the regions identified with high baseline inundation, tend to be sandy or muddy tidal flats (DCCEE 2009).

Table 4.3 Statistics for each coastal IBRA regions: area (km^2), coastline length (km), coastal area (km^2) within 14 km of coastline and area inundated (km^2) in 2009 and under future scenarios 2030max, 2100min and 2100max. The % of the bioregion inundated in 2009 is also given. The IBRA regions encompassing the coastal sections of the three case study areas are highlighted.

IBRA number	IBRA name	Bioregion area km^2	Coastline length km	Coastal area km^2	2009: Area inundated km^2	2030max: Area inundated km^2	2100min: Area inundated km^2	2100max: Area inundated km^2
1	Murray Darling Depression	196564	125	1170	1047	1048	1073	1080
2	Naracoorte Coastal Plain 2457	6	417	5076	6	10	89	106
3	Victorian Volcanic Plain 2440	3	88	1970	8	8	21	22
4	South East Coastal Plain	17492	1750	8865	363	373	773	823
5	South Eastern Highlands	80952	101	1786	0	0	1	1
9	Flinde rs	5337	1286	4978	73	85	146	176
10	South East Corner	25553	626	6243	133	146	209	221
13	Tasmanian South East	11061	1303	4588	20	32	65	82
14	Tasmania	15640	782	5245	14	17	31	45

IBRA number	IBRA name	Bioregion area km^2	Coastline length km	Coastal area km^2	2009: Area inundated km^2	2030max: Area inundated km^2	2100min: Area inundated km^2	2100max: Area inundated km^2
	n West							
15	Tasmanian Southern Ranges 7818		413	2004	4	6	12	17
20	Sydney Basin	38096	837	5566	83	85	183	194
22	Brigalow Belt North	136130	1854	9028	230	258 629	701	
27	NSW North Coast 3995	7	649	5733	44	46 103		125
31	Gawler	123641	215	2207	17	19 53	59	
33	Nulla rbor	197228	275	3959	2	4	15	30
34	Hampto n	10882	342	4269	5	6	9	11
35	Eyre Yorke Block 6090	9	2665	21470	63	86	344	433
36	Flinders Lofty Block	71263	51	1380	0	1 2 4		
37	Kanmanto o 8123		595	4923	7	8	16	26
39	Gulf Plains 2205	83	1383	11029	769	876	3470	3647
40	Cape York Peninsula	121158	3087	21293	84	145 372	633	
42	Wet Tropics	19988	1061	7063	19	36	90	162
43	Central Mackay Coast	14628	2324	6264	110	128 282	316	
52	Victoria Bonaparte	73009	1377	8579	2377	2486 3275	3279	
54	Carnarvon	84276	1858	13484	1177	1261 1680	1725	
57	Esperance Plains	29176	1202	9858	24	40	79	105
58	Dampierland	83617	1764	13897	1241	1302 1974	2029	
61	Jarrah Forest 4509	0	129	1694	2	2	7	11
62	Wa rren	8445	580	4216	2	7	79	89
64	Mallee	73976	124	2846	1	2	7	14
66	Northern Kimberley 8406	8	8427	22161	673	709	1069	1166
67	Geraldton Sandplains 3140	5	409	5347	4	7	16	28
68	Pilbara	178213	1383	7610	702	754	1418	1456
69	Swan Coastal Plain 1525	6	556	6385	13	29	77	101

IBRA number	IBRA name	Bioregion area km^2	Coastline length km	Coastal area km^2	2009: Area inundated km^2	2030max: Area inundated km^2	2100min: Area inundated km^2	2100max: Area inundated km^2
71	Yalgoo	50872	885	3127	35	40 60	88	
72	Gulf Coastal	27105	1070	6165	224	245 786	799	
74	South Eastern Queensland	78595	3043	14912	197	227 444	568	
77	Central Arnhem	34624	100	1316	10	11 23	24	
79	Darwin Coastal	28424	1699	12124	360	479	1231	1264
80	Tasmanian Northern Slopes	6231	62	1290	2	3 6 9		
81	Arnhem Coast 3331	8	4744	17615	392	454	969	1056
83	Tiwi Cobourg	10104	1879	9115	308	358 591	649	
85	King	4250	801	3041	9	15 32	48	

Table 4.4 Average shoreline retreat (m) and % of the coastal region (within 14km of coastline) inundated in 2009 and under three future climate scenarios. The IBRA regions encompassing the coastal sections of the three case study areas are highlighted.

	Average Retreat m				Coastal Inundation %			
IBRA #	2009	2030max	2100min	2100max	2009	2030max	2100min	2100max
1	8357	8369	8568	8623	89.5	89.6	91.7	92.3
2	15	24	214	254	0.1	0.2	1.8	2.1
3	88	91	233	252	0.4	0.4	1.0	1.1
4	207	213	441	470	4.1	4.2	8.7	9.3
5	4	4	9	13	0.0	0.0	0.1	0.1
9	57	66	113	137	1.5	1.7	2.9	3.5
10	212	233	335	353	2.1	2.3	3.4	3.5
13	15	25	50	63	0.4	0.7	1.4	1.8
14	18	21	40	58	0.3	0.3	0.6	0.9
15	10	14	29	41	0.2	0.3	0.6	0.9
20	99	101	219	232	1.5	1.5	3.3	3.5
22	124	139	339	378	2.6	2.9	7.0	7.8
27	67	71	159	192	0.8	0.8	1.8	2.2
31	80	89	245	276	0.8	0.9	2.4	2.7
33	6	16	56	109	0.0	0.1	0.4	0.8
34	15	17	26	33	0.1	0.1	0.2	0.3
35	24	32	129	163	0.3	0.4	1.6	2.0
36	4	13	43	86	0.0	0.1	0.2	0.3
37	11	14	27	44	0.1	0.2	0.3	0.5
39	556	633	2509	2637	7.0	7.9	31.5	33.1
40	27	47	121	205	0.4	0.7	1.8	3.0
42	18	34	85	153	0.3	0.5	1.3	2.3
43	47	55	121	136	1.8	2.0	4.5	5.0
52	1726	1805	2379	2381	27.7	29.0	38.2	38.2
54	634	679	904	929	8.7	9.4	12.5	12.8
57	20	33	66	88	0.3	0.4	0.8	1.1
58	703	738	1119	1150	8.9	9.4	14.2	14.6
61	12	19	55	83	0.1	0.2	0.4	0.6
62	3	12	136	154	0.0	0.2	1.9	2.1
64	7	18	56	110	0.0	0.1	0.2	0.5
66	80	84	127	138	3.0	3.2	4.8	5.3
67	10	17	39	70	0.1	0.1	0.3	0.5
68	508	545	1025	1053	9.2	9.9	18.6	19.1
69	23	52	138	181	0.2	0.5	1.2	1.6
71	39	45	68	100	1.1	1.3	1.9	2.8
72	210	229	735	746	3.6	4.0	12.8	13.0
74	65	75	146	186	1.3	1.5	3.0	3.8
77	103	107	235	244	0.8	0.8	1.8	1.9
79	212	282	725	744	3.0	4.0	10.2	10.4
80	31	44	100	147	0.2	0.2	0.5	0.7
81	83	96	204	223	2.2	2.6	5.5	6.0
83	164	191	314	345	3.4	3.9	6.5	7.1
85	11	18	40	59	0.3	0.5	1.1	1.6

4.4. Summary

All major components of the Australian coastal climate (terrestrial, marine and sea level) have changed over the last century and are projected to change over the next century under the climate change scenarios considered here, i.e. A1FI (high impact, high sensitivity) and A1B (medium impact, medium sensitivity). These changes vary regionally around the coastline as well as seasonally in many cases.

With respect to the terrestrial climate, air temperatures have risen by just under 1° C since 1910 with a particular decline in the frequency of extreme cold. The last decade was the warmest on record. Rainfall, which is highly variable both temporally and spatially in Australia, has declined since 1950 in eastern and south-western Australia, but increased in the north. No significant trends in the frequency or intensity of tropical cyclones has been detected however a decline in cyclones south of 20°C on the east coast has been observed.

Air temperature is projected to rise in all Australian coastal regions between 0.8 – 2.1°C by the 2030s and between 1.8 – 6.2°C by the 2070s. A relatively small change in the seasonality of temperatures is projected but warming is likely to be particularly notable in terms of increased minimum temperatures during colder months. Mean annual rainfall is projected to decline in all coastal regions by 4-58%, depending on region, by the 2030s. Rainfall in the wettest period, however, is projected to increase in North Queensland and south-western Western Australia. Solar radiation is also projected to increase throughout the Australian coastal zone, particularly in the east, but is projected to decrease during the warmest quarter in the south-west and south-east, with the exception of Tasmania. Soil moisture is projected to decline in all coastal areas by up to 28% by 2030. Projections concerning extreme events are highly uncertain but suggest a potential increase in the number of tropical cyclones in categories 3-5 along with an overall decline in the total number as well as a poleward shift in the regions of cyclone genesis and decay. Modelling also suggests a possible increase in coastal winds associated with extreme events as well as in response to increased ocean surface temperatures. A loss of east coast lows may also occur as a result of changes in the East Australian Current.

In the marine climate system, Australian sea surface temperatures have risen by 0.9°C since 1900 with the greatest rates of warming occurring over the last 50 years, particularly during summer, and in the south-east and south-west. Associated changes have included an increase in ocean salinity resulting in a latitudinal shift in sea surface climate of approximately 3° or 350 km. This is a higher degree of warming than the global average and has been driven by an intensification of the East Australian Current. Ocean pH has also fallen by 0.1 in Australia since 1750 and an increase in the frequency and intensity of large wave events along the southern coast has also been identified.

Projected changes in Australia's marine coastal climate under the scenarios considered here include a warming of sea surface temperatures by 0.2 – 1.2°C by the 2030s and 0.5 – 3.8°C by the 2070s, with the greatest degree of warming projected for the north-west and south-east. Southern and north-eastern coastal waters are also projected to become slightly fresher by the 2030s while western, northern and south-eastern waters are projected to become slightly saltier, patterns which are likely to intensify by the 2070s. Average ocean pH is projected to fall, particularly in the north-east, by 0.3 – 0.4 if CO_2 concentrations reach 540 – 979 ppm by the end of this Century making the ocean more acidic than at any time over the last 800 000 years.

Finally, sea level rose by an average of 1.2 mm/yr around Australia between 1920 and 2000 and is projected to increase over the next century, particularly in northern and western tropical coastal areas with low profiles that are not backed by rocky cliffs, e.g. estuarine systems. In the regions with extensive coastal zones considered here, coastal inundation is projected to increase up to 38 – 107 % by 2100.

5. CLIMATE CHANGE IMPACTS IN AUSTRALIAN COASTAL ECOSYSTEMS

Climate change is having significant and appreciable effects on ecosystems, communities and species on the land and in the sea (Walther et al. 2002, Parmesan and Yohe 2003, Steffen et al. 2009, Hoegh-Guldberg and Bruno 2010). Major effects include reduced size and replenishment of populations (e.g. Hoegh-Guldberg et al. 2007), shifts in latitudinal ranges of species (Perry et al. 2005, Pitt et al. 2010) and changes in taxonomic composition and community dynamics (Hughes et al. 2003, Ficke et al. 2007). This chapter considers observed and predicted impacts of climate change on Australian coastal ecosystems based on results of literature reviews and an expert panel workshop conducted during this project. Further details are available in the full Science Report accompanying this Synthesis Report.

5.1. Marine coastal ecosystems

5.1.1. Drivers of climate change impacts

The major drivers of climate change impacts in marine ecosystems will be increasing sea surface temperature and increased levels of dissolved CO_2 in ocean waters, thereby reducing pH (Pratchett et al. 2011). Changes in ocean circulation and currents are also likely to be significant. Other drivers of climate change impacts in marine coastal ecosystems are likely to include sea level rise, which will lead to a redistribution of shallow habitats and may enable tropical corals and temperate macroalgae to encroach on new habitats (Short and Neckles 1999). More extreme rainfall and runoff events will also increase sedimentation and eutrophication of coastal marine ecosystems which may smother substrates and inhibit recruitment of corals and kelp. Similarly, more intense tropical cyclones would cause greater damage to key habitat-forming species (Madin and Connolly 2006) and, in temperate regions, changes in the direction and intensity of storms could increase deforestation of macroalgal forests (Seymour et al. 1989).

Ocean temperature

Temperature has a significant influence on most marine organisms (e.g. fish), as they have limited capacity to maintain independent body temperatures, and therefore has a major bearing on the geographic ranges and general biology of many marine species (Brett 1969, Perry et al. 2005, Portner and Farrell 2008). Many marine organisms are relatively tolerant of short-term changes in temperature and tend to live well within their critical thermal limits (Brett 1956, Mora and Ospina 2001). However, most organisms have a ‘hump-shaped’ temperature-performance curve whereby performance (e.g. growth, reproduction or movement) increases with increasing temperature up until a certain point and then declines (Huey and Stevenson 1979, Portner and Farrell 2008). As temperature rises due to global warming, it is predicted that populations of thermally sensitive marine organisms will shift to higher latitudes while populations that endure warmer waters may exhibit changes in life history traits such as growth rates and longevity (Munday et al. 2008). Global warming is therefore likely to have significant consequences for the distribution and abundance of key species as well as the productivity and composition of marine communities.

Ocean acidification

Ocean acidification is caused by the uptake of additional carbon dioxide (CO_2) at the ocean surface which reacts with seawater to form weak carbonic acid, causing pH to decline and reducing the availability of dissolved carbonate ions that many marine organisms need to build their shells or skeletons (Orr et l. 2005, Hoegh-Guldberg et al. 2007, Fabry et al. 2008). Ongoing ocean acidification will reduce the growth and survival of many calcifying organisms and therefore the food webs which rely on them (Fabry et al. 2008, Doney et al. 2009). Ocean acidification may also directly affect marine organisms by influencing species' metabolisms and development, particularly during early life history stages, e.g. egg fertilisation and larval development in marine fish and invertebrates (Portner et al. 2004, Shirayama and Thornton 2005, Havenhand et al. 2008, Munday et al. 2009b).

Ocean currents

Changes to ocean circulation and current patterns expected as a consequence of climate change (e.g. Alory et al. 2007) could impact on marine organisms in two main ways. Firstly, currents and other hydrodynamic features play an important role in the retention and dispersal of pelagic larvae (James et al. 2002, Cowen 2002, Burgess et al. 2007) and changes to circulation patterns could have fundamental effects on spatial and temporal patterns of larval settlement and connectivity between populations (Munday et al. 2009). Secondly, currents are important for the delivery of food and nutrients to marine coastal habitats, influencing the production and distribution of plankton (Hays et al. 2005, McKinnon et al. 2007) and therefore the productivity and structure of coastal food webs.

5.1.2. Impacts on coral reefs

Climate change is widely recognised as the most important emerging threat to coral reef ecosystems and there are many ways that climate change will impact on coral reef species, communities and ecosystems (Hughes et al. 2003, West and Salm 2003, Hoegh-Guldberg et al. 2007, Wachnefeld et al. 2007). So far, the most devastating effects of climate change have been large-scale and severe episodes of coral bleaching resulting from increasing sea surface temperatures (Goreau et al. 2000). In 1998, coral bleaching occurred in over 50 countries around the world, killing up to 90% of corals and causing marked changes in the taxonomic composition of coral assemblages (e.g. Riegl and Purkis 2009).

Australian coral reefs were largely spared during the 1998 event and, whilst bleaching was conspicuous and widespread in the Great Barrier Reef, bleached corals mostly recovered well (Wilkinson 2004) and overall mortality rates were generally very low (Maynard et al. 2008, Anthony and Marshall 2009). The most extensive and severe bleaching event in the Great Barrier Reef occurred in 2002, in which bleaching was recorded in 54 % of surveyed reefs, and corresponded with the highest sea surface temperatures (> 33°C) ever recorded on the Great Barrier Reef (Berkelmans et al. 2004, Maynard et al. 2008). Bleaching was also more extensive and severe on inshore (i.e. coastal) reefs compared to offshore reefs (Berkelmans et al. 2004).

By 2050, most coral reefs are expected to be subject to annual thermal anomalies equivalent to that which occurred in 1998 (Hoegh-Guldberg 1999) suggesting that mass bleaching will occur at a frequency beyond that at which corals are able to recover between events (Donner at al. 2005). Effects of increasing temperature will be exacerbated by ocean acidification which reduces coral growth an increases susceptibility to coral bleaching (Hoegh-Guldberg et al. 2007).

Ocean warming and increased runoff are likely to father increase coral reef degradation since the recovery of coral reefs from bleaching may be limited by the colonisation and enhanced growth of macroalgae, particularly where there is low grazing pressure from fish or urchins, and suppression of coral recruitment (Ostrander et al. 2000, McClanahan et al. 2001, Diaz-Pulido and McCook 2002, Fabricius 2005, Hughes 2007). This may lead to a shift from coral to macroalgal dominated reefs.

5.1.3. Impacts on macroalgal forests

The abundance of giant kelp (*Macrocystisis pyerifera*) has declined dramatically over the past 30 years, particularly in south-eastern Tasmania (Edgar 1997). The total area of Australian kelp forests in the 1950s was estimated to be 120 km^2 but more recent estimates of 8km^2 in 1986 and 0.5 km^2 in 1998/89 indicate a major loss (Edgar 1997). Climate change, particularly increasing temperatures and strengthening of the East Australian Current, has been directly linked to changes in the distribution and abundance of herbivorous species (e.g. the black sea urchin, *Centrostephanus rogersii)* along the eastern coastline (Edgar 1999, Ling et al. 2009) which are likely to have strongly contributed to this dramatic loss (Edgar 1999). High densities of the black sea urchin have completely removed giant kelp and other macroalgae from patches of rocky habitat which now, as ‘urchin barren’s support a fraction of the biodiversity of former and adjacent macroalgal forests (Ling 2008).

Temperature is a major driver of distribution patterns of marine algae (Wernberg et al. 2009) and kelps are mostly limited to coldwater coastal zones with high concentrations of nitrogen (mostly arising from upwelling). Warm-water algae are expected to move polewards in response to global warming where they are likely to outcompete and replace cold-water species. Canopy-forming kelp have already been replaced by more ephemeral seaweed species in many locations (Steneck et al. 2002). In 1982-1983, marked warming caused by an extreme ENSO event led to extensive nutrient depletion that killed giant kelp throughout Alta and Baja California (Paine et al. 1998). Permanent shifts in temperature and nutrient regimes related to global warming therefore have the potential to significantly impact on kelp forests. Increasing frequency and intensity of extreme storm events, which have been linked to increasing sea surface temperatures (Graham and Diaz 2001), can also cause extensive deforestation of macroalgal forests.

5.2. Estuarine coastal ecosystems

5.2.1. Drivers of climate change impacts

Ecosystem-level impacts of climate change on estuarine ecosystems are likely to be driven to a large degree by changes to the dominant physical processes (i.e. river, tide and wave energy) which shape and maintain them as these are major determinants of the character of estuarine habitats and the species which inhabit them. Sea level rise is also likely to be a major driver both directly and by interacting with these dominant physical processes. Temperature, which is both a key driver of aquatic productivity and an environmental cue for many ecological processes (Allen et al. 2008), and an increased frequency and intensity of cyclones and extreme storm events, which can result in large-scale loss of seagrass beds in response to associated run-off and sediment loads (Carlson et al. 2010), are also likely to be significant.

River energy

A change in river energy and inflows into estuarine and coastal environments, including greater frequency and duration of extreme events (e.g. droughts), is likely to be a major and significant consequence of climate change in Australia (Baptista et al. 2010). Droughts can have significant effects on estuarine ecosystem structure and function including the loss of freshwater species and intrusion of marine species (Baptista et al. 2010). Demonstrated relationships between river flows and prawn catches in Australia (Loneragan and Bunn 1999) suggest that changes in river flows due to climate change will also have significant ramifications for estuarine productivity. Significant reductions in runoff and streamflow resulting from more frequent and longer droughts, projected under many climate change scenarios (e.g. Lake 2003), also have many consequences for patterns and rates of water exchange as well as sedimentary and geomorphological processes including the reduced export of sediments from tidal and fluvial deltas, increased intrusion of marine water resulting in stratification and possibly anoxia further upstream, closure of estuary entrances, decreased accretion of sediments on super-tidal and floodplain habitats and reduced export of larvae from estuaries.

Overall reductions in river flow associated with long-term dry spells are also projected, under climate change scenarios, to be punctuated by intense rainfall and flooding which will lead to short periods of very high river energy. The consequences of such extreme events are likely to include the temporary export from estuaries of large quantities of sediment and nutrients, complete flushing of water from estuaries, forced opening of estuaries by freshwater and temporary loss of estuarine conditions throughout entire estuaries.

Wave energy

Climate change scenarios and recent observed trends show increasing occurrence of El Nino and positive phases of Southern Annual Mode (SAM), both of which are associated with reductions in the strength and changes in the prevailing direction of wind systems in north-eastern and south-western Australia (Hemer et al. 2008). To date, there has been very little research into how wave energies may change in particular regions and what this might mean for estuaries.

Tide energy

Whilst little is known of how tidal cycles, magnitudes and variability may change under climate change scenarios, changes in wave and river energy will undoubtedly influence the tidal environment around Australia’s coastline with significant implications for physical processes, especially sediment dynamics, and connectivity (Adam 2002). Coastal geomorphological processes, for instance, can alter the ratio of wave to tide power and therefore patterns of sediment deposition with estuaries (Allard et al. 2009).

Sea level rise

Estuarine flooding associated with sea level rise pose threats to arrange of habitats (e.g. mangroves, saltmarsh, seagrass and tidal flats) as well as the connectivity within and between these (Poloczanska et al. 2009). Critically, while existing mangrove and saltmarsh habitats may be flooded (Poloczanska et al. 2009, Lopez-Medellin et al. 2011), new areas may also become available for colonisation as the tidal extent of estuaries grow in response to elevated sea levels (Gilman et al. 2008). Sea level rise will also affect the light environment in estuaries with reduced light in deeper habitats likely to be particularly detrimental to seagrass (Ralph et al. 2007).

5.2.2. Impacts on estuarine habitats

The capacity of inter-tidal communities (e.g. mangroves and saltmarsh) to move landward into new areas in response to sea level rise will be limited by the availability of substrates and particularly by the presence of human settlements and infrastructure (Gilman et al. 2008, Poloczanska et al. 2009). Mangroves, for instance, show great capacity to withstand moderate sea level rise due to their morphological and developmental flexibility, methods of dispersal and high growth rates (Gilman et al. 2008, Huxham et al. 2010, Lopez-Medellin et al. 2011) and some studies suggest that they can enhance surface accretion in areas susceptible to sea level rise (Kumara et al. 2010, McKee 2011). Saltmarsh communities are also perceived as somewhat flexible and mobile in response to sea level rise but to a lesser degree than mangroves (Adam 2001). Consequently, the invasion of saltmarsh habitats by mangroves is widely predicted in response to sea level rise (Harty 2004, French 2006, Rogers et al. 2006, Doyle et al. 2010). In locations where landward migration opportunities are limited by human developments, the squeeze on saltmarsh communities may result in significant losses of this habitat type.

Seagrass communities are likely to be negatively affected by rising sea levels as light penetration will be reduced at deeper sites (Ralph et al. 2007). Although the overall impacts are likely to be negative (Duarte 2002), opportunities for seagrass to colonise inundated tidal flats may also occur although these are likely to be influenced by interactions with water temperature, changes to river flow and runoff etc. (Blake and Emmett 2010, Carr et al. 2010, Grilo et al. 2011, Rasheed and Unsworth 2011).

Warming of coastal and estuarine waters has also been shown to alter larval recruitment, secondary production and trophic interactions (Allen et al. 2008). Increased temperature will not only alter patterns of productivity, but the associated increase in oxygen depletion in coastal waters will further threaten life in some estuarine habitats potentially leading to ‘dead zones’ in which only the most hypoxia-tolerant species can persist (Altieri 2008).

Furthermore, an increase in storms, as anticipated under a changed climate, will be likely to alter the dynamics of estuary metabolism since estuarine ecosystem metabolism is significantly depressed during high flow periods relative to low flow periods (Mead and Wiegner 2010). However, with longer duration of low flow conditions also anticipated (between the intense events), the balance of estuarine production will ultimately vary from one year to the next depending on local conditions.

5.3. Terrestrial interface coastal climate

5.3.1. Drivers of climate change impacts

Terrestrial interface coastal ecosystems are subject to both terrestrial and marine climate drivers, the relative influence of which vary locally on a gradient from the sub-aerial to sub-tidal zone. Changes to these dominant physical processes associated with climate change are likely to interact to drive ecological impacts of climate change. Sea level rise is also likely to be a particularly significant driver of climate change impacts in terrestrial interface coastal ecosystems.

Terrestrial climate drivers

Air temperature influences the biota of sub-aerial and intertidal zones of all terrestrial coastal ecosystems both directly, through limiting species distributions, and indirectly, e.g. by controlling food web interactions. Rainfall is also important, as this influences freshwater discharge which, in turn influences beach dynamics and groundwater levels (Schlacher et al. 2008). Given its influence on the transport of sand, and therefore beach and dune shape and stability, wind is also a particularly significant climate driver for the terrestrial interface coastal realm, and also determines wave direction and strength which further affect sediment dynamics and coastal morphology. All of these climate drivers are likely to change in the Australian coastal zone under climate change scenarios (see above and Chapter 4). Increased ultraviolet (UV) radiation is also likely to be directly related to global warming (Brown and McLachlan 2002).

More frequent and intense tropical cyclones and extreme storm events would also be major drivers of climate change impacts in terrestrial coastal ecosystems since these exert considerable influence on shoreline erosion and beach/dune morphology by affecting wave and wind energy as well as rainfall and flooding. Predictions are difficult, however, due to the unpredictable nature of individual future events (Abuodha and Woodroffe 2010).

Fire plays a significant role in coastal dune and headland ecosystems in Australia, affecting vegetation and habitat structure as well as directly influencing fauna (Keith 2006). Fire regimes are projected to change in response to global warming and associated declines in precipitation and humidity as well as altered wind speeds, with increased frequency and intensity of fires likely, particularly in southern Australia (Steffen et al. 2009).

CO_2 fertilisation may also have an impact in coastal dune and headland ecosystems by leading to the thickening of dune vegetation and invasion of grass-dominated areas by woody shrubs (Steffen et al. 2009).

Marine climate drivers

Sea surface temperature, projected to rise in response to climate change (see Chapter 4) can influence inter-tidal and sub-tidal coastal habitats both directly, e.g. through controls on organism metabolism, and indirectly, e.g. via food webs. Ocean acidification may also significantly affect the biological component of inter-tidal and sub-tidal communities since many beach species have calcified exoskeletons (McLachlan and Brown 2006). Changes to ocean currents, e.g. weakening of the

Leeuwin current, are also likely to affect marine productivity and therefore inputs into the food webs of sub-tidal and inter-tidal habitats (DSWEPAC 2011).

Sea level rise

Sea level rise is known to enhance coastal erosion due to landward recession of beaches (Church et al. 2008). With an increase in sea level rise, combined with increased storminess, beaches are likely to erode and migrate inland without human intervention (DCC 2009). Changes in wind, tide and current patterns will also alter local and longshore sediment transport patterns and therefore beach accretion and erosion.

5.3.2. Impacts on sandy beaches

Although there have not been any direct studies of climate change on beach ecosystems (Dafeo et al. 2009), sandy beaches are generally considered to be extremely vulnerable to climate change, particularly to the threats associated with sea level rise and higher storm surges (Jones 2008, Schlacher et al. 2008). Climate change impacts will vary geographically with biologically diverse dissipative beaches likely to be more at risk due to increased storm surges and cyclones (Castelle et al. 2008, Lucrezi et al. 2010) and beaches backed by low plains or dunes, rather than those with cliffs and rocky shores also considered more vulnerable (Abuodha and Woodroffe 2010). In some areas, climate change may induce a slow retreat of the coastline with few effects on beach ecosystems (Elliot et al. 2006) whilst total loss of sandy beach habitat might occur under more extreme climate change scenarios (Jones et al. 2008). At a local scale, the dune/beach interface is often the most affected by storm events and erosion and is considered the most sensitive area to climate change impacts (Brown and McLachlan 2002).

Increasing temperatures will have direct effects on beach species with those adapted to cooler conditions likely to decline with possibilities of local extinctions, particularly amongst species currently at their upper thermal limits (Jones et al. 2008). At a regional level, southern species are most likely to be affected. Jones et al. (2008), for instance, report that 3.7% of Victorian coastal marine invertebrates are endemic to the region with many limited to cool-temperate waters. Increased sand temperatures are also likely to impact on the recruitment of marine turtles since sex determination and hatching success are driven by sand temperatures (Fuentes et al. 2009).

Global warming will also have many indirect effects on beach ecosystems. Processes such as photosynthesis, decomposition and nutrient cycling, for instance, will all be affected by rising temperatures with implications for productivity and food web structure. One potential implication is accelerated decay of beach wrack which may de-oxygenate the underlying sand with deleterious effects for many sandy beach species (Jones et al. 2008). Changes to productivity and food web structure are also likely to arise from altered wave action, storm surges and ocean currents as well as the effects of ocean acidification (see above). Altered connectivity between coastal ecosystems, e.g. marine contributions to beach food webs, will also play a role (Jones et al. 2004).

Increased coastal erosion and loss of beach habitat due to sea level rise and associated processes will be major consequences of climate change with implications for the availability and suitability of breeding, feeding and resting habitat for significant beach macrofauna species including marine turtles, pinnipeds and shorebirds. Beach microfauna are considered to be relatively resilient to storm surges and associated disturbances but their long-term responses to altered frequency and intensity of such events is poorly understood.

5.3.3. Impacts on dune systems

Rising temperatures and sea levels and altered patterns of rainfall and storms due to global climate change will all impact on coastal dune ecosystems via processes including increased erosion, heat and drought stress – all of which are likely to result in reduced productivity (Brown et al. 2008). Changes in wave patterns also have the potential to influence the overall size and stability of dune systems at a local scale. Furthermore, accelerated dune erosion and destabilisation would probably result in the loss of dune vegetation, exacerbating dune destruction until the stabilisation of sea level (Jones et al. 2008). Such habitat losses would clearly have major direct impacts on dune fauna as well as indirect impacts on dune food webs and other coastal food webs due to declining inputs of organic matter (Jones et al. 2008). Nesting sites of shorebirds and turtles would also be lost as a result of rapidly eroding foredunes.

As in other coastal ecosystems, shifting temperature zones will probably result in poleward shifts in the distribution of coastal dune species which will be further influenced by altered precipitation patterns. The phenology, e.g. timing of flowering, and reproductive success of plants, birds and turtles that inhabit dunes are also likely to change in response to warming and changed rainfall patterns (e.g. Law et al. 2000, Chambers et al. 2005).

Dune vegetation may be further affected by altered wind patterns which may blow unstable sands onto dunes and bury vegetation and colonisation areas as well as causing mechanical and chemical (i.e. via salts) damage (e.g. Keith 2006). Projected changes to fire regimes, including increased frequency and intensity of burning, will have a further influence on dune vegetation, promoting dominance by fire tolerant species (e.g. Spencer and Baxter 2006). Fire can also affect the survival and reproduction of birds that use dunes, e.g. little penguins (*pers comm.* Chambers, 2011).

5.3.4. Impacts on rocky shores and headlands

Intertidal species are subject to both terrestrial and marine climate changes and may therefore be impacted by climate change via a wide range of mechanisms including altered water temperatures and upwelling regimes (Leslie et al. 2005), changed oxygen levels (Service 2004) and predator-prey changes (Harely 2003). Nevertheless, rocky shores and headlands are typically considered to be less vulnerable to climate change impacts than sandy coasts (Abuodha and Woodroffe 2010). However, significant changes in intertidal communities in rocky shores of Europe and North America have been observed as a result of poleward range expansions of warm-water species and range contractions of cold-water species (Helmuth et al. 2006, Mieskowska et al. 2006, Hawkins et al. 2008). Globally, poleward range edges of intertidal biota have shifted by up to 50 km per decade, which is considerably faster than shifts recorded for terrestrial species (Helmuth et al. 2006).

Headland ecosystems, like coastal dunes, are likely to be affected by rising temperatures, altered precipitation patterns, changed wind regimes, increased frequency and intensity of extreme storms and cyclones as well as changes fire regimes, all of which have the potential to alter vegetation and habitat structure as well as directly impact fauna (Menge et al. 2008). Other threats, like invasive species and eutrophication, may also be exaggerated by climate change due to synergistic effects with other factors (Adam 2009, Thompson et al. 2002). Menge et al. (2008) suggest that predictions of rocky shore intertidal community responses to climate change require detailed assessment of both direct thermal effects on species as well as the indirect consequences of temperature changes on other processes. Despite the significant capacity for climate change to influence rocky shore communities, it has been widely acknowledged that rocky shore biota are both resilient and resistant to change, so have a high capacity to respond to extreme events in particular (Thompson et al. 2002). Furthermore, Helmuth et al. (2006) reported that regional (tidal regime) and local (wave splash) patterns often overwhelm the potential impacts of changes in temperature, to the point that predictions of responses are complex and not the simple latitudinal gradients that had been previously anticipated.

5.4. Freshwater coastal ecosystems

5.4.1. Drivers of climate change impacts

The most publicised climate change threats to coastal freshwater wetlands are those from sea-level rise and salt-water intrusion. While wetlands may be able to retreat in some areas, depending on topography, coastal agricultural and urban development will place wetlands in ‘squeeze’ zones and their overall area is likely to be reduced. In addition, increased variability in rainfall patterns and heavier rainfall events, including flooding, will also impact strongly on coastal river systems, lakes and lagoons and forested wetlands. Rising temperatures will play a further role in determining hydrological responses as well as the species composition of freshwater coastal habitats.

Sea level rise

The impacts of sea level rise and associated saline intrusion into freshwater coastal ecosystems are likely to be profound. It is anticipated that many low-lying freshwater habitats (and the species that inhabit them) will be permanently inundated by the end of this century, effectively converting them from freshwater to estuarine-marine habitats. These long term trends in inundation will be further exacerbated by storm surges and spring tides. Furthermore, high evaporation and low rainfall and freshwater discharge is likely to cause some lowland wetlands and lakes to become hypersaline (Gräwe et al. 2010), further threatening the freshwater biota that currently inhabit them.

Temperature, rainfall and evaporation

Coastal lakes and lagoons are anticipated to become hyrdologically stressed as the climate gets warmer and drier throughout most of the Australian continent. There are also likely to be increases in potential evaporation of up to 8% per degree of global warming over most of Australia, with increases tending to be larger where there is a corresponding decrease in rainfall (Hughes 2003). The resulting decrease in annual moisture balance equates to decreases of 15–160 mm by 2030 and 40–500 mm by 2070, placing greater moisture stress on lakes and lagoons and freshwater wetlands. Similarly, Hadwen and Arthington (2011) used OzClim to evaluate the likely impacts of climate change on perched dune lakes and suggested that extended periods of drought are likely to lead to the complete drying out of previously perennial dune lake environments.

5.4.2. Impacts on freshwater habitats

Changes in the water balance of coastal freshwater ecosystems are likely to lead to a major shift in the structure and functioning of freshwater coastal ecosystems. Specifically, extension of dry spells is likely to convert some forested wetlands and shallow lakes and lagoons into terrestrial-dominated systems, greatly reducing the aerial extent and density of coastal freshwater habitats, which in turn is likely to have significant flow on effects for their endemic species, acid frogs in particular, that inhabit and require these specific habitat types.

For those habitats that are converted to terrestrial-dominated systems, there are also implications for some plant species that dominate these environments. Many *Eucalyptus* species, often dominant within coastal freshwater wetland fringing communities, have sharply defined, narrow geographic ranges that are closely associated with local environmental conditions such as soil and drainage and many have distributions spanning narrow temperature and mean annual rainfall ranges (Hughes et al. 1996). Although the actual climatic tolerances of many species may be wider than the climatic envelope they currently occupy, substantial changes in the Australian tree flora may be expected in the future if even a modest proportion of present day boundaries reflect thermal or rainfall tolerances (Hughes et al. 1996, 2003).

5.5. Summary

The major drivers of ecological impacts of climate change are similar amongst most Australian coastal ecosystems but vary in their intensity and effects both regionally and between realms. Overall, the main ecological impacts are likely to include reduced population sizes, shifts in species' ranges and changes in the composition, structure and dynamics of biological communities. The drivers, mechanisms and potential consequences of climate change on key components of coastal ecosystems are presented in Appendix 5. In addition, the drivers and specific change anticipated across marine, estuarine, freshwater and terrestrial realms are presented in Appendix 6.

Rising temperatures are generally expected to drive species' distributions southwards as well as affecting physiological and behavioural responses in some species and altering ecological processes including primary production. Coral reefs are particularly sensitive to temperature and extreme ocean temperatures lead to bleaching events which can result in mass coral mortality and significant shifts in community composition, including the replacement of corals by algae.

Sea level rise will redistribute shallow marine and intertidal habitats around the coastal zone, lead to saltwater intrusion into estuarine and freshwater coastal ecosystems and result in a loss of area of some habitats, particularly those experiencing coastal 'squeeze' as a result of human developments. Dominant coastal processes including wind, waves, tides, currents and hydrology are also likely to change and drive ecological impacts in all coastal ecosystems by altering the distribution, movement and processing of water, materials (i.e. sediments and nutrients) and biota.

Changes in the frequency and intensity of extreme events will further affect coastal ecosystems in all realms both directly, e.g. via mechanical damage to organisms or effects on sediment dynamics, and indirectly, e.g. by influencing the quantity and quality of terrestrial runoff entering coastal ecosystems. Increased levels of coastal erosion are also widely predicted.

In the marine coastal realm and intertidal and subtidal coastal habitats, ocean acidification is likely to result in further ecological impacts by reducing the growth and survival of the many organisms which rely on dissolved carbonate ions to build their shells or skeletons, with significant ramifications for the food webs which rely on them. Ocean acidification may also directly affect the development and metabolism of non-calcifying marine organisms.

In terrestrial coastal ecosystems, e.g. dunes and headlands, CO_2 fertilisation may lead to vegetation thickening and encroachment of grasslands by shrubs. Altered fire regimes resulting from rising temperatures and reduced precipitation are also likely to affect vegetation communities in these coastal ecosystems and the habitat they provide to fauna. Some fauna, e.g. penguins, may be affected directly by changed burning patterns as well.

Numerous ecological impacts of climate change have already been observed in coastal ecosystems in Australia and around the world. In the marine realm, these include severe, large-scale episodes of coral bleaching related to increased sea surface temperatures resulting in significant changes in community composition, although Australian reefs appeared to have been more resilient to these than reefs elsewhere in the world. Observed changes in the distribution and abundance of macroalgae herbivores, e.g. the black sea urchin, along Australia's east coast, linked to dramatic losses of giant kelp and the formation of 'urchin barrens', are also directly related to increased temperatures as well as strengthening of the East Australian Current. With respect to intertidal species of rocky shores, considerable range expansions of warm water species and range contractions of cold water species have been recorded in the northern hemisphere. Furthermore, Australian arrival and departure dates of migratory birds, including shorebirds, have shifted in line with temperature changes.

Certainty surrounding predictions of ecological impacts of climate change varies considerably between ecosystems and regions. Specific studies of climate change impacts in Australian coastal ecosystems are relatively limited with most work having been conducted on coral reefs, particularly the Great Barrier Reef, and mangroves. Climate change studies on sandy beach and coastal dune ecosystems as well as freshwater coastal habitats appear to be particularly lacking.

SECTION 3. ADAPTATION

6. ADAPTATION PATHWAYS

Adaptation can be defined as an "adjustment in natural or human systems in response to actual or expected climatic stimuli or their effect, which moderates harm or exploits beneficial opportunities" (IPCC 2001). This chapter summarises potential pathways for climate change adaptation for Australian coastal ecosystems, including autonomous ecological adaptation and managed human adaptation. Autonomous human adaptation is also possible, e.g. changes to fisheries practices in response to climate change, but was not considered in the project. Climate change adaptation strategies in existing legislation and policy are also reviewed. The chapter concludes with a summary of results of an Expert Panel Workshop conducted during this project to develop and trial a risk assessment approach to evaluating adaptation options for Australian coastal ecosystems.

6.1. Autonomous adaptation pathways

Autonomous adaptation, with respect to ecosystems, refers to the capacity of organisms and biological communities to adapt to climate change without human intervention. This is a relatively new area of research and poorly understood for most species and ecosystems. With respect to Australian coastal ecosystems, most relevant research refers to marine ecosystems and coral reefs in particular.

The major pathways for autonomous (ecological) adaptation at a species level include: i) acclimatisation, ii) adaptation, iii) epigenetic interactions, and iv) geographic range shifts. At a community level, autonomous adaptation might include changes in community composition.

Acclimatisation

Acclimatisation describes an organism's capacity to change its physiology when environmental conditions change (Prosser 1990). Acclimatisation generally occurs over short time periods (days to weeks) and enhances performance or survival under changed environmental conditions. The degree to which organisms are able to acclimatise is determined by their phenotypic plasticity, i.e. the flexibility in which they express biochemical and demographic traits. Acclimatisation may increase survival during periods of stress but may entail costs to growth or fecundity.

Adaptation

Adaptation is the process via which natural selection increases the frequency of individuals within a population with beneficial characteristics (i.e. genotypes). For adaptation to occur, populations must have genetically based and hereditary phenotypic variation. The larger the genetic basis of phenotypic variation, compared with environmentally-related variation, the faster a trait can change due to selection (Lynch and Walsh 1998).

Epigenetic interactions

Epigenetic evolution refers to changes in the expression and function of genes that cannot be explained by variation at the DNA level (Bossdorf et al. 2008). Whilst epigenetic regulation can be maintained over several generations, and can therefore be considered heritable at least in the short-term, the importance of this mechanism to acclimatisation and adaptation to climate change is currently poorly understood (Jablonka and Lamb 1998, Grant-Downton and Dickinson 2006, Richards 2006).

Geographic range shifts

Changes in species ranges are one of the most commonly recorded responses to climate change (Parmesan and Yohe 2003, Root et al. 2003, Parmesan 2006). Poleward migrations of species can be viewed as a potential adaptation strategy for species to avoid increasing temperatures.

Changes in community composition

At a community level, changes in the species composition towards hardier species can be viewed as a potential adaptation strategy (e.g. Done 1999, Coles and Brown 2003).

6.1.1. Adaptation of marine coastal species and ecosystems

Acclimatisation

There is limited evidence to suggest that some reef corals may be able to acclimatise to climate change based on geographic variation amongst populations in susceptibility to bleaching (Berkelmans and Willis 1999, Berkelmans 2002). In general, corals that have survived previous bleaching events are also less sensitive to future events, sometimes as a result of shuffling their dinoflagellate symbionts (Jones et al. 2008, McClanaham et al. 2009). Geographic variation in thermal tolerance also occurs amongst some macroalgal species (e.g. Pakker et al. 1996) suggesting potential for acclimatisation (e.g. Eggert et al. 2003).

Adaptation

Correlations between bleaching thresholds and local environmental conditions of geographically isolated coral populations suggest adaptation to local climates has occurred in the past (Hughes et al. 2003). There are also a couple of studies that indicate some potential amongst coral hosts and their symbiotic partners to adapt to future climate change via natural selection of adaptive traits such as coral host growth, dispersal ability and heat stress tolerance (Meyer et al. 2009 and Csaszar et al. 2010). The short generation times and high turn-over rates of dinoflagellate symbionts also suggests that evolutionary change on ecologically relevant time scales may be possible (Baskett et al. 2009).

Geographic range shifts

Extant coral taxa have expanded their geographic ranges during the last interglacial periods in response to sea surface temperature changes of at least 2°C (Greenstein and Pandolfi 2008). More recent range shifts in some Caribbean corals, consistent with climate change, have also been documented (Vargaas-Angel et al. 2003). Amongst the macroalgae, some species have contracted southwards over the last few decades (Wernberg et al. 2009), which may be perceived as a potential adaptation strategy to avoid increasing temperatures.

Changes in community composition

Coral communities can become more resistant to climate change if the composition of species shifts towards hardier species (Done 1999, Coles and Brown 2003). Coral species vary greatly in their susceptibility to bleaching and the rates of mortality incurred (Marshall and Baird 2000, Baird and Marshall 2002, McClanaham et al. 2009). Community level effects of bleaching therefore relate to initial species composition as well as the severity of the event (McClanahan et al. 2007, Smith et a. 2008). Reef recovery from bleaching is complex but may involve the recovery of more resilient survivors (Loya et al. 2001) or recruitment and growth of fast growing, but often more sensitive, species (Edwards et al. 2001, Pratchett et al. 2008). Climate change induced bleaching may therefore result in changes in the composition of coral communities which will depend on a range of local life history and demographic process (Arther et al. 2006), as well as time since bleaching (Smith et al. 2008), the severity of the event and the presence of further disturbance.

Climate change is also likely to have differential effects on different functional groups of coastal macroalgae (Diaz-Pulido et al. 2007). Increased dissolved CO_2, for instance, may enhance photosynthesis and growth in some non-calcifying species (Gao et al. 1993, Nystrom et al. 2000), whilst having negative impacts on calcifying species as a result of ocean acidification (Borowitzka and Larkum 1976, Borowitzka 1981). Climate change induced changes in community composition of macroalgal forests are therefore likely to see an increase in non-calcifying algal species (Breeman 1990, Hughes et al. 2006).

6.1.2. Adaptation of estuarine species and ecosystems

Amongst estuarine organisms, mangroves are widely considered to have high levels of plasticity, dispersal and capacity to adapt to local conditions (Alongi 2008, Proffitt and Travis 2010, Williamson et al. 2011), and are therefore expected to be able to accommodate, to some degree, many of the anticipated changes in climate. Evidence indicates that mangrove distributions have fluctuated with sea level changes over recent and longer time frames (Alongi 2008, Williamson et al. 2011). In the future, mangrove distributions are expected to move inland and southward as sea levels rise and the accessibility and availability of suitable habitats for colonisation shift (Semeniuk 1994, Hughes 2003, Williamson et al. 2011). There is already evidence that mangroves have expanded landward and increased in cover in northern Australia over the last 40 years (Williamson et al. 2011) and in subtropical Australia (Eslami-Andargoli et al. 2009). Responses vary considerably however amongst mangrove species and their local populations (Arnaud-Haond et al. 2006, Eslami-Andargoli et al. 2009, Proffitt and Travis 2010). Despite such recent increases in mangrove cover, however, rates of sediment accretion in mangrove forests are being vastly outpaced by sea level rise, so significant net losses are likely in the future (Woodroffe 2007, Gilman et al. 2008).

6.1.3. Adaptation of terrestrial interface coastal species and ecosystems

Studies of the adaptive capacity of Australian terrestrial organisms to climate change have typically concentrated on high altitude and cold climate species that are already at the edge of their tolerance limits and distributions (Hughes 2003). Consequently, the potential for terrestrial flora and fauna of Australian coastal ecosystems to accommodate climate change is largely unknown (Hughes 2003).

Many organisms inhabiting sandy beaches, coastal dunes and rocky shores, particularly invertebrates, exhibit traits and behaviours, e.g. burrowing ability, which facilitate a high degree of tolerance to short-term fluctuations in sea level and extreme conditions such as high winds or storm surge (Short and Woodroffe 2009). Vertebrate species using terrestrial coastal habitats, e.g. turtles, may also be able to alter their use of microhabitats to reduce the impacts of changed climatic conditions, e.g. warmer sands (Steffen et al. 2009). Whilst such behavioural changes may enable acclimatisation to climate change within sites, other species, e.g. shorebirds, may cope with shifting climatic conditions by migrating to new habitats.

6.1.4. Adaptation of freshwater coastal species and ecosystems

The flora and fauna of Australian freshwater environments are well adapted to high levels of climatic variability (Kingsford 2011), including organisms of coastal drainages which are well adapted to cycles of boom and bust on seasonal, annual or interannual cycles (Arthington et al. 2005, Balcombe et al. 2005, Sheldon 2005, Kingsford 2011). Consequently, Australian freshwater biota exhibit considerable capacity to tolerate at least some elements of climate change over the short- and medium-term (Boulton and Brock 1999, Bond et al. 2008).

Many Australian freshwater taxa are either resilient, resistant or tolerant to extended periods of drought (Lake 2003, Bond et al. 2008, Sheldon et al. 2010). For example, some taxa have desiccation-resistant life history stages, including species of crustaceans, frogs and turtles (Jenkins and Boulton 2003, James et al. 2008). Alternatively, winged organisms, like birds and many aquatic insects, can move across a drying landscape to find suitable habitats (Kingsford et al. 1999, Kingsford and Norman 2002, Kingsford 2011). The high mobility of winged organisms can also sustain the viability of less mobile freshwater taxa by virtue of their propagules being carried and distributed by birds (Green et al. 2002, Charalambidou and Santamaria 2005). Whilst contemporary persistence is maintained under current conditions via aerial dispersal, the capacity for aerial dispersal to maintain species under longer-term and more severe dry spells remains unknown.

6.2. Managed adaptation pathways

Although coastal ecosystems have a range of mechanisms through which autonomous adaptation to climate change may be possible (e.g. Pittock 1999, Gunderson 2000, Cropp and Gabric 2002), non-climatic human impacts, such as infrastructure and land use development and eutrophication, have degraded coastal ecosystems and reduced both their ecological resilience and capacity to adapt (Adger et al. 2005, SoE 2006, Church et al. 2008, APH 2010). Consequently, many coastal ecosystems are now more vulnerable to future climate change and may require human intervention to adapt (Abuodha and Woodroffe 2006). Given the high value and extensive ecosystem services of coastal ecosystems, maintaining, facilitating and building the adaptive capacity of coastal ecosystems via managed adaptation pathways has therefore become a global priority (Klein et al. 2001, Sharples et al. 2008, Abel et al. 2011).

Managed adaptation can be broadly considered under two categories: i) direct, on-ground approaches or tools and ii) policy responses and strategies that provide direction for the development and implementation of managed adaptation approaches and tools (Smit et al. 1999, Klein et al. 2001). Both are reviewed here with respect to Australian coastal ecosystems. A detailed list of potential adaptation approaches for each of the coastal ecosystems considered in the CERCCS Project is presented in Appendix 7.

6.2.1. Approaches to climate change adaptation

On-ground climate change adaptation approaches are developed to enable and/or natural coastal systems to better cope with the impacts of climate change (Few et al. 2007). Some adaptation approaches are designed to primarily benefit humans, e.g. revetment walls, groynes, dredging and beach nourishment (El-Raey et al. 1999), while others aim to benefit both human and natural systems, e.g. foreshore revegetation, pollution reduction etc. (Abel et al. 2011). More recent managed adaptation approaches, e.g. ecological and ecosystem engineering, aim to maintain and enhance the extent and health of natural habitats while also protecting coastal developments and investments (Borsje et al. 2010, Chapman and Underwood 2011).

In general, on-ground climate change adaptation approaches can be broadly categorised as either 'hard' or 'soft' measures (McClashan 2003) with the former referring to the use of fixed structures, e.g. seawalls and groynes. Depending on the application, hard and soft adaptation measures may be used in conjunction (Sharples et al. 2008).

General coastal adaptation approaches

Four broadly different approaches to managed adaptation in the coastal zone can be described, mainly with respect to sea level rise, each of which employs a range of practical measures:

1. Managed retreat: the planned abandonment of land to the sea as it advances (Bray et al. 1997), often involving removal of coastal armouring structures and relocation of infrastructure. This strategy has ecological benefits as it allows ecosystems to migrate landwards and thereby maintain functions and ecosystem services.

2. Limited intervention (or accommodation): allows continued occupation of coastal land by adapting to increased sea levels via modifying building designs so they can be moved or withstand inundation and using ecological and ecosystem engineering whereby different species are used to increase coastal elevation or absorb impacts of storms (Bray et al. 1997, Borsje et al. 2010).

3. Hold the line: use of hard engineering structures, e.g. seawalls and groynes, as well as soft engineering methods, e.g. beach nourishment, to attempt to prevent invasion by the sea beyond a set coastal position (Bray et al. 1997).

4. Do nothing: a wait and see approach which allows for the destruction of coastal infrastructure as the sea level rises but avoids costs of construction and maintenance of hard engineering structures (McGlashan 2003).

Minimisation of non-climatic human impacts

Minimisation of disturbance produced by non-climatic human impacts reduces the vulnerability of coastal ecosystems to climate change by enhancing their ecological resilience (Klein et al. 2001, Folk et al. 200, Hawke 2009). Examples of major non-climatic human impacts on coastal ecosystems which may be reduced through the development of policy and planning regimes include:

- unsustainable harvesting of organisms, e.g. fishing (Bellwood et al. 2004, Marshall and Schuttenberg 2006);
- reduction of water quality by pollution (Hughes et al. 2003);
- introductions of exotic species (Crooks 2002);
- development in erosion and flood prone areas (Brown and McLachlan 2002); and
- human adaption practices designed to protect human coastal systems, e.g. groynes and sea walls (Lucrezi et al. 2010).

Hard-engineering approaches

Hard-engineering involves the use of man-made structures to intervene in coastal processes, e.g. by altering the influence of waves on coastal erosion (Cooper and McKenna 2008). A wide range of structures have been used around the world to protect coastal investments from flooding and erosion including groynes, sea walls, revetments, rock armouring, gabions, offshore breakwaters, training walls, artificial reefs and geotextile sandbags (e.g. Bacchiocchi and Airoldi 2003). Such structures are also used to prevent sand loss via wave and current action and to maintain beaches for recreation and tourism (Airoldi et al. 2005).

Hard-engineering has been used extensively in coastal Australia and is likely to increase as sea level rises (Abel et al. 2011). Typically, hard-engineering is implemented for human benefits and ecological impacts are less well known (Dugan et al. 2008, Chapman and Underwood 2011). Hard-engineering structures tend to reduce sediment flow along coastlines (Miles et al. 2001, Gilman et al. 2008), accelerate beach erosion (Gletcher et al. 1997) and are attributed with the loss of over 80% of soft sedimentary shorelines (Brown and McLachlan 2002). Consequently, hard-engineering adaptation measures in erosion and flood prone coastal areas can be considered as maladaptation (Klein et al. 2001) by reducing ecological resilience, obstructing autonomous ecological adaptation and increasing coastal vulnerability to storms (Lucrezi et al. 2010).

Soft-engineering approaches

Soft engineering approaches to coastal ecosystem adaptation currently being investigated include managed retreat, beach nourishment and revegetation (French 2006).

Managed retreat

Managed retreat involves the removal of hard-engineering structures to allow coastal areas to retreat in response to rising sea level (Gilman et al.2008, USEPA 2009). Such structures are often replaced by more ecologically beneficial environments such as saltmarsh and mangrove vegetation (French 2006). Benefits include maintenance of coastal ecosystems and ecosystem services (Chapman and Underwood 2011), reduced costs of maintenance and management of public expectations in relation to permissible types of coastal development and the importance of coastal ecosystems (Titus 1991, Gilman et al. 2008). Primary drivers for adoption of managed retreat include recognition of the high value of resilient coastal ecosystems and the ecosystem services they provide and an acceptance that 'hold the line' hard engineering practices only lead to coastal erosion elsewhere (McGlashan 2003).

Revegetation

Revegetation is used extensively in Australian coastal dune systems and around the world. Benefits include maintenance of habitat for coastal species, reduction of wind and wave erosion, provision of a barrier to prevent sand and salt spray from damaging less tolerant inland plant species and protection against storms. Since dune vegetation is instrumental in dune formation (Section 3.3.2), dune revegetation can also influence the sand budget of a coastal area.

Beach nourishment

Beach nourishment is widely used to adapt to coastal erosion, particularly on high-use beaches for the benefit of tourism and recreation. Typically achieved by importing and bulldozing of sand, by transferring sand from low to high levels, beach nourishment can also be of benefit in maintaining the habitat of some coastal species but can also result in a decline in macrobenthos (Brown and McLachlan 2002). Recommendations to minimise ecological impacts of beach nourishment include: i) avoidance of sediment compaction, ii) careful timing of operations to minimise impacts and facilitate recovery, iii) locally-appropriate techniques, iv) use of several small projects (including numerous shallow applications) rather than one large project to avoid killing fauna by burial, v) careful spacing of operations to ensure interspersed unaffected areas and vi) importation and distribution of sediments that match beach conditions and profiles as closely as possible (Defeo et al. 2009).

Beach drainage

Beach drainage involves localised lowering of water tables beneath beaches to allow sand to dry and allow part of wave swash to 'soak in', thereby depositing part of its suspended sand on the beach (Parks 1991, Anon 1995).

Ecological engineering

Ecological engineering uses a mix of hard and soft adaptation measures to facilitate the protection of human coastal systems as well as reducing impacts on ecosystem health and function (Bergen et al. 2001, Chapman and Underwood 2011). The emphasis of this approach is on the creation of artificial habitats that potentially enable ecosystems to adapt by replacing habitat that has been destroyed or degraded or provides new habitat or habitat associated with existing hard-engineering structures (Borsje et al. 2011). Such artificial habitats are provided with an aim of increasing species abundance and diversity and enabling species to remain or move to new locations (NSW DPI 2011).

Retrofitting of hard engineering structures

Traditional hard engineering structures, e.g. groynes, rock walls and other forms of coastal armouring, can be retrofitted with design features that provide habitat such as holes and caves (Day et al. 2000, Borsje et al. 2011). In Sydney Harbour, artificial structures referred to as 'flower pots' have been retrofitted to sea walls with the aim of providing 'rock pools' (Browne 2009).

Artificial reefs

Artificial reefs are used widely around the world to encourage the development of marine habitat for the benefit of both human and natural coastal systems (NSW DPI 2010). Artificial reefs can provide habitat for numerous fish, coral and plant species and are often used to repair damaged habitat (Powers et al. 2003, Chou 1997, Sammarco et al. 2004) often with additional benefits for recreation fishing, surfing and diving industries (Jackson et al. 2001, PIRSA 2010). Artificial reefs can also be used in beach protection (Jackson et al. 2001, Antunes do Carmo et al. 2010).

Whilst the use of artificial reefs is promoted in NSW through its Estuarine and Offshore Artificial Reef programs, the NSW Marine Parks Authority outlines a number of issues in their *Artificial Reefs Policy* document including: i) whether or not artificial reefs increase biological production, ii) encouragement of aggregations of fish from other areas leading to over fishing, and iii) possible pollution from materials used to construct reefs. The South Australian Government has discouraged use of artificial reefs since 1993 due to concerns about their effectiveness (PIRSA 2010). The placement and construction of artificial reefs in Australia requires a sea dumping permit through the Environment Protection (Sea Dumping) Act 1981. There also remain significant concerns around invasive species associated with the placement and colonisation of artificial reefs.

Ecosystem engineering

Ecosystem engineering refers to the use of particular species that have the ability to 'engineer' or create ecosystems with particular characteristics (Dray et al. 2006, Myers 1983). Whilst such approaches can encourage the development of beneficial habitats and attract and shelter many organisms, coastal ecosystems may also be negatively affected if introduced ecosystem engineer species become invasive, replacing native species and interfering with physical processes with potentially major consequences for native populations, communities and food webs (Ruesink et al. 2005, Lang and Buschbaum 2010).

Oyster and mussel beds

Reef building species, such as mussels and oysters, can act as ecosystem engineers by modifying their local hydrodynamic and sedimentary surroundings (Borsje et al. 2010), thereby influencing other species (Padilla 2010). In particular, bivalves, such as oysters and mussels, provide new substrates for colonisation by other species, generating greater amounts of available habitat (Padilla 2010), as well as stabilising soft sediments to allow greater numbers of species to occur at a location (Lang and Buschbaum 2010).

Coral propagation and translocation

Coral seeding and transplantation practices are being used as a means of enabling coral reefs, and the many species that depend upon them, to recolonise existing locations after major disturbances or to migrate to new locations more suitable for their growth (Rinkeich 2008).

Dune grass

The use of ecosystem engineering dune grasses, e.g. Marram grass (*Ammophila arenaria*) to stabilise foredunes has been used widely throughout the world (Borsje et al. 2010). Unfortunately, there are also some instances where dune grasses have failed, or become invasive, so considerable care and planning is required to ensure that ecosystem stabilisation does not have significant negative ecological consequences.

6.2.2. Existing climate change adaptation strategies

A detailed search for climate change adaptation strategies in existing government conventions, legislation, policy and planning of relevance to Australian coastal ecosystems was undertaken during the CERCCS Project and is presented in the full Science Report accompanying this Synthesis Report. In addition to the database of climate change adaptation strategies presented in Appendix 8, a brief summary of this activity is included here.

Barriers to adaptation strategy development

Key barriers to human climate change adaptation include:

- uncertainty surrounding climate change models and projections;
- State land use planning legislation, e.g. Sustainable Planning Act 2009, which prevent local governments from prohibiting development (e.g. as part of managed retreat strategies;
- threat of exposure to legal liability and compensation;
- lack of adequate guidance for local governments in State and regional strategic planning frameworks on how to address climate change impacts in local planning instruments;
- limited financial capability to implement climate change adaptation actions (Zuch and Patching 2009).

Global strategies

Australia is signatory to numerous conventions and agreements that provide international support for the protection and maintenance of coastal species and ecosystem, e.g. World Heritage and Ramsar Convention. Although climate change adaption is not the main purpose of most of these, they are able to increase the adaptive capacity of coastal systems by helping to maintain ecosystem health as well as instigating the development of national and state climate change adaptation strategies.

Amongst those international strategies that have been formed specifically for the purposes of climate change mitigation and adaptation, Australia has ratified the *United National Framework Convention on Climate Change 1992* (UNFCCC) and the *Kyoto Protocol*, the main aims of which include assisting countries to adapt to climate change impacts (UNFCCC 2010).

National strategies

The Council of Australian Governments (COAG) developed the *National Climate Change Adaptation Framework* (NCCAF) in 2006, as part of its *Plan of Collaborative Action on Climate Change* (COAG 2006), to help meet its national climate change adaptation obligations under the UNFCCC and Kyoto Protocol. The CSIRO Climate Adaptation National Research Flagship and the National Climate Change Adaptation Research Facility (NCCARF) are amongst the programs instigated by the national agenda set out by the NCCAF.

More targeted climate change adaptation strategies include the *National Cooperative Approach to Integrated Coastal Zone Management – Framework and Implementation Plan* (ICZM Framework), which aims to manage coastal issues, including climate change, according to principles of ecologically sustainable development, and the *Climate Change Adaptation Actions for Local Government*, which identifies adaptation actions that can be used by local governments. The latter lacks detail in relation to coastal ecosystems, though, offering only two on-ground approaches, i.e. dune restoration and protection of dune vegetation, with other adaptation options given being for the benefit of human coastal systems.

Finally, the EPBC Act, which forms Australia's central piece of environmental legislation, has an important role to play in the development and implementation of climate change adaptation strategies. A review of this Act by Dr Allan Hawke in 2009, however, highlighted a number of shortfalls regarding the Act's application of climate change adaptation and suggested that current objectives of the Act to prevent ecological change are likely to fail as a result of climate change and may even exacerbate ecosystem losses (CSIRO 2008, Hawke 2009).

State strategies

Australian State strategies, e.g. the *Victorian Coastal Management Strategy 2008* and the *Queensland Coastal Plan*, offer a greater range of practical advice for on-ground adaptation approaches for coastal ecosystems. State governments also preside over national parks and therefore produce plans and strategies that can be used by managers for conservation, protection and enhancement of these areas. Some national parks, e.g. Kakadu, also have specific climate change management plans, i.e. the *Kakadu National Park Climate Change Strategy 2010-2015*.

Local strategies

Local governments are required to comply with State and Federal government coastal management policies which provide a legislative and regulatory framework within which local governments can operate and coordinate natural resource management activities (COAG 2006). Of the many local strategies that exist or are under development, this project focused on those of relevance to the three case study areas (see Section 6.2.3).

6.3. A risk assessment approach to evaluating adaptation actions

Despite some uncertainty around what the likely impacts of climate change may be in coastal ecosystems, climate change adaptation decisions need to be made now. As a result, and despite the significant gaps in our understanding of both ecosystem functioning and climate change impacts, it is critical that decisions around how we adapt to climate change are made.

To move from climate change impacts to climate change adaptation is in itself a major challenge and a knowledge gap worthy of considerable new research investment. The approach outlined in this chapter is grounded firmly with a view on existing management of coastal environments (see Fig. 6.1), both in terms of what drivers of the ecosystem may be able to be managed and what managers are currently doing in coastal areas. This approach enables us to dovetail into existing management actions and plans as well as to devise realistic (ie manageable) adaptation actions that have some scope for being implemented in coastal settings.

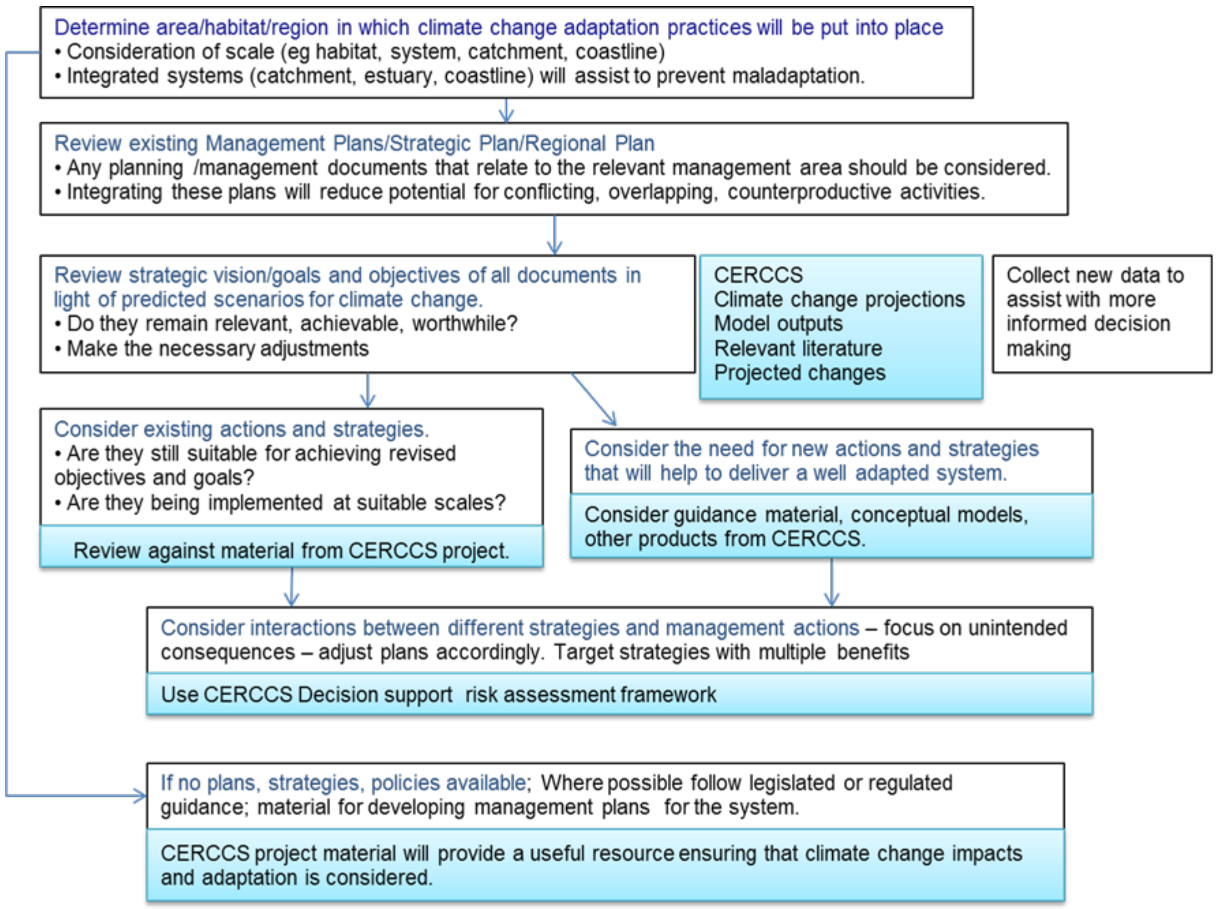

Figure 6.1. Coastal zone management context for the CERCCS project, with emphasis on where the project outputs can feed into existing strategies and provide information to support decision makers.

To ensure that the language and approach to climate change impacts and adaptation actions was consistent across all of the coastal ecosystems considered in this study, we used the climate change impacts tables presented in the realm-based chapters (see Appendix). These climate change impact tables represented a significant and necessary first step on the path towards developing adaptation actions. Structured initially across the four realms (marine, estuarine, terrestrial and freshwater), we did the following:

1. Identify the key ecological components, processes and ecosystem values at the realm-scale and within each of the habitats being considered. Importantly, we sought to identify broad geographical differences in the type and nature of coastal habitats where relevant, to ensure that evidence was regionally relevant.

2. Identify the major environmental (biotic and abiotic) drivers that maintain each of the identified ecosystem components.

3. Identify the major impacts of climate change on these ecological components, with emphasis on the drivers (from step 2) that will change given the projected influence of climate change. The focus on drivers is important as this will enables managers to focus actions around tangible elements of the system that are likely to change and have ecological consequences.

4. After identifying the climate change impacts on drivers that are likely to illicit ecological responses, we then asked the expert panel members to indicate (using three categories – high, medium and low) the severity (ecological consequence of the impact) and likelihood (certainty around the impact occur) for each of these impacts (again identifying broad geographical differences where relevant). Finally, to capture uncertainty around these rankings, we asked the expert panel members to attribute confidence to the above rankings (again using high, medium and low categories).

The risk assessment approach outlined above was then used, by analysing the ranking scores, to identify the most likely and most severe impacts and the drivers that are most likely to be able to be managed. Specifically, we asked participants to concentrate on mechanisms wherever possible, e.g. management drivers that manipulate temperature, light etc. This approach enabled us to determine a list of drivers, anticipated changes under a changed climate and suggested management actions to address these changes, for each habitat within each realm.

After considering all of the above, we asked the workshop participants to come up with adaptation actions that will address the anticipated changes to the drivers identified above. Importantly, we sought suggestions around actions that are intended to be real, on-the-ground and/or legislative actions that will address the threat, at the level of the driver. Finally, with a view on determining the efficacy and likely adoption of the suggested adaptation actions, we asked participants to rank (again using high, medium and low categories) the following:

1. The likely efficacy of the action – how well will the action address the targeted change?

2. The probable economic costs of executing the strategy – will it be expensive, will it require significant and long-term maintenance costs?

In addition to considerations of efficacy and cost and particularly with respect to the high connectivity between habitats and realms within the coastal zone, we then asked participants to list:

1. The likely impacts of the adaptation action being considered on other ecosystem components, both within and beyond the realm in question, and

2. The likely consequences of implementing the adaptation action being considered for current human activities (settlements, industries, recreation and other values) in the habitat and realm (and others connected to them)

These last two tasks represent an important opportunity to list and evaluate some of the important consequences that need to be considered by managers considering implementing the actions. Importantly, these ecological and human consequences can either be negative or positive.

After identifying the key ecosystem components within each habitat, all of the following steps in this process (see Fig. 6.2) provide critical information around which adaptation actions may be able to address the anticipated changes under a future climate. Critically, the ranking of likelihood, severity and confidence of climate change impacts and the efficacy and cost of adaptation actions provides decision makers with appropriate filters through which decisions and recommendations around particular adaptation actions can be made.

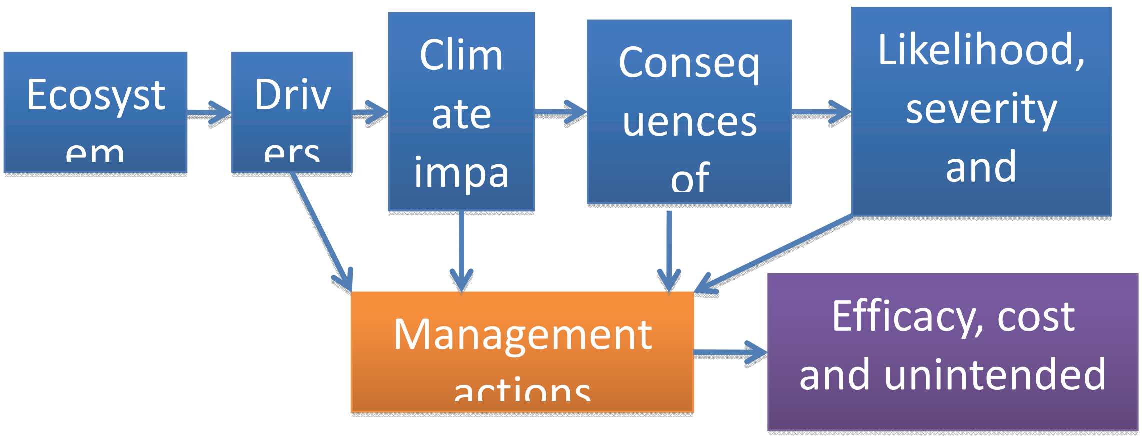

Figure 6.2. A risk assessment approach for the evaluation of climate change threats, drivers and possible adaptation actions across all habitats and realms in the coastal zone.

After going through the above process, for all habitats (within all realms), we assembled the following:

1. Lists of ecosystem components, drivers, climate change impacts on drivers (including short- and long-term impacts)

2. List of possible adaptation actions to address changes in drivers

3. List of unintended ecological consequences (both within and among habitats) for each adaptation action

4. List of unintended human consequences (both for communities and industries) for each adaptation action

These lists provide decision makers with a comprehensive database upon which adaptation decisions can be made. Coupled with regional and local understanding of planning zones and climate change information (from earlier Chapters), this information can provide managers with the capacity to rigorously evaluate the risks and opportunities associated with climate change and adaptation actions within their jurisdictions. This database and the regional climate change projection modelling output (see Climate Chapters) is currently being incorporated into a climate change adaptation decision making tool, which will be a web-based resource by which stakeholders can interrogate aspects of their local coastal environment and consider adaptation alternatives.

The outputs from this process are presented as appendices which summarise climate change drivers and their relevance to each of the coastal habitats considered in this project. Appendix # presents a summary of the climate change drivers and their relevance to each of the habitats examined in this project. The table represents a synthesis of the climate change impacts (by driver) presented in Appendix # represents the habitat specific adaptation actions that can address the major climate change drivers.

6.4. Summary

Pathways for climate change adaptation can be autonomous (ecological or human), or managed (human only). Autonomous ecological adaptation at a species level may occur via:

- acclimatisation: changes in physiology or life history toward phenotypes which can persist under changed conditions;
- adaptation: natural selection of genotypes which can persist under changed conditions;
- epigenetic interactions: changes in the function and expression of genes that are not explained at the level of DNA but which enable organisms to persist under changed conditions; or
- geographic range shifts: migration into areas with appropriate conditions

Shifts in community composition towards hardier species that are more tolerant of changed conditions may also be perceived as autonomous ecological adaptation at the community level.

Most research into autonomous ecological adaptation in coastal ecosystems has been conducted in the marine realm, particularly in relation to coral reefs. There is limited evidence to suggest that some coral species have the potential to acclimatise, adapt and migrate in response to climate change and that changes in communities composition may also occur. With respect to estuarine ecosystems, mangroves are considered to be particularly plastic with a high ability to adapt to changed conditions and migrate landward with sea level rise, provided appropriate habitats are not already occupied by human developments.

The adaptive capacity of coastal terrestrial and freshwater species and ecosystems is largely unknown although it is likely some species will tolerate changed conditions in situ, some will adapt life histories or behaviours, e.g. altered microhabitats for egg-laying amongst turtles, and other, more mobile or easily dispersed organisms, will migrate, e.g. shorebirds. In all coastal ecosystems, the potential for autonomous ecological adaptation pathways to 'keep up' with rates of climate change is largely unknown.

With respect to managed adaptation pathways in the coastal zone, four broad responses to climate change, particularly sea level rise, can be identified: 1. managed retreat, 2. limited intervention or accommodation, 3. hold the line and 4. do nothing. Each of these can entail a range of on-ground adaptation options which include:

- minimisation of existing non-climatic threats, e.g. invasive species;
- hard-engineering approaches, e.g. sea walls, groynes, armouring etc.;
- soft-engineering approaches, e.g. removing hard-engineering structures, revegetation, beach nourishment and drainage;
- ecological engineering, i.e. retrofitting hard engineering structures or introducing new structures to create artificial habitats; and
- ecosystem engineering, i.e. introduction of species which play a key role in shaping ecosystems structure and function, e.g. oysters, corals and dune grasses.

These adaptation approaches target a wide range of adaptation objectives and certainties surrounding the efficacy of each approach in achieving specific objectives varies considerably, both between approaches and with respect to different ecosystems and regions. All of these approaches are also likely to incur a range of unintended consequences, both ecological, e.g. effects on food webs, and socio-economic or cultural, e.g. impacts on human activities or loss of income, which, given the high level of connectivity amongst coastal ecosystems, can be far-reaching. Furthermore, these adaptation options entail varying costs, both in terms of time and resources involved in their implementation and maintenance as well as with respect to the risks involved. Selection of adaptation action is likely to be further limited by socio-economic and cultural context, e.g. recognition of high value of ecosystem services.

Many existing strategies of relevance to climate change adaptation for Australian coastal ecosystems can be identified amongst global, national, state and local conventions, legislation and policy. For the most part, these do not address climate change specifically but, by addressing non-climatic threats, can be perceived as adaptation strategies since they aim to enhance ecosystem resilience. With respect to specific climate change adaptation strategies, those at state and local levels tend to offer the greatest degree of practical advice concerning on-ground adaptation options, though these tend to be quite limited. Local strategies are also significantly constrained by state and federal legislation.

Due to the urgency with which climate change adaptation actions are needed for Australian coastal ecosystems as well as the uncertainties involved, it is recommended that adaptation planning should adopt a risk assessment approach. With respect to adaptation actions for Australian coastal ecosystems, consideration should be given to the efficacy of the action with respect to the desired result, economic costs of implementation and maintenance, impacts on other ecosystem components and process and consequences of the action for human settlements and activities.

7. CASE STUDIES

7.1. Introduction

The aim of this project was to facilitate the development and implementation of adaptation practices within Australia that can be used by coastal managers to reduce coastal ecosystem vulnerability to the impacts resulting from climate change. To aid in achieving this aim and to build on the lists of adaptation actions determined in the preceding Chapter, three case studies were chosen to display a range of coastal ecosystems and to provide contrast between the different coastal management practices currently used at each site. By cutting across different ecological realms and habitats, as well as different jurisdictional boundaries, the case studies provide an opportunity to apply and evaluate a consistent approach to facilitate climate change adaptation decision making processes for the benefit of coastal ecosystems.

The three case study areas - Kakadu National Park (NT), the Hunter River Estuary (NSW), and the Cairns region (QLD) - were selected following consultation with key stakeholders, the CERCCS steering committee and the project team. Although many other case study locations were considered for treatment in the project, the above three were selected on the basis of a) representativeness and coverage of all of the habitats and realms identified as critical elements of the study, b) perceived vulnerability to climate change impacts, and c) availability of data on existing management actions and climate change adaptation strategies and actions in planning or implementation phases.

The boundaries of the three case studies were all quite different, which also supported their selection. For example, Kakadu National Park is defined by the National Park boundary and was chosen as an example of a *near pristine* coastal ecosystem dominated by freshwater and terrestrial ecosystems (NLWRA, 2000). In contrast, the Hunter River Estuary was defined by its catchment area boundary and was chosen as an example of a *extensively modified* coastal system (NLWRA, 2000). Finally, the Cairns region is defined by both the Cairns and Cassowary Coast Regional Council boundaries and was chosen due to its extensive data availability, aligning with the Australian Bureau of Statistics local government boundaries (ABS, 2010), and with *largely unmodified* to *modified* coastal ecosystems, including some parts of the Great Barrier Reef (NLWRA, 2000).

Objectives

The key objectives of the case studies were to:

- synthesise the nature and extent of potential biophysical changes in coastal ecosystems as a result of both non-climatic human impacts and climate change;
- assess the potential impacts of climate change on coastal ecosystem services and what effects might have on local, regional and national economies;
- determine what adaptive management responses have been developed to reduce coastal ecosystem vulnerability to the potential impacts resulting from climate change; and

- evaluate the future of the case study area under different climate change adaptation strategies, namely ‘do nothing’, ‘hard option’ and ‘soft option’ storylines.

Approach

To achieve the objectives listed above, it was necessary to:

- Define the case study regions based on local government areas, regional and National Park boundaries and according to the NLWRA (2000);
- Review existing research, policy, planning and management initiatives that are currently available to protect, maintain and enhance the adaptive capacity of coastal ecosystems to the potential impacts of climate change;
- Identify the projected impacts of climate change for each of the case study sites;
- Identify the key ecological values of each case study site, such as mangroves forests, coral reefs and wetlands, that are vulnerable to climate changes impacts;
- Identify and prioritise the impacts resulting from climate change, as well as the most effective management responses appropriate for each case study.
- Assess the likely consequences of ‘do nothing’, ‘hard option’ and ‘soft option’ climate change adaptation strategies.

The above actions were undertaken both via literature reviews around existing management strategies (addressing both climatic and non-climatic threats) and workshop discussions amongst the project team and expert panel participants. In addition, specific climate change projections for the three relevant bioregions (as indicated in Appendix 2), including inundation projections based on sea level rise scenarios, are presented in Appendix 9.

We also undertook a series of additional discussions to interrogate existing management actions and possible future adaptation actions in each case study location. Specifically and with the help of stakeholders from each case study area that attended the workshop, we first identified all existing management actions with ecological objectives (these could include climate change adaptation actions if they exist) and identified the ecological components and habitats that the actions focused on. Second, we then asked the workshop participants to consider whether the management action had any potential as a climate change adaptation action – in other words, did the action address a driver that is likely to change as a result (direct or indirect) of climate change? This examination of existing management actions enabled us to examine the range of existing actions and their ecological targets and ecosystem drivers and to evaluate the potential applicability of current actions as climate change adaptation measures.

After evaluating existing management actions we then asked workshop participants to identify adaptation actions that fit into three alternative storylines for each case study area, namely:

1. ‘Do nothing’, which includes the maintenance of existing management but no new climate change adaptation actions,

2. Implement a ‘hard’ engineering adaptation action (and continue existing management actions), like a barrage or a sea wall, and

3. Implement a ‘soft’ adaptation action (and continue existing management actions), like planned retreat.

The rationale behind this approach was that it would be potentially quite revealing to consider the outcomes of these vastly different storylines. Specifically, we asked participants to evaluate each approach for the following:

1. The targets (both in terms of habitats and climate drivers),

2. The relative economic costs of implementing and maintaining the adaptation actions,

3. The likely efficacy of the action against the stated ecological objectives, and

4. The ecological and human consequences of the adaptation action (including both positive and negative consequences).

Within the scope of this project we were not able to fully evaluate all of the human aspects of climate change adaptation strategies in each case study area, so significant further research is required around the adaptation actions described in this chapter, both in terms of their effectiveness to enhance the adaptive potential of coastal ecosystems, and into their ease of implementation. Significant knowledge gaps in climate and ecosystem science, as well as in the methods of selecting appropriate policy responses, represent serious risks to the development of effective human adaptation practices. To this end, the case studies provide just a snapshot of the human climate change adaptation options and alternatives currently being proposed. As a result, significant further work is required to elucidate how to integrate climate change adaptation goals across environmental, social and economic bottom lines.

7.2. Case Study 1 - Kakadu National Park, Northern Territory

7.2.1. The Kakadu National Park region

The Kakadu National Park (KNP) is comprised extensively of floodplains which border the four principal rivers of the region, East, West and South Alligator Rivers and Wildman River. Located 150km east of Darwin, KNP is located in the wet-dry tropic of northern Australian, within the Northern Territory’s Alligator Rivers Region (Tremblay & Boustead, 2009). The region can be classified into three major landscapes: the plateau and escarpment; lowlands; and floodplains (Walden, 2000). The floodplains and associated intertidal wetlands cover approximately 217,450 hectares, with 89% freshwater wetlands.

Although the floodplains within the park have been used for grazing in the past, they are now essentially natural areas that are currently used for passive recreation and airborne sightseeing tourism purposes. The region is a highly dynamic environment that is subject to extreme rates of seasonal and interannual variation in climate, storm events, sea level fluctuation, and river discharge rates. Since National Park management has had to take into account this variability, its principles and policies may differ from those applied to management of less variable, temperate environments of the southern coasts of Australia (Baylis, Brennan, Eliot et al., 1997).

7.2.2. Potential climate change impacts to KNP

Climate change will have a significant impact on the coastal ecosystems of KNP (see Appendix 9 for detailed projections). A number of key threats to Kakadu's northern floodplains include:

- saltwater intrusion along estuaries and river systems into freshwater ecosystems;
- more intense storm activity;
- changing fire seasons;
- potential spread of exotic flora and fauna (Dunlop & Brown, 2008).

The threats imposed by climate change will also extend to the parks human population of locals and visitors alike. The parks indigenous communities and culture will be impacted by the loss of ecosystem services, as well as from the potential reduction in tourist numbers if the quality of the visitor experience decreases (Ibbett, 2010; Tremblay, 2010). Climate change is also likely to have extensive biodiversity changes, for example:

- higher temperatures are likely to affect life cycle events (e.g. reptile sex determination, crocodile breeding), population ecology, and suitable habitats for fish and reptile species (Dunlop & Brown 2008);
- altered water temperatures may change water quality (e.g. oxygen content and demand) leading to changes in fish populations in particular habitats (DNP, 2007);
- increased CO_2 may increase photosynthesis and plant biomass of certain species (Hyder, 2008). Mangrove and salt marsh communities are likely to benefit by an increase the area of habitat, which in return may also benefit the birds, fish and invertebrate species that are dependent on these habitats (Hyder, 2008);
- several changes to specific species or entire communities are not mutually exclusive and may occur together, such as:
    - survival within existing areas of distribution (e.g. abundance, behaviour or habitat);
    - evolutionary adaptation to enable survival (e.g. may be at a genetic, species or population level);
    - changes in population distribution; or

- extinction (Dunlop & Brown 2008).

This list is not exhaustive and there is still considerable uncertainty around the combination of impacts and changes to environmental conditions, including indirect effects of climate change. As a result, continuous monitoring of the health status of species and ecological communities, using appropriate health indicators, is important to prevent or limit reductions in ecosystem health (DNP, 2010).

7.2.3. Existing coastal ecosystem management strategies

Kakadu National Park Management Plan 2007-2014

The *Kakadu National Park Management Plan 2007-2014* describes the network of legislative requirements, lease agreements and international agreements which influence the management of KNP (DNP, 2007). Section 368 of the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act) not only requires that the KNP Management Plan is formed, but that it follows the objects of the EPBC Act, including:

- to provide for the protection of the environment, especially those aspects of the environment that are matters of national environmental significance;
- to promote ecologically sustainable development through the conservation and ecologically sustainable use of natural resources;
- to promote the conservation of biodiversity;
- to provide for the protection and conservation of heritage;
- to promote a co-operative approach to the protection and management of the environment involving governments, the community, land-holders and indigenous peoples;
- to assist in the co-operative implementation of Australia's international environmental responsibilities;
- to recognise the role of indigenous people in the conservation and ecologically sustainable use of Australia's biodiversity; and
- to promote the use of indigenous people's knowledge of biodiversity with the involvement of, and in cooperation with, the owners of the knowledge (Hawke, 2009).

All of the objects of the EPBC Act are conducive to the enhancement of ecosystem resilience and therefore underpin the development and implementation of many human adaptation strategies and practices in Australia, such as the Kakadu National Park Climate Change Strategy 2010-2015 (DEWHA, 2010) and the NSW Biodiversity and Climate Change Adaptation Framework 2007-2008 (DECC, DPI, DoP, et al., 2007).

7.2.4. Existing climate change adaptation strategies

Management in a changing environment

There is a need to develop experience and expertise in managing remote areas that are markedly affected by natural and human induced processes. Natural changes are those resulting from continuing fluctuations in the frequency and intensity of atmospheric, terrestrial, and marine processes, such as interannual variation in weather conditions, river discharge, and tidal action (Baylis et al. 1997). The extent or rate of natural variation in climatic and ecosystem functions can be modified by deliberate or inadvertent intervention by people, through, for example the uncontrolled access to sensitive places, infestation of weeds, fire damage and the introduction of feral animals (Baylis et al. 1997).

Climate change will undoubtedly have ecological impacts on floodplains of KNP, with many influences on the physical and biological systems over the course of the 21st century. However, as the area of KNP is quite large and occurs within a region of extensive natural vegetation and limited human impacts, the resilience of the healthy undisturbed ecosystems is expected to be greater than for more developed or high populated areas (DNP, 2007).

Kakadu National Park Climate Change Strategy 2010-2015

To aid resilience to potential climate change impacts, KNP Management Authority has implemented the *Kakadu National Park Climate Change Strategy 2010-2015*, that recommends preliminary adaptation, mitigation, and communication actions that are required to manage the consequences of climate change and reduce the carbon footprint of the park. The strategy is consistent with the policies and actions of the *Kakadu National Park Management Plan 2007-2014* and the objectives identified in the *Parks Australia Climate Change Strategic Overview 2009-2014.*

This strategy is an adaptive tool that will need continuous monitoring and revisions, and management will be required to be flexible as improvements in the understanding of climate change impacts occur over time (DNP, 2010). This is a 'first step' in a long-term process of promoting ecological resilience in the diverse and unique environment. The strategy contains a number human adaptation strategies to aid ecological conservation, including:

- Continue to implement strategic weed and feral pest monitoring and control programs.

- Continue to develop and implement landscape unit based fire management strategies.

- Identify species and habitats where impacts from feral pests, weeds and fire are likely to be exacerbated by climate change and revise existing feral pest, weed and fire management programs accordingly.

- Identify, map and protect areas likely to be used as transitional or habitat refugia that will allow for shifts in the distribution and abundance of species and communities in the face of climate change.

- Consult with expert engineers and environmental managers on measures needed to protect significant freshwater habitats from saltwater intrusion. Work with stakeholders to make decisions about the need for intervention and the choice of available options.

- Monitor changing environmental conditions and consult with the Director of Parks, in consultation with the relevant stakeholders, on further protective, restorative and/or adaptive measures that may be needed and feasible (DNP, 2010).

In order for the ecosystems within the park to cope with the rate of climate change, the climate change strategy intends to enhance the existing ecological resilience levels to maintain the natural and cultural values of the park (DNP, 2010).

Parks Australia Climate Change Strategic Overview 2009-2014

The management actions summarised in this strategy are aligned with the five objectives of the *Parks Australia Climate Change Strategic Overview 2009-2014*, which include:

- To understand the implications of climate change.
- To implement adaptation measures to maximise the resilience of our reserves.
- To reduce the carbon footprint of the reserves.
- To work with communities, industries and stakeholders to mitigate and adapt to climate change.
- To communicate the implications of, and or management response to, climate change (DNP, 2010).

7.2.5. Evaluation of existing management actions in Kakadu

In contrast to the Hunter and Cairns case study areas, Kakadu National Park represents a relatively pristine natural environment that is managed jointly by its Aboriginal Traditional Owners and the Director of National Parks (Australian Government website - http://www.environment.gov.au/parks/kakadu/). As a result, the values of the case study area are dominated by the environmental components of the National Park and the cultural and tourism values associated to the habitats and species that inhabit the region.

There are many existing management actions within Kakadu that aim to build resilience in the ecosystems (see above). These management actions focus on fire regimes, alien species (plants and animals) and to a lesser extent, tourism impacts. Given the emphasis on resilience, all of these existing management actions show promise as actions that can also address some climate change threats. However, the capacity of resilience building to mitigate against the consequences of sea level rise and salt water intrusion into freshwater wetlands remains open to question.

7.2.6. Evaluation of adaptation 'storylines' in Kakadu

Three storylines were considered as a way of evaluating adaptation options for the Kakadu case study area and the possible consequences of various approaches to climate change adaptation. The first storyline, "Do nothing" (= maintain existing management strategies), was considered to be reasonably robust approach to the threats posed by climate change, as many of the existing management actions focus on sustainability and building resilience in the natural ecosystems within the National Park.

The second storyline, the hard engineering approach to climate change adaptation, focused on the construction of a sea wall, with a view to limiting salt water intrusion into the freshwater wetlands of Kakadu National Park. Whilst this adaptation action was viewed as being reasonably efficient in meeting these stated objectives, there are a range of likely ecological consequences that need to be considered in more detail prior to the implementation of such an action (Table 7.1). For example, the unintended consequences of building a sea wall might be a restriction in connectivity between marine and freshwater habitats which will, in turn, have negative impacts on some freshwater fish species that utilise estuarine and marine habitats during some stages of their life histories.

The third storyline considered for the Kakadu case study area was that of a soft approach to climate change adaptation, principally via the retreat of human activities from areas that are vulnerable to climate change impacts. This option is perhaps the most confronting of those being proposed for the region, as it requires decision makers to accept significant changes to the ecosystems of the National Park (Table 7.1). This will also have likely have flow on effects for tourism in the region, so the environmental losses may be compounded by economic losses. This adaptation action also raises the question around what the goal of climate change adaptation should be – if the goal is to maintain ecosystems in their current state then this adaptation action fails badly. On the other hand, if the adaptation goal is to facilitate autonomous adaptation, then removing human barriers and allowing the environment to respond to change is certainly consistent with that goal.

A discussion which flowed on from considering planned retreat and the associated habitat losses expected in the region was whether a re-consideration of the purpose, position and management of the National Park (and all National Parks for that matter) might be warranted. For example, suitable breeding and feeding habitats for the Magpie Goose, an iconic species of Kakadu, lie outside the boundaries of the existing National Park, so one possible adaptation action might be to gazette new areas or move the existing boundaries of the National Park to adjust to climate change threats and to provide protection for critical habitats and species. This represents a major re-think of conservation planning and the role of National Parks, but is a consideration worthy of discussion in light of the anticipated changes in many coastal environments over the coming decades.

Table 7.1. Hard and soft adaptation storylines for the Kakadu National Park case study, with a focus on the construction of a sea wall (hard) and planned retreat (soft) and their goals and the likely cost, efficacy and consequences of implementation and maintenance. All ranked scores range from High (3) to Medium (2) to Low (1).

MANAGEMENT ACTION	DESCRIPTION	TARGET(S)	COST	EFFICACY (RELATING TO TARGET) (3,2,or 1)	ECOSYSTEM COMPONENT or VALUE	CONSEQUENCE	INTENDED (I) or UNINTENDED (U)?
HARD							
Sea wall	Construction of a rock seawall along the coast (area not defined)	sea level	3	2	Freshwater macrophytes	Retain current macrophyte community **I**	
		salinity				Facilitate expansion of freshwater habitats	I
				2	Freshwater fish	Restrict movement of highly mobile species- breeding, species loss etc.	U
						Maintain freshwater habitat	I
					Wetland waterbirds	Maintain current community structure **I**	
SOFT							
Retreat of human activities	Retreat (including removal of infrastructure) away from areas vulnerable to climate change, including those that are subject to inundation and saltwater intrusion	Facilitate autonomous adaptation; remove barriers 3		3	macrophytes	Significant loss of freshwater species; encroachment by saltwater tolerant species	I
					fish	Loss of some freshwater species; expansion of estuarine-marine habitats will support more brackish water species	I
					waterbirds	Movement of waterbirds to alternate feeding and nesting grounds (perhaps outside of	I

		the NP)	
	Tourists	Loss of icon tourist sites - may lead to loss of tourism activities; movement of tourist activities into less vulnerable areas U,	I

7.3. Case Study 2 - Hunter Estuary, Newcastle, New South Wales

7.3.1. The Hunter Estuary

Located on the eastern coast of New South Wales (NSW) the Hunter-Central Rivers Catchment covers 37,000km^2. Within the catchment, the Hunter River drains the largest coastal catchment in NSW, which covers 22,000km^2 (HCRCMA, 2010). Even though large areas consist of protected national parks, the Hunter coast is second only to Sydney/Central Coast as the most densely populated and developed strip in NSW (DECCW, 2008). This catchment supports nearly 1 million residents and a population of 350,000 that live in the Hunter region today with major urban centres around Newcastle, Maitland, Singleton, Scone, Muswellbrook, Cessnock and Raymond Terrace (HCRCMA, 2010).

Aboriginal communities (Awabakal, Worimi, Gringai, Kamilaroi, Wonaruah, Geawgal and Darkinjung) have occupied this region for several thousand years (HCRCMA, 2010).

7.3.2. Potential climate change threats to Hunter Estuary

Climate change drivers consist of changes in average temperature, rainfall and evaporation. However long-term consequences for the catchment are more likely to be seen from extreme weather events. Projections exhibit impacts will be felt from more hot days, bushfires, droughts and intense storms (see Appendix 9). The impacts alone or in combination, potentially place great threats on life, property and natural ecosystems (CSIRO, 2007).

Alterations in rainfall and increases in temperature leading to higher evaporation rates are likely to result in reduced river flows in the Hunter-Central Rivers Catchment. This could have downstream consequences on water resources, by reducing water quality. For example, there is a greater likelihood of harmful algal blooms from low flows, higher temperatures and elevated nutrients (CSIRO, 2007). An increase in fire activity in the catchment could contaminate water systems with sediment and ash particles. In addition, water quality could be affected by salinity problems that are exacerbated by changes in rainfall, temperature and stream flows (Beare and Heaney, 2002). Meanwhile, decreases in runoff during the winter seasons could reduce the functionality of internationally recognized wetlands in the Hunter-Central Rivers Catchment (CSIRO, 2007).

Rising sea-level and salt-water intrusion could affect surface water and the quality of coastal groundwater aquifers. In addition, the intrusion of sea water into estuaries may affect coastal habitats. The possibility of coastal retreat or migration may be limited due to hard infrastructure built along the coastline, greatly impacting the ecosystem functions and services these habitats provide. This could have great impacts on the biodiversity of the area (CSIRO, 2007).

Although the current impacts to catchment's biodiversity are a result from historical land clearing, alterations of river flows and water extraction, climate change is perceived to exacerbate the effects on the catchment's plants and animals. In 2006, there were 215 species, nine populations and 19 ecological communities in the catchment are classified as threatened or endangered (DEC, 2006).

It is projected that the changes in extreme temperatures will promote changes in the geographic distribution of species. Changes in the distribution of some plant and animal species may impact migration in or out of an area, altering the ecosystem function and health of the catchment (CSIRO, 2007). Extensive land clearing could lead to isolating habitats, not allowing for migration patterns to occur from changing environmental conditions, leaving plants or animals stranded in specific environments. It is uncertain how the accumulation of climate change impacts will affect the wetlands or some of the catchment's threatened or endangered species such as the Hastings River Mouse, the Giant Barred Frog and Regent Honeyeater (CSIRO, 2007).

7.3.3. Coastal ecosystem management strategies

This region is governed by the Hunter-Central Rivers Catchment Management Authority (CMA) Board under the *Catchment Management Authorities Act 2003*, which comprises a chairman and six board members who reside within the Hunter-Central Rivers region. This Board reports directly to the Minister for Climate Change and the Environment and sets the CMA's direction for investing in the future of the region's natural resources (HCRCMA, 2010).

The collaboration of fourteen Councils in the Hunter, Central and Lower North Coast of NSW has initiated the Hunter and Central Coast Regional Environmental Management Strategy, which aims to facilitate a regional approach to encourage ecologically sustainable development through the co-operation of member Councils, state and federal authorities, industry and community groups (CSIRO, no date).

There are numerous management strategies in place to rehabilitate, conserve or protect ecological areas of the Hunter Estuary. For example, the Hunter-Central Rivers CMA is actively restoring two major wetland areas in the Hunter River estuary: Hexham Swamp and Kooragang Wetlands. In addition, the Hunter River Estuary and wetlands are of international significance, being listed under the Ramsar wetland convention in 1984 (DSEWPC, 2011b), and utilised by 38 of the 66 migratory species protected by the Japan-Australia Migratory Bird Agreement (JAMBA) and China- Australia Migratory Bird Agreement (CAMBA) (DECCW, 2009). The Hunter River Estuary encompasses a diversity of habitats, including several Endangered Ecological Communities listed under the NSW *Threatened Species Conservation Act 1995*, as well as habitats critical to migratory birds (HCEMC, 2006).

The Hunter River Estuary and wetlands is also of state and national significance, being utilised by a range of species protected under the NSW *Threatened Species Conservation Act 1995* and the Federal *Environmental Protection and Biodiversity Conservation Act 1999* (HCEMC, 2006).

Numerous management strategies for the area are considered to have specific ecological targets. Several of the actions investigated for the purpose of this case study were considered to have great potential to address climate change impacts for the drivers that underpin the ecology. Such management strategies included:

- Wetland Rehabilitation.
- Ramsar protective management.
- Australian Quarantine and Inspection Service control of shipping and invasive species.
- Flood gate management.
- Fisheries catch limits – recreational and commercial.

7.3.4. Climate change adaptation strategies

The NSW Office of Environment and Heritage (OEH) aims to build the resilience of NSW's natural environment to maximise the benefits of adaptations and minimise the costs of climate change in the future. The NSW Government is working through the Council of Australian Governments to identify actions that are required within priority areas, including changes to existing policy settings (OEH, 2011). The NSW Government's *Climate Change Impacts and Adaptation Research Program* supports research by the NSW Department of Planning to collect high resolution terrain information along the NSW Central and Hunter coasts. This aids in the assessment of potential impacts of climate induced shoreline erosion, flooding and coastal inundation (CSIRO, no date).

NSW Biodiversity and Climate Change Adaptation Framework 2007-2008

The *NSW Biodiversity and Climate Change Adaptation Framework 2007-2008* recognises that adaptation is an essential element to reducing the extent that climate change impacts upon biodiversity. It also acknowledges that adapting our management practices to those that protect or minimise degradation also enables a reduction in vulnerability to the impacts of climate change (DECC, et al., 2007). The framework has identified six key action areas:

- Communicate the likely influence of climate change on biodiversity, and raise awareness of adaptation actions.
- Research and monitor impacts of climate change and how we can adapt to them.
- Incorporate adaptation strategies relating to the impacts of climate change on biodiversity into policy and management.
- Provide adaptation planning methods and tools to deal with climate change impacts on biodiversity.
- Minimise the impacts of climate change on key ecosystems and species.
- Minimise the increased threat of invasive species on native species that comes with climate change (DECC, et al., 2007).

Each of the key action areas specify a number of research based and educational human climate change adaptation approaches (DECC, et al., 2007), but fall short of providing any real detail on practical, on-ground adaptation actions.

Sea Level Rise Policy Statement 2009

To support human adaptation to sea level rise, the NSW Government has prepared a *Sea Level Rise Policy Statement 2009*. This policy statement sets out the Government's approach to sea level rise, the risks to coastal property owners and assistance the Government provides to councils to reduce the risks of coastal hazards (OEH, 2011). This policy acknowledges that the impacts of sea level rise will be complex and result in altered natural processes on the coasts and estuaries (DECCW, 2009). However, the focus is on minimising social disruption and economic costs for the private and public sectors and less so on environmental impacts. Some of the environmental considerations briefly discussed in this article refer to using sea level rise benchmarks for planning purposes, such as considering the impact on coastal and estuarine habitats and identifying valuable habitats most at risk from sea level rise and assessing the impact of changed salinity levels in estuaries, including implications for access to fresh water. No specific adaptation plans are discussed in this policy statement, as the NSW Government gives responsibility to local councils for planning and development assessment decisions in coastal areas.

The Sea Level Rise Policy Statement refers to several other related NSW Government initiatives, policies, programs, and legislation, including the NSW Coastal Policy 1997, *Environmental Planning and Assessment Act 1979* (EP&A Act), The State Environmental Planning Policy 71 – Coastal Protection (SEPP 71), and the NSW Flood Prone Land Policy. These policies are supported by the Government's coastal, estuary and floodplain management programs, which provide technical policy support and grants to local councils in order to identify and manage coastal hazards and flooding risks (DECCW 2009).

Summary of Climate Change Impacts Hunter Region 2008

As part of the NSW Climate Change Action Plan climate change impacts for the various regional areas of NSW have been developed. The *Summary of Climate Change Impacts Hunter Region 2008* covers a range of climate change impacts from increased temperature, decrease rainfall, increased sea levels, and also details the biophysical impacts biodiversity of the Hunter Region (DECC, 2008).

7.3.5. Evaluation of current management actions with ecological targets

There is a wide range of existing management actions within and around the Hunter River estuary that have ecological targets. Those that were explicitly considered at the expert panel workshop were:

- Wetland rehabilitation
- RAMSAR and other reserve protection
- Legislation regarding pollution and contamination
- AQIS control of shipping and invasive species
- Flood gate management, and
- Fisheries catch limits – for both recreational and commercial fishing

All of these management actions were considered by the expert panel members to have specific ecological targets. Furthermore, they all show some potential as actions that can address the climate change impacts on the drivers that underpin the ecology of the estuary. Whilst this conclusion was made quite easily among the group, it did come as a welcome surprise to many of the participants. However, further discussion both at the workshop and afterwards revealed that significant reconsideration of the objectives, baselines and triggers for action of these actions would be required for them to fulfill their potential. Significantly, many of these changes in the goal of the action would require significant thought and, in some cases, legislative changes. As a result, conversion of existing management actions into climate change adaptation actions does not represent a subtle modification of existing measures so much as a radical re-thinking and re-working of current actions. Critically, and as stated throughout this report, it is critical to the success of all climate change adaptation actions that within and between connectivity is explicitly incorporated into the decision making process to ensure that the risk of maladaptation in non-target habitats is limited.

7.3.6. Adaptation 'storylines' for the Hunter River estuary

Notwithstanding the significant changes required to modify existing management actions to address climate change detailed above, the fact that current actions focus on drivers that will be affected by climate change ensured that the 'Do nothing' scenario for the Hunter River estuary was not considered to be too bleak. Indeed, maintaining existing actions and not introducing any new actions will (and is intended to) build resilience in the estuarine environments within the estuary. To this end, the status quo currently represents a reasonably solid approach to the non-climatic threats facing the estuary. Whilst significant events (droughts, floods and storm surges) are likely to cause major ecological and socio-economic damage under this scenario that may always be the case, as extreme events are typically not manageable, or at least targeted by managers, by definition of their being statistically rare and extreme.

The 'hard approach' considered for the Hunter River estuary was the implementation of a barrage near the mouth of the estuary. Such a barrage has been considered as an adaptation to sea level rise and more recently, flooding associated with storm surges. On the basis of the discussion among participants at the expert panel workshop, this adaptation strategy was likely to be only useful during storm surge events and would not be used to mitigate the effects of sea level rise (Table 7.2). For such an expensive piece of infrastructure, both in terms of construction and maintenance, the focus on extreme events would probably make it untenable. Indeed, it was suggested that such a solution is almost completely unviable. There was also concern raised about the specifications of the barrage – would it be built to withstand a 1 in 100 year event, or worse? Regardless of the specifications, there was concern raised around the capacity of infrastructure like this to reduce resilience in the local community due to the expectation that the area would never be impacted by flooding after such infrastructure was put in place. Furthermore, once the design specifications are exceeded, the consequences would likely be catastrophic socially, economically and environmentally. The very recent example of the Wivenhoe Dam and flooding in Brisbane in January 2011 was cited as an example of this sort of event (Tim Smith, pers. comm.) and the consequences of community perception of how infrastructure is believed to be able to stop extreme events from ever occurring.

The 'soft approach' considered for the Hunter River estuary focused mostly on planned retreat – moving communities away from areas likely to be inundated by sea level rise, storm surges and local flooding – but also examined strategies to enhance connectivity within and between habitats and zoning regulations around habitats of conservation significance (Table 7.2) All of these approaches involve building ecosystem resilience by providing some scope for the natural ecosystems to retreat too, by removing barriers, like hard infrastructure, that currently limit the capacity of mangrove and saltmarsh habitats to move landward.

Of all three adaptation actions, planned retreat is certainly the most costly, but the return on investment is likely to be much greater as there will be much reduced costs associated with extreme events and inundation into the future. To this end, this strategy focuses on investing now and recognising that the benefits are still a long way from being realised. The other two management strategies are likely to be significantly less expensive to implement, especially if there is already scope to implement them, without disruption to existing activities in the catchment and/or revisions to planning documents. Whilst they both provide opportunities for adaptation of habitats and species within the estuary, these strategies do not provide opportunities for landward migration (because infrastructure and human settlements will remain as significant barriers). To this end, these strategies are likely to be positive in the short-term, but perhaps have limited capacity to deliver positive outcomes into the future.

7.3.7. Summary of current and future prospects for the Hunter River estuary

The expert panel workshop was intended to evaluate current management actions with possible climate change adaptation outcomes and to consider new climate change adaptation actions in the case study region. These activities were both thought-provoking and encouraging as many of the existing management actions (with ecological targets) show promise as addressing drivers that will be affected by climate change. However, it is clear that existing goals, targets and thresholds of these management actions would need to be re-considered to accommodate climate change threats and this is no small undertaking. Whilst there is scope for improvement and targeted adaptation actions, it is also clear that a major re-think of legislative and objectives will be required to ensure that actions are sustainable and not likely to be maladaptive in other habitats and/or detrimental to the existing economic and social values within the area.

The ‘storyline’ approach taken to the Hunter River estuary enabled us to examine proposed adaptation actions and evaluate their likely costs, efficacy (relating to their stated targets) and consequences. This approach is vitally important when making decisions about climate change adaptation, as even the most efficient and cost-effective actions should not be implemented if the adverse unintended consequences are too many or too dire.

In many ways the Hunter River estuary is unique in that it represents a catchment in which climate change adaptation has already been discussed in some detail. This has occurred because State government, regional councils and catchment management authorities have a coordinated approach to climate (and non-climate) issues. Significantly, funding from the Commonwealth has enabled this cohesive approach to problem issues, as evidenced by the wide range of plans that have been developed for the region (see above).

Although participants felt that the Hunter River estuary was better armed for adaptation than many other estuaries, there were many issues discussed around barriers to developing and implementing climate change adaptation plans. For example, improved coordination of existing databases and data-sharing arrangements between relevant authorities is required to ensure that the best possible information is brought to bear on decisions. Participants even suggested that new legislation, stipulating data sharing and database management, may be required to facilitate the need for all relevant information to be provided to decision makers.

Table 7.2. Workshop analysis of the 'hard' and soft' climate change adaptation approaches in the Hunter River estuary, with a focus on a barrage near the mouth of the estuary (hard) and retreat, maintaining corridors and rezoning (soft) and their goals and the likely cost, efficacy and consequences of implementation and maintenance. All ranked scores range from High (3) to Medium (2) to Low (1).

MANAGEMENT ACTION	DESCRIPTION	TARGET(S)	COST (3= High, 2 = Med, 1 = Low)	EFFICACY (RELATING TO TARGET) (3,2,or 1)	ECOSYSTEM COMPONENT/VALUE (as per worksheet 1)	CONSEQUENCE	INTENDED (I) / UNINTENDED (U)?
Barrage	Barrage constructed at mouth of estuary	To reduce local flooding in response to sea level rise, or more particularly, storm surge.	3	2	A lot of ecosystem components are influenced by flooding, including mangroves, saltmarsh, freshwater wetlands; flooding also has negative effects on seagrass and tidal flat habitats.	A barrage will not be an effective action to adapt to incremental sea level rise; therefore it is only potentially useful for extreme events and storm surges; operating the barrage may be subject to political or community pressure to maintain it as a closed system; very expensive to build and maintain - almost not viable, perhaps why there is not one there already; expectation of protection if it is there - residual risk;	I
retreat of human activities	Move existing infrastructure, activities and buildings away from vulnerable locations	Facilitate adaptation and, long-term reduce impacts of climate change on social, economic and environmental values.	3	3	Most ecosystem components will benefit from this strategy, although some may be adversely affected by climate change regardless of the actions we take.	Significant short-term consequences for people and local businesses etc; likely to be some short- and medium-term impacts on the environment – removing barriers and infrastructure to facilitate adaptation.	I

corridors and connectivity	eg flood gate operations; connectivity can be a positive or negative; inter-estuary connectivity; diadromous species; marine parks management need to consider changes to connectivity; invasives may use corridors and some indigenous taxa may not use them much	Build resilience and facilitate adaptation	1 for cases when we don't have to do much; 3 if we need to reverse historical decisions or buy back existing property rights	2	All habitats and species will benefit from improved within-estuary connectivity, with the possible exception being the spread of invasive species and the impacts associated with that	Increased resilience and dispersal (and therefore recruitment); possible negative consequences for communities and industries that may need to be moved or adjusted to accommodate the provision of corridors.	I
zoning plans and adjacent land use to wetlands	complementarity of activities; higher protection from development that restricts access eg heavy industry or military reserve (join the army for more reserves); important for early planning while land and thus option is still available; make plans and protection rules more flexible to accommodate future changes in species and habitat distributions	Enhance protection of threatened habitats and species; provide flexibility in plans to accommodate future change	1 if plan does not already allow development or coal extraction; 3 if opposite	3	All ecosystem components recognised in the plans will benefit from this strategy; managers will benefit from increased flexibility in plans	Significant benefits for habitats and species; likely to be costs to industry and communities as reserves will be less fixed (in space and time).	I

A wide range of revisions to existing legislation and regulations is required in the Hunter River estuary, to both accommodate non-climatic and industry changes and the threat that climate change superimposes over the catchment. For example, the following re-thinks of existing management were suggested by workshop participants:

- buffers around reserves and wetlands are required to allow migration/displacement of habitats
- revise thresholds values for water quality parameters etc
- weirs, in association with other land practices, in the Bega River may lead to hyper-saline estuaries; so we need new trading mechanisms to manage water between the tidal pool and further upstream
- new and revised instruments for water security – for both surface and groundwater
- need to consider buy backs of properties versus swapping parcels of land - developing infrastructure, shops schools, services in advance of asking people to move there
- development of compulsory land acquisition of high risk properties
- communication and education - residual risk, 1 in 100 year event can still happen tomorrow
- need to advise land holders perhaps with examples that market values will fall in the future
- housing design needs to be re-evaluated, especially in flood prone areas eg old Queenslanders are not built in underneath, designed to be cleaned out, power etc up high, rafters to store possessions
- Port Authority and Hunter Development Corporation - conflict of interest as they current can sign off on their own development proposals
- Consideration of dynamic environments and the possibility of a rolling easement of buffer to accommodate change - versus upfront massive buffer - cost of rolling case could be greater
- managed translocations - stringent risk assessment?- substrate considerations, build suitable habitat that may allow natural movement, rather than directly move animals or plants

It is clear from the above list that climate change adaptation will seriously challenge politicians, legislators and managers to become more dynamic and adaptive in the way they respond to threats. This is a significant change to the comparatively static approaches to many of the existing problems within the Hunter River estuary and will require significant effort and commitment from decision makers over a long period of time.

7.4. Case Study 3 - Cairns Region, Queensland

7.4.1. The Cairns Region

For the purposes of this case study, the Cairns Region includes both Cairns and Cassowary Coast Regional Council areas, extending from the northern Aboriginal community of Wujal Wujal, north of Cape Tribulation, to the town of Cardwell in the south (DIP, 2009). Longitudinally, the Cairns Region extends from the Atherton Tablelands in the west to the eastern most boundary of the Great Barrier Reef World

Heritage Area to the east (DIP, 2009). As such, the geographic boundaries of the Cairns Region Case Study also coincide with the Australian Bureau of Statistics local government region, ensuring a high level of data availability, such as population (residential population of the Cairns Region is 196,124), land development and environmental statistics (ABS, 2010).

The Cairns region is home to two World Heritage Areas of global significance, namely the Wet Tropics of Queensland and the Great Barrier Reef World Heritage Areas. Ecologically these ecosystems have high biodiversity and productivity, they provide habitat for millions of species, and contribute significantly to the employment of thousands of people and generate billions of dollars for economies both internationally and in Australia (Prideaux & Falco-Mammone, 2007; GBRMPA, 2008). However, due to the size of the Cairns Region and as a result of the complexities involved in considering both the terrestrial and marine realms, the Great Barrier Reef will form the focus of this study and provide an example of the management practices currently in use that could potentially contribute to climate change adaptation in the region. Another advantage of using the Great Barrier Reef as an example is the extent to which the management of the reef is interconnected with terrestrial management practices resulting from industries, such as tourism, urban development, grazing and agriculture (GBRMPA, 2009).

7.4.2. Potential climate change threats to the Cairns Region

There are numerous impacts resulting from climate change that will impact human and natural coastal systems within the Cairns Region (see Appendix 9). Human understanding of all the impacts of climate change is still relatively immature, with much research still to be carried out. However, some of the impacts of climate change are as follows.

Increased temperatures

Increased atmospheric temperatures warm sea water to the point where the symbiotic protozoa, known as zooxanthellae become distressed and either level the coral, die and/or lose their pigmentation (Vidal-Dupiol, Adjeroud, Roger, et al., 2009). Coral bleaching has begun to increase in frequency and severity due to rising sea temperatures, with approximately 5% of the reefs in the Great Barrier Reef severely damaged in 1998 and 2002 by coral bleaching (UoS, 2004). Water temperature projections suggest that coral bleaching will continue and may become an annual event over the next 100 years (GBRMPA, 2011). Coral bleaching will have severe impacts on the Great Barrier Reef and the ecosystems and economies that depend upon them.

Ocean acidification

The acidification of the ocean surface through the uptake of CO^2 is a serious threat to marine organisms, including coral and invertebrates (Hoegh-Guldberg, Mumby, Hooten, et al., 2007). The acidification of the oceans impacts calcifying marine plants and animals that use carbonate minerals (CaCO3) to form shells, skeletons, and tests, including crustose coralline algae, planktonic organisms, corals, and a range of benthic organisms (e.g., oysters, clams, sea urchins, and sea stars) (Guinotte & Fabry, 2009). As such, acidification could significantly impact on the Cairns Region due to the extent of its ecological and economic dependency on the Great Barrier Reef.

7.4.3. Coastal ecosystem management strategies

Due to the ecological and economic significance of the Great Barrier Reef to the international and national communities, the sustainable management of the many ecosystems that collectively form this World Heritage area is of great importance to governments, industries, researchers and the community as a whole (PC, 2003). The following legislative, policy and planning strategies are examples of those that, although not their original purpose, enable autonomous climate change adaptation to occur through the protection and maintenance of ecosystem health, resilience and adaptive capacity.

World Heritage

Internationally, the Great Barrier Reef was recognised as a World Heritage Area in 1981 and is the world's largest World Heritage area covering 348,000 km^2 (DSEWPC, 2008). Once World Heritage listing has been achieved governing bodies are obligated to regularly report to the World Heritage Committee on the state of conservation and the various protection measures put in place at the site. The World Heritage Committee advises the governing bodies responsible for the protection and management of World Heritage areas, and as such endorsed the report on *Predicting and Managing the Impacts of Climate Change on World Heritage 2006* (UNESCO, 2006) and the *Strategy to Assist State Parties to Implement Appropriate Management Responses 2006*. Both report and strategy outline various adaptation management responses that can be used to increase the resilience of World Heritage areas to the impacts of climate change. Therefore, relative to climate change adaptation, the World Heritage status of the Great Barrier Reef plays an influential role in the development of adaptive practices that protect and enhance the health and ecological resilience of these ecosystems.

Predicting and Managing the Impacts of Climate Change on World Heritage 2006

The *Predicting and Managing the Impacts of Climate Change on World Heritage 2006* report advises the following adaptation practices to protect the heritage values of World Heritage Areas:

- Creating new protected areas
- Enlarging existing protected areas
- Creating replicates of existing protected areas
- Designating "stepping-stone" or corridor protected areas
- Creating buffer zones of natural habitat around protected areas
- Increasing habitat heterogeneity within protected areas (e.g. altitudinal, latitudinal and topographic)
- Restoring, regulating or maintaining disturbance regimes
- Removing or reducing invasive alien species
- Reducing other environmental stresses
- Restoration or rehabilitation of natural habitat

- Translocation, reintroduction or introduction of species
- Expanding inventory, modelling, monitoring, sensitivity analysis, etc (UNESCO, 2006).

7.4.4. Climate change adaptation strategies

As the climate changes, maintaining the adaptive capacity of coastal ecosystems through the use of human adaptation practices is becoming a priority (Abel, Gorddard, Harman, et al., 2011; Klein, Nicholls, Ragoonaden, et al., 2001; Sharples, Attwater, Ellison, et al., 2008). Although many of the existing coastal protection policies and plans result in the development and implementation of adaptive management practices, a more targeted approach in the form of climate change adaptation strategies and practices is necessary.

Great Barrier Reef Climate Change Action Plan 2007 – 2011

The *Great Barrier Reef Climate Change Action Plan 2007 - 2011* outlines a coordinated Australia government response to the potential impacts from climate change on the reef ecosystems. It identifies strategies for direct actions and partnerships that will increase the resilience of the reef to climate change impacts. By maintaining the health and resilience of the reef ecosystems, the impact of climate change on ecosystem services and therefore, on reef industries, such as tourism and commercial and recreational fishing will be minimised (GBRMPA, 2007). The Action Plan incorporates four objectives including targeted science, resilient reef ecosystems, adaptation of industries and communities and reducing climate footprints. A climate footprint is the extent of influence that humans have on the climate (GBRMPA, 2007). Some of the climate change adaptation practices suggested include:

- identifying and protect alternative habitats to provide for shifts in species and ecosystems impacted by climate change,
- protect species and ecosystems particularly vulnerable to climate change, and
- reduce impacts that exacerbate climate change vulnerability (GBRMPA, 2007).

Cairns Regional Council Climate Change Strategy 2010 - 2015

The purpose of the *Cairns Regional Council Climate Change Strategy 2010 - 2015* is to provide direction for managing the risks resulting from climate change. The Strategy builds on the *Climate Change Adaptation Action Plan 2009* and the *Greenhouse Gas Mitigation Action Plan 2009/10*, also developed by Cairns Regional Council. The Strategy outlines four approaches that can be used in adapting to climate change:

Avoid: locate new development where it isn’t vulnerable to climate change impacts.

Planned retreat: enable land, ecosystems and structures in vulnerable areas to be made available for coastal retreat.

Accommodate: where development has already occurred on erosion prone areas allow for continued occupation but with altered building designs.

Protect: defend vulnerable areas, population centres, economic activities and coastal resources.

Climate Change Risks and Opportunities for the Cairns Region 2009

The *Climate Change Risks and Opportunities for the Cairns Region 2009* sets out a range of possible adaptation options for Cairns Regional Council. It also suggests a series of guidelines and recommendations for continued adaptation to potential changes in climate and the resulting risks. Section 3 of the Plan identifies possible adaptation actions for 27 risks associated with climate change. The 27 adaptation actions can be grouped into corporate governance, natural disaster planning and response, land use planning and flooding, assets and operations, environment and community health. In the interests of selecting the most appropriate adaptation action for a particular climate change risk the report recommends a qualitative multi-criteria assessment.

7.4.5. Evaluation of the Cairns case study area – existing management

Local government climate change policy and concerns in the Cairns Wet Tropics Case study area were discussed during the expert panel workshop. Firstly ten local ecosystem components were identified (Table 7.3). These components ranged from ecological components such as biodiversity and conservation but also included biosecurity (water resources), economic aspects (sustainable industries, tourism) and social aspects (recreation, life style).

7.4.6. Adaptation 'storylines' for the Cairns case study region

After examining existing management actions, we then defined the management actions, present or future that could be used to maintain the value of the ecosystem components, particularly in light of the climate change threats. We considered three scenario's or storyline approaches and for each scenario we identified the direct targets and indirect beneficiaries using five categories (Table 7.4). The scenarios evaluate were: 1) Do nothing (= maintain current approaches – see Table 7.5), 2) hard approaches (see Table 7.6), and 3) soft approaches (see Table 7.7).

Unlike the other case studies, many of the suggested adaptation actions (including hard and soft approaches) are already in place in the Cairns region. Indeed, it was noted that local government is well informed about both climate and non-climate related threats and they have both hard engineering and soft plans in place to mitigate climate and non-climate change related effects. Critically, lack of financial support was identified as the major impediment to the implementation of many of the identified management actions.

Table 7.3: Ecosystem component/value identified in workshop discussions.

Ecosystem component/value
Biodiversity
Water resource (quality and security)
Active and passive recreation
Climate
Productive sustainable industries (agriculture, fishing, marine industry)

Tourism
Sustainable Economy
People and culture
Life Style (space, way of life, closeness to nature)
Conservation of wilderness (terrestrial and marine)

Table 7.4: Definition of targets for management actions

Types of targets
(H) Human capital (human capacity to implement actions)
(S) Social capital (networks that make society function effectively)
(F) Financial capital (cash or in-kind)
(N) Natural capital (biodiversity)
(B) Built capital (Infrastructure)

It was identified that projects aiming to clean waste-water could develop spin-off activities revolving around energy production and generation. Such approaches could also increase water security, a key issue for local governments. It was also noted that reef rescue plans that focus on land practices, principally with the view of building resilience in reef communities by reducing non-climatic threats, could have flow-on effects for flora and fauna.

Table 7.5 Storyline 1: Do nothing (= maintain current approaches) storyline for the Cairns case study area

Management action	Primary targets	Indirect beneficiaries	Climate Adaptation
Rehabilitation†	N	H, S, F, N	Yes
Enacting current management plans	all	all	Yes
Land acquisition in high conservation areas (Daintree and Mission Beach)	N	F, N	Yes
Defence of highly vulnerable land (Clifton and Machan's beaches)	F, B	H, F, B	Yes
Cleaner seas project (cleaner waste water)	N	F, N, B	Yes
Reef plan (coordinating mechanism, improve water quality in GBR lagoon)	N	H, S, F, N	Yes
Reef rescue (implement changes of practice on the land)	N	all	Yes
Eradication of weeds and pests (invasive species)	N	H, S, F, N	Yes
Implementation of marine park zoning	N	all	Yes
Parks and reserves management	N	all	Yes
Implement development assessment frameworks (local, state and federal levels)	N	all	Yes
Awards and industry accreditation*	H, S	H, S	

Planning for food security§	all	all	Yes

†Rehabilitation included increase in area and quality of habitat (riparian veg)
*Awards and industry accreditation included education and community and can also drive innovation
§Planning for food security included:

a. Zoning plan that avoids areas of high conservation value,
b. Urban footprint legislation to prevent urbanisation of valuable agricultural land (that may become more important in the future as other areas of Australia become drier),
c. Preserve genetic diversity of commercial species to allow adaptation to climate change

Table 7.6 Storyline 2: Hard adaptation storyline for the Cairns case study area.

Management action	Primary targets	Indirect beneficiaries	Climate Adaptation	Description
Rehabilitation	N	H, S, F, N	Yes	stabilization of river banks, redirection of flow and building raised board walks.
Defend land acquired in high conservation areas (to protect investment)	N	F, N	Yes	sea walls and fences to protect against sea level rise, storm surge, salt water intrusion and pests.
				build or extend sea wall/ coastal barrages OR
				artificial breakwaters at sea to reduce coastal wave action
Defence of highly vulnerable land (Clifton and Machan's beaches)	F, B	S, N	Yes	
				upgrade of sewage treatment plants,
				development of waste water treatment facilities at point of discharge,
Cleaner seas project (cleaner waste water)	N	F, N, B	Yes	install recycled water infrastructure
Reef plan (coordinating mechanism, improve water quality in GBR lagoon)	N	H, S, F, N	Yes	sediment and nutrient traps

Reef rescue (implement changes of practice on the land)	N	all	Yes	build artificial wetland
Eradication of weeds and pests (invasive species)	N	H, S, F, N	Yes	fences or canals as barriers to keep pests out/in
Implementation of marine park zoning	N	all	Yes	Construction of artificial reefs
				fences or canals as barriers to keep pests out/in
Parks and reserves management	N	all	Yes	development of infrastructure for visitors (eg sky rail; boardwalks)
Climate proof houses by changes to construction principles				floating houses on pylons a la marinas

Table 7.7 Storyline 3: Soft adaptation storyline for the Cairns case study area.

Management action	Primary targets	Indirect beneficiaries	Climate Adaptation	Description
Rehabilitation	N	H, S, F, N	Yes	Strategic rehab (identifying priority areas) - maintaining/building connectivity
Establish funding framework through offset programs				Need to map high priority areas and provide linkages between HP and rehab areas
Increase the capacity of current management plans to deal with CC	all	all	Yes	continue to implement, action and extend management plans (raising awareness and resources), Identify sectors without management plans and help them formulate and implement them; Building regular review process to facilitate adaptation
Land acquisition and/or compensation of high conservation areas with existing development rights (Daintree and Mission Beach)	N	F, N	Yes	Post-acquisition management (links to rehabilitation)
Risk mapping				Use modelling to identify high risk areas
Land acquisition of highly vulnerable coastline areas				protection of vulnerable land from development. No protection against erosion etc.
Cleaner seas project (cleaner waste water)	N	F, N, B	Yes	Use weather/climate predictions to modify current practice (ie farmers need to have fertilisation plans specific for the weather predictions for that year)\

Reef plan (coordinating mechanism, improve water quality in GBR lagoon)	N	H, S, F, N	Yes	Actions in response to changes from baseline levels (review and react)
				continual improvement program and redefinition of best practice with improved technology;
Reef rescue (implement changes of practice on the land)	N	all	Yes	expanding practice to other sectors (eg more agricultural sectors)
				sunset clause to prevent acquisition of new pets in high conservation areas;
				regulation of plant sales from nurseries;
				regulation of pet industry eg tilapia; management and treatment of ballast water
Eradication of weeds and pests (invasive species)	N	H, S, F, N	Yes	
Implementation of marine park zoning	N	all	Yes	
Parks and reserves management	N	all	Yes	commercialisation to generate revenue to improve capacity to manage for climate change
				better coordination among agencies, levels and funding for policy outcomes
Implement legislative policy frameworks (local, state and federal levels)	N	all	Yes	To review legislation with regards to climate change (identify gaps and coordinate different tiers of government)
Ecosystem payments to landholders				Pay farmers to retain and maintain wetlands instead of developing them for production

				sacrifice productive land for ecological service;
				Provide resources to re-educate and re-skill
Managed transition of industries (economic diversification)				Plan and manage new use of resources
Climate change scientific research at the regional level				Provide scientific information to inform policy at local levels
climate change tourism				shift from high volume tourism to high quality tourism
managed retreat				identify sensitive areas currently inhabited and plan to repossess land after natural disaster
				sunset clause (buy back of land when it becomes available)
awards and industry accreditation				education and community awareness
planning for food security				flexibility in zoning plans to allow for changes in land use to allow small farms
Rehabilitation	N	H, S, F, N	Yes	stabilization of river banks, redirection of flow and building raised board walks.
Defend land acquired in high conservation areas (to protect investment) N		F, N	Yes	sea walls and fences to protect against sea level rise, storm surge, salt water intrusion and pests.
Defence of highly vulnerable land	F, B	H, F, Bd	Yes	build or extend sea wall/ coastal barrages OR

(Clifton and Machan's beaches)				artificial breakwaters at sea to reduce coastal wave action
				upgrade of sewage treatment plants,
				development of waste water treatment facilities at point of discharge,
Cleaner seas project (cleaner waste water)	N	F, N, B	Yes	install recycled water infrastructure
Reef plan (coordinating mechanism, improve water quality in GBR lagoon)	N	H, S, F, N	Yes	sediment and nutrient traps
Reef rescue (implement changes of practice on the land)	N	all	Yes	build artificial wetland
Eradication of weeds and pests (invasive species)	N	H, S, F, N	Yes	fences or canals as barriers to keep pests out/in
Implementation of marine park zoning	N	all	Yes	Construction of artificial reefs
				fences or canals as barriers to keep pests out/in
Parks and reserves management	N	all	Yes	development of infrastructure for visitors (eg sky rail; boardwalks)
climate proof houses by changes to construction principles				floating houses on pylons a la marinas

7.5. Synthesis of case study findings

7.5.1. Comparative analysis of climate change adaptation plans

As detailed above, the three case studies were all chosen on the basis of their representativeness of the realms and habitats covered in this report. To this end, they are all quite different, not just in terms of the habitats, but also with respect to the range of climate change threats anticipated. For example, coral bleaching due to higher atmospheric temperatures, as well as larger infestations of Crown of Thorns starfish due to faster algal growth, are of particular concern to the Great Barrier Reef as a result of climate change (GBRMPA, 2009; Marshall & Schuttenberg, 2006). Artificial barriers as a result of coastal development are more of a specific issue for the extensively modified Hunter River Estuary and prevent the migration of Ramsar listed wetland species due to climate change (NLWRA, 2000). Despite these obvious differences, a number of major coastal ecosystem impacts exist that are common to all 3 case study areas, as the all reside at the interface between marine and terrestrial influences. To this end, the shared climate change impacts include sea level rise, salt water intrusion, coastal retreat, reduced freshwater flows, increased nutrient and sediment flushing and wind and wave damage from extreme weather events (USEPA, 2009).

Whilst the current management strategies and practices at each of the three case studies locations are habitat specific, many of the strategies are similar in that they principally aim to build resilience in the threatened ecosystems. Critically, a great number of these plans have been developed independently of climate change adaptation goals and as such, the largely reflect approaches to mitigating the impacts of non-climatic threats. Whilst these strategies represent affordable pre-emptive human adaptation responses to projected climate change impacts that are considered to be successful climate change adaptation approaches (Sharples et al. 2008), it should also be remembered that resilience-building strategies like these, whilst valuable in reducing non-climatic threats, will almost certainly not save all species in light of the anticipated changes in climate over the coming decades.

Many of the existing non-climatic focused plans have goals that are specific to the environmental stressor being targeted. Significantly, they do not tend to articulate the goal of the adaptation action in terms of the end-point to be attained (aside from a vaguely stated objective of building resilience) in the ecosystem or habitat. This represents a major flaw in the context of climate change adaptation decision making where alternative goals may be suggested in response to the threat that climate change poses and the capacity of managers to address the threat. For example, possible climate change adaptation goals include a) keep the system as it is, b) improve the condition of the system, or c) move the system to a new alternate state. More thorough consideration of these alternative goals and articulation of which goal is to be targeted is required to ensure that climate change adaptation actions can be implemented with realistic end-points in mind.

7.5.2. Plans and on-ground climate change adaptation actions

Despite the large body of literature around climate change adaptation legislation, policy, frameworks, strategies and plans that are currently available in Australia, the number of on-ground human climate change adaptation practices remains very limited. Indeed, even within the three case study areas there are many plans that detail the importance, benefit and necessity to develop and implement on-ground climate change adaptation practices, but few actually detail how these plans can lead to on-ground actions. As a result, the number of theoretical strategies and plans vastly outnumber the practical recommendations needed to enable the implementation of on-ground human adaptation responses.

The only exception to the conclusion that on-ground actions are few and far between relates to the variety of management actions that have been designed to protect the health of coastal ecosystems – ie those that target non-climatic threats – and these approaches were the most common strategies employed in all three case study areas. For example, the Kakadu National Park Climate Change Strategy 2010-2015 recommends the continuation of many of the existing management actions currently being implemented by both the Kakadu National Park Management Plan 2007-2014 and the objectives identified in the Parks Australia Climate Change Strategic Overview 2009-2014 (DEWHA, 2010).

A similar situation exists within the federal and state government settings, where a number of beneficial climate change adaptation approaches occur as a result of legislation and planning strategies that have been developed for the primary purpose of ecosystem projection or sustainable development. For example, the objects of the EPBC Act, such as ‘protecting biodiversity’ and ‘the implementation of Australia’s international environmental responsibilities’, can also be used as part of a human climate change adaptation response. Another example is NSW Native Vegetation Management Act 2003 which aims to prevent the broad scale clearing of vegetation, although the complexity of programs like this needs to be well understood, particularly when multiple objectives and approaches are being considered. Broadly speaking, this aim is congruent with the intent of the existing climate change adaptation plans by reducing sediment outflows and thereby enhancing the resilience of coastal ecosystems such as the Great Barrier Reef.

All three case study locations are also influenced by international conventions and agreements. KNP and the Cairns Region are bound by the World Heritage Convention (UNESCO, 2009) and the Hunter River Estuary, although not World Heritage listed, contains a Ramsar site, as does Kakadu (DSEWPC, 2010). In the case of World Heritage listing the governing body responsible for the site’s management is required to ensure adequate measures are implemented to maintain and protect the natural and/or cultural features of the area to a standard agreed to by both parties in the agreement (UNESCO, 2006). For example, the GBRMPA has developed a Heritage Strategy 2005 to protect the natural heritage values of the Great Barrier Reef World Heritage Area through an array of policy and planning instruments (GBRMPA, 2009). As such, the protection of World Heritage values, such as the 2904 coral reefs and the high levels of marine biodiversity (DSEWPC, 2008), maintains and enhances the ecological resilience of the reef and thereby, although not the original intent of the convention or strategy, can be considered as contributing to human climate change adaptation. In addition to these maintenance activities, the World Heritage Committee has generated two documents, Predicting and Managing the Impacts of Climate Change on World Heritage 2006 and the Strategy to Assist State Parties to Implement Appropriate Management Responses 2006, which are designed to assist managers to maintain the heritage values of their sites under the influence of climate change impacts (UNESCO, 2006) - (See Case Study 3 - Cairns Region section 4.4 for the adaptation practices suggested in the Predicting and Managing the Impacts of Climate Change on World Heritage 2006 report).

Despite the large number of plans and, in some cases, on-ground actions that build resilience in the case study areas, there remain significant barriers and disincentives which hamper their development and on-ground implementation. Examples of these barriers to human climate change adaptation include the uncertainty that surrounds the accuracy of climate change projections, institutional and policy development barriers, the cost of implementing adaptation practices (including discussions of who should pay), a lack of understanding by the community and political reluctance to take action (Scheraga et al. 2003).

7.5.3. Common themes around climate change adaptation

Whilst significant differences in the challenges and stage of climate change adaptation planning existing between the three case study areas, there were still some common themes associated with the challenge of climate change adaptation. The major challenges that were raised were as follows:

1. Data uncertainty
   In addition to existing uncertainty around climate change projections, modeled scenarios, land- and ocean-based climate models, additional sources of uncertainty, like scaling projections to local and regional spatial scales, also make decision making difficult.

2. Knowledge gaps
   Notwithstanding the issues raised in #1 above, there remains a high level of ecological uncertainty both relating to how coastal ecosystems function now and, even moreso, to how coastal environments are likely to function in the future in light of the anticipated changes in climate.

3. Availability and sharing of data
   Decision making requires information and it is clear that the best available information is not always available to decision makers, even in the three case study areas (which are significantly advanced in their planning and implementation of actions compared with much of coastal Australia). Critically, information needs to be made available across all sectors and this includes climate projections, ecology, physical and chemical environmental parameters and all of the social and economic institutions within each case study area. A mechanism to collate, store and make available all of these diverse datasets would greatly enhance decision making capabilities.

4. Funding limitations
   The issue of who should pay for climate change adaptation and how is a common thread among all case study discussions. Consensus exists around the need for local adaptation actions, but there remains a strong demand for National funding support, both due to the magnitude and cost of the actions (well beyond the budgets of most local councils and CMAs) and the perceived need for an approach that is coordinated at the National level.

5. Legislation and planning limitations
   The list of possible adaptation actions is seriously limited in the context of current planning and legislative frameworks. Calls for more dynamic and flexible legislation and planning institutions call for significant changes in how policies are developed and implemented, but they offer the promise of huge gains in terms of the breadth and depth of adaptation options.

6. Timeframes of decision making/makers
   Time is a problem. Climate change adaptation decisions need to be made now, but with a view on the long-term changes in climate and ecosystems – out to 2100. These timeframes are a stretch for many scientists, let alone the public and politicians, so negotiating the implementation of difficult adaptation actions now for future benefit represents a major communication challenge.

7. Factoring in the unintended consequences
   Most climate change adaptation actions discussed and implemented to date do not explicitly consider the flow on effects and unintended consequences. This represents a major flaw in current practice, as maladaptive actions are likely to be implemented if the connectivity and associated consequences throughout the coastal zone are not explicitly stated and considered. The only saving grace for most existing strategies is that they predominantly focus on building ecological resilience by removing or reducing non-climatic threats, so to this end the most commonly implemented strategies implicitly consider flow on effects to all habitats and ecosystems.
   It is clear that there are many more challenges than those stated above in areas where data and institutional capacity to develop climate change adaptation strategies and on-ground actions is more limited than in the three case study areas that have been interrogated here. Critically, these case studies do represent fairly advanced scenarios in terms of climate change adaptation planning and to this end the magnitude of the task confronting most of the Australian coastline should not be underestimated.

Common themes emerging from consideration of current approaches to climate change adaptation for Australian coastal ecosystems, particularly with respect to the three case study areas examined here (i.e. Kakadu National Park, the Hunter River estuary and the Cairns region) include:

- climate change impacts tend to be common amongst coastal regions but issues associated with their impacts may differ;
- current management strategies share an overarching aim to build resilience in threatened ecosystems by targeting non-climatic threats;
- current on-ground climate change adaptation actions are limited;
- adaptation decision-making is hampered by a lack of certainty and availability of information and funding;
- adaptation is also impeded by existing legislation and the timeframes involved;
- unintended consequences of adaptation actions require greater consideration.

SECTION 4. SYNTHESIS

8. KNOWELDGE GAPS AND RESEARCH PRIORITIES

8.1. Introduction

Coastal ecosystems have evolved a range of autonomous response mechanisms through which adaptation to climate change may be possible (Cropp & Gabric, 2002; Gunderson, 2000; Pittock, 1999). However, coastal ecosystems degraded by non-climatic human impacts (APH, 2010; Church, et al., 2008; SoE, 2006) have reduced capacity to cope with climate stimuli and may revert into a simpler state with greatly reduced productivity and without the capacity to recover (Adger, et al., 2005). Human intervention in the form of human adaptation practices for coastal ecosystems may be required as a means of preventing or minimise human disturbances allowing coastal ecosystems to recover and adapt (Abuodha & Woodroffe, 2006).

The review of existing human adaptation strategies and practices presented in Chapters 6 and 7 highlight a number of knowledge gaps and research priorities that if addressed may enable coastal ecosystems to adapt to the impacts of climate change. This chapter provides a summary of these knowledge gaps and research priorities to address these.

8.2. Knowledge gaps for managed adaptation of Australian coastal ecosystems

8.2.1. Are on-ground human adaptation practices effective at enhancing resilience?

A number of human adaptation practices, such as creating protected areas and soft engineering practices are designed to benefit both human and natural coastal systems by maintaining and enhancing the adaptive capacity of coastal ecosystems (Borsje, et al., 2010; Chapman & Underwood, 2011). Examples of protected areas include national parks and no-take zones, while soft engineering includes beach nourishment, set back provisions and managed retreat (Abel, et al., 2011). Ecological and ecosystem engineering adaptation practices have also been developed to work with ecological coastal processes rather than against them (Borsje, et al., 2010). However, the short and long-term effectiveness of human adaptation practices for coastal ecosystems is largely unknown (Sahin & Mohamed; Torresan, et al., 2008). For example, whether beach nourishment has a negative or positive effect on species abundance on sandy beaches is unclear (Barber, et al., 2009). Also the retrofitting of existing hard defence structures with technology aimed at enhancing habitat potential is still being trialled (Borsje, et al., 2010).

8.2.2. Consistent climate change adaptation terminology

Industries, government departments and jurisdictions often use different terminology in referring to human adaptation practices or strategies (Burton, 2005). For example, in the policy development arena the term *building resilience* to climate change is often used without any reference to the term *adaptation* (Hawke, 2009). Not only does the usage of terms change from one organisation to another, but the definition of the same word, such as adaptation, can also vary (Smit, et al., 1999). The incorporation of scientific information into policy becomes more difficult when scientific and policy agencies define or use terminology in different ways when dealing with the same issues. Different terminology also results in cross jurisdictional communication and cooperation being less effective (Hinkel, 2010). A commonly accepted terminology that can be used by organisations in dealing with both human and autonomous adaptation practices will be required if humans are to enable coastal ecosystems to adapt to climate change (Hinkel, 2010).

8.2.3. Unknown thresholds of ecological resilience

Ecological resilience refers to the capacity of an ecosystem to absorb or cope with disturbance or stress while continuing to maintain ecosystem function (Gibbs, 2009; Ryu, et al., 2011). The resilience threshold is the point where the addition of only a small impact can cause sudden and sometimes catastrophic shifts in ecosystem type and function (Conley, et al., 2009; Hughes, et al., 2010). With decreased resilience due to non-climatic human impacts, climate change might exceed the resilience threshold of coastal ecosystems, shifting them to a state where recovery or adaptation to further impacts is less likely (Brierley & Kingsford, 2009). The components of coastal ecosystems that can be used as indicators of ecological resilience to climatic and non-climatic impacts are still being determined (Lenton, et al., 2008). Knowing the current state of resilience of coastal ecosystems, as well as the threshold tipping points, allows for the prioritisation of activities to reduce non-climatic human impacts and to enhance ecological resilience (Brierley & Kingsford, 2009; Voice, 2006).

8.2.4. Unknown interconnectivity between ecosystem components

A greater knowledge of the interconnectivity between the physical and biological components of coastal ecosystems is necessary to gain an understanding of how non-climatic human impacts and climate change impacts will threaten coastal ecosystems (Bergen, et al., 2001). For example, understanding how climate change impacts might affect the complexity of coastal ecosystems requires a detailed knowledge of the interconnectivity of intersecting and overlapping food chains and physical conditions (Airoldi, et al., 2005). In particular how chemical energy is transferred from one trophic level (the position that an organism occupies on a food chain) to another is knowledge necessary in the development, implementation and monitoring of effective human adaptation practices that allowing coastal ecosystems to adapt to impacts (Bergen, et al., 2001).

8.2.5. How to maintain connectivity?

Connectivity exists at landscape, habitat, ecological and evolutionary scales (Loss, et al., 2011; Mackey, et al., 2010). Maintaining and improving connectivity between the scales will potentially allow species to progressively adjust their habitat ranges in response to shifting climate zones (DECCW, 2009; Mackey, et al., 2010; McLachlan, et al., 2005; Root & Schneider, 2006). Climate zones refer to the geographical zones that are determined by the prevailing climatic conditions, for example temperate, sub-tropical and arid climate zones (Vos, et al., 2010). Climate change will likely alter the structure and function of coastal ecosystems, forcing some species to become extinct and others to migrate to other habitats with more favourable climatic conditions (Hughes, et al., 2010). Knowledge gaps exist on which species are capable of shifting their habitat range and whether they can shift fast enough to keep on track with anthropogenic climate change (Root & Schneider, 2006). Filling these gaps in knowledge will allow human adaptation practices to become more relevant and effective at enhancing the resilience of coastal ecosystems to climate change impacts.

Other connectivity knowledge gaps exist in relation to not only the movement of native species, but also the potential for the spread of pest plants and animals, disease and fire (Dunlop, 2008). Therefore, decision makers need a greater understanding of the potential advantages and disadvantages likely to result from changing levels of connectivity at various spacio-temporal scales (Mackey, et al., 2010).

8.2.6. How is protected area conservation likely to be affected by climate change?

A primary goal of conservation policy in Australia is to conserve species and ecological communities *in situ* (DERM, 2010). However, climate change may impact protected areas by altering the climate conditions preferred by resident species forcing them to migrate to other locations (Coope, 2004). Therefore, climate changes may reduce the suitability of some protected areas as habitat for some species (Williams, et al., 2001). The ability of humans to achieve the goals of policies that aim to maintain protected areas as fixed ecosystems will become increasingly tested as climate change progresses (Araujo, et al., 2011). The focus of protected areas on preventing ecological change will need to shift towards managing and adapting to change (Araujo, et al., 2011; Lawler, et al., 2010; Loss, et al., 2011). Knowledge gaps exist on the extent of ecosystem change, the possible migration corridors and the locations for new protected areas to establish migrating corridors (Hannah, 2009). Filling these gaps in knowledge will allow policy developers to produce more effective policy to manage the ecosystems within protected areas (Hughes, et al., 2010).

Despite the threats that climate change poses for protected areas and the challenge ahead for re-visioning the role and purpose of protected areas, it is also clear that protected areas can play a role in ensuring resilience in the areas that are threatened by climate change. To this end, protected areas managed with climate change objectives in mind can be critically important elements of a regional climate change adaptation plan.

8.2.7. How can local governments enhance coastal ecosystem resilience through state government legislative support mechanisms?

The on-ground management and implementation of human adaptation practices for coastal ecosystems is primarily the responsibility of local governments (Corfee-Morlot, et al., 2011; England, 2006; Leitch & Robinson, 2009). However, a lack of legislative support from state governments has produced an array of communication, political, financial, and legal barriers for local governments in the implementation on-ground adaptive practices (Thom, 2008). The state government push for coastal development often undermines the power of local governments to control the type and location of development, as well as the extent and/or rate of population growth (Abel et al. 2011). As a result development continues in places where it is vulnerable to SLR and requires the use of hard engineering defence practices. Knowledge of how to reconcile state and local government coastal management priorities and goals towards those that promote the use of resilience enhancing adaptive practices is required (Abel et al. 2011).

8.2.8. How to enable the timely and flexible development of relevant policy?

The development and implementation of new policy settings can be subject to a range of barriers which make it difficult for policy to evolve in time with changing climatic conditions (Briggs, 2006; Ross & Dovers, 2008). A major barrier to policy change in coastal areas is the use of hard engineering defence structures, such as revetment walls and sea walls, which are a form of adaptation where the continued economic success of many coastal cities now depend (Airoldi, et al., 2005; Chapman & Underwood, 2011). These adaptation practices are known as lock-ins, where policies are required to remain fixed, unable to evolve to meet changing climatic and societal needs and conditions (Huitema & Meijerink, 2010; Tompkins, et al., 2010). Knowledge of how to develop policies capable of identifying and avoiding potential policy lock-ins, as well as being able to incorporate alternate adaptation practices that enhance the resilience of coastal ecosystems is required (Jones, et al., 1999).

The ability to develop relevant and effective legislation to enable human adaptation for coastal ecosystems is also dependent on the successful incorporation of scientific knowledge, such as climate change data and/or ecosystem function, into the legislative development process (Lazarow, 2006; Scarlett, 2010). How scientific information can be packaged and presented to policy makers so that it can be incorporated into policy is another important knowledge gap restricting the on-ground implementation of adaptive practices by local governments (Jones, et al., 1999).

8.2.9. Uncertainty in climate change modelling

The modelling of future climate change is an important element in developing and implementing effective coastal management actions (Addo, et al., 2008). However, the number of uncertainties in the accuracy of climate change modelling projections have resulted in a lack of consistency in approaching the issue of human adaptation across jurisdictions and thus, varying degrees of commitment from national and state governments (Abel et al. 2011; Thom, 2010). The uncertainties of climate modelling have led some policy makers to believe that climate modelling does not provide sufficient accuracy for it to be used to support policy development (Green, et al., 2009). Some of the gaps in knowledge that require attention to improve the accuracy of climate change modelling are as follows:

Computer models capable of accurately accounting for the extent and rate of SLR are still being refined (Bray, et al., 1997), with frequent advancements being made in our understanding of this technology (Dickson, et al., 2007; Walkden & Hall, 2005).

Global Circulation Models (GCM) – The scientific understanding of GCMs is constantly advancing with new models providing greater accuracy (Gregory, et al., 2001).

Intergovernmental Panel on Climate Change (IPCC) emission scenarios provide a range of greenhouse gas emissions that might be produced by humans in future (Nakicenovic, 2000). The type of IPCC emission scenario used in the modelling process will alter the outcome of the projections. Which emission scenario will become a reality in future is uncertain and therefore the projections themselves are also uncertain.

The Bruun Rule is used by a number of climate change models to undertake SLR and coastal retreat projections. The idea of the Bruun Rule was first proposed in 1962 by Per Bruun (Bruun, 1962), and was coined the Bruun Rule by Maurice Schwartz in 1967 (Schwartz, 1967). The Bruun Rule can be applied to assist in determining the extent of sandy beach erosion that might occur per unit increase in sea level (Cooper & Pilkey, 2004). Bruun Rule has been criticised for not considering the availability of off-shore sediment and the rate of sediment transport through longshore drift (Cooper & Pilkey, 2004; Komar, et al., 1991).

Gaps in the data used in the models, such storm frequency and intensity, shoreline response times and accretion rates are examples of data essential for SLR modelling, but unavailable in some locations.

The gap in knowledge regarding the dynamic nature of the coastal ecosystems makes projections of future impacts uncertain (Addo, et al., 2008; Miller, et al., 2007; Thieler & Danforth, 1994).

8.2.10. The extent and rate of climate change impact on coastal ecosystems is unknown

Climate change will significantly impact coastal ecosystems in the future, with impacts on species and ecological systems already evident (Loss, et al., 2011; Parmesan, 2006; Williams, et al., 2007). The following are examples of the potential impact of SLR on coastal ecosystems:

increased salinity of rivers, bays and coastal aquifers resulting from saline intrusion (Winn, et al., 2006; Zambo, 2008);

- a changed dynamic between accretion and erosion resulting in the loss of important mangroves, saltmarshes and other wetlands (Saintilan & Williams, 1999);
- increases in water depth impacting marine ecosystems, such as coral reefs (Lough, 2008; Pittock, 1999; Wilkinson, 1996) and seagrass beds (Short & Neckles, 1999);
- the flooding of low lying coastal areas and the landward retreat of shorelines will displace human populations and greatly impact coastal ecosystems (Brown, 2006); and
- increased storm surge intensity and frequency will have an even greater impact due to higher sea levels and concomitant coastal retreat (McInnes, et al., 2009).

Although the expected impacts of climate change are relatively well known, the rate and extent of the impact on ecosystems is still unclear. This situation represents a significant knowledge gap in the development of human adaption practices capable of enhancing the ecological resilience of coastal ecosystems to climate change impacts (Scarlett, 2010). This lack of knowledge also reduces the ability to prioritise the use of on-ground adaptation practices and design of research projects.

8.2.11. What are effective human adaptation practices across different spatial and temporal scales?

To determine the type and effectiveness of human adaptation practices, temporal and spatial scales need to be considered (Knutti, 2008; Millner, 2011; Stainforth, et al., 2007). Increasing the connectivity between ecosystems over large spatial scales, such as bioregional or climatic zones, is an important adaptive practice. For example, coastal species migrate over large continental scales, shifting to higher latitudes and elevations (Hickling, et al., 2006; Parmesan, 2006) and moving along coastlines and rivers (Hodgson, et al., 2009). Yet little is known about the large scale responses of species to climate change across a diversity of landscape scales (Vos, et al., 2008).

As current and predicted rates of anthropogenic SLR greatly exceed most of the sea level increases over the last 420,000 years (Hoegh-Guldberg, et al., 2007; Loss, et al., 2011; Petit, et al., 1999), the use of temporal scales to determine the impact of climate change and the effectiveness of human adaptation practices is an important consideration (Hoegh-Guldberg, et al., 2007). The rate of anthropogenic SLR threatens the survival of coastal species as it requires species to rapidly shift their ranges and/or adapt (Loss, et al., 2011; McLachlan, et al., 2005; Root & Schneider, 2006). Where climate change is occurring over rapid temporal scales the resultant impacts on coastal ecosystems and the effectiveness of human adaptation practices are still under investigation (Niemi, et al., 2004).

8.3. Research priorities for managed adaptation of Australian coastal ecosystems

Research priorities have been identified through the synthesis of relevant literature presented in preceding chapters and from the knowledge gaps identified. Outcomes from the following research priorities would greatly advance the development and implementation of effective human adaptation practices for the benefit of Australian coastal ecosystems:

- Develop mechanisms that enable the incorporation of scientific knowledge on climate change impacts and human adaptation practices into the formation of state government coastal development legislation.

- Develop legislation that incorporates climate change uncertainties and the need for alternate adaptation practices that enhance the resilience of coastal ecosystems to climate change impacts.

- Determine the impact of climate change on coastal ecosystems over rapid temporal and large spatial scales.

- Identify ecological thresholds for coastal ecosystems to enable the prioritisation of human adaptation activities.

- Develop human adaptation practices that maintain or enhance the resilience of coastal ecosystems to the impacts of climate change over a range of spatial and temporal scales.

- Assess the goals of protected area management to ascertain factors that currently enhance ecological resilience and that also need to be modified to incorporate climate change induced migration and range shift patterns.

- Incorporate data regarding the interconnectivity between physical and biological components of coastal ecosystems into the development and implementation of coastal adaptation strategies.

- Develop adaptation strategies that work towards maintaining and enhancing the species and habitat connectivity between various spatial scales, such as landscapes, bioregions and climate zones.

9. COMMUNICATION AND EDUCATION MESSAGES

For human adaptation practices to effectively enhance the resilience of coastal ecosystems from the potential impacts of climate change, there is a need for successful integration of scientific knowledge into coastal management, planning and policy frameworks (Folke et al. 2004). Successfully integrating knowledge into diverse disciplines requires a range of communication and education programs. The programs must be targeted to fit the needs of those making decisions about the management of coastal ecosystems (Briggs, 2006). The decision makers include non-governmental organisations that are actively involved in promoting public awareness and understanding of climate change issues through lobbying, education and training and media activities (DEH, 2005).

The need for climate change adaptation communication and education is discussed within a number of government reports, such as the Climate Change Adaptation Actions for Local Governments report (SMEC, 2010), however, there remains a number of areas where improved communication and education is required.

9.1 Science and policy development

Open and clear channels of communication between policy makers and scientists are necessary if coastal managers are going to make decisions capable of enhancing the resilience of coastal ecosystems to the impacts of climate change (Wilbanks & Kates, 2010). However, the communication between scientists and policy makers is often subject to the following barriers:

Scientists and policy makers operate under different time constraints. Greater appreciation of the time required to produce accurate and reliable scientific information, capable of supporting effective coastal management decisions, is necessary (Briggs, 2006).

Scientists are sometimes unwilling to enable policy makers to gain an in-depth understanding of the science for fear of losing ownership of knowledge and/or its interpretation, whereas policy makers can sometime fear losing power if they aid scientists in gaining access to power or to those who have power, such as politicians or senior executives (Briggs, 2006).

The terminology used by policy makers is often different from that used by scientists and vice versa, resulting in confusion and a lack of understanding (Hinkel, 2010; Burton, 2005; Smit et al. 1999). Scientists and policy makers need a greater understanding of the terminology used by each other to enable more successful communication to be achieved (see section 20.2 below).

9.2 Terminology issues

Different industries, government departments and jurisdictions often use different terminology in referring to human adaptation practices or strategies (Burton, 2005). How particular terms, such as adaptation, are defined by one organisation is often different to how they are defined by another (Smit et al. 1999). Increasing awareness, through education, of the different terminologies used by different organisations will aid in the incorporation of scientific information into policy and improve across jurisdictional cooperation (Hinkel, 2010).

9.3 Communication across jurisdictional boundaries

Federal, state and local governments in Australia have a range of responsibilities in managing coastal ecosystems and play a variety of roles in the development and implementation of human adaptation practices (ALGA, 2005; DCCEE, 2010; Fussel, 2007). As such, to enable the development and implementation of human adaptation practices that enhance the resilience of coastal ecosystems effective communication between the different levels of government will be required (Wilbanks & Kates, 2010; Thom, 2008). For example, implementing human adaptation practices for the benefit of coastal ecosystems of national significance, such as World Heritage and Ramsar sites, will require cross jurisdictional communication between federal, state and local governments (UNESCO, 2006). In the case of Kakadu World Heritage area communication with the local indigenous owners will also be required before human adaptation practices can be implemented (DCCEE, 2010).

As the climate changes some species and ecosystems will need to migrate to keep within specific levels of climatic tolerance, such as temperature and rainfall (Parmesan, 2006; Loss et al. 2011). Protected area managers will require education on the extent and likelihood of certain species migrating due to a shift in species habitat range as a result of climate change and how this might influence the connectivity between and location of protected areas (Hodgson et al. 2009). Channels of communication between local, state and territory governments will need to be improved so that cross jurisdictional migration of species and the formation of new migratory corridors can be effectively managed (Hannah, 2009).

9.4 Communicating impacts of climate change on protected areas

Climate change will likely impact protected areas in a number of ways. Protected area managers will need education in not only what these changes might be, but also in the recommended techniques designed to manage those changes (Bardsley & Sweeney, 2010). Communication and education programs will need to be implemented to cover a range of climate change impacts and human adaptation practices for protected area management (Bardsley & Sweeney, 2010). Examples include:

- Changing species migration patterns and shifting habitat ranges (Coope, 2004; Williams, et al., 2001).
- Establishing migration corridors and new protected areas that maximise connectivity at various landscape, habitat, ecological and evolutionary scales (Loss et al. 2011; McLachlan et al. 2005; Root & Schneider, 2006).
- Identifying possible changes to the structure and function of coastal ecosystems, such as species likely to migrate, become extinct or remain (Root & Schneider, 2006).

- The potential spread of pest plants and animals, disease and fire (Dunlop, 2008).

9.5 Educating local government decision makers

One of the barriers for local governments in developing and implementing policies that promote resilience enhancing adaptation practices for coastal ecosystems is a lack of trained staff and planners capable of instigating these changes (ALGA 2005). Local governments often lack the capacity to initiate and implement adaptive practices that don't rely of hard engineering to protect coastal investments (Abel et al. 2011). The education of local government decision makers in the science of climate change impacts (Leitch & Robinson, 2009), as well as the range of human adaptation practices available to them, is important if ecological resilience enhancing human adaptation practices are to be implemented (Folke et al. 2004).

9.6 Community engagement and awareness raising

Increasing community awareness of the value of coastal ecosystem services is an important strategy in managing community expectations (Wilbanks & Kates, 2010) and in facilitating the implementation of human adaptation practices that enhance the resilience of coastal ecosystems to climate change impacts (Airoldi et al. 2005; Bergen et al. 2001). Evidence suggests that the impact of climate change on coastal ecosystems will increase due to limited community awareness of coastal climate change impacts (Franck, 2009). For example, coastal communities who continue to use hard engineering defence structures to protect coastal investments will likely reduce the resilience of coastal ecosystems to sea level rise and prevent them from effectively adapting (Lucrezi et al. 2010). Communicating the importance of coastal ecosystem services will also work towards achieving the sustainability of human coastal activity and is in itself a human adaptation practice.

Legislative support for community education programs exists in a number of states. For example, the New South Wales' *Coastal Policy* recognizes the importance of community participation and involvement through community restoration projects and the development of education and awareness programs (NSW Government, 1997). South Australia's *Living Coast Strategy (2004)* provides substantial policy support for education, including the objective of delivering enhanced community awareness and education (DEH, 2004).

10. SYNTHESIS AND RECOMMENDATIONS

This chapter provides a synthesis of the key findings of the project and identifies major uncertainties and knowledge gaps associated with our understanding of Australian coastal ecosystems, climate change impacts and pathways for adaptation. Major recommendations for policy and management as well as future research are also presented.

10.1. Key findings

Australian coastal ecosystems

- There is a relatively good understanding of the key physical processes (i.e. atmospheric, hydrologic, hydrodynamic and sea level variation) shaping Australian coastal landforms.

- Ecological understanding varies considerably amongst Australian coastal ecosystems and regions with most research having focused on marine ecosystems, especially tropical coral reefs, and estuarine ecosystems, especially mangroves.

- Major knowledge gaps exist with respect to coastal ecosystem structure and function in the terrestrial and freshwater realms, especially with respect to sandy beach and dune systems and coastal forested wetlands, as well as across northern Australia.

- Connectivity within and between Australian coastal ecosystems is particularly important and contributes to their high productivity and biological diversity.

- Non-climatic threats to Australian coastal ecosystems are broadly comparable and include terrestrial land and water management practices, invasive species, direct disturbances resulting from human actives, harvesting of species and materials, and expansion and intensification of human developments, i.e. ‘coastal squeeze’.

- There has been a recent trend towards more holistic and integrated approaches to the management of Australian coastal ecosystems, e.g. catchment management practices.

Coastal climate change impacts

- Changes have been observed in all major elements of Australia’s coastal climate (i.e. terrestrial, marine and sea level) over the last century although there have been considerable regional differences.

- Changes are projected in all major elements of the Australian coastal climate (i.e. terrestrial, marine and sea level) over the next century with considerable regional variation in the magnitude and direction of these changes.

- Uncertainties associated with coastal climate change projections stem partly from uncertainties regarding emissions scenarios used in modelling. High degrees of uncertainty are associated with projecting future impacts of climate change on rainfall, hydrology, waves and wind as well as the frequency and intensity of extreme events.

- There are no existing climate models which provide integrated information about the Australian coastal zone and climate projections must currently be drawn from separate terrestrial and marine climate models.

- Observed ecological impacts of climate change in Australian coastal ecosystems include geographic range shifts of species, severe episodes of coral bleaching, changes in the abundance and distribution of invasive species and altered behavioural patterns in migratory shorebirds.

- Major ecological impacts of climate change in Australian coastal ecosystems in the future are likely to include reduced population sizes and changes in community composition, structure and dynamics.

- There are substantial knowledge gaps and uncertainties associated with predicting ecological impacts of climate change on Australian coastal ecosystems with the majority of research having focused on marine ecosystems, particularly tropical coral reefs, and estuarine ecosystems, particularly mangroves.

- There is a particular dearth of studies relating to climate change impacts on Australian terrestrial and freshwater coastal ecosystems.

Adaptation pathways

- There is limited evidence that some Australian coastal species and ecosystems may be able to adapt autonomously to climate change. Whether or not autonomous adaptation pathways will be able to ‘keep up’ with climate change, however, remains a significant unknown.

- There are many options for managed adaptation available but these all involve risks in terms of uncertainties concerning their efficacy and potential risks, both to ecological and human systems. Implementation and maintenance of adaptation actions are also significantly constrained by the human (e.g. community values) and geographic setting (e.g. remoteness).

- Existing strategies of relevance to adaptation for Australian coastal ecosystems offer relatively few practical suggestions and tend to concentrate on enhancing ecosystem resilience via the management of existing threats.

- Barriers to adaptation include a information and resource constraints, legislative and social constraints.

10.2. Recommendations

10.2.1. Principles for climate change adaptation

Climate change adaptation needs to happen now to provide coastal ecosystems and communities the capacity to accommodate the anticipated changes resulting from climate change. One of the major challenges in climate change adaptation, is therefore, selling the significance and magnitude of the task and getting stakeholders to buy into the adaptation decision making process. In terms of getting both managers (and all levels of government) and the general public to buy into climate change adaptation it is critical to:

a) clearly articulate the likely impacts of climate change,
b) spell out the goals (including all of the alternatives) of climate change adaptation,
c) highlight the long-term opportunities afforded by making smart decisions and implementing actions now, and
d) identify how maladaptive actions, which do not consider all stakeholder interests and the connectivity within and between habitats, will only exacerbate the threat that climate change poses in coastal areas.

Once stakeholders are engaged in climate change adaptation decision making, we strongly recommend that the following questions are asked (and answered) with respect to evaluating all of the proposed adaptation actions:

1) What are the goals of the action?
2) What climate change driver or ecological consequence does the action address?
3) What type of adaptation action is it? Engineered, resilience building etc.
4) What are the spatial and temporal scales for implementation?
5) What are the likely intended ecological consequences?
6) What are the unintended ecological consequences, both within the target and non-target habitat?
7) What are the unintended human consequences, including local and regional impacts on settlements, infrastructure and communities?
8) What are the likelihoods and impacts of the unintended consequences?
9) What are the efficacy and costs (social and economic) associated with the action?
10) What are biophysical and socioeconomic constraints that might inhibit uptake and implementation?

If all potential adaptation actions are subjected to this level of scrutiny it will greatly improve decision making. By identifying the unintended consequences of actions (both ecological and human) at local and regional scales this approach will greatly reduce the likelihood of the adoption and implementation of maladaptive actions.

On the basis of the synthesis and integration components of this project, we propose seven principles of climate change adaptation, as follows:

1. *Climate change adaptation needs clearly defined goals.* Whilst it may not be immediately obvious, it is highly likely that the goal of climate change adaptation will be different from one location to the next. For example, in some locations, especially near pristine coastal environments, we may wish to ‘keep the system as it is’. In contrast, in other places, especially those in highly developed coastal areas, we may want to ‘significantly improve the condition of the system’ or, perhaps, even ‘move the system to a new alternative state (ie

simply maintain the function of the system and accept that there will be species loss along the way)'. These three goals represent very different alternatives in terms of the approach and resources required and the specific adaptation actions that may be required to be implemented to achieve them. Whilst this seems quite intuitive, most climate change adaptation actions and plans do not explicitly state which of these goals (or any of the other possible alternatives) are being considered. This lack of explicit goal setting represents a major flaw in the way that climate change adaptation plans have been produced to date. Indeed, we recommend that it may be worthwhile revisiting existing adaptation plans and considering all three alternatives (with all stakeholders in the room together) to aid in the decision making process.

2. *Climate change adaptation decision making must include stakeholders from environmental, social and economic realms.* Climate change adaptation is all about making sustainable decisions and these cannot be made in a vacuum. For example, the best adaptation action for a mangrove forest will not likely be implemented if it strongly impinges on current (and/or future) social and economic values in the region. To this end, it is critical to include all aspects of sustainability in climate change adaptation decision making processes, to ensure that the actions that are recommended have the greatest likelihood of being adopted.

3. *Climate change adaptation decision making requires data to be easily available and shared*. Decision making requires information and it is clear that the best available information is not always available to decision makers, even in the three case study areas (which are significantly advanced in their planning and implementation of actions compared with much of coastal Australia). Critically, information needs to be made available across all sectors and this includes climate projections, ecology, physical and chemical environmental parameters and all of the social and economic institutions within each case study area. Issues around data availability also highlight the need for monitoring across all sectors to ensure that there is data with which managers can make decisions. Finally, a mechanism to collate, store and make available all of these diverse datasets would greatly enhance decision making capabilities.

4. *Climate change adaptation demands a drastic re-think of existing policy and planning constraints.* We need to be more flexible and dynamic (spatially and temporally) in how we view climate change and how we consider adaptive pathways. We need to move beyond political cycles, because unlike some non-climatic threats, climate change and the stress associated with changes in our climate will be with us for a very long time. This temporal component of climate change requires the management flexibility mentioned above, because even the most sensible adaptation action in 2011 may not represent the best solution for the system in 2051. To this end, decisions made now should provide for flexible responses into the future. In other words, inflexible and constrained adaptation actions that are implemented now may shut the door on sensible future adaptation actions, so this needs to be considered in the current decision making process.

5. *Climate change adaptation in the coastal zone requires a thorough understanding of connectivity, both within ecosystems and between them.* Critically, adaptation actions in a particular habitat, like saltmarsh for example, will have flow on effects in neighbouring habitats and, in turn, will be influenced by other processes in neighbouring habitats. To this end, the interactivity within and between coastal zone land, rivers, estuaries and the ocean must be

understood and incorporated into climate change adaptation decision making processes.

6. *Adapt at local/regional scales, but don't lose sight of the bigger picture.* Climate change adaptation has to occur at the local/regional scales, as local context will largely determine which adaptation actions are appropriate on the basis of the social, economic and environmental features of the region. However, some local activities may impinge upon the capacity of some species to persist at the regional or larger scale, so it is important to include larger scale considerations while deciding on adaptation actions.

7. *Climate change adaptation should not be considered in isolation of the many non-climatic threats that coastal environments already face.* The coastal zone is already threatened by a host of natural and anthropogenic threats, and climate change adaptation should focus on sustainability in the coastal zone, so the explicit assessment of non-climatic threats is required. This is even more critical as climate change is likely to influence some of the drivers of non-climatic threats.

Following these principles and the approach outlined in this report will enable to coastal zone resource managers to adapt to climate change whilst also striking the balance between maintaining healthy environments and flourishing coastal communities.

10.2.2. Recommendations for future research

The key recommendations for research to inform climate change adaptation for Australian coastal ecosystems emerging from this project are:

- Improved projections of future climate change for the Australian coastal zone would be aided by the development of a coastal climate model which integrates existing terrestrial, marine and sea level models and considers the interactions amongst these. In particular, improved information is required with respect to climate change impacts on winds and hydrodynamics (i.e. waves, tides and currents) around the Australian coastline.

- There is a need for much basic ecological information for many Australian coastal ecosystems to contribute to an improved understanding of ecosystem structure, function and connectivity. In particular, research is needed on sandy beach and dune ecosystems and coastal forested wetlands around the country as well as most coastal ecosystems in northern Australia.

- Ecological monitoring is lacking for many Australian coastal ecosystems and regions. Research is needed to identify robust indicators and appropriate methods for collecting and analysing ecological data with respect to assessing climate change impacts and the efficacy of adaptation actions in the Australian coastal zone.

- Research is needed to assess the efficacy and potential unintended ecological consequences of different proposed adaptation actions and how these vary depending on setting and in terms of interactions with each other and non-climatic stressors.

- Research is needed to support the development of robust decision-making approaches which can integrate ecological, social, economic and cultural objectives and information. This should include an assessment of information needs across stakeholder groups as well as an examination of constraints and barriers to adaptation and how these might be overcome.

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APPENDICES

APPENDIX 1 – BIOCLIM climate layers for projecting future climate.

BIOCLIM climate layers for projecting future climate in Australia. Options in red may be unsuitable for climate change studies where detailed spatial analysis is required. This may be due to contouring problems, spatial discontinuities and unexpected patterning. Variables highlighted in red were selected as priority for coastal ecosystems project.

No.	Climate Variable	Unit	Details
1	Annual Mean Temperature	°C	The mean of all the weekly mean temperatures. Each weekly mean temperature is the mean of that week's maximum and minimum temperature.
2	Mean Diurnal Range (Mean(period max-min))	°C	The mean of all the weekly diurnal temperature ranges. Each weekly diurnal range is the difference between that week's maximum and minimum temperature.
3	Isothermality 2/7	-	The mean diurnal range (parameter 2) divided by the Annual Temperature Range (parameter 7).
4	Temperature Seasonality (C of V)	%	The temperature Coefficient of Variation (C of V) is the standard deviation of the weekly mean temperatures expressed as a percentage of the mean of those temperatures (i.e. the annual mean). For this calculation, the mean in degrees Kelvin is used. This avoids the possibility of having to divide by zero, but does mean that the values are usually quite small.
5	Max Temperature of Warmest Period	°C	The highest temperature of any weekly maximum temperature.
6	Min Temperature of Coldest Period	°C	The lowest temperature of any weekly minimum temperature.
7	Temperature Annual Range (5-6)	°C	The difference between the Max Temperature of Warmest Period and the Min Temperature of Coldest Period.
8	Mean Temperature of Wettest Quarter	°C	The wettest quarter of the year is determined (to the nearest week), and the mean temperature of this period is calculated.
9	Mean Temperature of	°C	The driest quarter of the year is determined (to the nearest week), and the mean temperature of this period is calculated.

	Driest Quarter		
10	Mean Temperature of Warmest Quarter	°C	The warmest quarter of the year is determined (to the nearest week), and the mean temperature of this period is calculated.
11	Mean Temperature of Coldest Quarter	°C	The coldest quarter of the year is determined (to the nearest week), and the mean temperature of this period is calculated.
12	Annual Precipitation	mm	The sum of all the monthly precipitation estimates.
13	Preci pitation of Wettest Period	mm	The precipitation of the wettest week
14	Preci pitation of Driest Period	mm	The precipitation of the driest week
15	Precipitation Seasonality(C of V)	%	The Coefficient of Variation (C of V) is the standard deviation of the weekly precipitation estimates expressed as a percentage of the mean of those estimates (i.e. the annual mean).
16	Preci pitation of Wettest Quarter	mm	The wettest quarter of the year is determined (to the nearest week), and the total precipitation over this period is calculated.
17	Precipitation of Driest Quarter	mm	The driest quarter of the year is determined (to the nearest week), and the total precipitation over this period is calculated.
18	Precipitation of Warmest Quarter	mm	The warmest quarter of the year is determined (to the nearest week), and the total precipitation over this period is calculated.
19	Precipitation of Coldest Quarter	mm	The coldest quarter of the year is determined (to the nearest week), and the total precipitation over this period is calculated.

20	Annual Mean Radiation	J/m2 (joules/m2)	The mean of all the weekly radiation estimates.
21	Highest Period Radiation	J/m2	The largest radiation estimate for all weeks.
22	Lowest Period Radiation	J/m2	The lowest radiation estimate for all weeks.
23	Radiation Seasonality (C of V)	%	The Coefficient of Variation (C of V) is the standard deviation of the weekly radiation estimates expressed as a percentage of the mean of those estimates (i.e. the annual mean).
24	Radiation of Wettest Quarter	J/m2	The wettest quarter of the year is determined (to the nearest week), and the average radiation over this period is calculated.
25	Radiation of Driest Quarter	J/m2	The driest quarter of the year is determined (to the nearest week), and the average radiation over this period is calculated.
26	Radiation of Warmest Quarter	J/m2	The warmest quarter of the year is determined (to the nearest week), and the average radiation over this period is calculated.
27	Radiation of Coldest Quarter	J/m2	The coldest quarter of the year is determined (to the nearest week), and the average radiation over this period is calculated.
28	Annual Mean Moisture Index	Range from 0 (dry) to 1 (saturated)	The mean of all the weekly moisture index values.
29	Highest Period Moisture Index	Range from 0 (dry) to 1 (saturated	The maximum moisture index value for all weeks.
30	Lowest Period Moisture Index	Range from 0 (dry) to 1 (saturated	The minimum moisture index value for all weeks.

31	Soil Moisture Index Seasonality (C of V)	Range from 0 (dry) to 1 (saturated	The Coefficient of Variation (C of V) is the standard deviation of the weekly moisture index values expressed as a percentage of the mean of those values (i.e. the annual mean).
32	Mean Soil Moisture Index of Highest Quarter MI	Range from 0 (dry) to 1 (saturated	The quarter of the year having the highest moisture index value is determined (to the nearest week), and the average moisture index value is calculated.
33	Mean Soil Moisture Index of Lowest Quarter MI	Range from 0 (dry) to 1 (saturated	The quarter of the year having the lowest moisture index value is determined (to the nearest week), and the average moisture index value is calculated.
34	Mean Soil Moisture Index of Warmest Quarter	Range from 0 (dry) to 1 (saturated	The warmest quarter of the year is determined (to the nearest week), and the average moisture index value is calculated.
35	Mean Soil Moisture Index of Coldest Quarter	Range from 0 (dry) to 1 (saturated	The coldest quarter of the year is determined (to the nearest week), and the average moisture index value is calculated.

APPENDIX 2 – Interim Biogeographic Regionalisation for Australia with coastline.

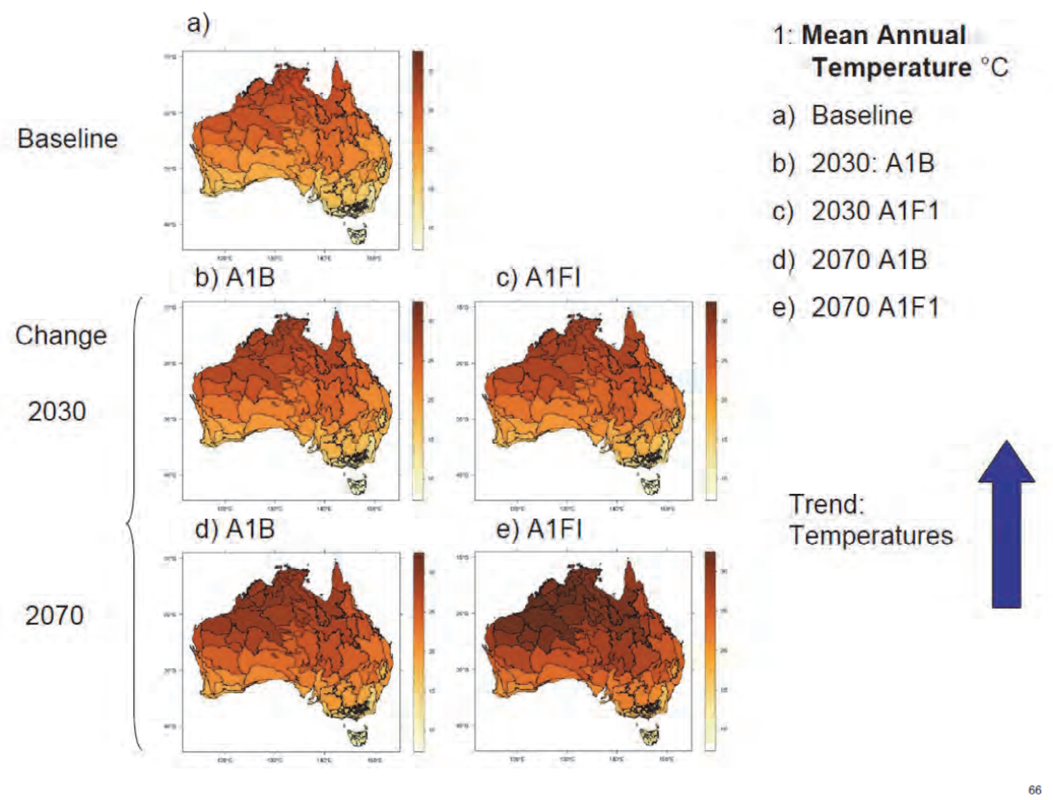
Interim Biogeographic Regionalisation for Australia (IBRA) regions with coastline. The regions encompassing the three case study areas are highlighted: Cairns (WT, Wet Tropics), Kakadu (DAC, Darwin Coastal) and Hunter River Catchment (SB, Sydney Basin)

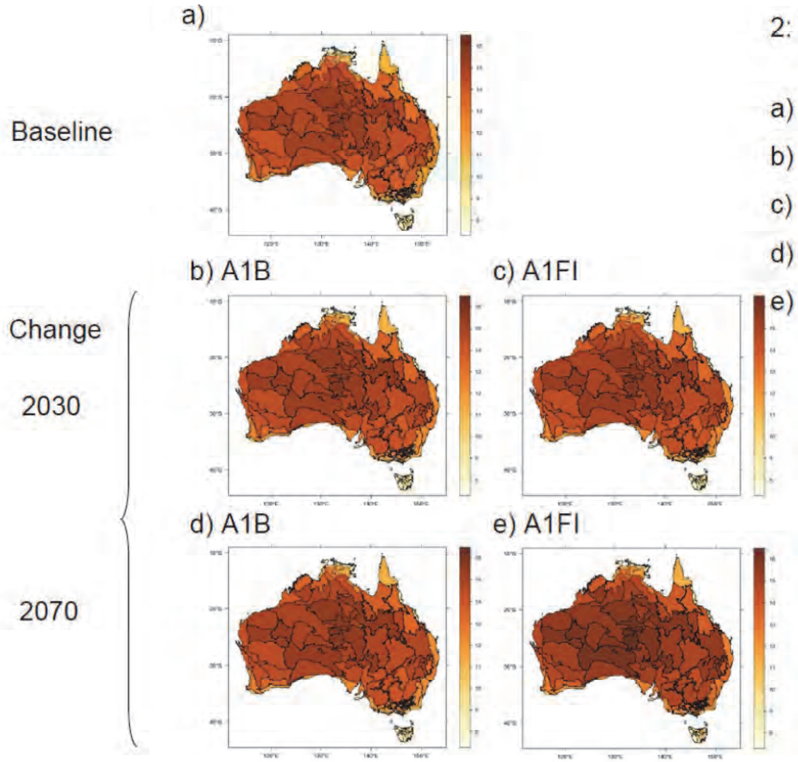
Region Number	Region Code	Region Name	Area km^2	Coastline length km
1	MDD	Murray Darling Depression	196564	125
2	NCP	Naracoorte Coastal Plain	24576	417
3	VVP	Victorian Volcanic Plain	24403	88
4	SCP	South East Coastal Plain	17492	1750
5	SEH	South Eastern Highlands	80952	101
9 FLI		Flinders	5337	1286
10	SEC	South East Corner	25553	626
13	TSE	Tasmanian South East	11061	1303
14 TWE		Tasmanian West	15640	782
15	TSR	Tasmanian Southern Ranges	7818	413
20	SB	Sydney Basin	38096	837
22	BBN	Brigalow Belt North	136130	1854
27	NNC	NSW North Coast	39957	649
31 GAW		Gawler	123641	215
33 NUL		Nullarbor	197228	275
34 HAM		Hampton	10882	342
35	EYB	Eyre Yorke Block	60909	2665
36	FLB	Flinders Lofty Block	71263	51

37 KAN		Kanmantoo	8123	595
39 GUP		Gulf Plains	220583	1383
40	CYP	Cape York Peninsula	121158	3087
42	WT	Wet Tropics	19988	1061
43	CMC	Central Mackay Coast	14628	2324
52 VB		Victoria Bonaparte	73009	1377
54 CAR		Carnarvon	84276	1858
57 ESP		Esperance Plains	29176	1202
58 DL		Dampierland	83617	1764
61 JF		Jarrah Forest	45090	129
62 WAR		Warren	8445	580
64 MAL		Mallee	73976	124
66 NK		Northern Kimberley	84068	8427
67 GS		Geraldton Sandplains	31405	409
68 PIL		Pilbara	178213	1383
69	SWA	Swan Coastal Plain	15256	556
71 YAL		Yalgoo	50872	885
72 GUC		Gulf Coastal	27105	1070
74	SEQ	South Eastern Queensland	78595	3043
77 CA		Central Arnhem	34624	100
79	DAC	Darwin Coastal	28424	1699
80	TNS	Tasmanian Northern Slopes	6231	62

81 ARC		Arnhem Coast	33318	4744
83 TIW		Tiwi Cobourg	10104	1879
85 KIN		King	4250	801

APPENDIX 3 - Maps showing the change in climate parameter values between the baseline and the future scenarios for IBRA regions.





2: **Mean Diurnal Range °C**

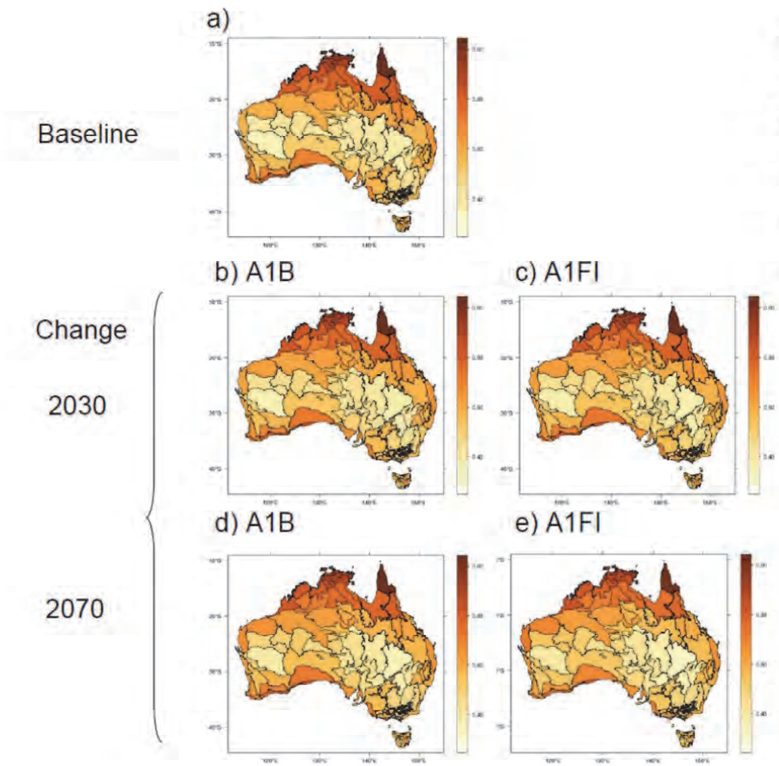
a) Baseline

b) 2030: A1B

c) 2030 A1F1

d) 2070 A1B

e) 2070 A1F1



3: **Isothermality**

a) Baseline

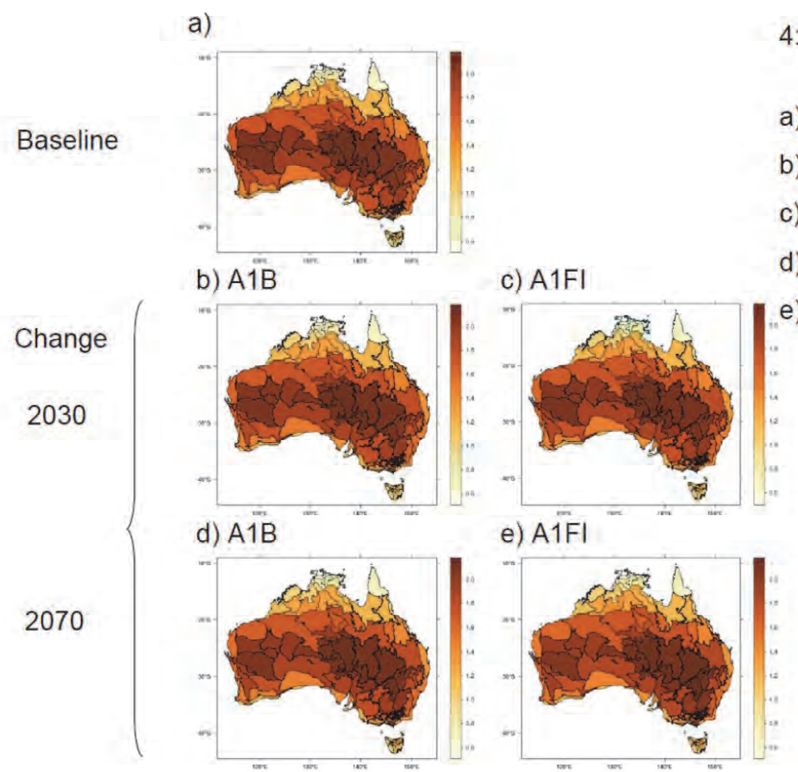
b) 2030: A1B

c) 2030 A1F1

d) 2070 A1B

e) 2070 A1F1

68



4: **Temperature Seasonality %**

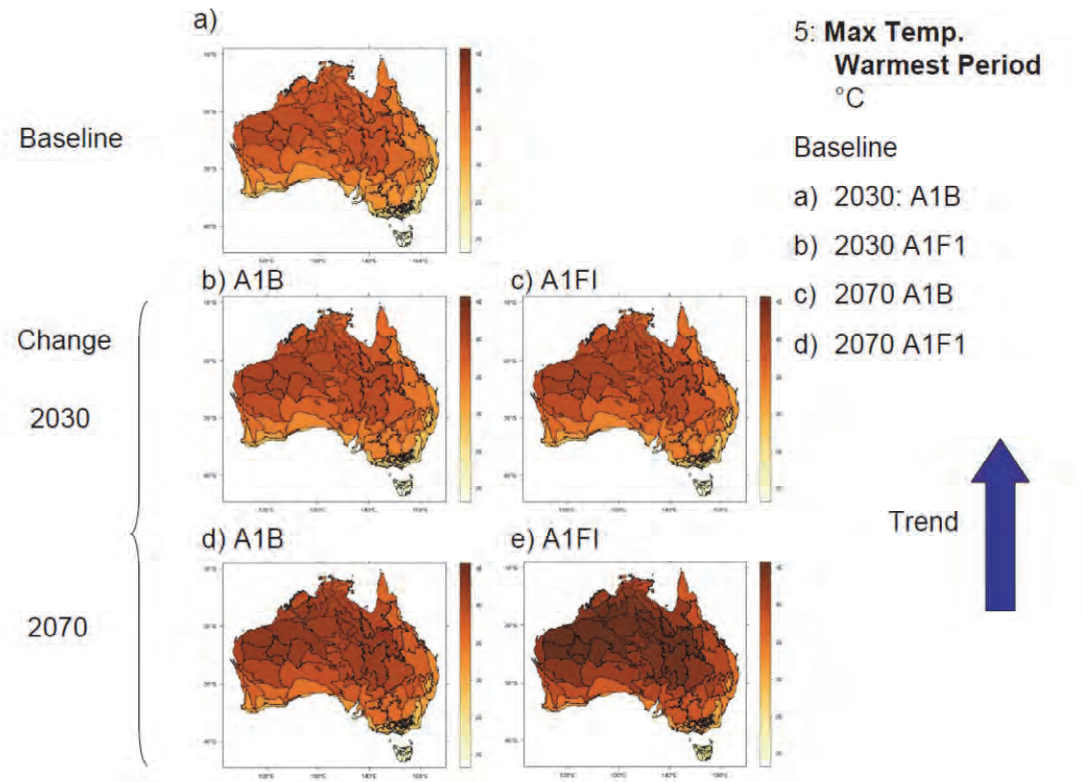
a) Baseline

b) 2030: A1B

c) 2030 A1F1

d) 2070 A1B

e) 2070 A1F1



5: **Max Temp.**
Warmest Period
°C

Baseline

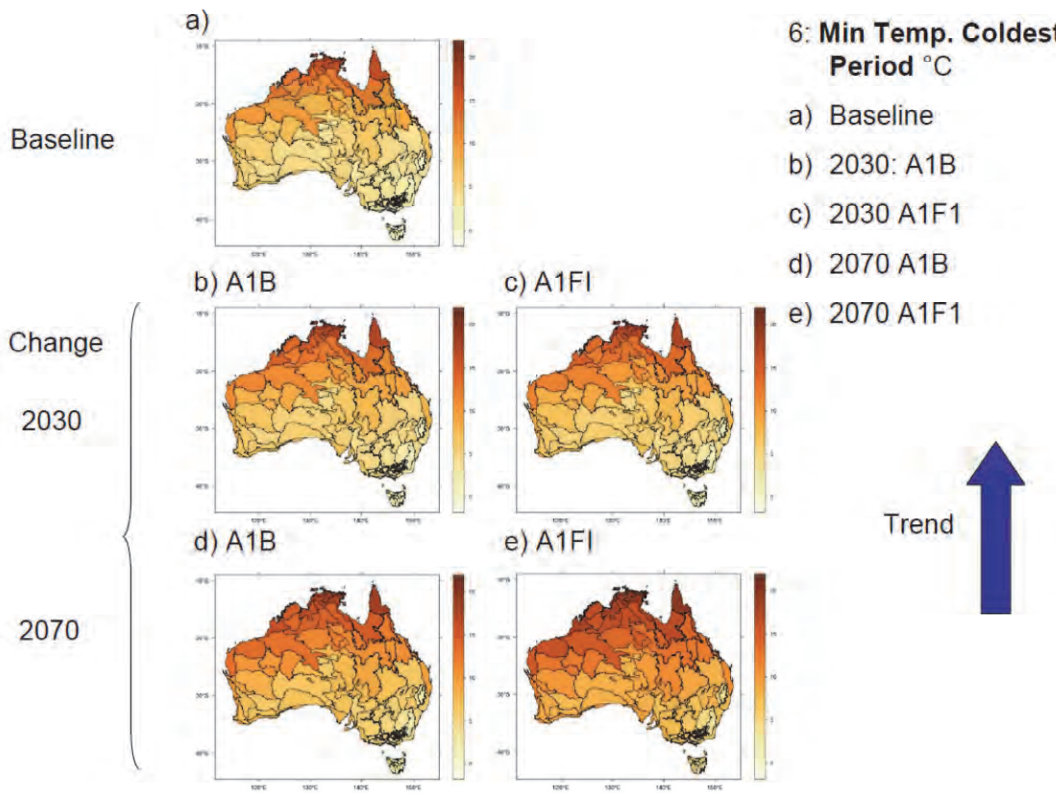
a) 2030: A1B

b) 2030 A1F1

c) 2070 A1B

d) 2070 A1F1

70



6: **Min Temp. Coldest Period** °C

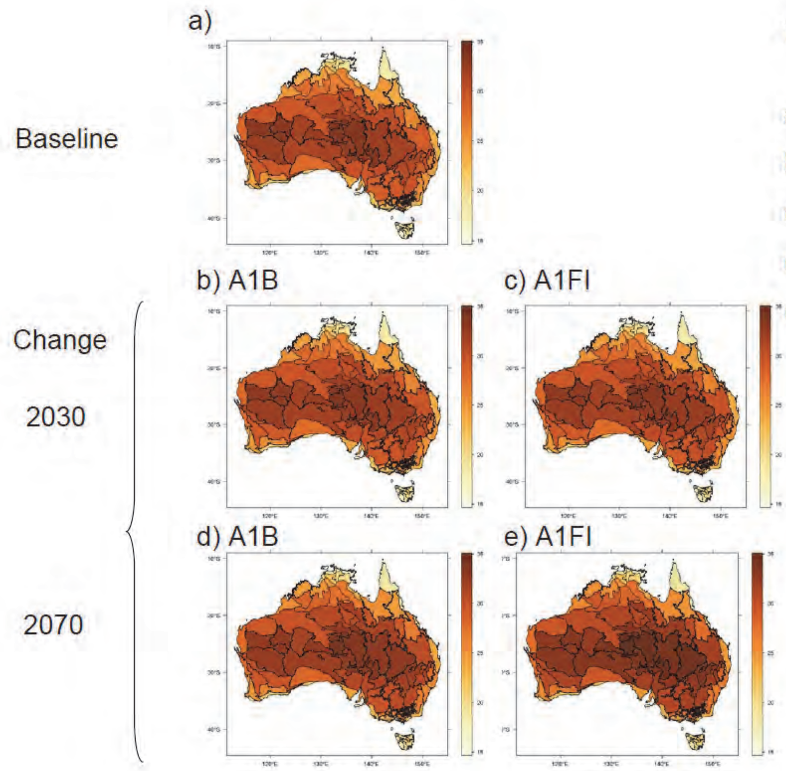
a) Baseline

b) 2030: A1B

c) 2030 A1F1

d) 2070 A1B

e) 2070 A1F1



7: **Temp. Annual Range** °C

a) Baseline

b) 2030: A1B

c) 2030 A1F1

d) 2070 A1B

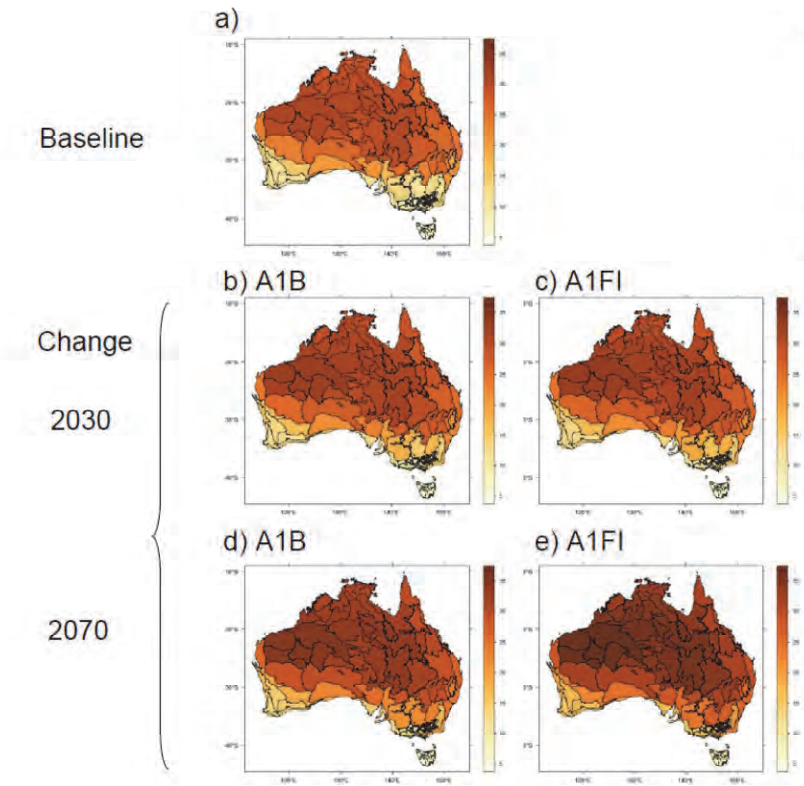
e) 2070 A1F1

Trend

East

West

72



8: **Mean Temp. Wettest Quarter**
°C

a) Baseline

b) 2030: A1B

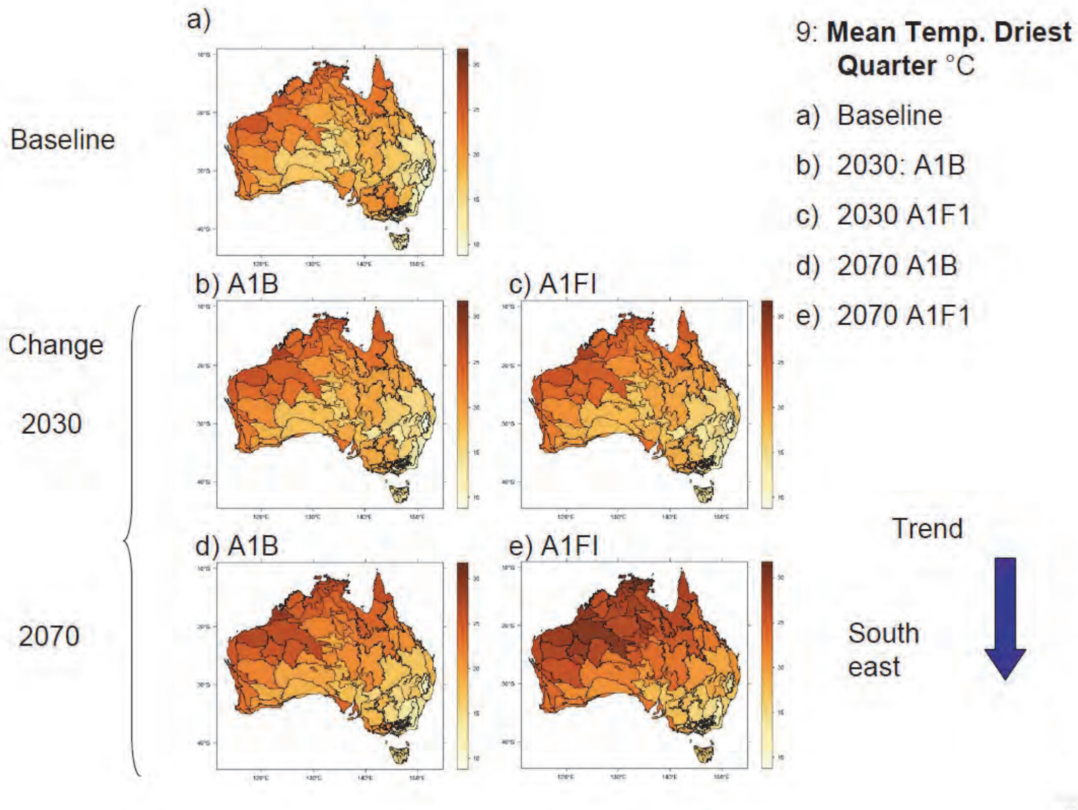
c) 2030 A1F1

d) 2070 A1B

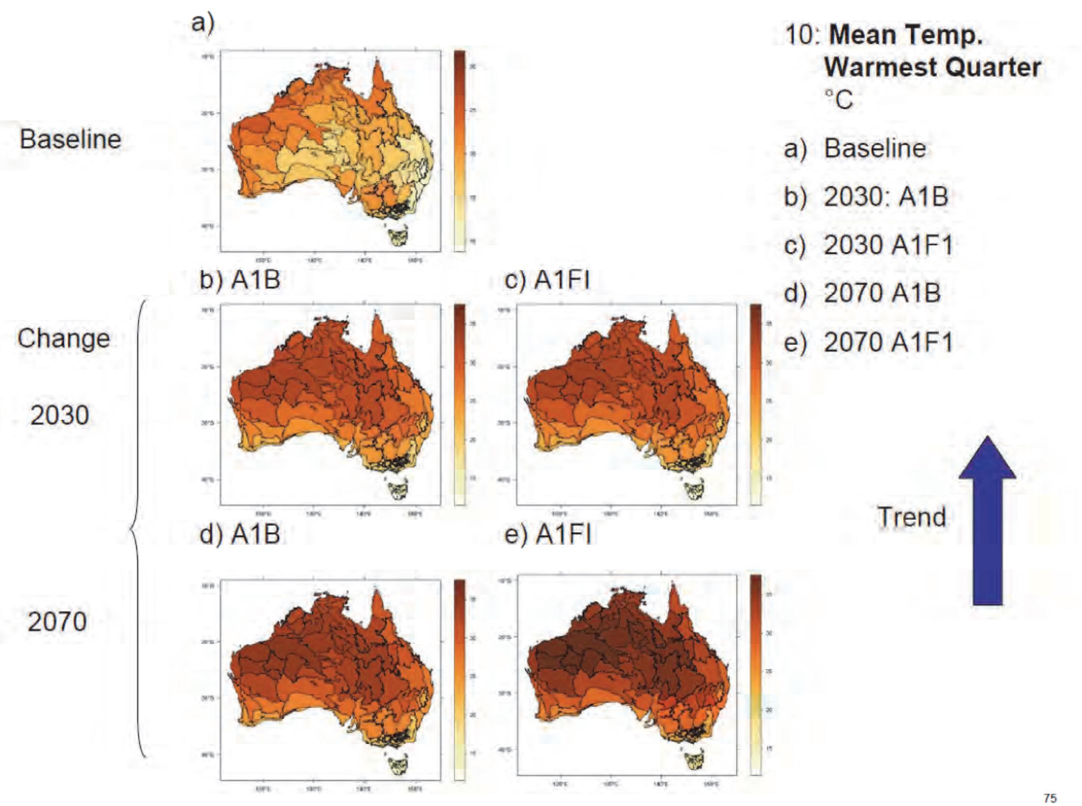
e) 2070 A1F1

Trend

South east

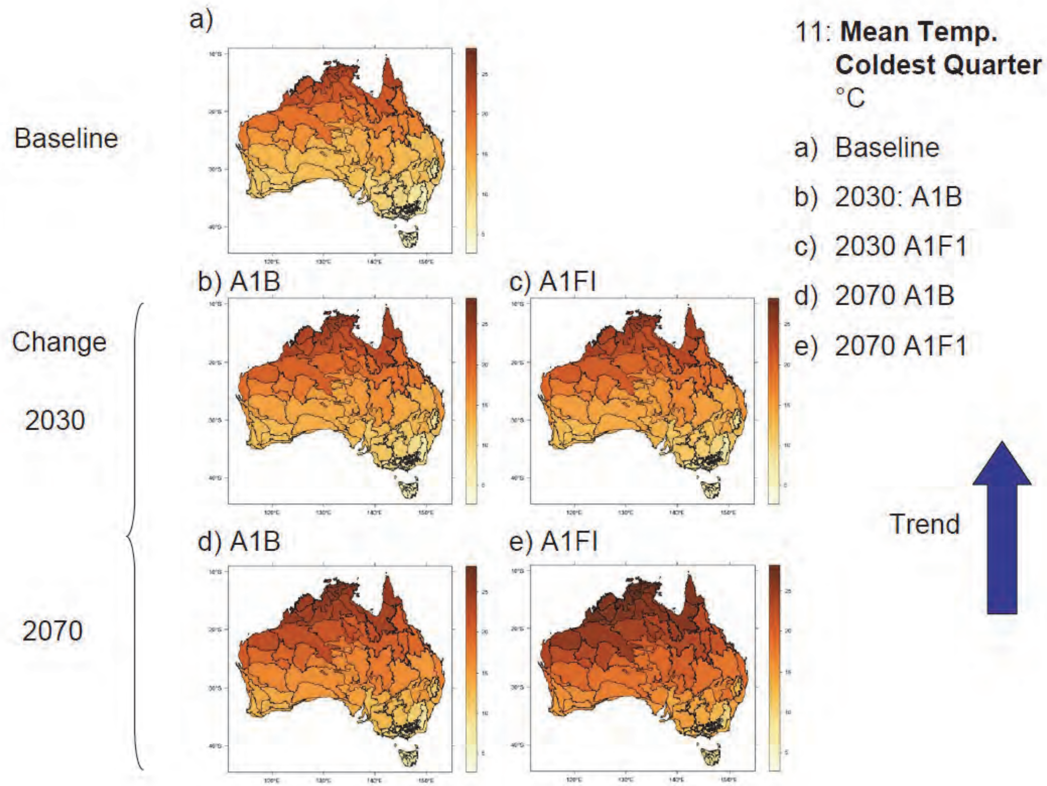


Baseline
Change
2030
2070
a)
b) A1B
c) A1FI
d) A1B
e) A1FI
9: **Mean Temp. Driest Quarter** °C
a) Baseline
b) 2030: A1B
c) 2030 A1F1
d) 2070 A1B
e) 2070 A1F1
Trend
South east



10: **Mean Temp. Warmest Quarter**
°C

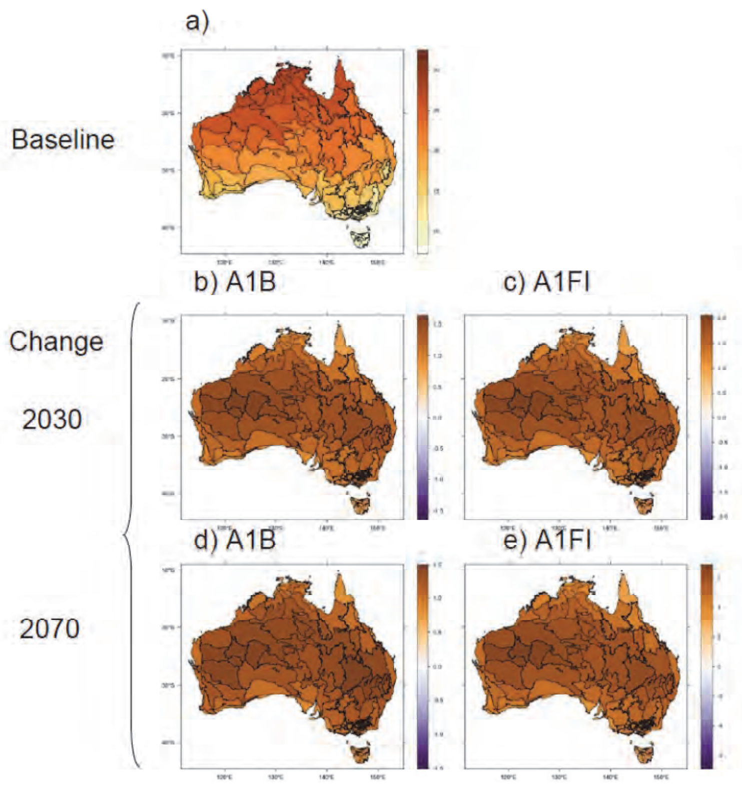
a) Baseline
b) 2030: A1B
c) 2030 A1F1
d) 2070 A1B
e) 2070 A1F1



11: **Mean Temp. Coldest Quarter**
°C

a) Baseline
b) 2030: A1B
c) 2030 A1F1
d) 2070 A1B
e) 2070 A1F1

76



1: **Change Mean Annual Temperature** °C

a) Baseline

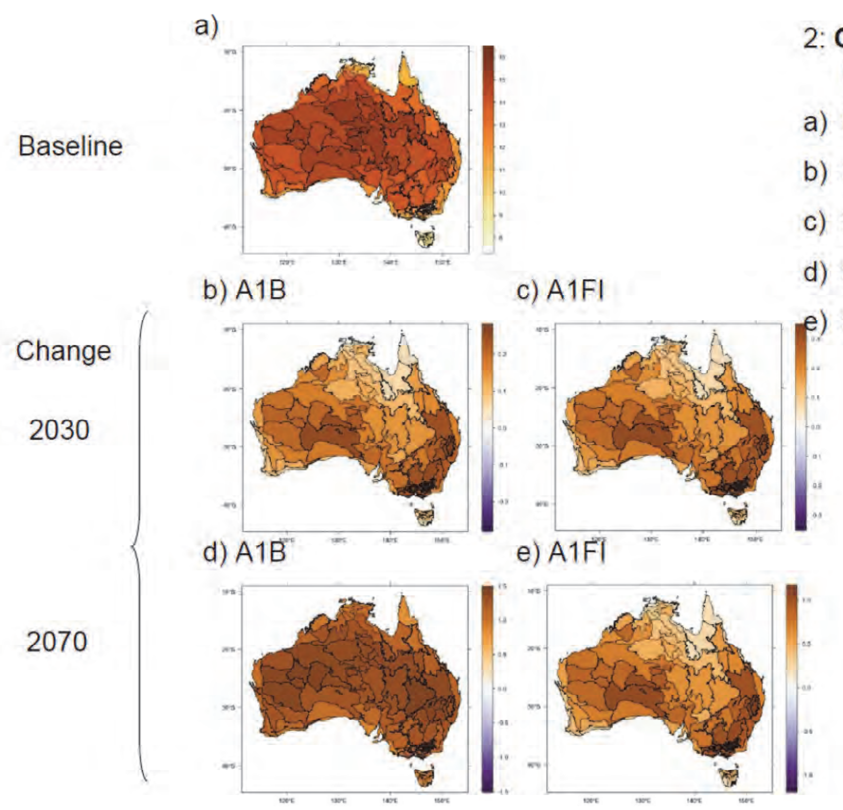
b) 2030: A1B

c) 2030 A1F1

d) 2070 A1B

e) 2070 A1F1

Trend: Temperatures



2: **Change Mean Diurnal Range °C**

a) Baseline

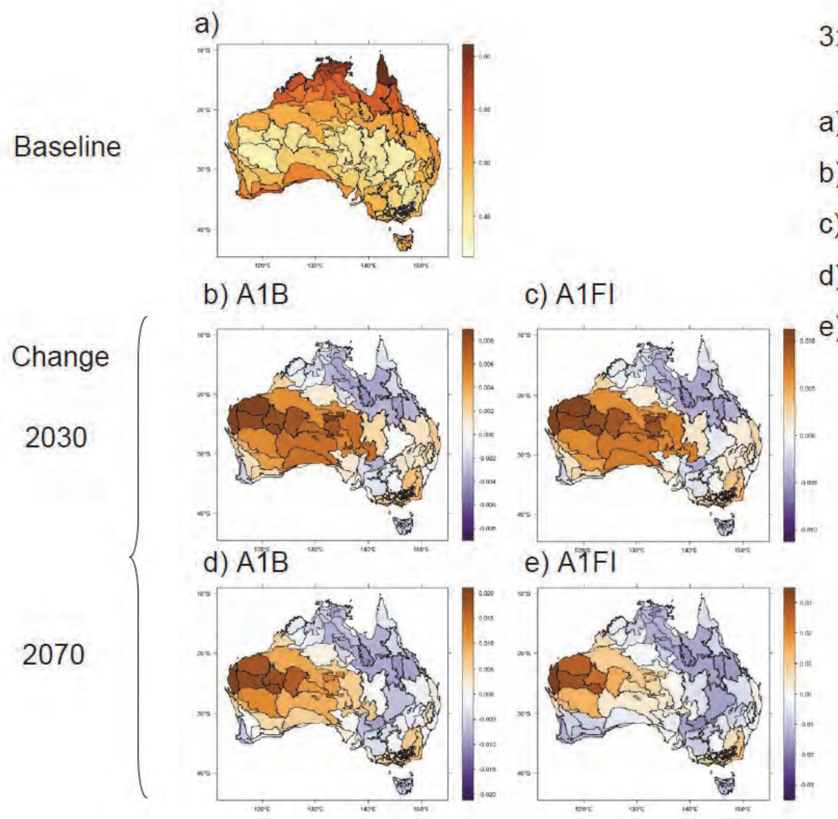
b) 2030: A1B

c) 2030 A1F1

d) 2070 A1B

e) 2070 A1F1

78



3: **Change Isothermality**

a) Baseline

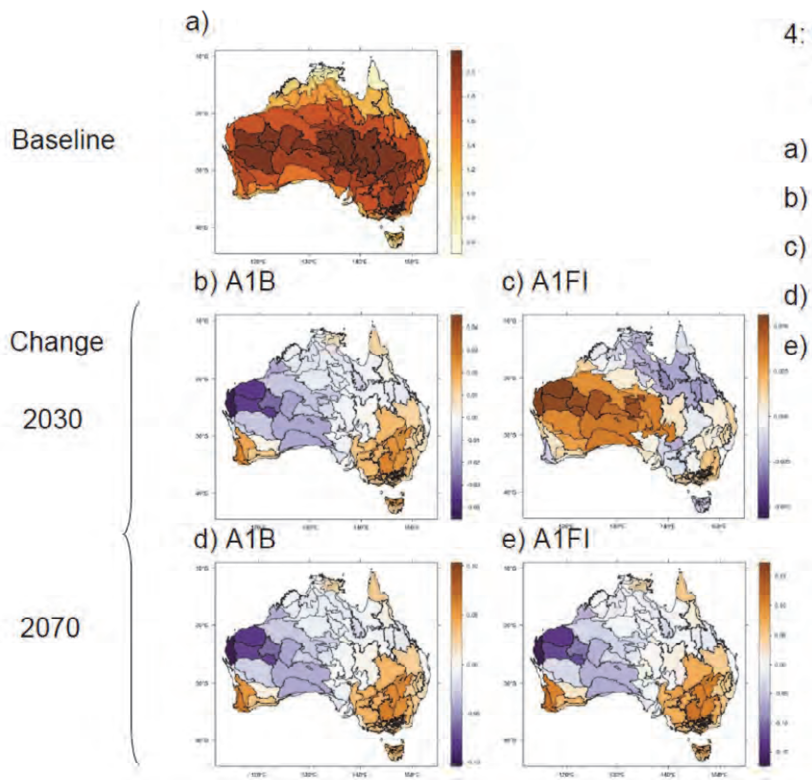
b) 2030: A1B

c) 2030 A1F1

d) 2070 A1B

e) 2070 A1F1

Trend



4: **Change Temperature Seasonality %**

a) Baseline

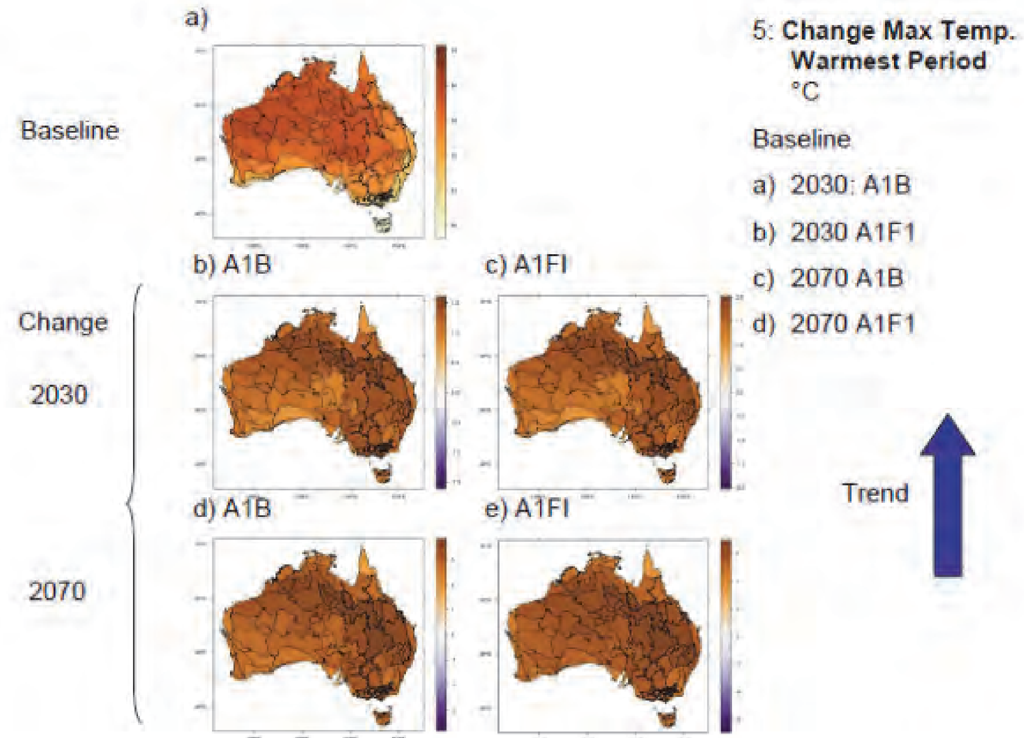
b) 2030: A1B

c) 2030 A1F1

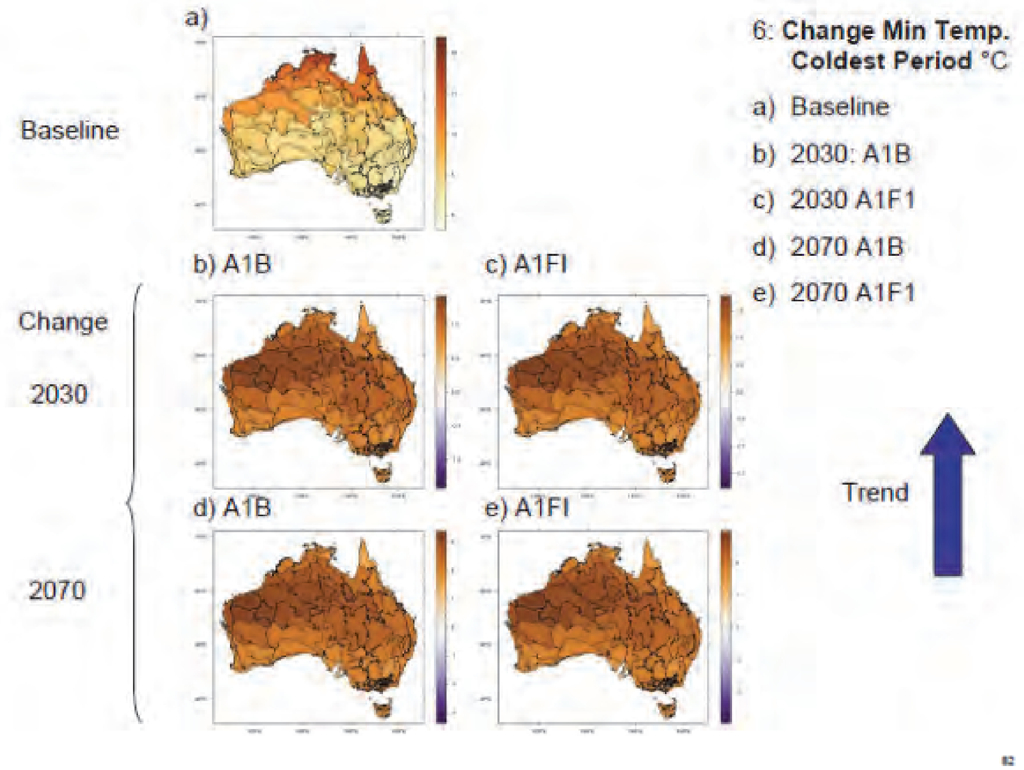
d) 2070 A1B

e) 2070 A1F1

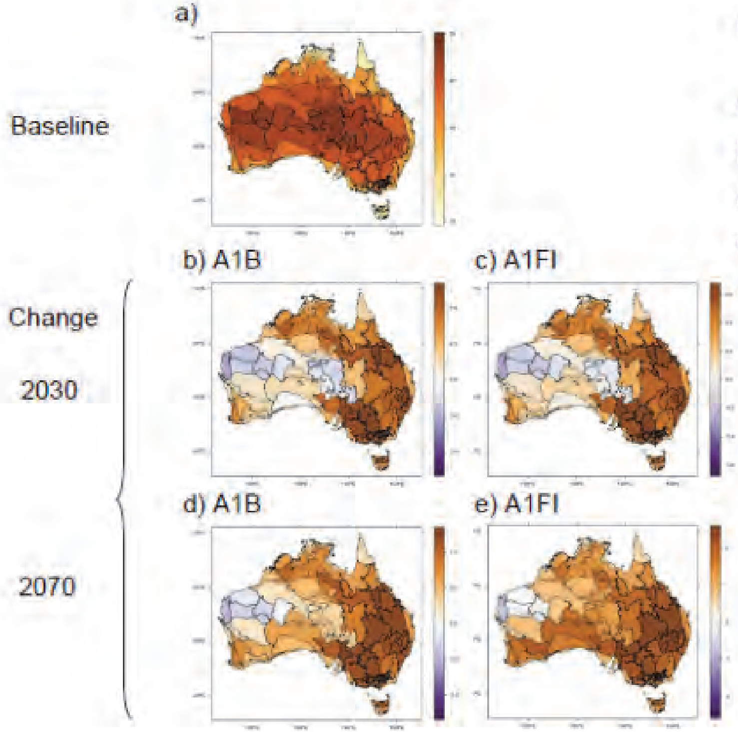
80



a)
Baseline
b) A1B
c) A1FI
Change
2030
d) A1B
e) A1FI
2070
5: Change Max Temp.
Warmest Period
°C
Baseline
a) 2030: A1B
b) 2030 A1F1
c) 2070 A1B
d) 2070 A1F1
Trend



6: **Change Min Temp. Coldest Period** °C
a) Baseline
b) 2030: A1B
c) 2030 A1F1
d) 2070 A1B
e) 2070 A1F1
Baseline
Change
2030
2070
a)
b) A1B
c) A1FI
d) A1B
e) A1FI
Trend
82



7: **Change Temp. Annual Range** °C

a) Baseline

b) 2030: A1B

c) 2030 A1F1

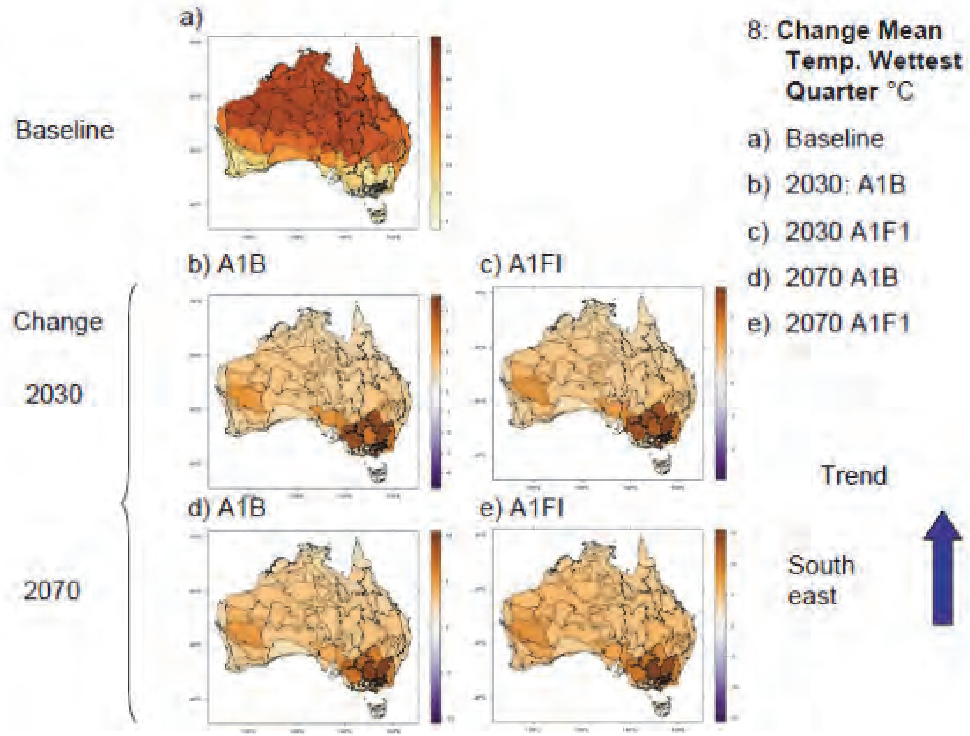
d) 2070 A1B

e) 2070 A1F1

Trend

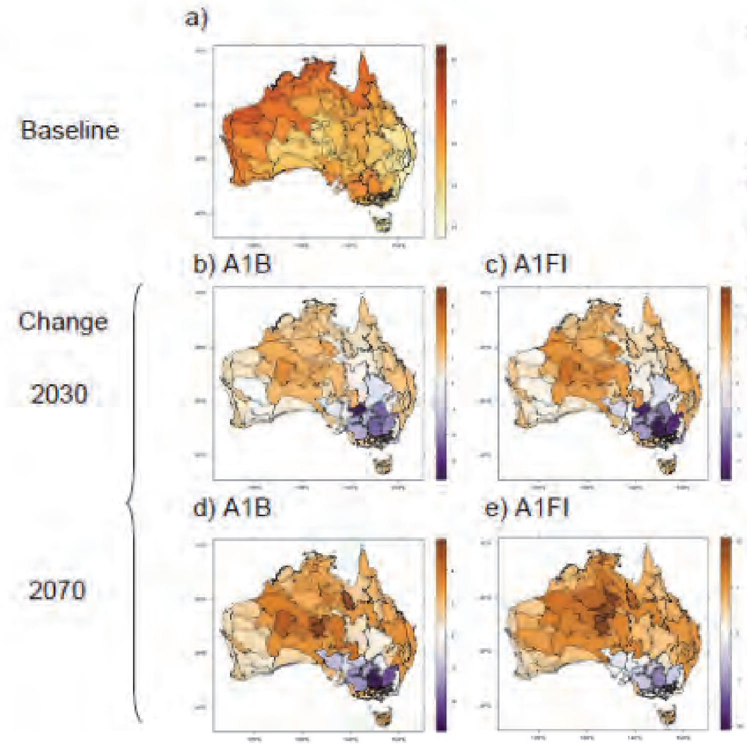
East

West


Baseline
Change
2030
2070
a)
b) A1B
c) A1FI
d) A1B
e) A1FI
8: **Change Mean Temp. Wettest Quarter** °C
a) Baseline
b) 2030: A1B
c) 2030 A1F1
d) 2070 A1B
e) 2070 A1F1
Trend
South east

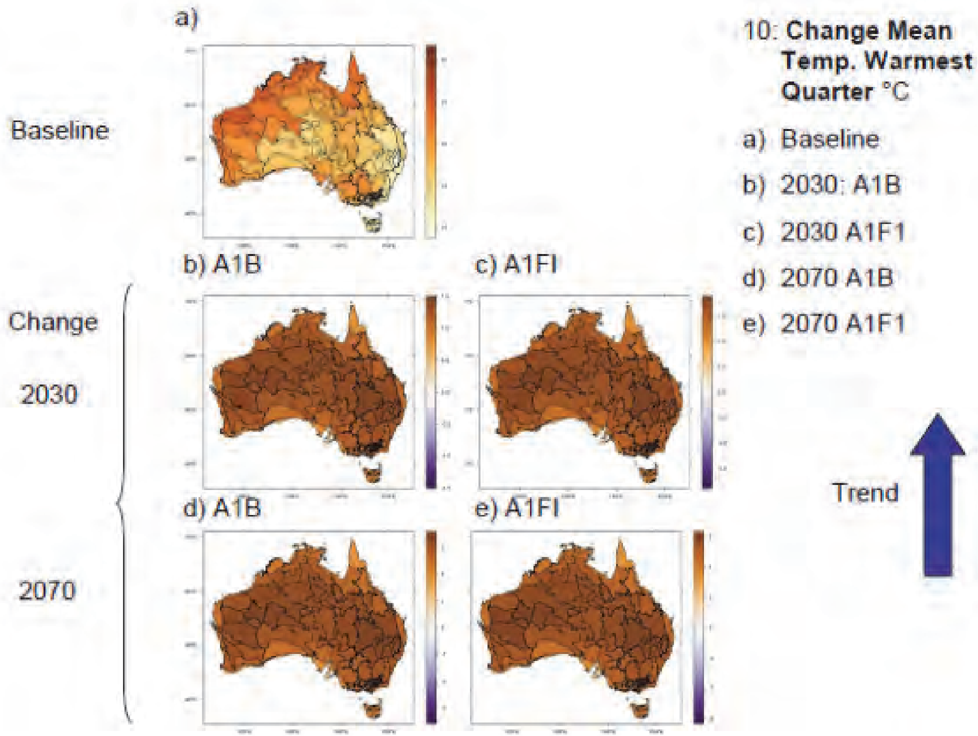
9: **Change Mean Temp. Driest Quarter** °C

a) Baseline
b) 2030: A1B
c) 2030 A1F1
d) 2070 A1B
e) 2070 A1F1



Trend

South east



10: **Change Mean Temp. Warmest Quarter** °C

a) Baseline

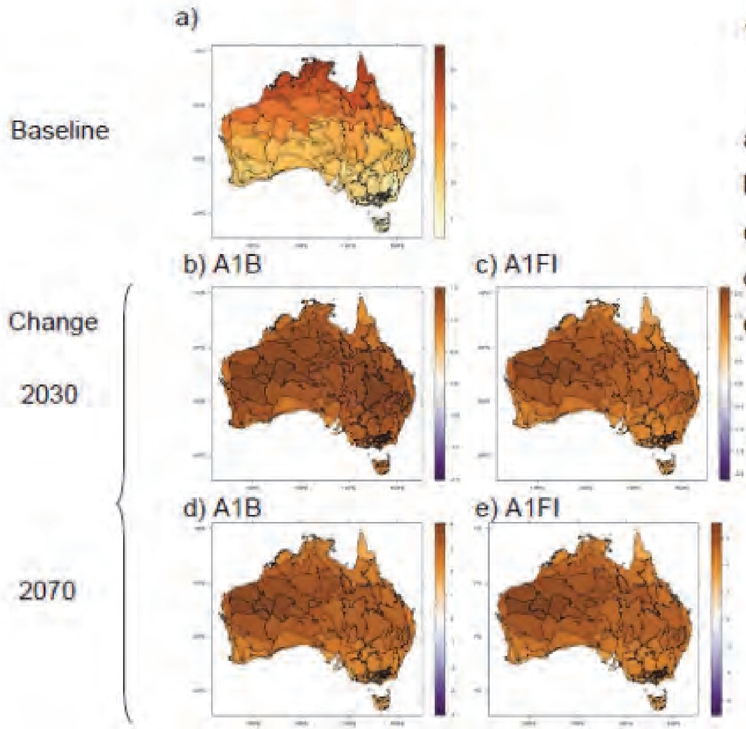
b) 2030: A1B

c) 2030 A1F1

d) 2070 A1B

e) 2070 A1F1

86



11: **Change Mean Temp. Coldest Quarter** °C

a) Baseline

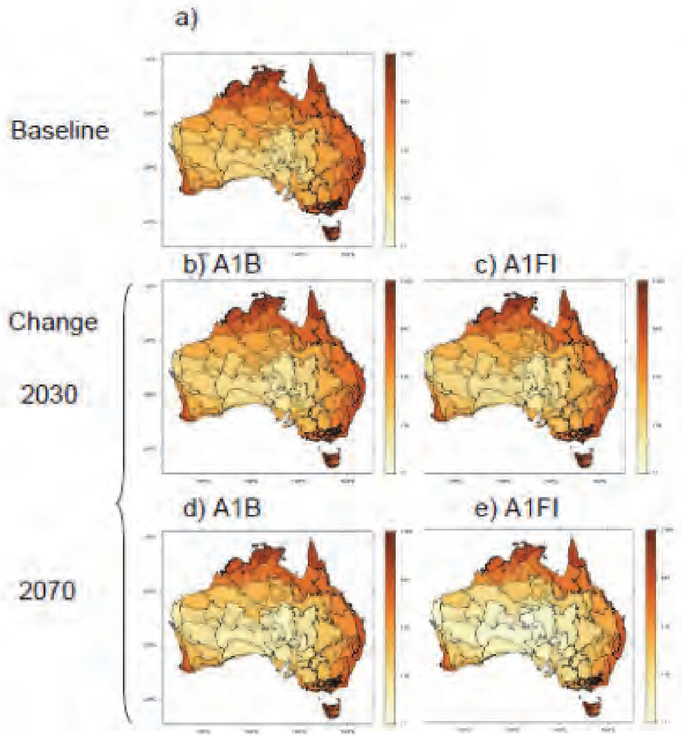
b) 2030: A1B

c) 2030 A1F1

d) 2070 A1B

e) 2070 A1F1

Trend



12: **Mean Annual Precipitation mm**

a) Baseline

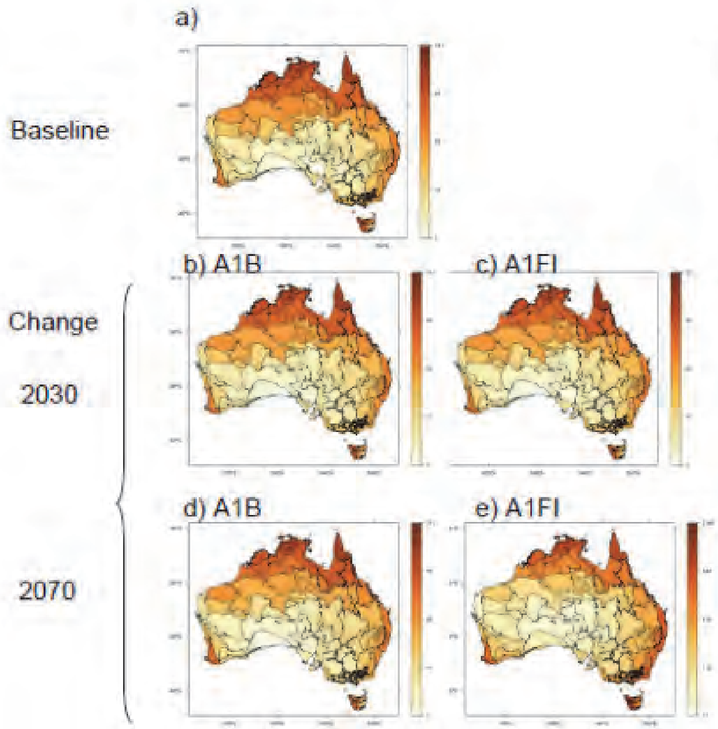
b) 2030: A1B

c) 2030 A1F1

d) 2070 A1B

e) 2070 A1F1

Trend:



13: **Precipitation of Wettest Period mm**

a) Baseline

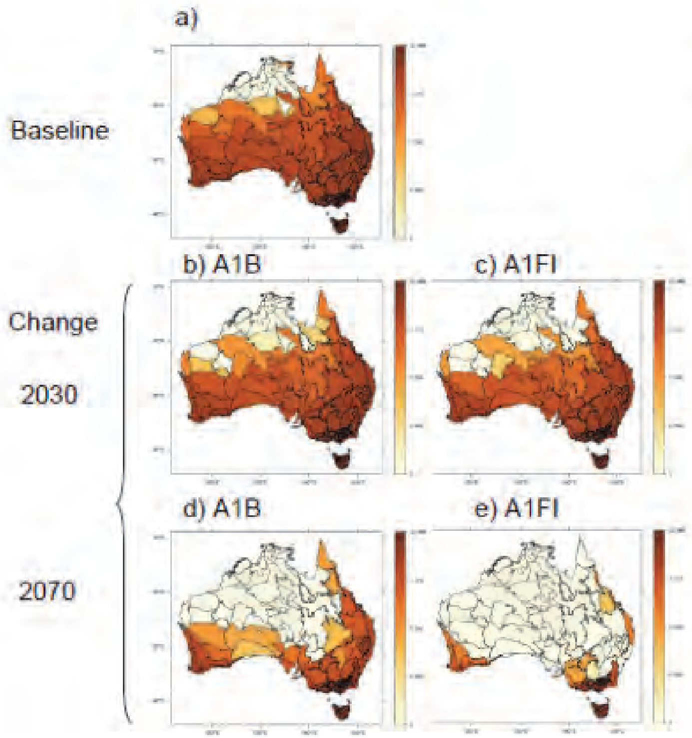
b) 2030: A1B

c) 2030 A1F1

d) 2070 A1B

e) 2070 A1F1

North Qld and SW WA



14: **Precipitation of the Driest Period**

a) Baseline

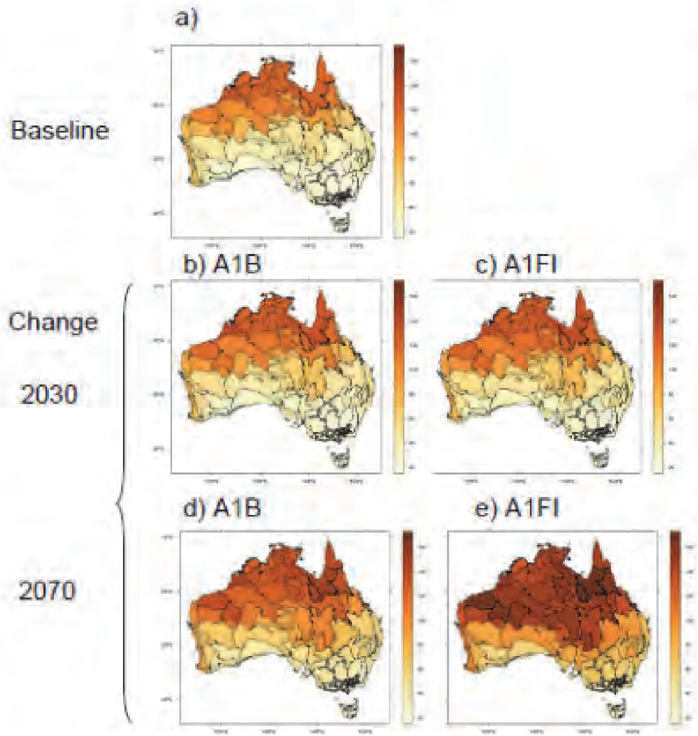
b) 2030: A1B

c) 2030 A1F1

d) 2070 A1B

e) 2070 A1F1

90



15: **Precipitation Seasonality** %

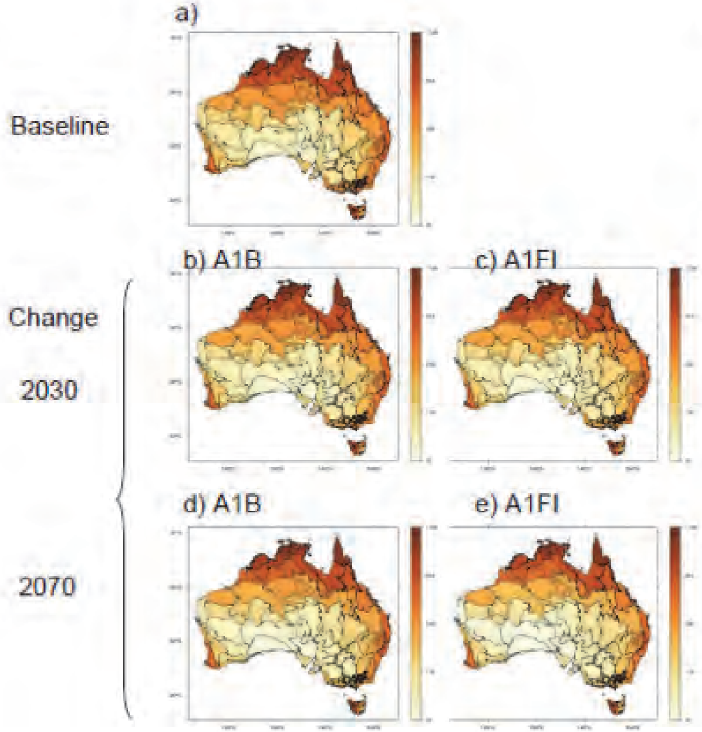
a) Baseline

b) 2030: A1B

c) 2030 A1F1

d) 2070 A1B

e) 2070 A1F1



16: **Precipitation of Wettest Quarter mm**

Baseline

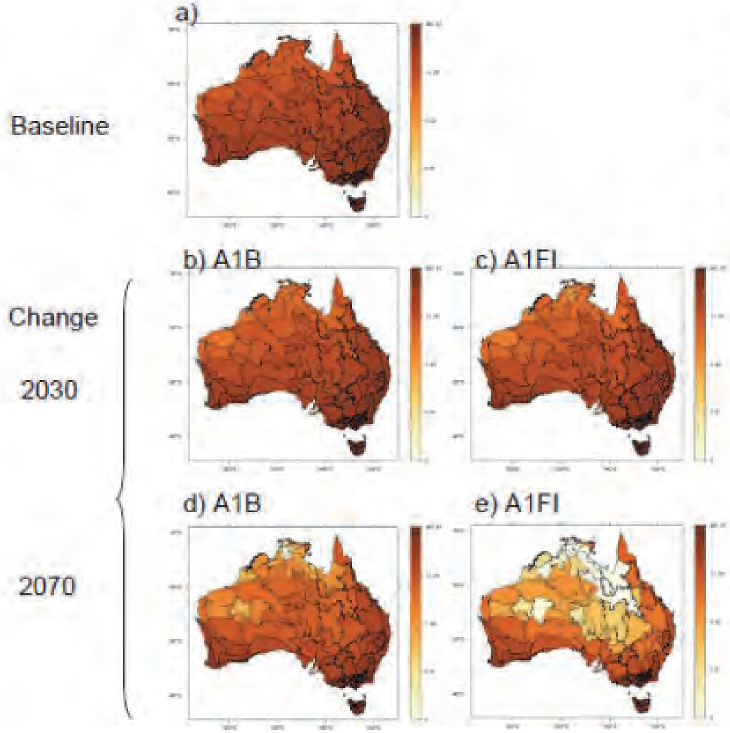
a) 2030: A1B

b) 2030 A1F1

c) 2070 A1B

d) 2070 A1F1

92



17: **Precipitation of Driest Quarter mm**

a) Baseline

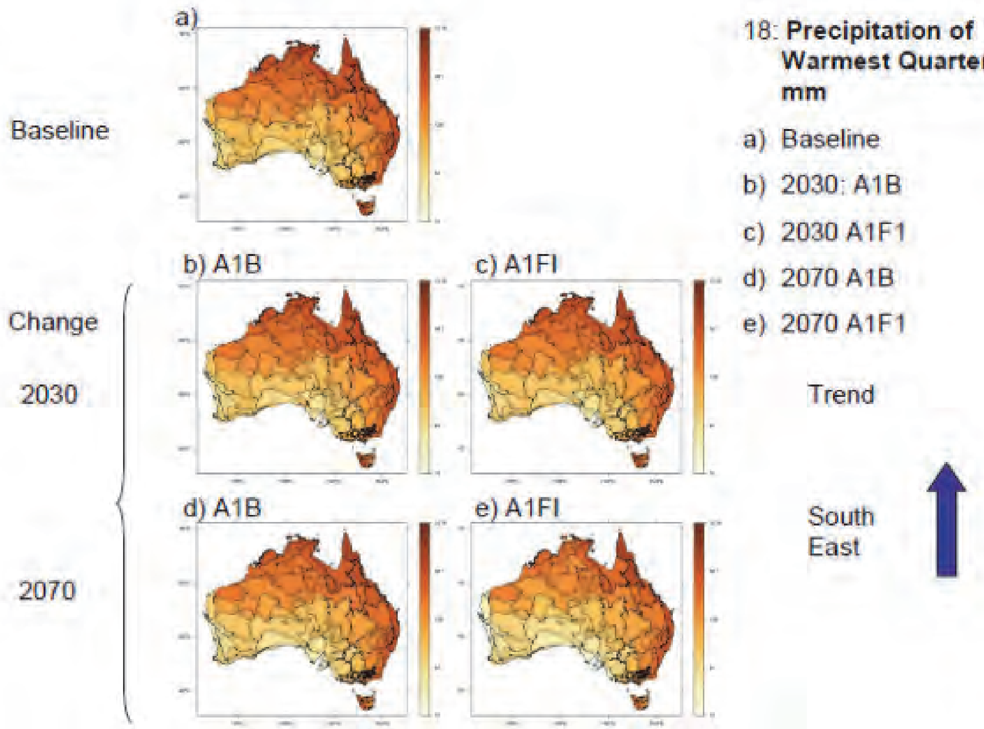
b) 2030: A1B

c) 2030 A1F1

d) 2070 A1B

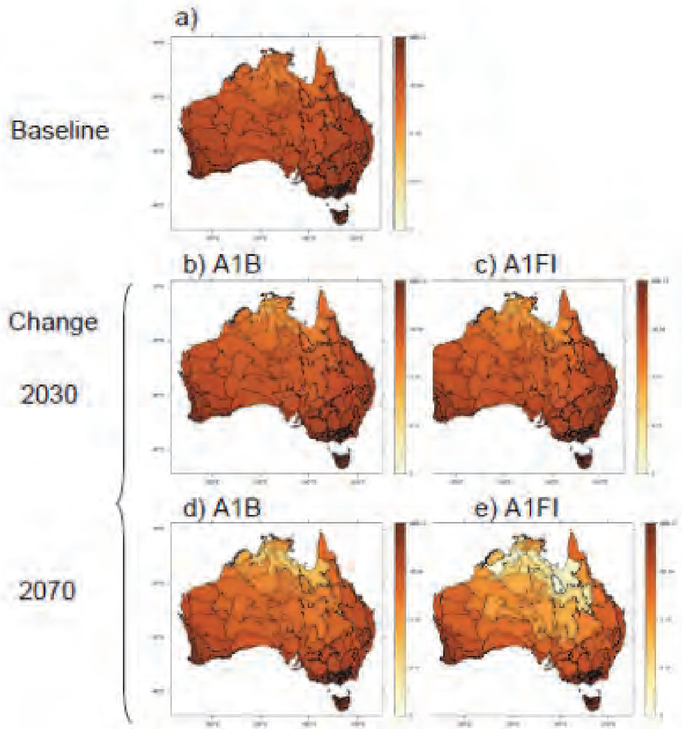
e) 2070 A1F1

Trend



18: **Precipitation of Warmest Quarter mm**

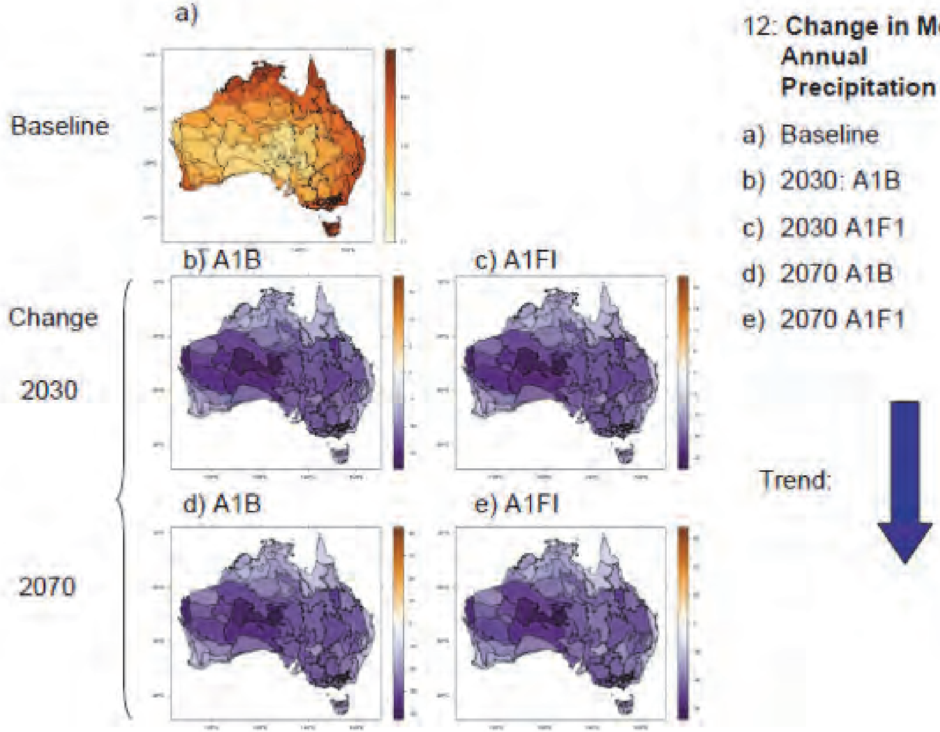
a) Baseline
b) 2030: A1B
c) 2030 A1F1
d) 2070 A1B
e) 2070 A1F1



19: **Precipitation of Coldest Quarter mm**

a) Baseline
b) 2030: A1B
c) 2030 A1F1
d) 2070 A1B
e) 2070 A1F1

Trend



12: **Change in Mean Annual Precipitation %**

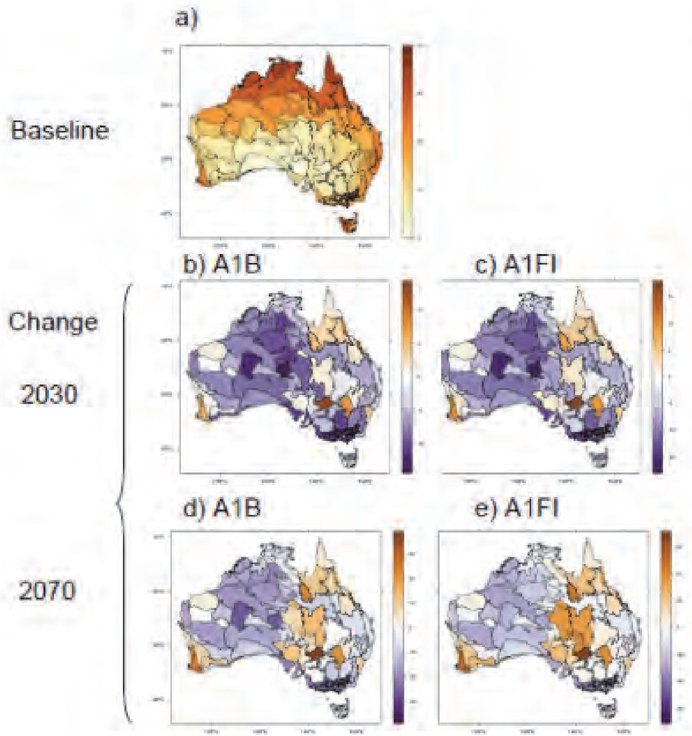
a) Baseline

b) 2030: A1B

c) 2030 A1F1

d) 2070 A1B

e) 2070 A1F1



13: **Change in Precipitation of Wettest Period %**

a) Baseline

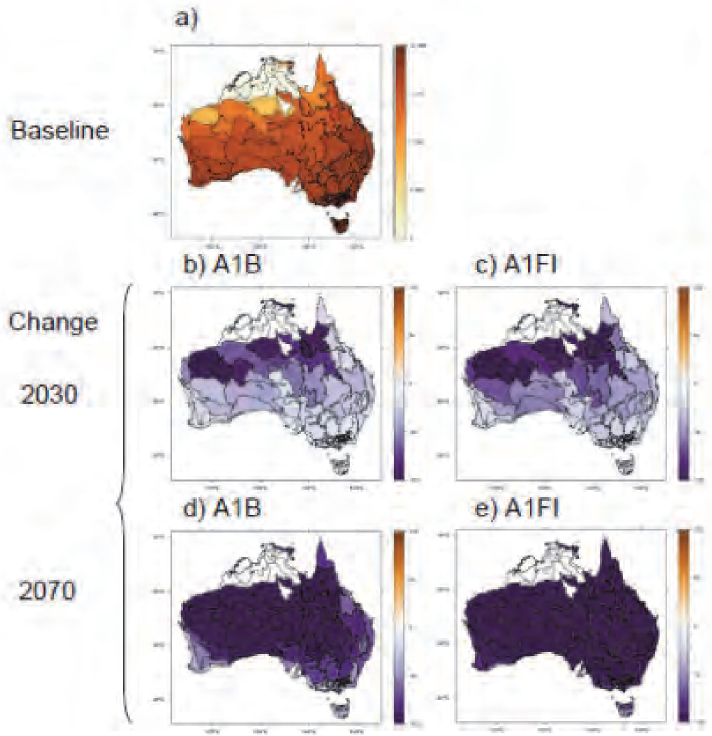
b) 2030: A1B

c) 2030 A1F1

d) 2070 A1B

e) 2070 A1F1

North Qld and SW WA



14: **Change in Precipitation of the Driest Period %**

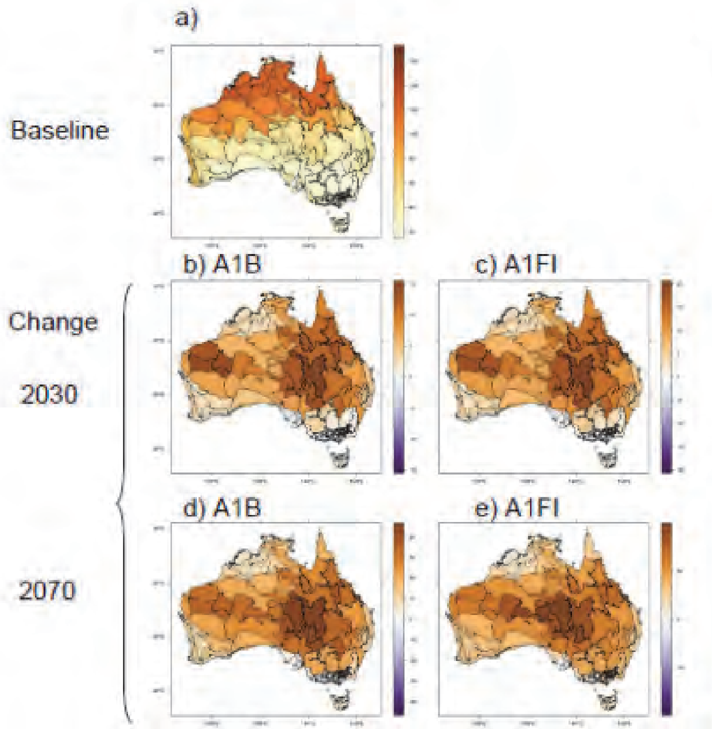
a) Baseline

b) 2030: A1B

c) 2030 A1F1

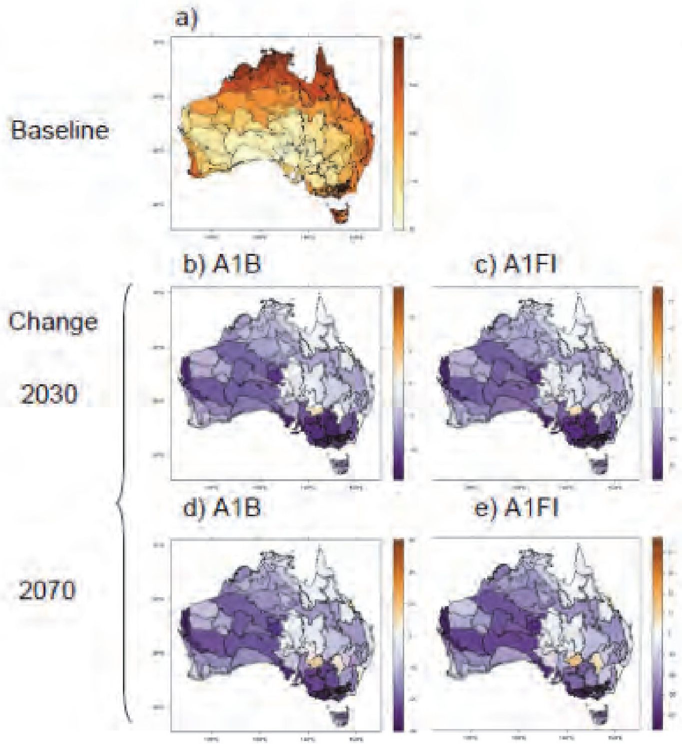
d) 2070 A1B

e) 2070 A1F1



15: **Change in Precipitation Seasonality**

a) Baseline
b) 2030: A1B
c) 2030 A1F1
d) 2070 A1B
e) 2070 A1F1



16: **Change in Precipitation of Wettest Quarter** %

Baseline

a) 2030: A1B

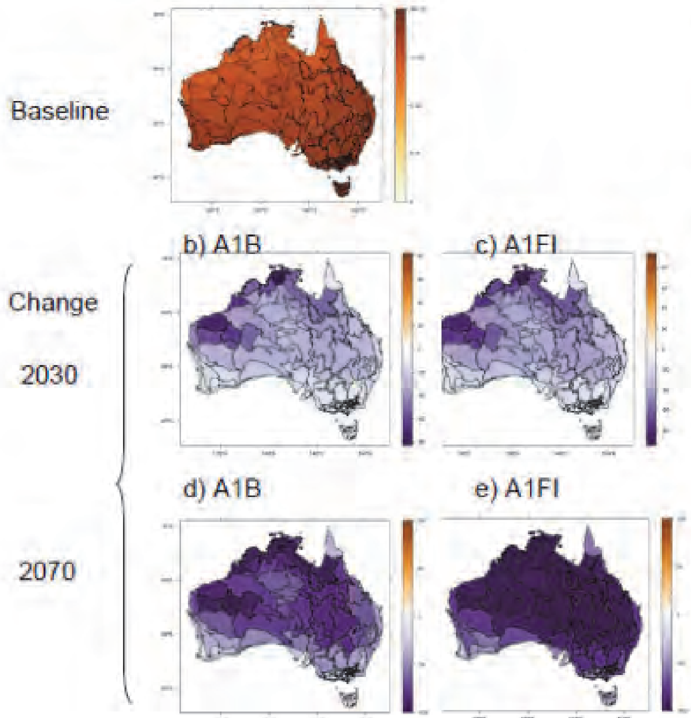
b) 2030 A1F1

c) 2070 A1B

d) 2070 A1F1

Trend

100



17: **Change in Precipitation of Driest Quarter %**

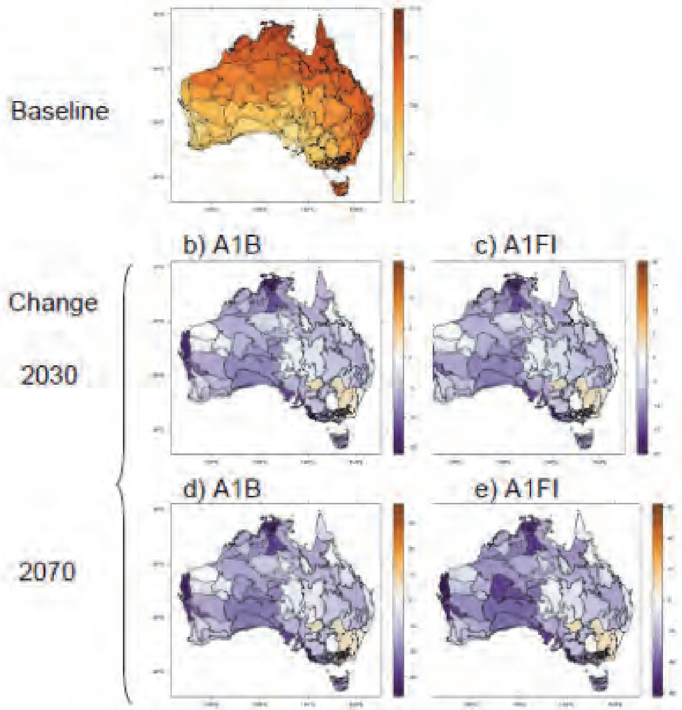
a) Baseline

b) 2030: A1B

c) 2030 A1F1

d) 2070 A1B

e) 2070 A1F1

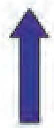


18: **Change in Precipitation of Warmest Quarter** %

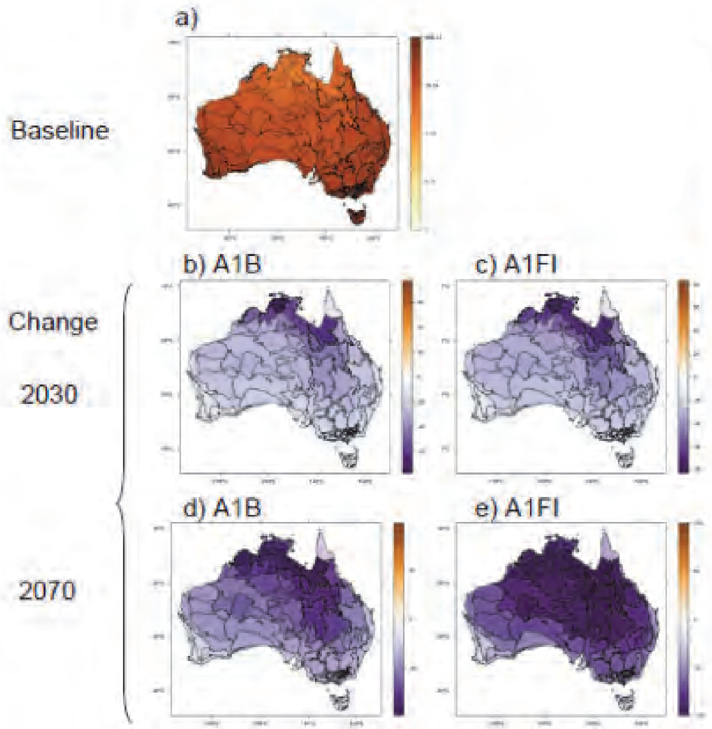
a) Baseline
b) 2030: A1B
c) 2030 A1F1
d) 2070 A1B
e) 2070 A1F1

Trend

South east



102



19: **Change in Precipitation of Coldest Quarter** %

a) Baseline

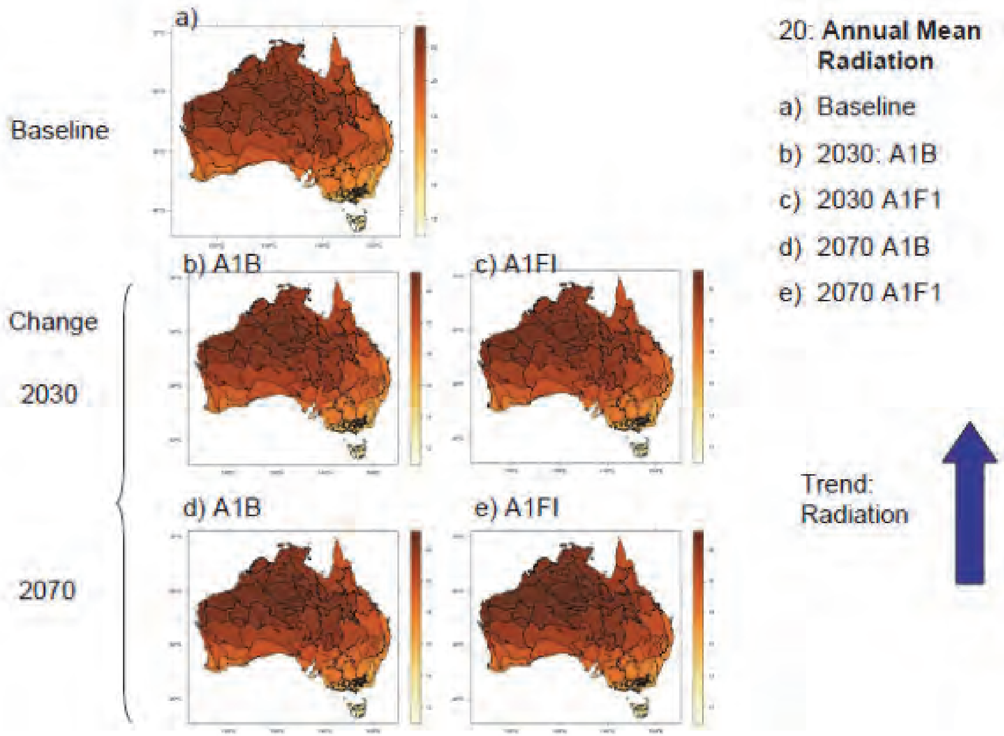
b) 2030: A1B

c) 2030 A1F1

d) 2070 A1B

e) 2070 A1F1

Trend



20: **Annual Mean Radiation**

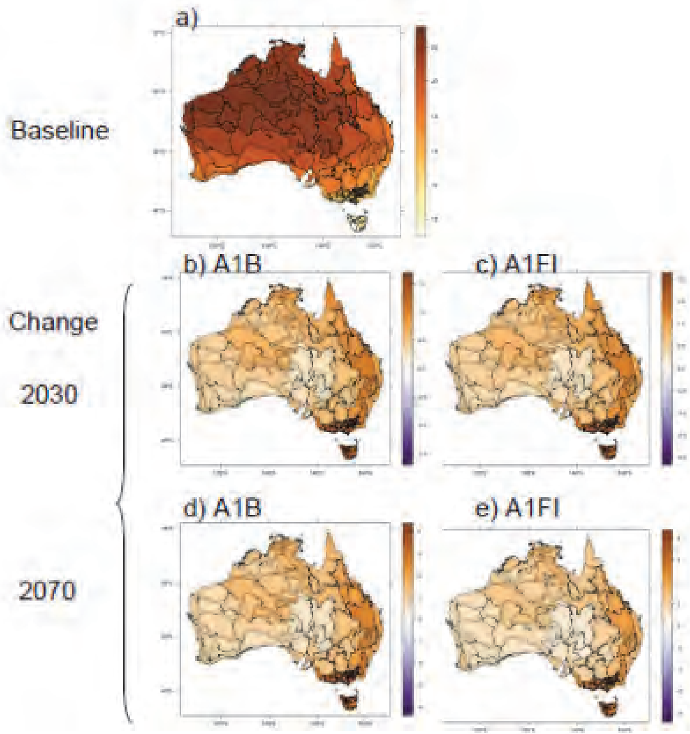
a) Baseline

b) 2030: A1B

c) 2030 A1F1

d) 2070 A1B

e) 2070 A1F1



20: **Change in Annual Mean Radiation %**

a) Baseline

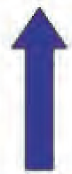
b) 2030: A1B

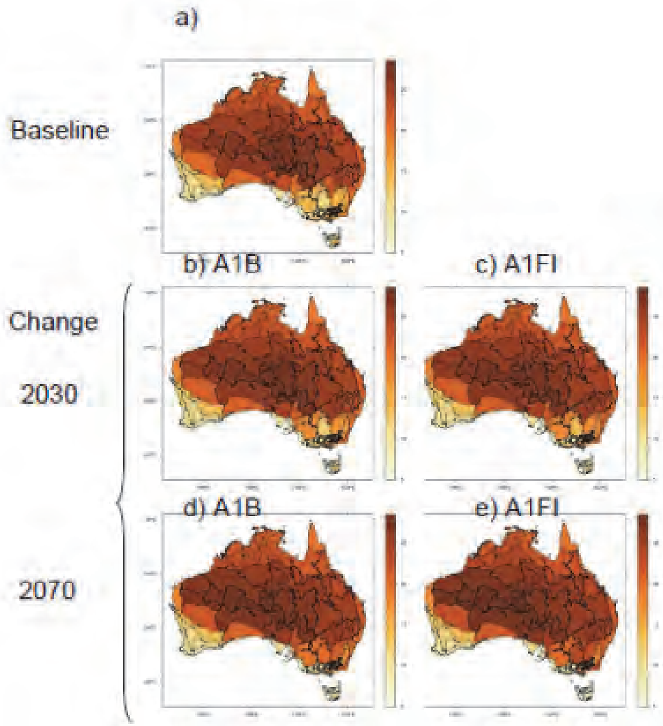
c) 2030 A1F1

d) 2070 A1B

e) 2070 A1F1

Trend: Radiation





24: **Mean Radiation Wettest Quarter J/m²**

a) Baseline

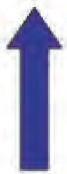
b) 2030: A1B

c) 2030 A1F1

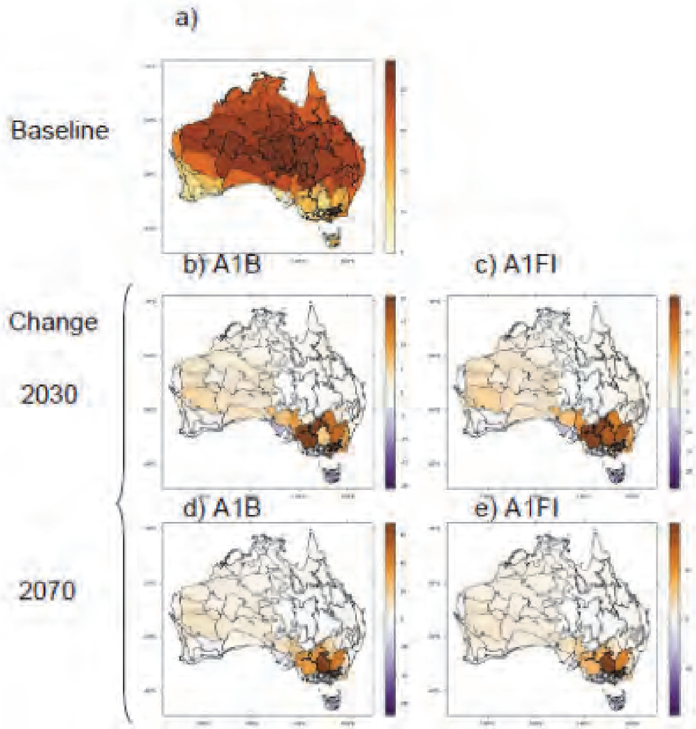
d) 2070 A1B

e) 2070 A1F1

Trend:
South East



106



24: **Change in Mean Radiation Wettest Quarter** %

a) Baseline

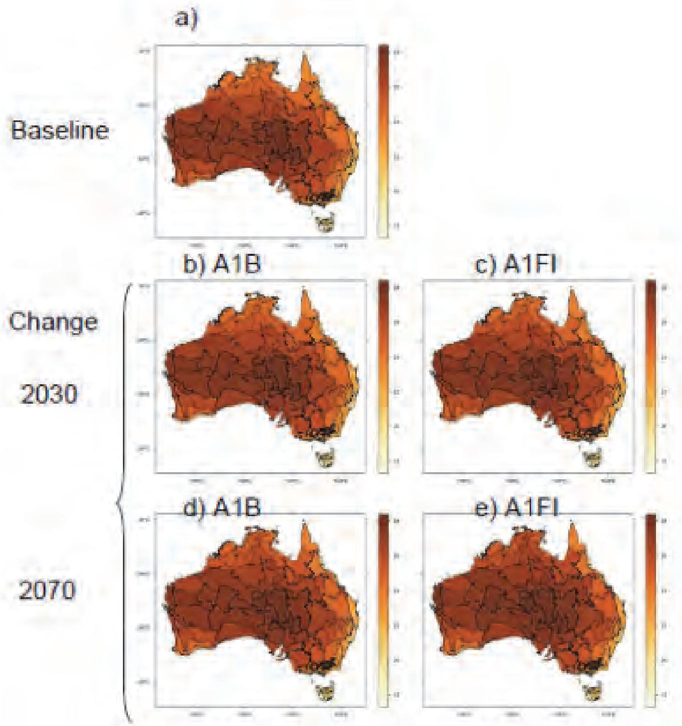
b) 2030: A1B

c) 2030 A1F1

d) 2070 A1B

e) 2070 A1F1

Trend:
South East



26: **Mean Radiation Warmest Quarter J/m²**

a) Baseline

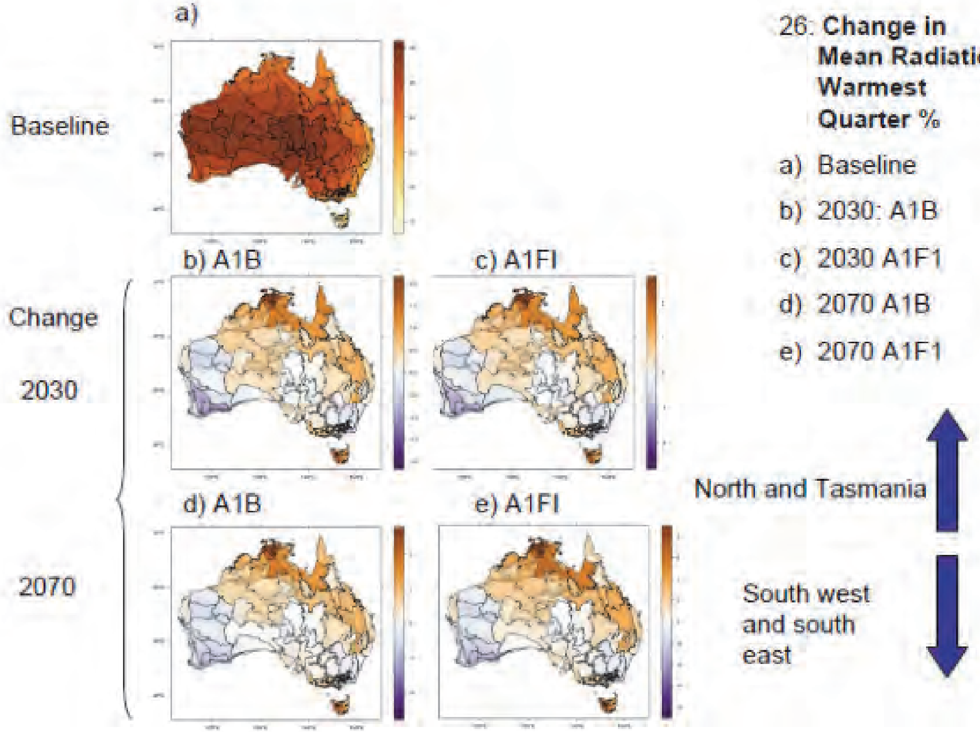
b) 2030: A1B

c) 2030 A1F1

d) 2070 A1B

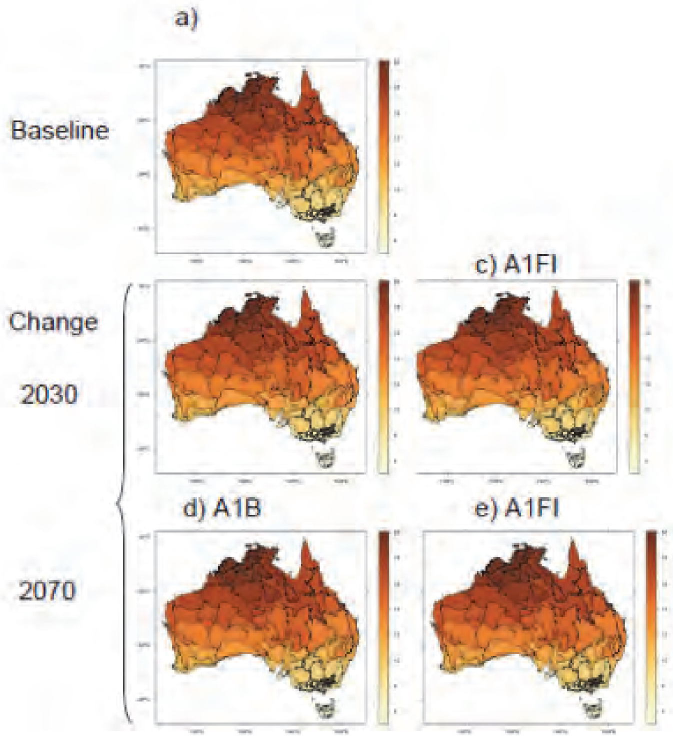
e) 2070 A1F1

108



26: **Change in Mean Radiation Warmest Quarter** %

a) Baseline
b) 2030: A1B
c) 2030 A1F1
d) 2070 A1B
e) 2070 A1F1



27: **Mean Radiation Coldest Quarter J/m²**

a) Baseline

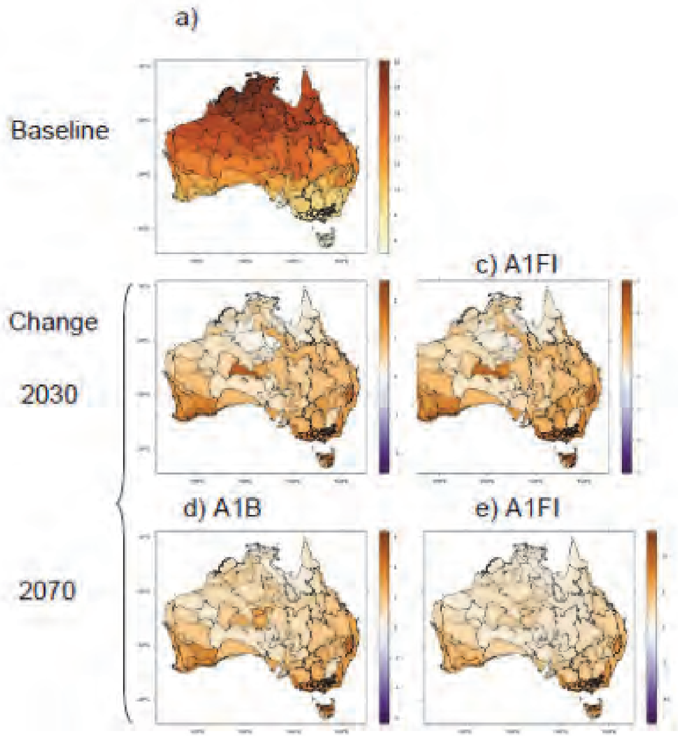
b) 2030: A1B

c) 2030 A1F1

d) 2070 A1B

e) 2070 A1F1

110



27: **Change in Mean Radiation Coldest Quarter** %

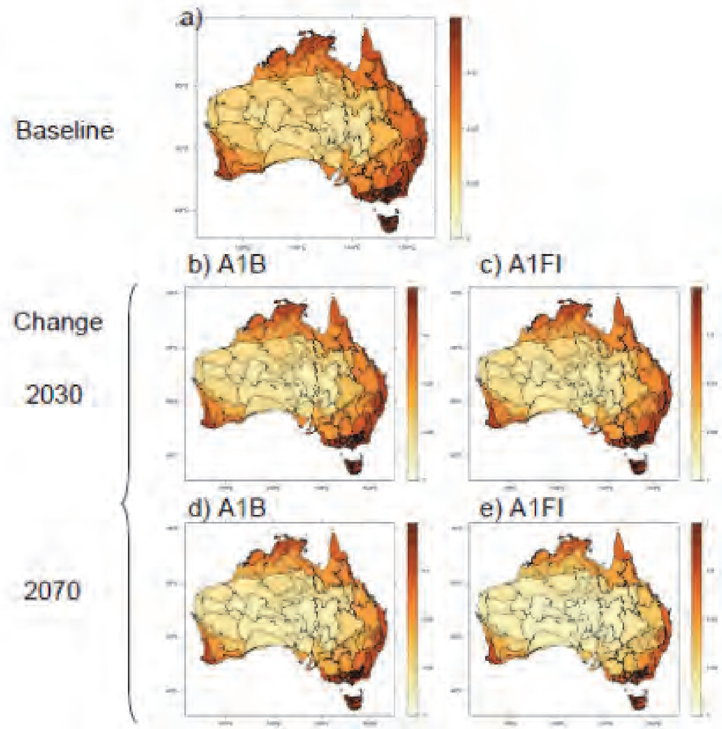
a) Baseline

b) 2030: A1B

c) 2030 A1F1

d) 2070 A1B

e) 2070 A1F1



28: **Annual Mean Moisture Index** [0,1]

a) Baseline

b) 2030: A1B

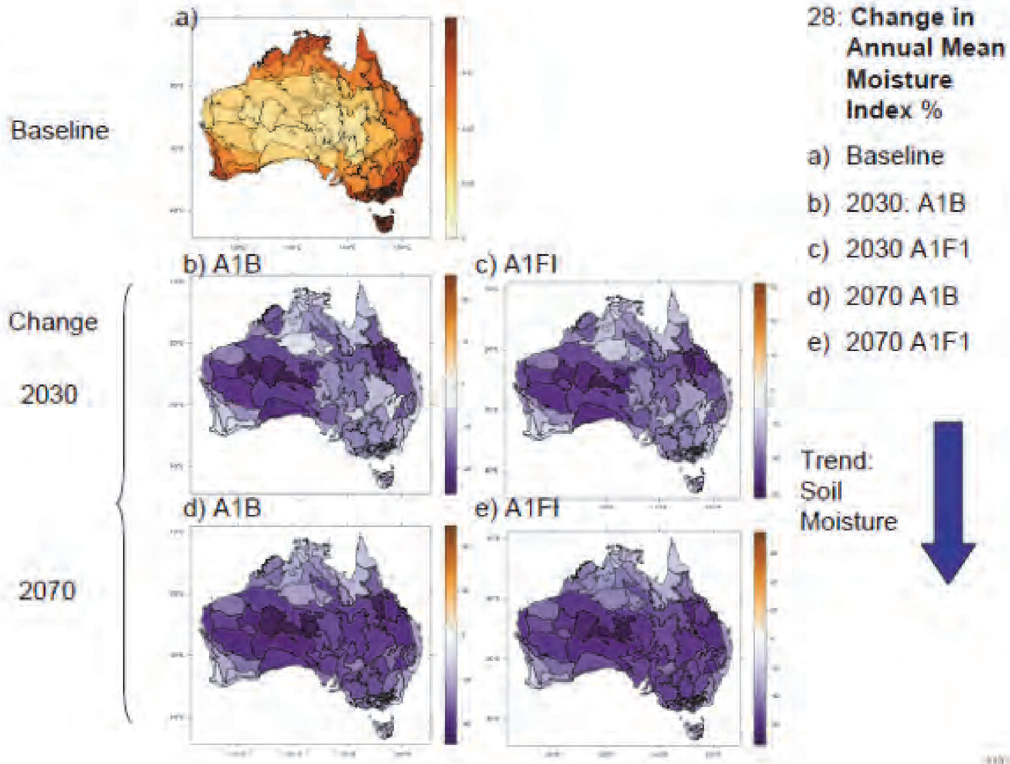
c) 2030 A1F1

d) 2070 A1B

e) 2070 A1F1

Trend: Soil Moisture

112



28: **Change in Annual Mean Moisture Index** %

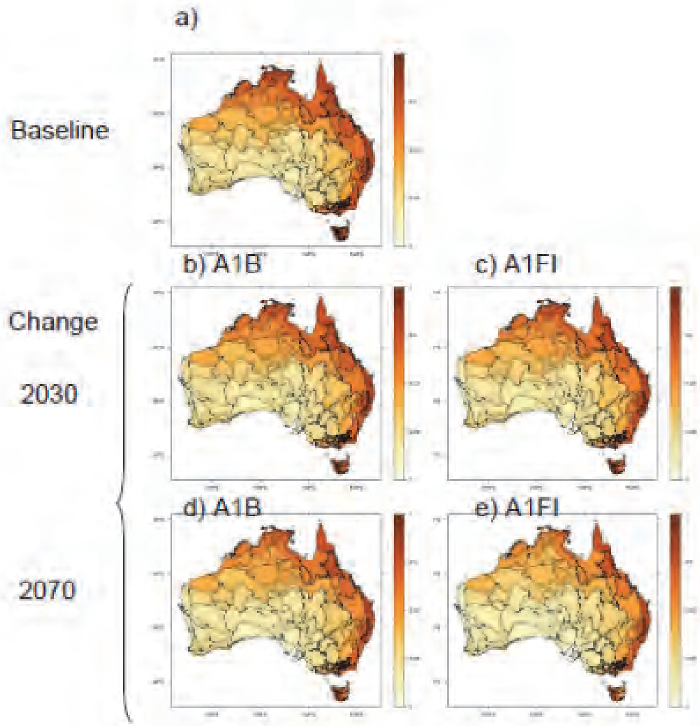
a) Baseline

b) 2030: A1B

c) 2030 A1F1

d) 2070 A1B

e) 2070 A1F1



34: **Mean Moisture Index Warmest quarter** [0,1]

a) Baseline

b) 2030: A1B

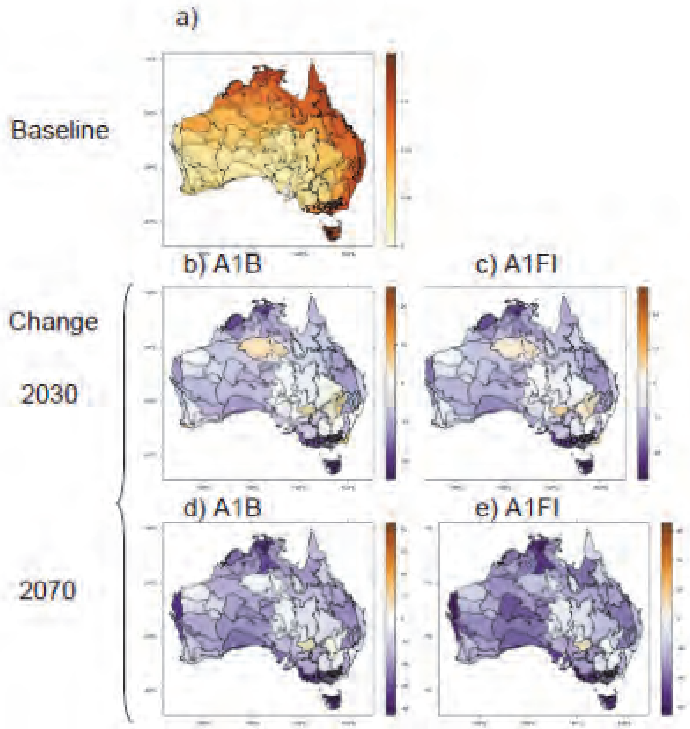
c) 2030 A1F1

d) 2070 A1B

e) 2070 A1F1

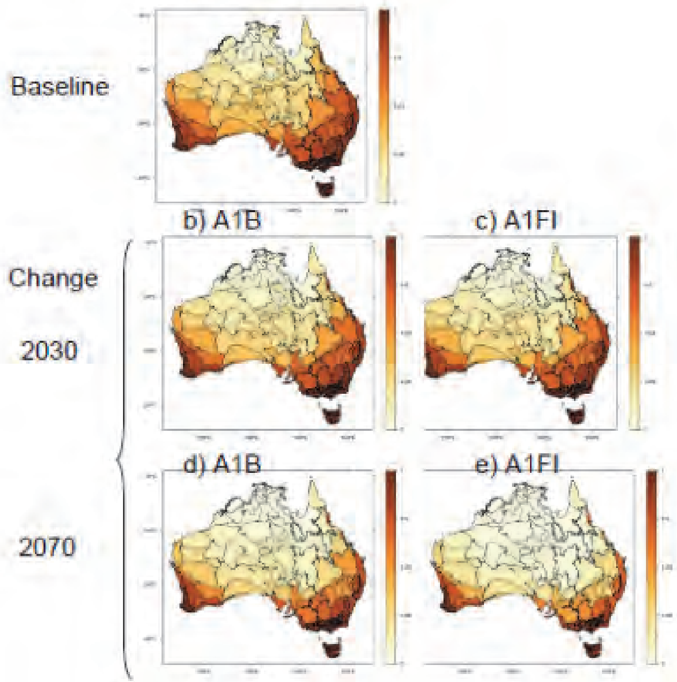
Trend: Soil Moisture

114



34: **Change in Mean Moisture Index Warmest Quarter %**

a) Baseline
b) 2030: A1B
c) 2030 A1F1
d) 2070 A1B
e) 2070 A1F1



35: **Mean Moisture Index Coldest quarter** [0,1]

a) Baseline

b) 2030: A1B

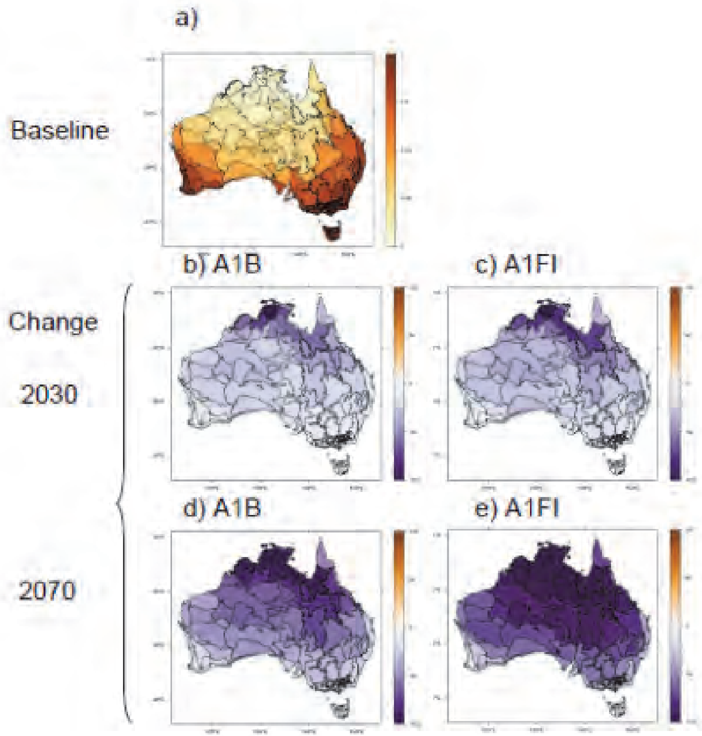
c) 2030 A1F1

d) 2070 A1B

e) 2070 A1F1

Trend: Soil Moisture

116



35: **Change in Mean Moisture Index Coldest Quarter %**

a) Baseline

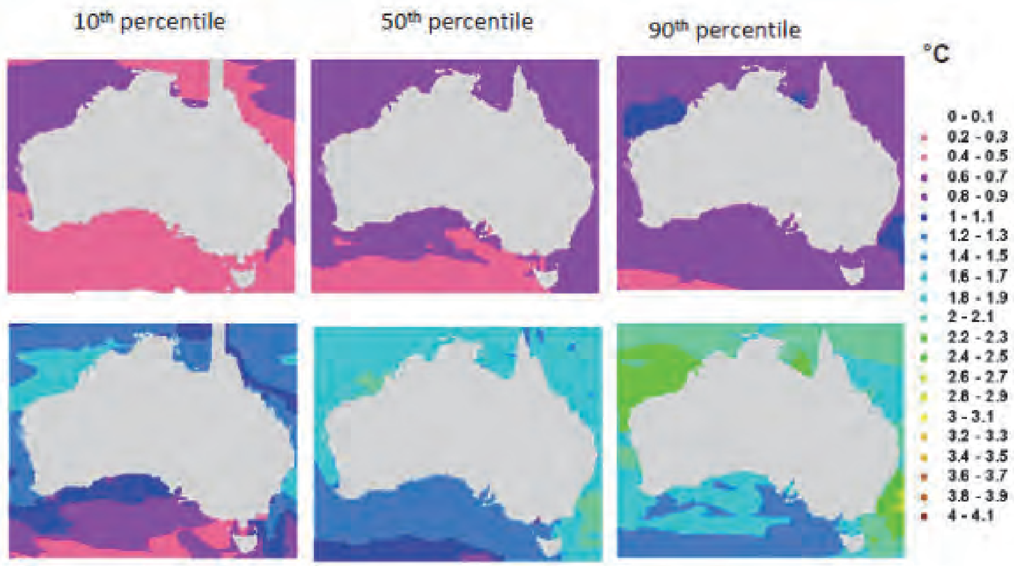
b) 2030: A1B

c) 2030 A1F1

d) 2070 A1B

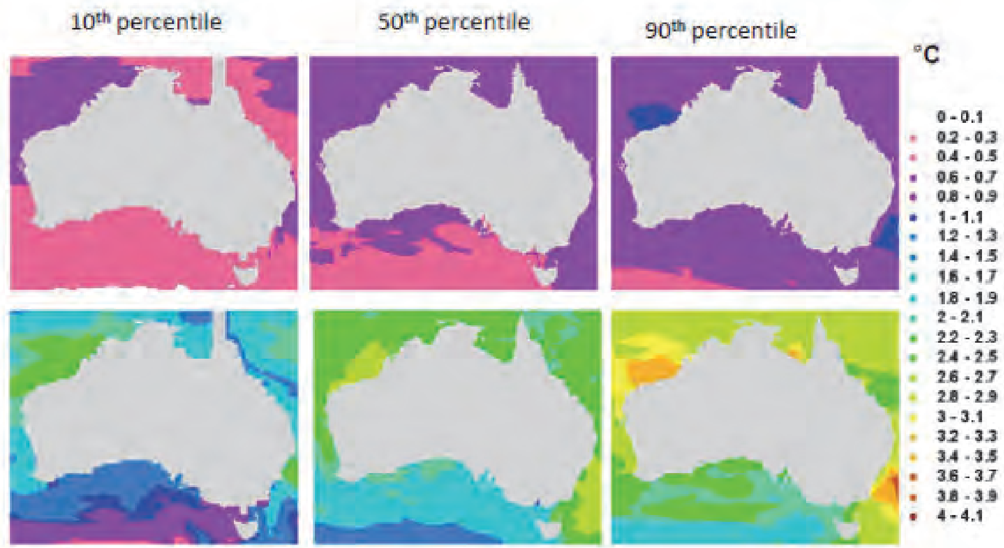
e) 2070 A1F1

APPENDIX 4 – Change in sea surface temperature and salinity between baseline and the future scenarios.

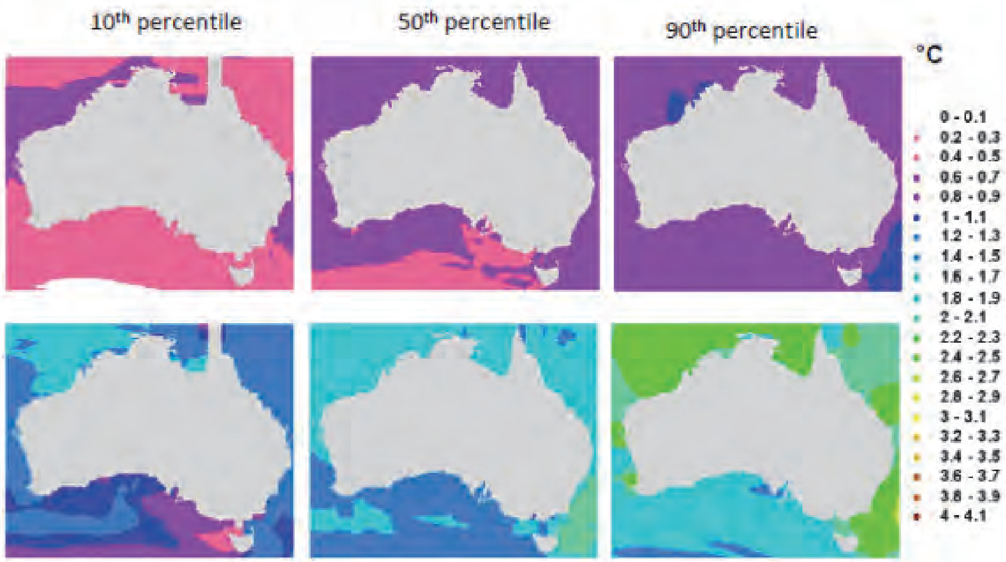


Spring Sea Surface Temperature warming (°C) from 1990 baseline under scenario A1B by 2030 (top row) and 2070 (bottom row)

119

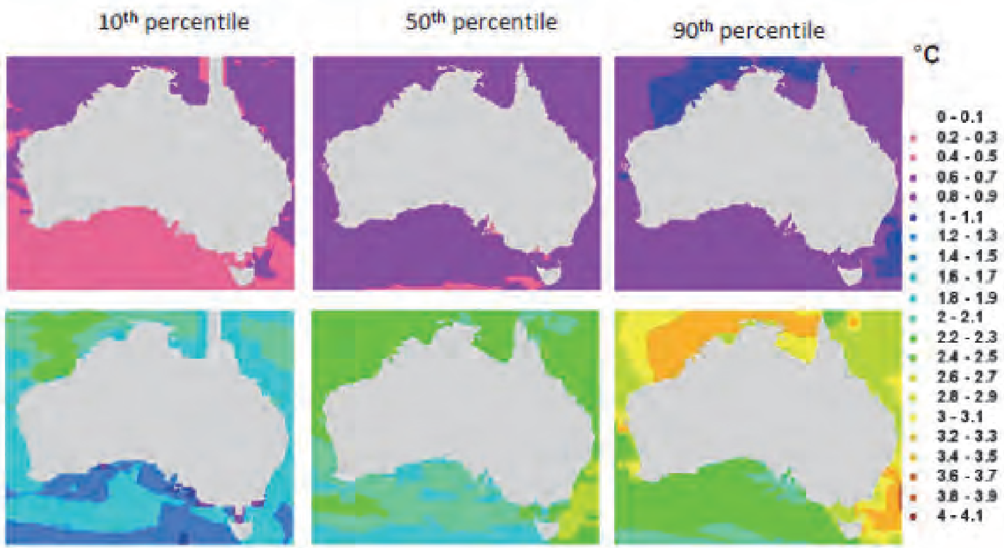


Spring Sea Surface Temperature warming (°C) from 1990 baseline under scenario A1FI by 2030 (top row) and 2070 (bottom row)

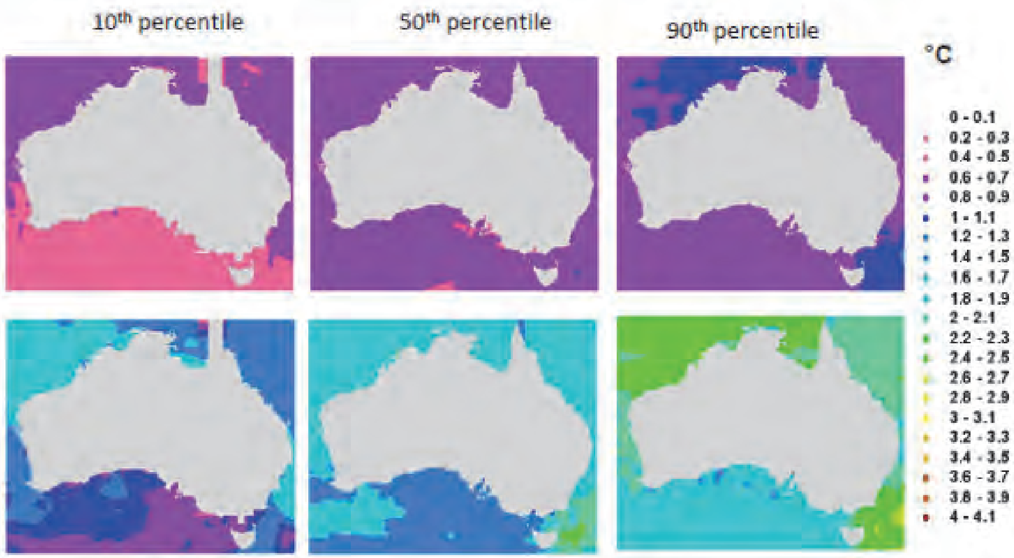


Summer Sea Surface Temperature warming (°C) from 1990 baseline under scenario A1B by 2030 (top row) and 2070 (bottom row)

121

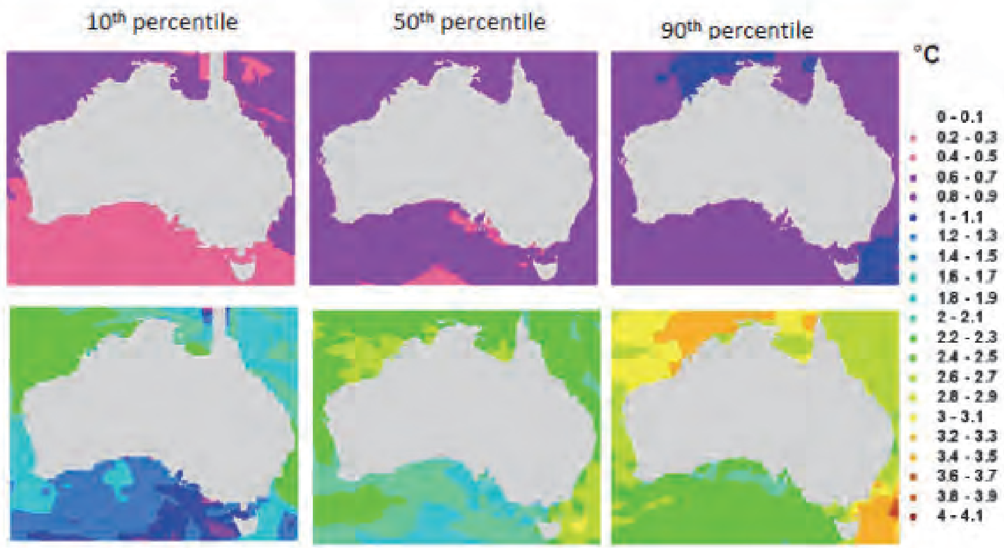


Summer Sea Surface Temperature warming (°C) from 1990 baseline under scenario A1FI by 2030 (top row) and 2070 (bottom row)

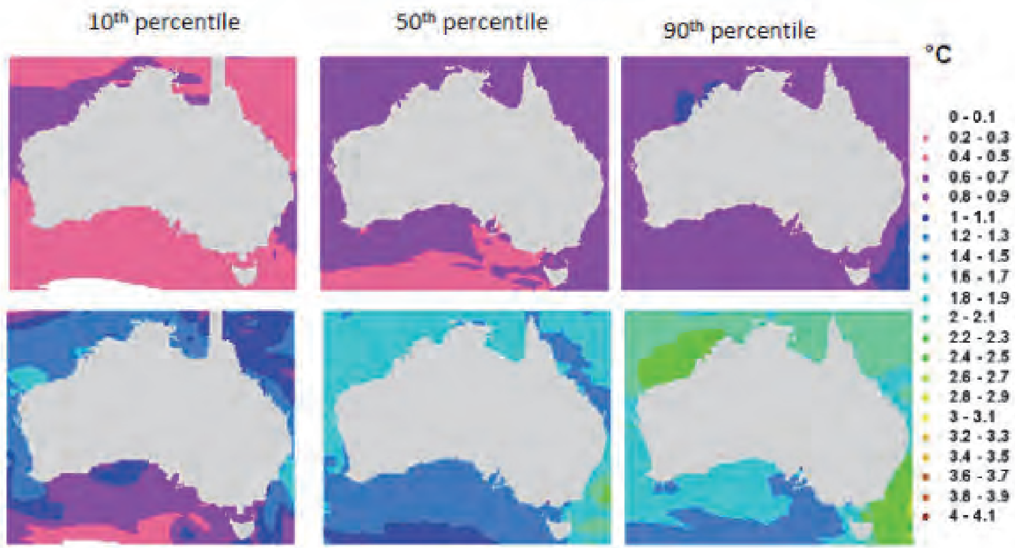


Autumn Sea Surface Temperature warming (°C) from 1990 baseline under scenario A1B by 2030 (top row) and 2070 (bottom row)

[123]

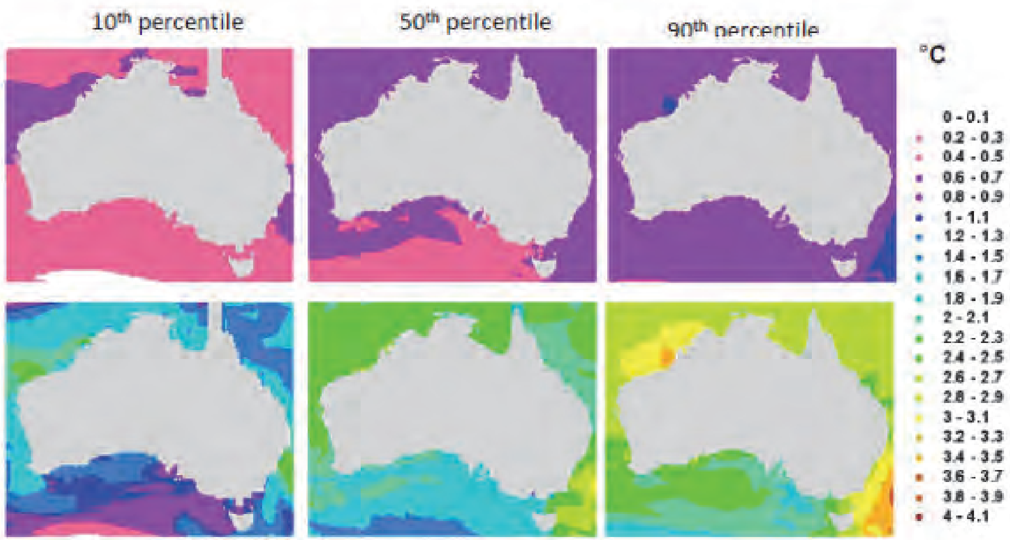


Autumn Sea Surface Temperature warming (°C) from 1990 baseline under scenario A1FI by 2030 (top row) and 2070 (bottom row)



Winter Sea Surface Temperature warming (°C) from 1990 baseline under scenario A1B by 2030 (top row) and 2070 (bottom row)

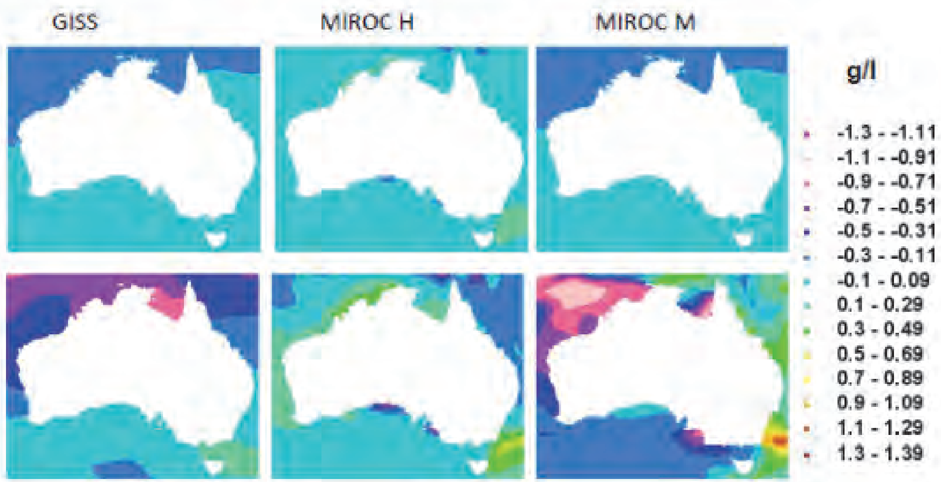
125



Winter Sea Surface Temperature warming (°C) from 1990 baseline under scenario A1FI by 2030 (top row) and 2070 (bottom row)

Change in mean summer Sea Surface Salinity (g/l) from 1990 baseline under scenario A1B by 2030 (top row) and 2070 (bottom row) projected by three GCMs

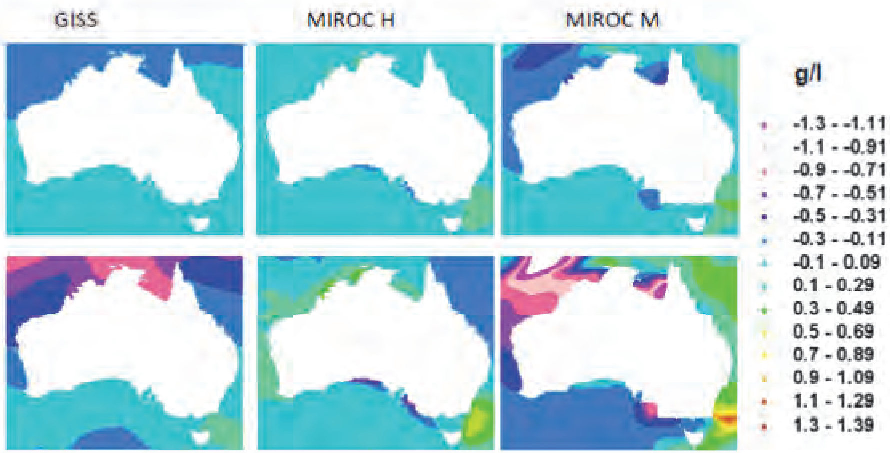
127



Change in mean summer Sea Surface Salinity (g/l) from 1990 baseline under scenario A1FI by 2030 (top row) and 2070 (bottom row) projected by three GCMs

Change in mean winter Sea Surface Salinity (g/l) from 1990 baseline under scenario A1B by 2030 (top row) and 2070 (bottom row) projected by three GCMs

129



Change in mean winter Sea Surface Salinity (g/l) from 1990 baseline under scenario A1FI by 2030 (top row) and 2070 (bottom row) projected by three GCMs

APPENDIX 5 – Drivers, mechanisms and potential consequences of climate change for key components in Australian coastal ecosystems.

Drivers, mechanisms and potential consequences of climate change on key components and processes of coral reef ecosystems

KEY COMPONENT	DRIVER	MECHANISM	CONSEQUENCE
Corals	Temperature	increased ocean temperature	coral bleaching - loss of coral cover, loss of species diversity
			increased disease
			Increased coral growth rates
			Increased benthic algal growth rates
T	emperature	Increase in stratification	decrease nutrient availability, change in coral-algal interactions
	Sea level rise	Reduction in light penetrating to depth of coral	Reduced coral survival and growth rates
			Reduced species diversity
			Changed species diversity
	Sea level rise	more habitat for colonisation	Broader distribution of corals
	Ocean currents (NW)	slight decrease in intensity of Leewin current	Reduced connectivity
			Changes in species diversity/survival/distribution
	Ocean currents (NE)	Significant increase in intensity of EAC	Increased connectivity
			Increased long distance dispersal
			Changes in species diversity or distribution
	Ocean currents (N)	Change in intensity	Changes in connectivity
	Increased dissolved CO2	decreased aragonite saturation state	Decreased growth rates
			Dissolution of coral skeletons
			Decreased recruitment
	Increase in climate variability	Increased severity of cyclones	Increased mechanical damage and mortality
		Increased wave energy	Increased mechanical damage and mortality
		Decreased wave energy	Increase in coral bleaching

KEY COMPONENT	DRIVER	MECHANISM	CONSEQUENCE
	Change in intensity and frequency of extreme rainfall events	increased turbidity, following extreme rainfall events	Decreased growth, increased mortality
		decreased salinity following extreme rainfall events	Coral bleaching and mortality
		Changes in nutrients and pollutants following extreme rainfall events	Decreased resilience (decreased health, growth)
			Change in competitive interactions with algae
	increased incidence and duration of drought	reduced turbidity and sediment delivery to reef	increased coral growth
		reduced nutrients and pollutants	reduced algal growth
			improved coral condition
Macroalgae	Temperature	Increased ocean temperature	Change in competitive interactions
			Physiological stress (decreased health, growth, increased mortality)
			Increased disease
			Increased growth rates of some species
	Altered ocean currents	Southward extension of EAC	Physiological stress (decreased health, growth, increased mortality)
			Increased predation by Centrostephanus rodgersii
			Increased diversity and distribution of species at southern range
	Change in climate patterns	Increased wave energy	Change in community composition; loss of spp
	Change in extreme rainfall events	increased turbidity	Reduction in primary productivity; mortality
		decreased salinity	increased mortality
			increased disease

KEY COMPONENT	DRIVER	MECHANISM	CONSEQUENCE
		Changes in nutrients and pollutants	increased mortality
			increased disease
	Sea level rise	reduced light penetration	reduced growth rates
			reduced survivorship
			changes in species composition of community at depth
		increased habitat available for colonisation	increased distribution of some species
coralline algae	temperature	increase ocean temperature	increased growth rates, to a point
		increase in extreme temperature events	decreased growth rate and increased mortality from bleaching
	sea level rise	reduced light penetration	"drowning", significant loss of species and abundances
	increased dissolved CO_2	decreased aragonite saturation state	decreased deposition of aragonite -> decreased growth rates
			likely loss of species in the long term
fishes	temperature	increased ocean temperature	increased metabolism -> increased cost of living
			increased growth rates
water	quality	increased nutrients and fresh water from terrestrial runoff from extreme rainfall	temporary reduction of biomass and abundance
	prey	high prey availability due to high productivity	increase biomass and abundance
		temporary loss of resources following high flow/storm events	temporary loss of biomass and abundance
	mechanical damage to reef from extreme events	increased breakage of corals - increased habitat heterogeneity	decreased coral cover ->decreased structural complexity
			decreased structural complexity-> decreased recruitment and habitat
			increased structural complexity - change in species recruitment success
food	resources	temporary loss of resources following high flow/storm events	reduce productivity
		increased availability owing to increased increase	productivity

KEY COMPONENT	DRIVER	MECHANISM	CONSEQUENCE
		production and decomposition rates	
		possible loss of resources due to pH impacts on crustaceans etc	change in diet, loss of biomass, changes in energy flows

Drivers, mechanisms and potential consequences of climate change on key components and processes of ecosystems dominated by macroalgae.

KEY COMPONENT	DRIVER	MECHANISM	CONSEQUENCE
Macroalgae	temperature	increased ocean temperature	increased growth rates
			increased physiological stress
			change in species composition and biomass - consequence of competition and growth
		changes in abundance of predators	death of macroalgae, deforestation and shift towards turf algae
	sea level rise	increased depth of habitats	"drowning"
		reduced light regime for deeper species	
nutrient	s	increased nutrients and freshwater from terrestrial runoff from extreme rainfall	death of macroalgae, change competitive interactions among species
			medium term recovery may be stimulated by nutrients
	extreme weather events	mechanical damage during storms	remove canopy allowing colonisation of turf algae
	altered ocean currents	strengthening of EAC (East Australian Current)	increase in consumer (urchin)
			change in species composition driven by changes in dispersal and recruitment processes
urchins	temperature	increased ocean temperature	changes in competitive interactions, reduced food if deforestation occurs
	altered ocean currents	strengthening of EAC (East Australian Current)	range expansion, increased predation on kelp
crustaceans	increased dissolved CO2	pH implications for crustaceans - potential loss of crustacean taxa	change in community assemblage
			change in food web structure and energy flows
fishes	temperature	increased ocean temperature	increased metabolism -> increased cost of living
			increased growth rates
	water quality	increased nutrients and fresh water from terrestrial	temporary reduction of biomass and abundance

KEY COMPONENT	DRIVER	MECHANISM	CONSEQUENCE
		runoff from extreme rainfall	
	prey	high prey availability due to high productivity	increase biomass and abundance
		temporary loss of resources following high flow/storm events	temporary loss of biomass and abundance
food	resources	temporary loss of resources following high flow/storm events redu	ce productivity
		increased availability owing to increased production and decomposition rates	increase productivity
		possible loss of resources due to pH impacts on crustaceans etc	change in diet, loss of biomass, changes in energy flows

Drivers, mechanisms and potential consequences of climate change on key components and processes of ecosystems dominated by mangroves.

KEY COMPONENT	DRIVER	MECHANISM	CONSEQUENCE
mangroves	nutrients	pulses during storm events	stimulate productivity
		reduced inputs during periods of low river flows	reduce productivity
		rates of denitrification and decomposition to increase, with temperature increases	changes in nutrient deposition and transport
	light	high light during extended dry spells	increased productivity
	available substrate	sea level rise	change in available substrate - loss of old areas
			facilitate landward migration of mangroves - new areas inundated
		wave action and scour during storms	change in available substrate - new areas inundated
			loss of available substrate
	temperat ure	increased air and water temperatures	increased productivity, due to increased metabolism and growth rates
			facilitate southern migration of mangroves
epiphytes	nutrients	pulses during storm events	increased productivity
		reduced inputs during periods of low river flows	reduced productivity - nutrient limitation
		rates of denitrification and decomposition to increase, with temperature increases	DO consumption
	light	pulses of highly turbid water after storm events	temporary reduced light penetration and reduced productivity
		high light during extended dry spells	increased productivity
	available substrate	smothered epiphytes and pneumatophores following storm events	loss of standing stocks
			reduced available habitat for colonisation
	temperat ure	increased air and water temperatures	increased productivity, due to increased metabolism and growth rates
	tides	sea level rise	inundate previously dry areas - vertical migration of

KEY COMPONENT	DRIVER	MECHANISM	CONSEQUENCE
			epiphytes
			loss of epiphytes near the sediment due to light reduction
benthic fauna	temperat ure increa	sed water temperature	increased metabolism (and growth) due to increased temperature
		increased incidence of extreme temperatures	exceed thermal tolerance for some species - loss of biomass and diversity
oxygen		high rates of decomposition (linked to higher temperatures) - oxygen depletion	oxygen sags
		increased epiphytic algal production - oxygen increase	increased oxygen availability in benthos
		diel sag in oxygen concentrations - algal production versus decomposition oxygen	sags
	food resource s	increased resources from high production and decomposition rates (coupled with temperature increases) stimulate	productivity
		temporary loss of resources following high flow/storm events	reduce productivity
fish	increase d dissolved CO_2	pH implications for crustaceans - potential loss of crustacean taxa	change in community assemblage
			change in food web structure and energy flows
	temperat ure increa	sed water temperatures	increased metabolism (and growth) due to increased temperature
		increased incidence of extreme temperatures	exceedence of thermal tolerance for some species - loss of biomass and diversity
	food resource s	temporary loss of resources following high flow/storm events	reduce productivity
		increased availability owing to increased production and	increase productivity

KEY COMPONENT	**DRIVER**	**MECHANISM**	**CONSEQUENCE**
		decomposition rates	
		possible loss of resources due to pH impacts on crustaceans etc	change in diet, loss of biomass, changes in energy flows
birds	habitat availabilit y	sea level rise	increased inundated habitat in some areas
			loss of mangrove habitats in deeper areas
	food resource s	temporary loss of resources following high flow/storm events	reduce productivity
		increased availability owing to increased production and decomposition rates	increase productivity
		possible loss of resources due to pH impacts on crustaceans etc	change in diet, loss of biomass, changes in energy flows
	availabilit y	loss of roosts after extreme events	reduced breeding success
		changed distribution of habitat due to sea level rise	modified breeding success, depending on the spatial and temporal provision of roosts
canopy invertebrates	prey	temporary loss of resources following high flow/storm events	temporarily reduced feeding
		increased availability owing to increased production and decomposition rates	higher productivity
	availabilit y of leaves	loss of leaves after extreme storm events	loss of standing stock and breeding success

Drivers, mechanisms and potential consequences of climate change on key components and processes of ecosystems dominated by saltmarsh.

KEY COMPONENT	DRIVER	MECHANISM	CONSEQUENCE
herbaceous plants	light	high light due to increased solar radiation	increase productivity
	nutrients	pulses of nutrients following storm events	increase productivity
		reduced nutrient delivery during dry spells	reduce productivity
	temperature	increased air and water temperatures increa	se productivity
		increased bacterial processing of organic matter	increase productivity
			possible oxygen depletion
	available substrate	sea level rise	change in available substrate - loss of old areas
			facilitate landward migration of saltmarsh - new areas inundated
			competition with mangroves (where they co-exist) for new habitats
	wave action and scour during storms	change in available substrate - new areas inundated	opportunities for local changes in distribution
		loss of available substrate	local loss of saltmarsh communities
	water quality	reduced water quality following storm events	reduced productivity
		improved water quality during dry spells	increased productivity
	sedimentation	high sediment loads during storm events	reduced productivity
		increased sediment retention during dry spells	increased productivity
benthic fauna	temperature	increased water temperature	increased metabolism (and growth) due to increased temperature
		increased incidence of extreme temperatures	exceedence of thermal tolerance for some species - loss of biomass and diversity
oxygen		high rates of decomposition (linked to higher temperatures) - oxygen depletion	oxygen sags

KEY COMPONENT	DRIVER	MECHANISM	CONSEQUENCE
		increased epiphytic algal production - oxygen increase	increased oxygen availability in benthos
		diel sag in oxygen concentrations - algal production versus decomposition oxygen	sags
	increased dissolved CO_2	pH implications for crustaceans - potential loss of crustacean taxa	change in community assemblage
			change in food web structure and energy flows
	water quality	water quality declines follow storm events	reduced abundance and biomass
		changes in pH affecting calcium deposition	change in community composition
	sedimentation	deposition following storm events	reduced abundance and biomass
fish temperature		increased water temperature	increased metabolism (and growth) due to increased temperature
		increased incidence of extreme temperatures	Exceed thermal tolerance for some species - loss of biomass and diversity
food	resources	increased resources from high production and decomposition rates (coupled with temperature increases) stimulate	productivity
		temporary loss of resources following high flow/storm events	reduce productivity
		possible loss of resources due to pH impacts on crustaceans etc	change in diet, loss of biomass, changes in energy flows
	water quality	water quality declines follow storm events	reduce biomass and abundance
birds temperature		increased water temperature	increased metabolism (and growth) due to increased temperature
		increased incidence of extreme temperatures	exceedence of thermal tolerance for some species - loss of biomass and diversity
	food resources	increased food availability due to high productivity	increased abundance and biomass
		possible loss of resources due to pH impacts on crustaceans etc	change in diet, loss of biomass, changes in energy flows
	predators	high productivity may outstrip consumption rates	increased abundance and biomass
	prey	high prey availability due to high productivity	increase biomass and abundance

KEY COMPONENT	DRIVER	MECHANISM	CONSEQUENCE
		temporary loss of resources following high flow/storm events	temporary loss of biomass and abundance
	availability of roosts	loss of roosts after extreme events	loss of biomass and abundance
	prey	temporary loss of resources following high flow/storm events	reduced biomass and abundance
		increased availability owing to increased production and decomposition rates	increased biomass and abundance

Drivers, mechanisms and potential consequences of climate change on key components and processes of ecosystems dominated by seagrasses.

KEY COMPONENT	DRIVER	MECHANISM	CONSEQUENCE
seagrass	light	increased light due to increased solar radiation	increased productivity
		reduced light due to sea level rise	reduced productivity
			changes in community composition
		reduced light following storm events	reduced productivity
	nutrients	pulses following major flow events	stimulate productivity, but depends on light regime
		reduced delivery during dry spells	reduced productivity
	temperature	increased air and water temperatures increa	sed productivity
			changes in community composition
	sedimentation	high deposition following storm events	loss of biomass, abundance and productivity
		reduced deposition during dry spells	increased productivity
salinity		reduced salinity during periods of high freshwater flows	possible exceedence of tolerance limits for some species
		increased salinity during dry spells	possible exceedence of tolerance limits for some species
epiphytes/macroalgae	light	increased light due to increased solar radiation	increased productivity
		reduced light due to sea level rise	reduced productivity
			changes in community composition
		reduced light following storm events	reduced productivity
	nutrients	pulses following major flow events	stimulate productivity, but depends on light regime
		reduced delivery during dry spells	reduced productivity
temperature		increased temperatures increa	sed productivity
			changes in community composition
	sedimentation	high deposition following storm events	loss of biomass, abundance and productivity
		reduced deposition during dry spells	increased productivity
	salinity	reduced salinity during periods of high freshwater	possible exceedence of tolerance limits for some species

KEY COMPONENT	DRIVER	MECHANISM	CONSEQUENCE
		flows	
		increased salinity during dry spells	possible exceedence of tolerance limits for some species
benthic fauna	temperature	increased water temperature	increased metabolism (and growth) due to increased temperature
		increased incidence of extreme temperatures	exceed thermal tolerance for some species - loss of biomass and diversity
oxygen		high rates of decomposition (linked to higher temperatures) - oxygen depletion	oxygen sags
		increased epiphytic algal production - oxygen increase increa	sed oxygen availability in benthos
		diel sag in oxygen concentrations - algal production versus decomposition	oxygen sags
	increased dissolved CO2	pH implications for crustaceans - potential loss of crustacean taxa	change in community assemblage
			change in food web structure and energy flows
food	resources	increased resources from high production and decomposition rates (coupled with temperature increases) stimulate	productivity
		temporary loss of resources following high flow/storm events	reduce productivity
		possible loss of resources due to pH impacts on crustaceans etc	change in diet, loss of biomass, changes in energy flows
fish temperature		increased water temperatures	increased metabolism (and growth) due to increased temperature
		increased incidence of extreme temperatures	exceedence of thermal tolerance for some species - loss of biomass and diversity
food	resources	temporary loss of resources following high flow/storm events	reduce productivity
		increased availability owing to increased production	increase productivity

KEY COMPONENT	DRIVER	MECHANISM	CONSEQUENCE
		and decomposition rates	
		possible loss of resources due to pH impacts on crustaceans etc	change in diet, loss of biomass, changes in energy flows
	habitat availability	sea level rise	potential loss of seagrass habitat in some areas, with implications for fish
			local loss of species diversity

Drivers, mechanisms and potential consequences of climate change on key components and processes of ecosystems dominated by tidal flats.

KEY COMPONENT	DRIVER	MECHANISM	CONSEQUENCE
microphytobenthos /benthic microalgae	nutrients	pulses during storm events	increased productivity
		reduced inputs during periods of low river flows	reduced productivity - nutrient limitation
		rates of denitrification and decomposition to increase, with temperature increases	DO consumption
	light	pulses of highly turbid water after storm events	temporary reduced light penetration and reduced productivity
		high light during extended dry spells	increased productivity
sedim	entation	smothering following storm events	loss of biomass and productivity
temperature		increased temperatures increa	sed productivity
			changes in community composition
	tides	sea level rise	inundate previously dry areas - increase in available substrate
			possible loss of biomass and abundance in deeper areas
salinity		reduced salinity during periods of high freshwater flows	possible exceedence of tolerance limits for some species
		increased salinity during dry spells	possible exceedence of tolerance limits for some species
benthic fauna	temperature	increased water temperature	increased metabolism (and growth) due to increased temperature
		increased incidence of extreme temperatures	exceedence of thermal tolerance for some species - loss of biomass and diversity
oxygen		high rates of decomposition (linked to higher temperatures) - oxygen depletion	oxygen sags
		increased epiphytic algal production - oxygen increase increa	sed oxygen availability in benthos
		diel sag in oxygen concentrations - algal production versus decomposition	oxygen sags

KEY COMPONENT	DRIVER	MECHANISM	CONSEQUENCE
food	resources	increased resources from high production and decomposition rates (coupled with temperature increases) stimulate	productivity
		temporary loss of resources following high flow/storm events	reduce productivity
		possible loss of resources due to pH impacts on crustaceans etc	change in diet, loss of biomass, changes in energy flows
	increased dissolved CO2	pH implications for crustaceans - potential loss of crustacean taxa	change in community assemblage
fish temperature		increased water temperature	increased metabolism (and growth) due to increased temperature
		increased incidence of extreme temperatures	exceedence of thermal tolerance for some species - loss of biomass and diversity
food	resources	temporary loss of resources following high flow/storm events	reduce productivity
		increased availability owing to increased production and decomposition rates	increase productivity
		possible loss of resources due to pH impacts on crustaceans etc	change in diet, loss of biomass, changes in energy flows
birds	temperature	increased air and water temperatures	increased metabolism (and growth) due to increased temperature
		increased incidence of extreme temperatures	exceedence of thermal tolerance for some species - loss of biomass and diversity
food	resources	temporary loss of resources following high flow/storm events	reduced biomass and abundance
		increased availability owing to increased production and decomposition rates	increased biomass and abundance
		possible loss of resources due to pH impacts on crustaceans	change in diet, loss of biomass, changes in energy flows

Drivers, mechanisms and potential consequences of climate change on key components and processes of sandy beach ecosystems.

KEY COMPONENT	DRIVER	MECHANISM	CONSEQUENCE
meiofauna (bacteria, plankton etc.) light		increased turbidity through increased wave action from increased storms, floods etc.	loss of productivity
temperature		increased temperature increa	sed productivity
nutrient	s	increased nutrients due to increased flooding/ intense high flows	increased productivity
			shift in composition/ diversity loss/ homogenisation
	extreme weather events increa	sed frequency of extreme events	reduction of habitat & frequency & duration of recovery periods
		changed wind direction due to changed patterns of ocean circulation and weather patterns	range shifts
crustaceans	increased dissolved CO_2	increased acidity due to ocean acidification	population reductions due to pH effects on growth and prey, loss of biodiversity
			changes in community composition
			changes in food web structure and flows of energy
	temperature	increased sand & water temperature	increased productivity for some species
			increased physiological stress - possible loss of biomass, abundance and diversity
	extreme weather events increa	sed frequency of extreme events	reduction of habitat & frequency & duration of recovery periods
		changed wind direction due to changed patterns of ocean circulation and weather patterns	range shifts
habitat	availability	loss of habitat area due to sea level rise and increased frequency of extreme events	reduced populations, biodiversity loss
		shift in distribution (& local increase) of habitat due to sediment deposition	range shifts, local population increase
reptiles (turtles, sea temperature		increased temperature	changed sex ratios (turtles, crocs)

KEY COMPONENT	DRIVER	MECHANISM	CONSEQUENCE
snakes,crocodiles)			
			changed metabolisms - range shifts
			exceedance of thermal tolerance - death
		increased temperature leading to shift in seasons	change in cues, timing of breeding, food availability etc.
		increased temperature & humidity	disease from pathogens
rainfall		increased rainfall (e.g. northern Australia) moistens sand	reduces legal fungi, population increase
		increased rainfall makes sand easier to dig	increased breeding
	habitat availability	loss of habitat area due to sea level rise	reduced breeding
		increase of habitat availability to sea level rise (e.g. centre of islands)	increased breeding (dependent on island character)
food	resources	temporary loss of resources following high flow/storm events	reduce productivity
		increased availability owing to increased production and decomposition rates	increase productivity
		possible loss of resources due to pH impacts on crustaceans etc	change in diet, loss of biomass, changes in energy flows
birds (including migratory shorebirds) temperature		increased sand temperature	reduced egg viability and hatching success
		increased temperature leading to shift in seasons	change in cues for breeding events & migration
	rainfall	increased rainfall in northern Australia	flood nests, reduced breeding, populations
			decreased flooding of nests, increased breeding success
	habitat availability	loss of habitat area due to sea level rise	reduced breeding & food availability,
		increase of habitat availability to sea level rise (e.g. centre of islands)	increased food availability (crustaceans!)
food	availability	changed ocean circulation leading to altered upwelling and productivity etc.	reduced population abundance

KEY COMPONENT	DRIVER	MECHANISM	CONSEQUENCE
		temporary loss of resources following high flow/storm events	reduce productivity
		increased availability owing to increased production and decomposition rates	increase productivity
		possible loss of resources due to pH impacts on crustaceans etc	change in diet, loss of biomass, changes in energy flows
fish and marine mammals (sharks, dolphins, rays) temperature		increased temperature	increased growth rate, increased mortality, reduced activity
		increased ocean temperatures	range shifts, altered migratory patterns
runoff		increased runoff as a result of increased rainfall either via increased extreme events or increased annual rainfall in northern Australia	increased numbers and diversity due to increased food availability
			loss of biodiversity and numbers due to declining water quality
food	resources	temporary loss of resources following high flow/storm events	reduce productivity
		increased availability owing to increased production and decomposition rates	increase productivity
		possible loss of resources due to pH impacts on crustaceans etc	change in diet, loss of biomass, changes in energy flows
burrow nesters	rainfall	increased rainfall leading to erosion of nesting habitat & dune	loss of beach breeding habitat & access to dune habitat
	extreme weather events	increased frequency of storm surges leading to changed beach topography	reduced access to breeding habitat
mammals (kangaroos, dingo, sea lions)	temperature	increased temperature leading to shift in seasons	change in cues for breeding events & migration

KEY COMPONENT	DRIVER	MECHANISM	CONSEQUENCE
		increased rainfall in northern Australia	Increased breeding, change populations & predator/prey/herbivory interactions
	rainfall	Decreased rainfall	Decreased breeding success, decline in populations,
		loss of habitat area due to sea level rise	reduced breeding & food availability,
	habitat availability	Altered vegetation structure and composition	Altered food availability and quality, changed population structure
food	availability	temporary loss of resources following high flow/storm events	reduce productivity
		increased availability owing to increased production and decomposition rates	increase productivity
		possible loss of resources due to pH impacts on crustaceans etc	change in diet, loss of biomass, changes in energy flows
vegetation community	temperature	increased air temperatures	increased biomass and productivity (for some species)
		increased incidence of extreme temperature events	exceedance of thermal tolerances, mortality etc.
		changed seasonality in temperature fluctuations	changes to phenology, cues etc.
		increased air temperature - increased fire risk	altered community composition - reduction of buffering capacity for hinddunes etc.
			increased abundance of invasive (weed) species
			mortality, changed soil structure & erosion - substrate available for colonisation etc., altered communities
	rainfall	reduced rainfall	reduced biomass, biodiversity loss, range shifts
		increased rainfall	increased biomass, shift in composition, range shifts, phenology
		extreme events	loss of substrate, mortality
		reduced groundwater quantity & quality	reduced biomass, biodiversity loss, shift in composition - loss of groundwater dependent ecosystems

KEY COMPONENT	DRIVER	MECHANISM	CONSEQUENCE
	increased atmospheric CO2	CO2 fertlisation	increased biomass, shifts in composition towards woody, shrubby species, grasses, invasives

Drivers, mechanisms and potential consequences of climate change on key components and processes of dune ecosystems.

KEY COMPONENT	DRIVER	MECHANISM	CONSEQUENCE
vegetation community	temperature	increased air temperatures	increased biomass and productivity (for some species)
		increased incidence of extreme temperature events	exceedance of thermal tolerances, mortality etc.
		changed seasonality in temperature fluctuations	changes to phenology, cues etc.
		increased air temperature - increased fire risk	altered community composition - reduction of buffering capacity for hinddunes etc.
			increased abundance of invasive (weed) species
			mortality, changed soil structure & erosion - substrate available for colonisation etc., altered communities
	rainfall	reduced rainfall	reduced biomass, biodiversity loss, range shifts
		increased rainfall	increased biomass, shift in composition, range shifts, phenology
		extreme events	loss of substrate, mortality
		reduced groundwater quantity & quality	reduced biomass, biodiversity loss, shift in composition - loss of groundwater dependent ecosystems
	increased atmospheric CO2 CO2	fertlisation	increased biomass, shifts in composition towards woody, shrubby species, grasses, invasives
crustaceans	temperature	increased air and sand temperatures	altered metabolism and activity - some species will grow faster, others will have their tolerances exceeded
			change in community composition
	habitat availability	loss of habitat area due to sea level rise and increased frequency of extreme events	reduced populations, biodiversity loss
		shift in distribution (& local increase) of habitat due to deposition	range shifts, local population increase

KEY COMPONENT	DRIVER	MECHANISM	CONSEQUENCE
reptiles (turtles, sea snakes,crocodiles)	temperature	increased temperature	changed sex ratios (turtles, crocs)
			changed metabolisms - range shifts
		increased incidence of extreme temperature events	exceedance of thermal tolerance - death
		increased temperature leading to shift in seasons	change in cues, timing of breeding, food availability etc.
		increased temperature & humidity	disease from pathogens
rainfall		increased rainfall (e.g. northern Australia) moistens sand	reduces lethal fungi, population increase
		increased rainfall makes sand easier to dig	increased reproductive success
		reduced rainfall (southern Australia)	reduced resource availability
	habitat availability	loss of habitat area due to sea level rise	reduced breeding
		increase of habitat availability to sea level rise (e.g. centre of islands)	increased breeding (dependent on local character)
birds (mainly seabirds)	temperature	increased air and sand temperatures	reduced egg viability and hatching success
		increased temperature leading to shift in seasons	change in cues for breeding events & migration
		increased incidence of extreme temperature events	mortality due to heat stress
	rainfall	increased rainfall in northern Australia	flood nests, reduced breeding, populations
			decreased flooding of nests, increased breeding success
		reduced rainfall in southern Australia	reduced resource availability
	habitat availability	loss of habitat area due to sea level rise	reduced reproductive success & food availability
			loss of roost availability
		increase of habitat availability to sea level rise (e.g. centre of islands)	possible increase in local food availability
		changed habitat structure due to altered rainfall & temperature	biodiversity loss & range shifts
	food availability	changed ocean circulation leading to altered	reduced population abundance

KEY COMPONENT	DRIVER	MECHANISM	CONSEQUENCE
		upwelling and productivity etc.	
		changed ocean temperature and stratification, ENSO	reduced numbers, biodiversity, range shifts
		changed species composition owing to ocean acidification	reduced availability of sensitive taxa (especially crustaceans)
fire		increased frequency & intensity of fire due to increased temp and reduced rainfall etc.	loss of habitat, mortality, reduced productivity
	extreme weather events	increased frequency & intensity of extreme events	mortality & breeding success
mammals		*See sandy beaches*	

Drivers, mechanisms and potential consequences of climate change on key components and processes of rocky shore and headland ecosystems.

KEY COMPONENT	DRIVER	MECHANISM	CONSEQUENCE
headland vegetation	temperature	increased air temperatures	increased biomass and productivity (for some species)
		increased incidence of extreme temperature events	exceedance of thermal tolerances, mortality etc.
		changed seasonality in temperature fluctuations	changes to phenology, cues etc.
		increased air temperature - increased fire risk	altered community composition - reduction of buffering capacity for hinddunes etc.
			increased abundance of invasive (weed) species
			mortality, changed soil structure & erosion - substrate available for colonisation etc., altered communities
	rainfall	reduced rainfall	reduced biomass, biodiversity loss, range shifts
		increased rainfall	increased biomass, shift in composition, range shifts, phenology
		extreme events	loss of substrate, mortality
		reduced groundwater quantity & quality	reduced biomass, biodiversity loss, shift in composition - loss of groundwater dependent ecosystems
	increased atmospheric CO2 CO2	fertlisation	increased biomass, shifts in composition towards woody, shrubby species, grasses, invasives
wave	action	increased erosion due to increased storm intensity	loss of plant community
		loss of vegetation cover from intense wind and salt	change in the composition of the plant community
rock pool algae	temperature	increased air and water temperatures	increased metabolism (and growth) due to increased temperature
		increased incidence of extreme temperatures	exceedence of thermal tolerance for some species - loss of biomass and diversity
	increase	decreased aragonite saturation state	reduced abundance and diversity of sensitive taxa (like coralline

KEY COMPONENT	DRIVER	MECHANISM	CONSEQUENCE
	dissolved CO_2		algae)
			change in species composition and structure of rock pool food webs
	sea level rise	inundate previously dry areas	colonisation of new substrates and habitats
		increased water depth	loss of deeper algae due to reduced light penetration
	rainfall	reduced rainfall during drought periods	changes in salinity, which may influence species interactions
		increased rainfall associated with storm events	changes in salinity, which may influence species interactions
			increased sediment deposition during storm events - may lead to smothering and local loss of species
wave	action	increased wave action associated with storm events	physical loss of sensitive species
		waves to reach higher due to sea level rise and storm surge	increased exposure of taxa at the edge of high water mark
			mechanism of dispersal and recruitment into new habitat for some species
	nutrients	pulses during storm events	temporary decrease in productivity, but may be followed by a subsequent increase in productivity
	light	pulses of highly turbid water after storm events	temporary reduced light penetration and reduced productivity
		high light during extended dry spells	increased productivity
benthic invertebrates	temperature	increased air and water temperatures	increased metabolism (and growth) due to increased temperature
		increased incidence of extreme temperatures	exceedence of thermal tolerance for some species - loss of biomass and diversity
	sea level rise	inundate previously dry areas	colonisation of new substrates and habitats
	increased dissolved	changes in pH affecting calcium deposition	change in community composition and loss of sensitive taxa (especially crustaceans)

KEY COMPONENT	DRIVER	MECHANISM	CONSEQUENCE
	CO2		
			change in food web structure and energy flows
	rainfall	reduced rainfall during drought periods	changes in salinity, which may influence species interactions
		increased rainfall associated with storm events	changes in salinity, which may influence species interactions
wave	action	increased wave action associated with storm events	physical loss of sensitive taxa
		waves to reach higher due to sea level rise and storm surge	physical loss of sensitive taxa
			mechanism of dispersal and recruitment into new habitat for some species
	sedimentati on	deposition following storm events	reduced abundance and biomass
	food resources	increased food availability due to high productivity	increased abundance and biomass
		possible loss of resources due to pH impacts on crustaceans etc	change in diet, loss of biomass, changes in energy flows
		temporary loss of resources following high flow/storm events	reduce productivity
	predators	high productivity may outstrip consumption rates	increased abundance and biomass
fish temperature		increased water temperatures	increased metabolism (and growth) due to increased temperature
		increased incidence of extreme temperatures	exceedence of thermal tolerance for some species - loss of biomass and diversity
	rainfall	reduced rainfall during drought periods	changes in salinity, which may influence species interactions
		increased rainfall associated with storm events	changes in salinity, nutrients and turbidity, which may influence species interactions
wave	action	increased wave action associated with storm events	stranding of small fish in isolated and exposed rock pools
		waves to reach higher due to sea level rise and storm surge	stranding of small fish in isolated and exposed rock pools

KEY COMPONENT	**DRIVER**	**MECHANISM**	**CONSEQUENCE**
			mechanism of dispersal and recruitment into new habitat for some species
	food resources	temporary loss of resources following high flow/storm events	reduce productivity
		increased availability owing to increased production and decomposition rates	increase productivity
		possible loss of resources due to pH impacts on crustaceans etc	change in diet, loss of biomass, changes in energy flows

Drivers, mechanisms and potential consequences of climate change on key components and processes of freshwater lakes and lagoons.

KEY COMPONENT	DRIVER	MECHANISM	CONSEQUENCE
phytoplankton	nutrients	pulses during storm events	increased productivity, possible composition changes
		reduced inputs during periods of low river flows	reduced productivity - nutrient limitation
		rates of denitrification and decomposition to increase, with temperature increases	DO consumption
	light	pulses of highly turbid water after storm events	temporary reduced light penetration and reduced productivity
		high light during extended dry spells	increased productivity
temperature		increased metabolism (and growth) due to increased temperature	increased productivity
rainfall/flows		reduced water residence time and increased turbulence during high flow/rainfall events	reduced biomass accrual
		increased water residence time during low flow/rainfall periods	increased biomass accrual, with possible composition changes
periphyton/biofilm	nutrient s	pulses during storm events	increased productivity
		reduced inputs during periods of low river flows	reduced productivity - nutrient limitation
		rates of denitrification and decomposition to increase, with temperature increases	DO consumption
	light	pulses of highly turbid water after storm events	temporary reduced light penetration and reduced productivity
		high light during extended dry spells	increased productivity
available	substrate	smothered substrates following storm events	loss of standing stocks
			reduced available habitat for colonisation
		delivery of substrates in storm/flow events	increased available habitat (post event) for colonisation
temperature		increased metabolism (and growth) due to increased temperature	increased productivity
rainfall/flows		reduced water residence time and increased turbulence during high flow/rainfall events	reduced biomass accrual

KEY COMPONENT	DRIVER	MECHANISM	CONSEQUENCE
		increased water residence time during low flow/rainfall periods	increased biomass accrual, with possible composition changes
		increased risk of scour during high flow events	loss of biomass
macrophytes	nutrients	pulses during storm events	increased productivity
		reduced inputs during periods of low river flows	reduced productivity - nutrient limitation
		rates of denitrification and decomposition to increase, with temperature increases	DO consumption
	light	pulses of highly turbid water after storm events	temporary reduced light penetration and reduced productivity
		high light during extended dry spells	increased productivity
available	substrate	macrophytes smothered by sediment during high flow/storm events	loss of standing stocks
			reduced available habitat for colonisation
		additional substrate delivered in high flow events	increased available habitat (post event) for colonisation
temperature		increased metabolism (and growth) due to increased temperature	increased productivity and biomass accrual
rainfall/flows		reduced water residence time and increased turbulence during high flow/rainfall events	reduced biomass accrual
		increased water residence time during low flow/rainfall periods	increased biomass accrual, with possible composition changes
		increased risk of scour during high flow events	loss of biomass
riparian vegetation	nutrients	pulses during storm events from overland flow and flooding stimulate	productivity
		reduced inputs during periods of low river flows	reduce productivity
		rates of denitrification and decomposition to increase, with temperature increases	changes in nutrient deposition and transport
	light	high light during extended dry spells	increased productivity
	bank stability	increased scour during high flow events	change in available substrate - loss of old areas
		slumping following high flow events	change in available substrate - new areas inundated

KEY COMPONENT	DRIVER	MECHANISM	CONSEQUENCE
			loss of available substrate
temperature		increased metabolism (and growth) due to increased temperature	increased productivity
rainfall/flows		reduced water residence time and increased turbulence during high flow/rainfall events	reduced biomass accrual
		increased water residence time during low flow/rainfall periods	increased biomass accrual, with possible composition changes
		increased risk of scour during high flow events	loss of biomass
		low flows will encourage riparian species recruitment in littoral zone	increased biomass and productivity
macroinvertebrates (benthic and pelagic)	nutrients	poor water quality during high flow/storm events	loss of biomass and sensitive taxa
temperature		increased metabolism (and growth) due to increased temperature	increased productivity
	oxygen	poor water quality during high flow/storm events	loss of biomass and sensitive taxa
		poor benthic water quality during extended periods of lake stratification	changes in benthic-pelagic coupling
			loss of sensitive benthic taxa
		poor water quality immediately following breakdown of lake stratification	oxygen sag may lead to loss of biomass and sensitive taxa
rainfall/flows		reduced water residence time and increased turbulence during high flow/rainfall events	loss of biomass of pelagic species e.g. Zooplankton
		increased water residence time during low flow/rainfall periods	stability likely to lead to biomass increases
		increased risk of scour during high flow events	loss of flow-sensitive taxa in pelagic and benthic habitats
		increased variability in rainfall/flow	loss of reproductive cues for some taxa
resource	availability	increased primary productivity	increased macroinvertebrate productivity, unless harmful algal types dominate

KEY COMPONENT	DRIVER	MECHANISM	CONSEQUENCE
		increased variability in available habitats	maintain species diversity (over long time scales) but with losses over short time scales
fish	nutrients	poor water quality during high flow/storm events	loss of biomass, particularly if dissolved oxygen is very low
temperature		increased metabolism (and growth) due to increased temperature	increased productivity
			increased reproductive output and success
	oxygen	poor water quality during high flow/storm events	temporary loss of biomass and species
		poor benthic water quality during extended periods of lake stratification	changes in benthic-pelagic coupling
		poor water quality immediately following breakdown of lake stratification	oxygen sag may lead to loss of biomass and species
rainfall/flows		increased water residence time during low flow/rainfall periods	stability likely to lead to biomass increases
		increased variability in rainfall/flow	loss of reproductive cues for some taxa
resource	availability	increased primary productivity and secondary productivity	increased fish productivity, unless harmful algal types dominate
		variability in food resource response to flow events	variable responses in terms of fish productivity and reproductive success
		increased variability in available habitats	maintain species diversity (over long time scales) but with losses over short time scales
frogs	nutrients	poor water quality during high flow/storm events	loss of biomass and species
temperature		increased metabolism (and growth) due to increased temperature	increased productivity
rainfall/flows		increased water residence time during low flow/rainfall periods	stability likely to lead to biomass increases
		increased risk of scour during high flow events	reduced abundance and potential loss of eggs
		increased variability in rainfall/flow	loss of reproductive cues for some taxa
	resource availability	increased primary productivity	increased abundance and reproductive success

KEY COMPONENT	DRIVER	MECHANISM	CONSEQUENCE
		increased variability in available habitats	maintain species diversity (over long time scales) but with losses over short time scales
birds	availability of roosts	loss of roosts after extreme events reduced	breeding success
		increased roost availability due to increased riparian productivity increa	sed breeding success
resource	availability	temporary loss of resources following high flow/storm events	reduced feeding likely to influence biomass and abundance
		increased availability owing to increased production and decomposition rates	higher productivity and reproductive output and success

Drivers, mechanisms and potential consequences of climate change on key components and processes of freshwater forested wetlands.

KEY COMPONENT	DRIVER	MECHANISM	CONSEQUENCE
trees nutrient	s	pulses during storm events from overland flow and flooding stimulate	productivity
		reduced inputs during periods of low river flows	reduce productivity
		rates of denitrification and decomposition to increase, with temperature increases	changes in nutrient deposition and transport
	light	high light during extended dry spells	increased productivity
	substrate stability	increased scour during high flow events	change in available substrate - loss of old areas
temperature		increased metabolism (and growth) due to increased temperature	increased productivity
	rainfall/flows	increased duration of dry spells	loss of wetland species, encroachment of terrestrial species
		increased intensity of storm/rainfall/flow events	increased likelihood of storm damage and loss of biomass
understorey vegetation nutrient	s	pulses during storm events from overland flow and flooding stimulate	productivity
		reduced inputs during periods of low river flows	reduce productivity
		rates of denitrification and decomposition to increase, with temperature increases	changes in nutrient deposition and transport
	light	high light during extended dry spells	increased productivity
	substrate stability	increased scour during high flow events	change in available substrate - loss of old areas
temperature		increased metabolism (and growth) due to increased temperature	increased productivity
	rainfall/flows	increased duration of dry spells	loss of wetland species, encroachment of terrestrial species
		increased intensity of storm/rainfall/flow events	increased likelihood of storm damage and loss of biomass
periphyton/biofilm nutrient	s	pulses during storm events	increased productivity

KEY COMPONENT	DRIVER	MECHANISM	CONSEQUENCE
		reduced inputs during periods of low river flows	reduced productivity - nutrient limitation
		rates of denitrification and decomposition to increase, with temperature increases	DO consumption
	light	pulses of highly turbid water after storm events	temporary reduced light penetration and reduced productivity
		high light during extended dry spells	increased productivity
available	substrate	smothered substrates following storm events	loss of standing stocks
			reduced available habitat for colonisation
		delivery of substrates in storm/flow events	increased available habitat (post event) for colonisation
temperature		increased metabolism (and growth) due to increased temperature	increased productivity
rainfall/flows		reduced water residence time and increased turbulence during high flow/rainfall events	reduced biomass accrual
		increased water residence time during low flow/rainfall periods	increased biomass accrual, with possible composition changes
		increased risk of scour during high flow events	loss of biomass
macroinvertebrates	nutrients	poor water quality during high flow/storm events	loss of biomass and sensitive taxa
temperature		increased metabolism (and growth) due to increased temperature	increased productivity
	oxygen	poor water quality during high flow/storm events	loss of biomass and sensitive taxa
		poor benthic water quality during extended periods of lake stratification	changes in benthic-pelagic coupling
			loss of sensitive benthic taxa
rainfall/flows		reduced water residence time and increased turbulence during high flow/rainfall events	loss of biomass of pelagic species e.g. Zooplankton
		increased water residence time during low flow/rainfall periods	stability likely to lead to biomass increases
		increased risk of scour during high flow events	loss of flow-sensitive taxa in pelagic and benthic habitats
		increased variability in rainfall/flow	loss of reproductive cues for some taxa

KEY COMPONENT	DRIVER	MECHANISM	CONSEQUENCE
resource	availability	increased primary productivity	increased macroinvertebrate productivity, unless harmful algal types dominate
		increased variability in available habitats	maintain species diversity (over long time scales) but with losses over short time scales
frogs	nutrients	poor water quality during high flow/storm events	loss of biomass and species
temperature		increased metabolism (and growth) due to increased temperature	increased productivity
rainfall/flows		increased water residence time during low flow/rainfall periods	stability likely to lead to biomass increases
		increased risk of scour during high flow events	reduced abundance and potential loss of eggs
		increased variability in rainfall/flow	loss of reproductive cues for some taxa
	resource availability	increased primary productivity	increased abundance and reproductive success
		increased variability in available habitats	maintain species diversity (over long time scales) but with losses over short time scales
birds	availability of roosts	loss of roosts after extreme events reduced	breeding success
		increased roost availability due to increased riparian productivity increa	sed breeding success
resource	availability	temporary loss of resources following high flow/storm events	reduced feeding likely to influence biomass and abundance
		increased availability owing to increased production and decomposition rates	higher productivity and reproductive output and success

APPENDIX 8 - Database of coastal adaptation approaches in existing global, national, state, regional and local government strategies, policy and legislation.

N.B. At the state, regional and local government level, only those relevant to the selected case study areas are considered.

GLOBAL APPROACHES

1. The World Heritage Convention

UNESCO (2010). Climate Change and World Heritage. Retrieved 21/12/2010, from http://whc.unesco.org/en/climatechange

The United Nations Educational, Scientific and Cultural Organisation (UNESCO) adopted the 'Convention Concerning the Protection of the World's Cultural and Natural Heritage' (World Heritage Convention) in 1972. Once natural areas have been listed as World Heritage sites the governing bodies are obligated to take the necessary actions required to ensure the protection and maintenance of sites under the agreement. Governing bodies are also required to regularly report on the state of conservation and the various protection measures put in place at their sites. As such, the necessary actions required to protect World Heritage areas against the impacts resulting from climate change is the implementation of a climate change adaptation strategy.

In July 2006 the World Heritage Committee endorsed the report on *Predicting and Managing the Impacts of Climate Change on World Heritage* and the *Strategy to Assist State Parties to Implement Appropriate Management Responses* (see Strategy below). Both report and strategy outline various adaptation management responses to assist land managers of World Heritage areas to enhance the resilience of World Heritage area to the impacts of climate change.

2. Strategy to Assist State Parties to Implement Appropriate Management Responses

UNESCO (2006). Strategy to Assist State Parties to Implement Appropriate Management Responses: United Nations Educational, Scientific and Cultural Organisation, World Heritage Commission. 55pp.

Prepared by the World Heritage Committee in order to provide a number of management responses and strategies that can be implemented at National, State and local government levels and can provide a number of relevant actions in responding to the threats imposed by climate change. These actions include preventative actions, corrective actions and knowledge sharing. It also suggests that climate change should be addressed in the broader context and not in isolation from other natural area management issues.

3. Policy Document on the impacts of Climate change on World Heritage Properties

UNESCO (2007). Policy Document on the Impacts of Climate Change on World Heritage Properties. Paris: United Nations Educational, Scientific and Culture Organisation, World Heritage Committee.

The World Heritage Committee General Assembly of State Parties adopted the 'Policy Document on the Impacts of Climate Change on World Heritage Places' in 2007. The policy document recognises that climate change will adversely affect the conservation of World Heritage places and provides guidance to policy and decision makers on key issues such as synergies with other International conventions and organisations, research needs and legal issues.

4. Ramsar Strategic Plan 2009-2015

Ramsar (2009). Ramsar Strategic Plan 2009-2015: The Ramsar Convention.

The Ramsar Strategic Plan 2009-2015 contributes to a common understanding of the Ramsar Conventions purposes and principles. It also focuses on providing advice on how the Convention on Wetlands should be implemented until 2015. Ramsar's mission is "the conservation and wise use of all wetlands through local, regional and national actions and international cooperation, as a contribution towards achieving sustainable development throughout the world".

The Strategic Plan includes climate change adaptation and mitigation which are recognised as important components in achieving the goals and strategies of Ramsar Convention. In particular implementing responses to climate change through adaptation and mitigation are viewed as vital to:

- ensuring the conservation and wise use of wetlands of international significance
- recognising the cross-sectoral importance of wetland services
- ensuring that national policies and wetland management plans are based on the best available scientific knowledge
- ensuring ecosystem-based approaches are included in planning activities and decision-making processes
- forming synergies and partnerships with international and regional multilateral environmental agreements (MEAs) and other intergovernmental agencies (IGOs).

5. Japan, China and Republic of Korea Australia Migratory Bird Agreements

DFA (1981). Japan-Australia Migratory Bird Agreement, Australian Treaty Series 1981, No. 6. *Department of Foreign Affairs.* Retrieved 22/12/2010, from http://www.austlii.edu.au/au/other/dfat/treaties/1981/6.html

DFA (1988). China-Australia Migratory Bird Agreement, Australian Treaty Series 1988, No. 22. *Department of Foreign Affairs.* Retrieved 22/12/2010, from http://www.austlii.edu.au/au/other/dfat/treaties/1988/22.html

DFA (2007). Republic of Korean-Australia Migratory Bird Agreement, Australian Treaty Series 2007, ATA 24. *Department of Foreign Affairs.* Retrieved 22/12/2010, from http://www.austlii.edu.au/au/other/dfat/treaties/2007/24.html

The Japanese Australia Migratory Bird Agreement (JAMBA), formed in 1974, and the China Australia Migratory Bird Agreement (CAMBA), formed in 1986 were the first two bilateral agreements relating to the conservation of migratory birds. The Republic of Korea Australia Migratory Bird Agreement (ROKAMBA) entered into force in 2007. These agreements, formed through the Department of Foreign Affairs, provide important mechanisms for pursuing conservation outcomes for migratory birds, including migratory shorebirds, and requires that appropriate measures are taken to preserve and enhance their habitat.

Without directly referring to climate change adaptation or mitigation the requirements of these agreements will necessitate the development and implementation of adaptive measures through the protection of habitat that ensures the health of migratory bird species.

6. Convention of Migratory Species

UNEP/CMS (2006). Migratory Species and Climate Change: Impacts of a Changing Environment on Wild Animals. Bonn: UNEP / CMS Secretariat.

The Convention on Migratory Species (CMS), also known as the Bonn Convention, entered into force in 1983 and currently has nearly 100 countries as Contracting Parties. The Convention aims to conserve terrestrial and marine migratory species, throughout their range, by entering into multilateral agreements for the conservation and management of migratory species and by undertaking co-operative research activities.

Climate change and its impact on migratory species is of vitally importance to the CMS with numerous reports being developed in association with other International conservation agencies and organisations. Of particular relevance to this project the CMS reports detail the difficulty in responding to climate change through adaptation due to the vast distances that many migratory species travel.

7. Millennium Ecosystem Assessment

MEA (2005). Ecosystems and Human Well Being: Policy Responses, Chapter 3: Climate Change, Millennium Ecosystem Assessment.

The Millennium Ecosystem Assessment (MEA) looks at the consequences of ecosystem change for human well-being. Their findings provide a state-of-the-art scientific appraisal of the condition and trends in the world’s ecosystems and the services they provide, as well as the scientific basis for action to conserve and use them sustainably.

The MEA considers climate change amongst the other anthropogenic threats to the World’s ecosystems, with many of the other anthropogenic threats currently having a greater impact. Chapter 3 (Drivers of Ecosystem Change) and Chapter 9 (Coastal Systems) of the MEA’s ‘Current State and Trends’ report discuss climate change as a significant future impact on ecosystems around the World. However, Chapter 13 (Climate Change) of the MEA's 'Policy Responses' report conducts a detailed analysis of the impacts of climate change and the climate change adaptation responses necessary.

8. Intergovernmental Panel on Climate Change (IPCC)

IPCC (2007b). Climate Change 2007: Impacts, Adaptation and Vulnerability, Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds, Cambridge University Press, Cambridge, UK: 976 pp.

The IPCC provides policy and decision makers with an objective source of information about climate change. It assess and peer reviews the latest scientific, technical and socio-economic literature relevant to the understanding of the risk of human-induced climate change and the options available for adaptation and mitigation responses. Chapter 17 of this report provides a detailed assessment of current climate change adaptation practices, options, constraints and capacity.

9. United Nations Framework Convention on Climate Change

UNFCCC (2010). United Nations Framework Convention on Climate Change - Adaptation. Retrieved 29/12/2010, from http://unfccc.int/adaptation/items/4159.php

The United Nations Framework Convention on Climate Change (UNFCCC) was adopted by the United Nations Intergovernmental Negotiating Committee in 1992 and entered into force in 1994. Governments who have ratified the convention have agreed to develop and implement national climate change adaptation strategies. The UNFCCC recognises that climate change adaptation is vital in reducing the current and future impacts of climate change. The UNFCCC highlights a range of climate change adaptation issues and approaches that are being adopted by Governments and that can be used International.

10. Adaptation to Climate Change: International Policy Options

Burton, I., Diringer, E., Smith, J. (2006). *Adaptation to Climate Change: International Policy Options*: Arlington, USA: Pew Center on Global Climate Change.

The *Adaptation to Climate Change: International Policy Options* report outlines the historic and present day efforts undertaken by humans in adapting to climate change. It looks at how barriers to future climate change adaptation can be overcome and highlights key issues in the design of adaptation policy. Three potential approaches are discussed to strengthen international efforts in climate change adaptation. These include: the facilitation of climate change adaptation strategies under the United Nations Framework Convention on Climate Change, the integration of climate change adaptation efforts with development and the establishment of an insurance fund which can assist vulnerable countries with climate related damages.

NATIONAL APPROACHES

1. Environment Protection & Biodiversity Conservation Act 1999

DSEWPC (2010). *Environment Protection and Biodiversity Conservation Act 1999*. Canberra: Department of Sustainability, Environment, Water, Population and Communities.

The *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) is the key environmental legislation enacted by the Australian Government. Its main aim is to protect areas of national environmental significance and does this through six objectives:

- provide for the protection of 8 matters of national environmental significance
- conserve Australian biodiversity
- national environmental assessment and approvals process
- enhance the protection and management of important natural and cultural places
- control the international movement of plants and animals
- promote ESD through the conservation and ecologically sustainable use of natural resources

The EPBC Act doesn't in itself refer to climate change adaptation, but it does refer to protecting against threatening processes that can impact upon areas of national environmental significance. The primary mechanism through which the EPBC Act influences climate change adaptation is ESD. The requirement to uphold the principles of ESD can be used by Courts of Law to prevent unsustainable coastal developments from receiving approval. However, a review by Hawke (2008) of the EPBC Act has called for significant improvements and increases in the extent to which the EPBC Act refers to and acknowledges climate change mitigation and adaptation.

2. National Climate Change Adaptation Framework

COAG (2006). *National Climate Change Adaptation Framework*. Canberra: Council of Australian Governments.

The *National Climate Change Adaptation Framework* was endorsed by the Council of Australian Governments (COAG) in 2007 and is designed to enact strategies and actions over a 5 - 7 year timeframe. A key focus of the framework is to enable decision makers to include climate change in policy development and decision making across jurisdictions and at various scales and degrees of vulnerability.

The framework has two priority areas of 'building understanding and adaptive capacity' and 'reducing vulnerability in key sectors and regions'. A number of nationally focused strategies and actions have been developed to achieve these priorities, including the development of an Australian centre for climate change adaptation, the development and dissemination of regional climate change vulnerability information, the undertaking of integrated regional vulnerability assessments, the development of a climate change information, tools and communication strategy, the development and maintenance of International connections and partnerships.

Relative to coastal regions, the framework aims to build on the work undertaken by the Framework for a National Cooperative Approach to Integrated Coastal Zone Management and will undertake a national assessment of Australia's coastal vulnerability. The Climate Change Risks to Australia's Coast report is one of the key actions identified in the National Climate Change Adaptation Framework.

3. National Cooperative Approach to Integrated Coastal Zone Management - Framework and Implementation Plan

NRMMC (2006). National Cooperative Approach to ICZM - Framework and Implementation Plan: National Resource Mgt Ministerial Council.

The *Framework for a National Cooperative Approach to Integrated Coastal Zone Management* has been developed to encourage more active rehabilitation, protection and improvement of coastal zone assets through proactive planning and management. The State of the Environment Report (2001) observed that the condition of the coastal zone had not significantly improved, despite efforts to do so, and the rate that coastal ecosystems where being impacted was exceeding the recovery time required by those environments. Endorsed by the Natural Resources Management Ministerial Council in 2003, the framework will integrate with the Regional Marine Planning Program to form a comprehensive natural resources management approach under the Natural Heritage Trust (NRMMC, 2003).

The Framework outlines the need to develop appropriate responses to climate change, and recommends the integration of climate change adaptation strategies into existing coastal zone conservation, planning and management regimes. The framework suggests the development of information, guidelines and tools for coastal managers on climate change adaptation options. Forward planning that builds on existing National and State programs, such as the Climate Change Forward Strategy and the National Greenhouse Framework is also recommended. The objectives and actions of Priority Area 3.2 of the implementation plan focuses on the development of strategies to effectively identify and manage climate change threats and opportunities within the coastal zone.

4. Climate Change Risks to Australia's Coast Report

DCCEE (2009). Climate Change Risks to Australia's Coast - A first pass national assessment. Canberra: Department of Climate Change and Energy Efficiency.

One of the key actions identified in the National Climate Change Adaptation Framework was to carry out an assessment of climate change risk to the Australian coast. The development of the Climate Change Risks to Australia's Coast Report resulted from this assessment. The assessment identified the major risks to both natural and human coastal systems, the barriers that hinder the development and implementation of adaptive responses and the identification of National adaptation priorities.

5. Managing our coastal zone in a changing climate - The time to act is now

APH (2010). *Managing our coastal zone in a changing climate: the time to act is now* Canberra: House of Representatives Standing Committee on Climate Change, Water, Environment and the Arts, Australian Government.

The 'Managing our coastal zone in a changing climate: the time to act is now' report details the pressures placed on Australia's coastal zone by climate change and other non-climatic impacts imposed by humans, such as population growth. The report reviews existing policies and programs related to coastal zone management and analyses the environmental impacts of population growth and climate change. A total of 47 recommendations are made that outline how national leadership can be provided in a collaborative framework with State and Local Governments and how the community as a whole can be involved in the process. The report details 3 key coastal issues as climate change impacts, environmental impacts and governance arrangements.

Chapter 3 of the report focuses on climate change adaptation, with a review of major national initiatives, such as the National Climate Change Adaptation Framework, federal climate change adaptation programs and the role of State and Local Governments.

6. Planning for climate change: Leading Practice Principles and Models for Sea Change Communities in Coastal Australia

Gurran, N., Hamin, E., Norman, B. (2008). *Planning for climate change: Leading Practice Principles and Models for Sea Change Communities in Coastal Australia* Sydney: University of Sydney.

This report outlines the impact of climate change on sea change communities in an environmental, social, and economic context. It identifies leading practice in planning for climate change mitigation and adaptation and outlines the current planning policy and practice used in Local Government areas. The report recommends that an intergovernmental agreement between all tiers of government within Australia is formed, which clearly states the commitments and responsibilities of Federal, State and Local Government in planning for climate change.

7. Adapting to Climate Change in Australia - An Australian Government Position Paper

DCCEE (2010). *Adapting to Climate Change in Australia - An Australian Government Position Paper*. Canberra: Department of Climate Change and Energy Efficiency.

This report details the Australian Government's position on climate change and sets out its vision for enabling Australia to adapt to the impacts of climate change and suggests a series of practical steps to allow this vision to become reality, including:

- embedding of climate change impacts into policy development
- providing public good information

- the establishment of partnerships between Federal, State and Local Governments to allow for effective cross jurisdictional communication and alignment of programs.

This report also details the respective roles that each level within Government is expected to play in successfully adapting to climate change.

8. CSIRO Climate Adaptation Flagship

CSIRO (2007). Climate Adaptation Flagship, Retrieved 07/01/11, from http://www.csiro.au/org/ClimateAdaptationFlagshipOverview.html

The purpose of CSIRO Climate Adaptation Flagship is to deliver the best available scientific information and expertise to support Australia's efforts to adapt to climate change. Four research themes have been established by the flagship, including:

- Pathways to adaptation: positioning Australia to deal effectively with climate change
- Sustainable cities and coasts
- Managing species and natural ecosystems in a changing climate
- Primary industries, enterprises and communities adapting to climate change

9. National Strategy for the Conservation of Australia's Biological Diversity 1996

DEST (1996). *National Strategy for the Conservation of Australia's Biological Diversity 1996*. Canberra: Australian Government, Department of Sustainability, Environment, Water, Population and Communities.

The National Strategy for the Conservation of Australia's Biological Diversity was agreed to by the Australian, State and Territory governments in 1996 and provides goals, principles and objectives consistent with the international Convention on Biological Diversity 1992. It emphasises a multiple-use management approach through the development of integrated national policies on a bioregional basis, with improved mechanisms for coordinating and integrating the different levels of government, industry and the community. The objectives and principles of ESD are promoted throughout the Strategy and play a large role in its development.

The Strategy recognises that biological diversity provides the basis for adaptation to changing environments and that a range of supporting measures is necessary to minimise the impact of external factors, such as climate change. Section 3 deals with 'Managing threatening processes' and the impact of climate change on biological diversity, however, ensuring the existence of altitudinal and latitudinal buffer zones to enable the migration of species in the event of shifting climatic zones, is the only climate change adaptation measure detailed. This Strategy has since been superseded by the 'Australia's Biodiversity Conservation Strategy 2010 - 2030' as detailed below.

10. Australia's Biodiversity Conservation Strategy 2010 - 2030

NRMMC (2010). *Australia's Biodiversity Conservation Strategy 2010 - 2030*. Canberra: Australian Government, Department of Sustainability, Environment, Water, Population and Communities.

The vision of the *Australian Biodiversity Conservation Strategy 2010 - 2030* is to maintain Australia's biodiversity in a healthy condition so that it remains resilient to threats, is valued in its own right and continues to provide essential ecosystem services for humans. This strategies reference to climate change adaptation and ecosystem resilience is much more extensive that its predecessor, *The National Strategy for the Conservation of Australia's Biological Diversity*. In order to maintain the health of ecosystems through the conservation of biodiversity, the Strategy identifies priority areas and allocates a series of actions to achieve each priority. The Strategy also includes 10 interim national targets which will be assessed and modified, as needs be, on an ongoing basis.

11. Climate Change Adaptation Actions for Local Government

AGO (2007). *Climate Change Adaptation Actions for Local Governments*. Canberra: Department of the Environment and Water Resources.

The *Climate Change Adaptation Actions for Local Government* report identifies a number of adaptation options and actions that are relevant to Australia's climatic conditions and risks and that can be implemented by local governments. The way climate change will impact upon the functions and frameworks of local governments is outlined, along with a series of adaptation responses appropriate for infrastructure and property services, the provision of recreational facilities, health services, planning and development approvals, natural resource management, water and sewerage services, general adaptation measures and regional and partnership approaches. A process for local governments to perform risk assessments for their local environments is also provided.

12. The National Strategy for Ecologically Sustainable Development

COAG (1992). *National Strategy for Ecologically Sustainable Development*. Council of Australian Governments. Department of Sustainability, Environment, Water, Population and Communities.

The purpose of the *National Strategy for Ecologically Sustainable Development* is to enhance the well-being and equity within and between current and future generations while protecting the biological diversity that maintains ecological processes and life-support systems. Through the Strategy governments will make changes to their institutional arrangements to ensure that ESD principles and objectives are taken into consideration in relevant policy making processes.

Objective 30.5 within Chapter 30 of the Strategy recognises the challenge of providing the knowledge, techniques and technologies needed to achieve the goals of ESD in all sectors by continuing to support RD & D that is directed at improving understanding of the natural variability of climate, the possible impacts of climate change, and to identify cost-effective mitigation options to encourage the integration of technical, economic and social research in this context.

13. Climate Change in Australia: Regional Impacts and Adaptation - Managing the Risk for Australia

PMSEIC (2007). *Climate Change in Australia: Regional Impacts and Adaptation – Managing the Risk for Australia*, Report Prepared for the Prime Minister's Science, Engineering and Innovation Council: Independent Working Group, Canberra.

This report highlights the likely impacts that will result from climate change and details the risks associated with those impacts. Key areas of action identified by this report include the identification of potential adaptation responses, the development of climate change adaptation plans, the education of individuals and communities about the importance of climate change adaptation and the promotion and facilitation of climate change adaptation research. The report also identifies key area that are most vulnerable to climate change and that require immediate action in terms of climate change adaptation planning.

14. Notes on applying 'real options' to climate change adaptation measures, with examples from Vietnam

Dobes, L (2010) Notes on applying 'real options' to climate change adaptation measures, with examples from Vietnam, CCEP working paper 7.10, Centre for Climate Economics and Policy, Crawford School of Economics and Government, The Australian National University, Canberra, retrieved on 02/01/11, from http://ccep.anu.edu.au/data/2010/pdf/wpaper/CCEP-7-10.pdf

The working paper investigates the application of 'real options' approach as an adaptation strategy. The implementation of a real options approach allows for an incremental and flexible approach to the uncertainty of climate change whilst conserving community resources. A positive to the 'real options' approach is the ability to manipulate adaptation measures as better knowledge becomes available over time. Due to the uncertainty surrounding flooding and inundation, it is suggested that a better alternative than sea walls and levee banks is to construct a wall high enough to offer protection for current circumstances. This barrier can then be raised later if appropriately designed or sandbagged for occasional flooding. This saves community resources by not adhering to worst case scenario, rather adapting to current condition, therefore full cost is not incurred until required.

The working paper provides examples from Vietnam to illustrate adaptation options using the real options approach. The use of land easements as an option for the future extensions of dykes is explored as well as methods for raising the floor level of hazard prone buildings. A further adaptation option explored is the usage of water tanks as a real option for cyclone shelters.

15. Great Barrier Reef Climate Change Action Plan 2007-2012

Great Barrier Reef Marine Park Authority (2007) Great Barrier Reef Climate Change Action Plan 2007-2012, Australian Government, Commonwealth of Australia

Climate change is now recognised as one of the largest long-term threats to the health of the Great Barrier Reef. The action plan identifies two major factors dictating the health of the Reef as the rate and extent of climate change and the resilience of the

Reef ecosystem to climate change. It is recognised in the plan that the current anthropogenic threats will be further exacerbated by the advent of climate change. To secure a future for the reef a resilience based management approach has been undertaken by the Great Barrier Reef Marine Park Authority (GBRMPA). Actions already underway include the Reef Water Quality Protection Plan and the Great Barrier Reef Marine Park Zoning Plan. The GBR Climate Change Action Plan identifies strategies for actions and partnerships that will increase the resilience of the Reef to climate change and is underpinned by the knowledge and adaptation measures that have been established and observed through the GBR Climate Change Response Program.

STATE APPROACHES

N.B. The state/territory approaches adopted by the Northern Territory, Queensland and NZW have been detailed below. These states have been chosen as they are home to the three case study sites selected as part of the CERCCS project. The case study sites are Kakadu National Park (NT), the Cairns area (QLD) and the Hunter Valley (NSW). Many of the strategies below are state wide strategies and therefore will also affect the case study areas within the respective states.

NORTHERN TERRITORY

1. Kakadu National Park Climate Change Strategy 2010 - 2015

DNP (2010). *Kakadu National Park Climate Change Strategy 2010 - 2015*. Director of National Parks, Department of the Environment, Water, Heritage and the Arts, Canberra, Australia.

The management of Kakadu National Park can take advantage of both a scientific understanding climate change impacts and the accumulated traditional knowledge of climate changes over thousands of years. The policies and actions of this Strategy are inline with those of the *Kakadu National Park Management Plan 2007-2014*, as well as the objectives of the *Parks Australia Climate Change Strategic Overview 2009-2014*. These objectives include the implementation of adaptation measures to maintain the adaptive resilience of Kakadu, including weed and feral animal management, and the involvement of industry and community groups in the development of climate change adaptation.

2. Northern Territory Climate Change Policy

Department of the Chief Minister (2009) Northern Territory Climate Change Policy. Retrieved 12/01/2011, from http://www.greeningnt.nt.gov.au/climate/docs/Climate_Change_Policy.pdf

The Northern Government has created a policy in ‘greening’ their land and economy. The policy target actions are becoming carbon neutral by 2018, improving land management practices to remove carbon from the atmosphere and controlling the rate of clearing to protect the carbon bank. Relevant to this synthesis will be efforts to protect important coastal wetlands at risk from rising sea levels. Specific interventions will aim to reduce salt water intrusion, protect fishing and save biodiversity. By 2011, the Territory aims to complete the Territory Climate Change Adaptation Action Plan

3. Kakadu National Park Management Plan 2007-2014

Director of National Parks (2007) Kakadu National Park Management Plan 2007-2014. Department of Sustainability, Environment, Water, Population and Communities Retrieved 10/01/2011, from
http://www.environment.gov.au/parks/publications/kakadu/management-plan.html

This is the 5th Management Plan for Kakadu National Park. This document outlines priorities, impacts and management strategies for a seven period beginning in 2007. . It was prepared by the Kakadu Board of Management and the Director of National Parks. Kakadu National Park is Aboriginal land, home to one of the oldest continuous cultures in the world. It is an internationally significant World Heritage Area, jointly managed with its Aboriginal traditional owners. This plan focuses on developing partnerships between government, the private sector and traditional owners to provide new opportunities for visitors and new business opportunities for local Aboriginal people. Climate change and improving the resilience of our habitats and species are also key considerations.

In this report, some of the potential management implications from climate change include loss of biodiversity, increases in drought and flood activity, extreme weather events, changed fire regimes and relocation of infrastructure from high risk areas. Section 5.6 of the management plan outlines the policies directly related to climate change adaptation.

4. National Environmental Protection Council (Northern Territory) Act 2004

Northern Territory of Australia (2004) National Environmental Protection Council (Northern Territory) Act 2004 Retrieved 12/01/2011, from
http://notes.nt.gov.au/dcm/legislat/legislat.nsf/d989974724db65b1482561cf0017cbd2/4e666369e7dbf36c69256e5b000bd669/$FILE/Repn024.pdf

The National Environment Protection Council (NEPC) originated from an agreement made between the Prime Minister, Premiers and Chief Ministers, held in October 1990 at the Special Premier's Conference. It was agreed to develop an Intergovernmental Agreement on the Environment. The National government is responsible for making National Environment Protection Measures (NEPMs) in ensuring that Australian citizens are equally protected from air, water, soil and noise pollution. All participating jurisdictions (i.e. the Commonwealth and all of the state and territory governments) have coordinating legislation established under the NEPC, which is a statutory body with law-making powers. Implementation of NEPMs is the responsibility of each participating jurisdiction, and each minister on the NEPC reports to the NEPC each year on the implementation of each NEPM in his/her jurisdiction.

Schedule 5 states the parties have acknowledged the potential impacts of greenhouse enhanced climate on the natural, social and working environment, as well as on an international scale. Section 5.3 outlines that a National Greenhouse Response

Strategy based on the interim planning target must include positive measures for adapting to the impacts of climate change.

QUEENSLAND

1. Far North Queensland Regional Plan 2009-2031

DIP (2009). Far North *Queensland Regional Plan 2009 - 2031.* Department of Infrastructure and Planning, Queensland Government.

The Far North Queensland (FNQ) Regional Plan takes precedence over all other planning instruments for the FNQ region. The plans purpose is to guide and manage the region's development and address key regional environmental, social, economic and urban objectives. Part C (Strategic directions) of the Plan discusses to need to consider climate change in managing the region, but its main focus is on mitigation.

The Plan discusses climate change adaptation measures in the form of maintaining connectivity through the development of wildlife corridors to enable wildlife to migrate as a result if climate change. This is a measure aimed at increasing the adaptive resilience to climate change of biodiversity. Part E (Regional policies) talks about the need to reduce non-climatic threats to biodiversity to ensure ecosystem health and the ability of ecosystems to adapt to climate change. Section 1.2 of Part E also covers coastal management issues relating to climate change and sea level rise. In relation to coastal management the Plans objectives are to prevent development in erosion prone zones or areas at risk of inundation, except in accordance with State and local management planning. The Plan also stipulates that undeveloped coastal areas where coastal retreat can occur naturally need to identified and protected from development.

2. The Marine Parks Act 2004

DERM (2009). Marine Parks Act 2004. Department of Environment and Resource Management, Queensland Government.

The purpose of the Marine Parks Act 2004 is the conservation of Queensland's marine environment through the declaration of marine parks, the zoning, planning and the enforcement of regulations.

Although climate change adaptation isn't discussed directly in the Act, strategies are identified through which the purpose of the Act can be achieved. These strategies ensure climate change adaptation is a consideration in the management of marine parks through Australia's adherence to its international and national responsibilities, such as intergovernmental agreements and other environment conservation legislation.

3. Sustainable Planning Act 2009

DIP (2009). *Sustainable Planning Act 2009*. Act No. 36. Department of Infrastructure and Planning, Queensland Government.

The purpose of the Sustainable Planning Act 2009 is to aid in the achievement of ESD. It does this by managing the process of development so that it is accountable, effective and efficient and is undertaken in such a way that is sustainable for biodiversity and ecosystems. The purpose of the Act is to ensure decision making processes take into consideration the impact of development on climate change and vice versa. Section 11 of the Act concerns itself with ecological sustainability and the maintenance of societies wellbeing through the potential impacts of climate change being taken into account and adapted to.

4. Queensland Coastal Plan 2009

DERM (2011). *Queensland Coastal Management Plan*. Department of Environment and Resource Management, Queensland Government.

The *Queensland Coastal Plan 2009* contains 2 components the *State Coastal Management Policy* and the *State Planning Policy for Coastal Protection*.

State Coastal Management Policy

The purpose of the State Coastal Management Policy (the Policy) is to provide policy direction and guidance on the management of coastal land.

The policy outcomes ensure that the impacts of climate change, such as coastal erosion and inundation, are considered into decision making on how the coast should be managed.

State Planning Policy for Coastal Protection

The purpose of the State Planning Policy for Coastal Protection (the Planning Policy) is to protect coastal resources through the completion of land use planning and development assessments.

The Planning Policy ensures that development in coastal areas that are at risk of coastal retreat and/or inundation is kept to a minimum and that buildings in these areas are designed and located in such a way as to also minimise risk of exposure to climate change impacts. The Planning Policy reflects other coastal management plans by maintaining the resilience of coastal ecosystems by allowing for coastal retreat to occur where possible.

5. Climate Q - towards a greener Queensland

DERM (2009). *Climate Q - towards a greener Queensland*. Department of Environment and Resource Management, Queensland Government.

The *Climate Q - towards a greener Queensland* (Climate Q) strategy builds on and complements the *Climate Smart Adaptation 2007-2012* and the *Climate Smart 2050* strategies. The Climate Q strategy outlines 5 themes underpinning Queensland's response to climate change. Theme 4 and 5 relate to increasing the resilience of ecosystems and human communities to the impacts of climate change by managing non-climatic human threats, and in providing the necessary information and training required to deal with the impacts of climate change.

6. Climate Smart Adaptation 2007 - 2012

DNRW (2007). *Climate Smart Adaptation 2007 - 2012 - An action plan for managing the impacts of climate change*. Department of Natural Resources and Water, Queensland Government.

The purpose of the Climate Smart Adaptation 2007-2012 strategy is to focus on 'enhancing resilience' to climate change. It does this by building on national climate change adaptation frameworks, plans and programs, including the National Climate Change Adaptation Framework, the National Agriculture and Climate Change Action Plan, the National Biodiversity and Climate Change Action Plan and the Great Barrier Reef Climate Change Response Program.

The Climate Smart strategy has developed three strategies that support a total of 62 actions. The strategies include, building and sharing knowledge, including climate change in decisions and reducing vulnerability and increase resilience to climate change.

NEW SOUTH WALES

1. NSW Coastal Policy 1997

NSW Government (1997) *NSW Coastal Policy 1997: a sustainable future for the New South Wales coast*, State of New South Wales, Australia, retrieved 05/01/11, from http://www.planning.nsw.gov.au/plansforaction/pdf/CPPARTA.PDF

The NSW Coastal Policy 1997 requires that climate change is considered in planning and development assessment applications with a strong emphasis on ecologically sustainable development (ESD) and the precautionary principle based on the principles contained in the Intergovernmental Agreement on the Environment (IGAE) signed in 1992. This policy recognises the range of governmental and non-governmental organisations that manage the coastal zone and aims to integrate coastal management by these bodies as well as all levels of government.

Key actions and initiatives of The Coastal Policy pertaining to adaptation include:

- Improving water quality in coastal waters, estuaries and rivers
- Protection and restoration of important fisheries habitats (eg. Seagrasses and mangroves)
- Enforcement, protection and extension of coastal wetlands
- Assessment of coastal lands and aquatic environments with conservation values and appropriate tenures, reservations, zonings and regulation implemented to protect and restore ecosystem resilience
- Development of comprehensive and representative protected areas and reserves in the coastal zone, inclusive of marine and terrestrial parks.

2. NSW Sea Level Rise Policy Statement

NSW Government (2009) NSW Sea Level Rise Policy Statement, Department of Environment, Climate Change and Water, NSW retrieved 03/01/11, from http://www.planning.nsw.gov.au/LinkClick.aspx?fileticket=ukmXcVJesYA%3D&tabid=177

The statement sets five objectives to assist and support local councils on reducing risks to private and public property from coastal hazards. These include the promotion of adaptive risk-based approach to management of sea level rise as well as providing guidance to local councils to support adaptation planning. Emergency management will continued to be provided to the community by the government however, compensation will not be provided for the effects of erosion or sea level rise and risks from natural processes and hazards rests with property owners. The statement sets sea level rise planning benchmarks for adaptive management by local bodies at an increase of 40cm by 2050 and 90cm by 2100 from 1990 levels.

The intention of the policy statement is to promote adaptive risk-based approaches to managing sea level rise and to provide guidance and information to local council to support adaptation planning.

3. NSW Coastal Planning Guideline: Adapting to sea level rise

NSW Government (2010) NSW Coastal Planning Guideline: Adapting to sea level rise, State of New South Wales through the Department of Planning, Australia, retrieved 05/01/11, from http://www.planning.nsw.gov.au/LinkClick.aspx?fileticket=VYjmQirQIAk%3D&tabid=177

The guideline was prepared by the Department of Planning to provide guidance on "how sea level rise and its associated impacts are to be considered in land use planning and development assessment in coastal NSW". The guideline acknowledges the threat of sea level rise and promotes ecologically sustainable development (ESD) whilst encouraging the application of a precautionary approach to land use planning and development assessment in coastal areas. The guideline is structured in three distinct sections; identification of coastal risk areas, providing information to integrate how sea level rise impacts are able to be factored in strategic and statutory land use planning and considering sea level rise in development applications within the coastal zone. The NSW government has clearly placed a priority on the need to address comprehensive coastal planning, identify high risk areas and protection of coastal environments.

4. NSW Biodiversity and Climate Change Adaptation Framework 2007-2008

NSW Government (2007) *NSW Biodiversity and Climate Change Adaptation Framework*, Prepared by the NSW Inter-agency Biodiversity and Climate Change Impacts and Adaptation Working Group, Department of Environment and Climate Change, NSW, retrieved 10/01/11, from http://www.environment.nsw.gov.au/resources/threatenedspecies/0762biodivccadapt.pdf

This framework acknowledges the serious threat climate change poses to biodiversity. The document explicitly states the importance of adaptation measures to reduce the vulnerability of species and ecosystems to climate change by improving resilience and reducing anthropogenic impacts. The purpose of the framework was to outline actions to be undertaken in the two years following the document and provides a starting point for building understanding and awareness of climate change and subsequent impacts. It also aims to increase the capacity of agencies and sectors to implement adaptation planning. The framework identifies six key action areas for climate change adaptation including:

- Shared knowledge about climate change and raised awareness of adaptation options
- Research and monitoring of, and adaptation to, climate change
- Incorporation of adaptation strategies that pertain to the impacts of climate change on biodiversity into policy and operation
- Provision of adaptation planning methods and tools
- Minimising the impacts of climate change on key ecosystems and species
- Minimising the threat of invasive species on native species

5. State Environmental Planning Policy No 71 – Coastal Protection (SEPP 71)

NSW Government (2003) State Environmental Planning Policy No 71 – Coastal Protection, under the Environmental Planning and Assessment Act 1979, retrieved on 09/01/11, from
http://www.austlii.edu.au/au/legis/nsw/num_epi/seppn71cpn22003523685.pdf

This environmental planning instrument requires that land use planning and development assessment in the NSW Coastal Zone (as defined under clause 4) considers the impact of coastal processes on development and the likely impact of the developments on coastal processes and hazards. SEPP 71 falls under the Environmental Planning and Assessment Act 1979. The aims of SEPP 71 include the protection of natural, cultural, recreation and economic attributes of the NSW coast and to ensure that development is appropriate for designated locations and protects and improves the natural scenic quality of the surrounding area. SEPP 71 also outlines matters in which a consent authority must have regard to when determining development applications. climate change adaptation related matters include; conservation of threatened animals, plants and associated habitats, protection of wildlife corridors from impacts of development and the likely impact of coastal processes and coastal hazards on development.

SEPP 71 requires that approval for development application and Local Environment Plans meets criteria that protects ecosystems and includes the impact of coastal processes and hazards. This highlights the power of enforceable legislation as a climate change adaptation tool.

6. NSW Greenhouse Plan

NSW Government (2005) NSW Greenhouse Plan, NSW Greenhouse Office, Published by NSW Government, retrieved on 05/01/11, from http://www.environment.nsw.gov.au/resources/climatechange/2811FINALNSWGHPlanweb.pdf

The Greenhouse Plan was developed to set out the action for the NSW Government for the three years following the document in regards to reducing emissions and climate change. The main objectives of the plan were to increase the awareness amongst sectors that are expected to be most affected by climate change impacts, the development of adaptation strategies and to place NSW in a position to meet the targets of limiting 2025 emissions to 2000 levels.

The key measures for adaptation that the NSW government has proposed are:

- Establishing an impacts and adaptation research program
- Incorporating climate change into environmental monitoring systems
- Developing a capacity building program to support adaptation through levels of government, industry organisation and the non-government sector

REGIONAL APPROACHES

For the purposes of this review, regions are defined by natural resource management (NRM) regions.

1. Wet Tropics NRM Region

FNQ NRM Ltd & Rainforest CRC (2004). *Sustaining the Wet Tropics: A Regional Plan for Natural Resource Management 2004–2008*. FNQ NRM Ltd, Innisfail (208pp).

The Cairns Regional Council sits within the Wet Tropics NRM Region along with the Cassowary Coast and Hinchinbrook Regional Councils. The purpose of NRM Plan is to sustainably manage the natural and cultural values of the region through a series of actions, mechanisms and partnerships.

Climate change mitigation is mentioned throughout the NRM Plan and in a number of cases activities designed to mitigate climate change are referred to as adaptation. However, two of the management action targets (MAT), within the NRM Plan are allocated towards adapting to the potential impacts of changing climate. These targets include implementing strategies to address adaptation issues arising from climate change and revising policies from within the various sectors and levels that deal with climate change.

2. Hunter-Central Rivers Catchment Action Plan (CAP)

Hunter-Central Rivers Catchment Management Authority (2007) Hunter-Central Rivers Catchment Action Plan, Published by the Hunter-Central Rivers Catchment

Management Authority, NSW retrieved on 20/10/10, from
http://www.hcr.cma.nsw.gov.au/articles/news.asp?news_id=15

The Catchment Action Plan (CAP) was developed in consultation with local communities and is derived from the collective expertise of individual landholders, community member, businesses, industry and all levels of government. Key objectives of the plan are to improve aquatic health, enhance/protect estuaries and wetlands, protect marine areas and maintain biodiversity. The CAP focuses on restoring the environment to a natural state and works such as revegetation as well as the implementation of economic tools such as carbon trading as opposed to the NCMP that focuses mostly on engineering solutions.

The document makes reference to climate change and provides some guiding principles to best maintain and enhance ecosystem resilience. The CAP recommends restriction of development in hazard prone areas in conjunction with flood mitigation schemes that maintain floodplain connectivity. The catchment authority also recommends implementation of sustainable farming practices that improve the resilience of ecosystems to be established now along with the protection of existing vegetation and revegetation. This CAP highlights the benefits of widespread consultation with a range of stakeholders in sourcing an innovative and comprehensive array of climate change adaptation approaches.

LOCAL GOVERNMENT APPROACHES

1. Cairns Regional Council Climate Change Strategy 2010 - 2015

CRC (2010). *Cairns Regional Council Climate Change Strategy 2010-2015*. Cairns Regional Council.

The purpose of the Cairns Regional Council Climate Change Strategy 2010 - 2015 is to provide direction for managing the risks resulting from climate change. The Strategy builds on the Climate Change Adaptation Action Plan and the Greenhouse Mitigation Action Plan, also developed by Cairns Regional Council.

The Strategy outlines four approaches that can be used in adapting to climate change:

Avoid - locate new development where it isn’t vulnerable to climate change impacts

Planned retreat - enable land, ecosystems and structures in vulnerable areas to be made available for coastal retreat

Accommodate - where development has already occurred on erosion prone areas allow for continued occupation but with altered building designs

Protect — defend vulnerable areas, population centres, economic activities and coastal resources.

A Climate Change Strategy Implementation Plan is included in Appendix A which details key adaptation actions to be undertaken by Council.

2. Positive Change - Climate Change Risks and Opportunities for the Cairns Region - Climate Change Adaptation Action Plan

AECOM (2009). *Positive Change - Climate Change Risks and Opportunities for the Cairns Region - Climate Change Adaptation Action Plan*. AECOM Australia Pty Ltd, Cairns Regional Council.

This climate change adaptation Action plan sets out a range of possible adaptation options for Cairns Regional Council. It also suggests a series of guidelines and recommendations for continued adaptation to potential changes in climate and the resulting risks. Section 3 of the Plan identifies possible adaptation actions for 27 risks associated with climate change. The 27 adaptation actions can be grouped into corporate governance, natural disaster planning and response, land use planning and flooding, assets and operations, environment and community health. In the interests of selecting the most appropriate adaptation action for a particular climate change risk a qualitative multi-criteria assessment is recommended.

3. Draft Coastal Zone Management Plan for Byron Shire Coastline (CZMP)

Byron Bay Council (2010) Draft Coastal Zone Management Plan for Byron Shire Coastline, Byron Bay Council, NSW, retrieved on 20/01/11, from http://www.byron.nsw.gov.au/publications/draft-coastal-zone-management-plan-for-byron-shire-coastline

Based on the goals of the NSW Coastal Policy 1997, the purpose of the CZMP is to set in place guidelines and implement strategies for long-term management of the coastline. These include; management of coastal hazards, protection and enhancement of the coastal environment and sustainable use of the coastline to maintain ecological, social, economic, recreational and aesthetic values. Part A of the CZMP outlines the basis of Byron Bay Council's 'planned retreat' policy and management approach (defined Chapter 4.1). Part B includes the emergency action plan and describes roles and responsibilities pertaining to erosion/inundation events as well as the constraints the planned retreat approach places on emergency response actions.

The Byron Bay CZMP provides a comprehensive array of investigated climate change adaptation strategies. Included in the plan are groynes and artificial headlands, terminal protection (sea walls), offshore breakwaters and submerged reefs, beach nourishment, erection of educational signage, revegetation works and planned retreat. It is yet to be seen if the controversial planned retreat approach will pass legal and stakeholder acceptance.

4. Newcastle Coastline Management Plan (NCMP)

Umwelt Environmental Consultants (2003). *Newcastle Coastline Management Plan*. Hunter Coast and Estuary Management Committee, The City of Newcastle, retrieved on 20/12/10, from http://www.newcastle.nsw.gov.au/__data/assets/pdf_file/0007/5569/newcastle_coastline_management_plan.pdf

The NCMP provides the council with an integrated planning framework to best serve the long term interests of the coastline. It was prepared in conjunction with the Hunter Coast and Estuary Management Committee, Newcastle City Council, State government and community input. The NCMP aims to focus on sustainable management of coastal processes and hazards, the natural environment, coastal ecology and anthropogenic pressures on the coast amongst other objectives. The region is unique in that the coastline is almost entirely in public ownership and zoned for open space, recreation or special uses in accordance with its Local Environmental Plan. In theory, this would make the region ideally suited to implement a planned retreat approach as opposed to Byron Bay that has large amounts of coastline under private ownership. However, this plan leans towards hard engineering adaptation solutions.

The NCMP outlines some low cost adaptation strategies such as revegetation, prohibiting off road vehicle access to areas of beach and erection of educational signage to protect the integrity of sensitive ecosystems such as rocky platforms. However, the main focus of adaptation measures is hard engineering solutions including installation of large sand bag protection works and extensions to current rock sea walls.

APPENDIX 9 – Future climate scenarios for Kakadu, Hunter River estuary and Cairns (Wet Tropics) case study areas.

Temperature, precipitation, radiation and soil moisture index

IBRA 79 Darwin Coastal

Darwin Coastal region, which encompasses much of coastal Kakadu, is projected to become warmer and drier (Table 5). Warming is projected for the means, minimums and maximums of the temperature variables, resulting in little or no change in projected mean diurnal temperature range and temperature seasonality. Annual mean precipitation (1463 mm) is projected to decrease by 29% by 2070s under A1FI, with a 13.3% decrease during the wettest quarter and 46.4% decrease during the warmest quarter. Mean annual solar radiation is projected to increase slightly (up to 4%) by the 2070s with increases up to 7.9% in the warmest quarter and a decrease of up to 6.4% in the driest quarter.

Table 1 Projections for IBRA 79 Darwin Coastal. Isothermality and seasonality (temperature, precipitation, radiation and Soil Moisture Index (SMI)) the actual projected values are given. All other projected values are absolute change or percent change.

Variable Number	Variable Name	Baseline	A1B	A1FI	A1B	A1FI
			Change 2030		Change 2070	
1	**Annual Mean Temp °C**	27.5 °C	0.9 °C	1.1 °C	2.1 °C	3.7 °C
2	**Mean Diurnal Range °C**	11.1 °C	0.0 °C	0.1 °C	0.1 °C	0.2 °C
3	**Isothermality**	0.6	0.6	0.6	0.6	0.6
4	**Temp Seasonality (C of V) %**	0.7	0.7	0.7	0.7	0.7
5	**Max Temp Warmest Period (week) °C**	35.5 °C	0.9 °C	1.2 °C	2.2 °C	4.0 °C
6	**Min Temp Coldest Period (week) °C**	16.8 °C	0.8 °C	1.0 °C	1.9 °C	3.4 °C
7	**Temp Annual Range °C**	18.7 °C	0.1 °C	0.2 °C	0.3 °C	0.6 °C
8	**Mean Temp Wettest Quarter °C**	28.5 °C	0.9 °C	1.1 °C	2.1 °C	3.7 °C
9	**Mean Temp Driest Quarter °C**	24.6 °C	0.9 °C	1.1 °C	2.3 °C	5.0 °C
10	**Mean Temp Warmest Quarter**	29.6 °C	0.9 °C	1.1 °C	2.2 °C	3.8 °C
11	**Mean Temp**	24.5 °C	0.9 °C	1.1 °C	2.1 °C	3.7 °C

	Coldest Quarter					
12	**Annual Precipitation**	1463 mm	-7 %	-9 %	-17 %	-29 %
13	**Precipitation Wettest Period**	87 mm	-1 %	-1.5 %	-2.5 %	-3.0 %
14	**Precipitation driest period mm**	0	0	0	0	0
15	**Precipitation Seasonality %**	111	117	119	127	141
16	**Precipitation Wettest Quarter**	979 mm	-3.2 %	-4.0 %	-7.6 %	-13.3 %
17	**Precipitation Driest Quarter**	5mm	-84 %	-98 %	-100 %	-100 %
18	**Precipitation Warmest Quarter**	420 mm	-12.8 %	-15.9 %	-28.6 %	-46.4 %
19	**Precipitation Coldest Quarter**	6 mm	-72 %	-77 %	-83 %	-88 %
20	**Annual Mean Radiation**	21 J/m^2	0.0 %	1 %	2 %	4 %
21	**Highest Radiation Period (week)**	25 J/m^2	4 %	4 %	8.5 %	11.2 %
22	**Lowest Radiation Period (week)**	18 J/m^2	0	0	0	0
23	**Radiation Seasonality**	8.9	9.7	9.9	10.9	12.1
24	**Radiation Wettest Quarter**	20 J/m^2	0	0	1 %	2 %
25	**Radiation Driest Quarter**	20 J/m^2	- 1.0 %	-1.6 %	-2.4 %	-6.4 %
26	**Radiation Warmest Quarter**	23 J/m^2	2.0 %	2.5 %	4.9 %	7.9 %
27	**Radiation Coldest Quarter**	20 J/m^2	0	0	1.0 %	1.2 %
28	**Annual Mean SMI**	0.49	-7.6 %	-9.2 %	-15.9 %	-26.2 %
29	**Highest Period (week) SMI**	1.0	0 %	0 %	0 %	0 %

30	**Lowest Period (week) SMI**	0	0 %	0 %	0 %	0 %
31	**SMI Seasonality**	88	96	98	106	120
32	**SMI Highest Quarter**	1	0 %	0 %	0 %	0 %
33	**SMI Lowest Quarter**	0.01	0 %	0 %	0 %	0 %
34	**SMI Warmest Quarter**	0.52	-13 %	-17 %	-31 %	-52 %
35	**SMI Coldest Quarter**	0	0 %	0 %	0 %	0 %

IBRA 42 Wet Tropics

The Wet Tropics region, which encompasses Cairns, is projected to become warmer and drier during the driest and coldest quarters (Table 6). Precipitation is projected to decline by 22% under the worst case scenario (A1FI by 2080s) but with little reduction (3.9 %) during the wettest quarter. Warming is projected for the means, minimums and maximums of the temperature variables, resulting in little or no change in projected mean diurnal temperature range and temperature seasonality. Mean annual solar radiation is projected to increase slightly (up to 4%) by the 2070s. The annual mean soil moisture index is projected to decline by 28% by 2070s under A1FI with the index declining by 12% (from 0.88) during the warmest quarter and 50% (from 0.8) during the coldest quarter.

Table 2 Projections for IBRA 42 Wet Tropics. Isothermality and seasonality (temperature, precipitation, radiation and Soil Moisture Index (SMI)) the actual projected values are given. All other projected values are absolute change or percent change.

Variable Number	**Variable Name**	**Baseline**	**A1B**	**A1FI**	**A1B**	**A1FI**
			Change 2030		**Change 2070**	
1	**Annual Mean Temp °C**	22.6 °C	0.8 °C	1.1 °C	2.0 °C	3.6 °C
2	**Mean Diurnal Range °C**	9.1 °C	0.1 °C	0.1 °C	0.2 °C	0.3 °C
3	**Isothermality**	0.5	0.5	0.5	0.5	0.5
4	**Temp Seasonality (C of V) %**	0.9	0.9	0.9	0.9	0.9
5	**Max Temp Warmest Period (week) °C**	30.6 °C	0.9 °C	1.2 °C	2.2 °C	3.9 °C
6	**Min Temp Coldest Period (week) °C**	13.2 °C	0.7 °C	0.9 °C	1.8 °C	3.1 °C
7	**Temp**	17.3 °C	0.2 °C	0.2 °C	0.5 °C	0.8 °C

	Annual Range °C					
8	**Mean Temp Wettest Quarter °C**	25.2 °C	0.9 °C	1.2 °C	2.2 °C	3.9 °C
9	**Mean Temp Driest Quarter °C**	20.1 °C	1.0 °C	1.3 °C	2.5 °C	3.5 °C
10	**Mean Temp Warmest Quarter**	25.7 °C	0.9 °C	1.1 °C	2.1 °C	3.7 °C
11	**Mean Temp Coldest Quarter**	18.7 °C	0.8 °C	1.0 °C	2.0 °C	3.4 °C
12	**Annual Precipitation**	2040 mm	-5 %	-7 %	-13 %	-22 %
13	**Precipitation Wettest Period**	111 mm	8 %	10 %	20 %	35 %
14	**Precipitation driest period mm**	7.8 mm	-25 %	-36 %	-69 %	-96 %
15	**Precipitation Seasonality %**	84	93	95	107	132
16	**Precipitation Wettest Quarter**	1136 mm	0 %	0 %	0 %	1 %
17	**Precipitation Driest Quarter**	129 mm	-15 %	-19 %	-36 %	-57 %
18	**Precipitation Warmest Quarter**	940 mm	2 %	3 %	5 %	8 %
19	**Precipitation Coldest Quarter**	164 mm	-13 %	-17 %	-32 %	-50 %
20	**Annual Mean Radiation**	19 J/m^2	1 %	1 %	2 %	4 %
21	**Highest Radiation Period (week)**	25 J/m^2	1 %	1 %	3 %	8 %
22	**Lowest Radiation Period (week)**	14 J/m^2	1 %	2%	3 %	4 %
23	**Radiation Seasonality**	18.0	18.4	18.5	19.1	20.1
24	**Radiation Wettest Quarter**	19 J/m^2	0	0	1 %	3 %
25	**Radiation Driest**	19 J/m^2	3 %	4 %	7 %	6 %

	Quarter					
26	**Radiation Warmest Quarter**	20 J/m^2	0 %	0 %	0 %	2 %
27	**Radiation Coldest Quarter**	16 J/m^2	1 %	1 %	2 %	2 %
28	**Annual Mean SMI**	0.77	-6 %	-8 %	-15 %	-28 %
29	**Highest Period (week) SMI**	1.0	0 %	0 %	0 %	0 %
30	**Lowest Period (week) SMI**	0.25	-11 %	-21 %	-57 %	-92 %
31	**SMI Seasonality**	36	43	45	56	75
32	**SMI Highest Quarter**	1	0 %	0 %	-1 %	-1 %
33	**SMI Lowest Quarter**	0.38	-10 %	-7 %	-36 %	-62 %
34	**SMI Warmest Quarter**	0.88	-2 %	-3 %	-7 %	-12 %
35	**SMI Coldest Quarter**	0.80	-14 %	-17 %	-30 %	-50 %

IBRA 20 Sydney Basin

Sydney Basin region, which encompasses the Hunter estuary, is projected to become warmer and drier (Table 7). Annual mean temperatures are projected in arm by 1.3-1.6°C by 2030s and 3.0-5.3°C by 2070s – a much greater warming than projected from Darwin Coastal or the Wet Tropics. Under the worst case scenario, A1FI, by the 2070s the mean diurnal range has expanded from 11.9°C to 12.8°C and the annual temperature range from 24.7°C to 26.8°C. The mean temperature of the warmest and coldest quarters are projected to warm by 5.2 and 4.7 °C by the 2070s under scenario A1FI and 3.0 and 2.6°C under A1B. The minimum temperature of the coldest week doubles by 2070 under A1FI. Mean annual solar radiation is projected to increase slightly (up to 3%) by the 2070s. The annual mean soil moisture index is projected to decline by 28% by 2070s under A1FI with the index declining by 12% (from 0.88) during the warmest quarter and 50% (from 0.8) during the coldest quarter.

Annual precipitation is projected to increase, by 26% by 2070s under A1FI however, there is no or little change in precipitation during the wettest quarter (2-3% by the 2070s) and warmest quarter (3-5% by the 2070s).

Table 3 Projections for IBRA 20 Sydney Basin. Isothermality and seasonality (temperature, precipitation, radiation and Soil Moisture Index (SMI)) the actual projected values are given. All other projected values are absolute change or percent change.

Variable Number	Variable Name	Baseline	A1B	A1FI	A1B	A1FI
			Change 2030		Change 2070	
1	**Annual Mean**	15.9 °C	1.3 °C	1.6 °C	3.0 °C	5.3 °C

	Temp °C					
2	**Mean Diurnal Range °C**	11.9 °C	0.2 °C	0.5 °C	0.3 °C	0.9 °C
3	**Isothermality**	0.5	0.5	0.5	0.5	0.5
4	**Temp Seasonality (C of V) %**	1.5	1.6	1.6	1.6	1.6
5	**Max Temp Warmest Period (week) °C**	28.2 °C	1.3 °C	1.6 °C	3.1 °C	5.5 °C
6	**Min Temp Coldest Period (week) °C**	3.4 °C	0.8 °C	1.0 °C	1.9 °C	3.4 °C
7	**Temp Annual Range °C**	24.7 °C	0.5 °C	0.6 °C	1.1 °C	2.1 °C
8	**Mean Temp Wettest Quarter °C**	20.1 °C	1.4 °C	1.7 °C	3.2 °C	5.5 °C
9	**Mean Temp Driest Quarter °C**	11.0 °C	1.1 °C	1.4 °C	2.9 °C	5.1 °C
10	**Mean Temp Warmest Quarter**	21.4 °C	1.2 °C	1.6 °C	3.0 °C	5.2 °C
11	**Mean Temp Coldest Quarter**	10.1 °C	1.1 °C	1.4 °C	2.6 °C	4.7 °C
12	**Annual Precipitation**	893 mm	-6 %	-8 %	-17 %	-26 %
13	**Precipitation Wettest Period**	27 mm	4 %	4 %	9 %	18 %
14	**Precipitation driest period mm**	10 mm	-21 %	-29 %	-70 %	-98 %
15	**Precipitation Seasonality %**	28	35	37	49	71
16	**Precipitation Wettest Quarter**	307 mm	0 %	0 %	2 %	3 %
17	**Precipitation Driest Quarter**	153 mm	-20 %	-27 %	-52 %	-90 %
18	**Precipitation Warmest Quarter**	282 mm	1 %	1 %	3 %	5 %
19	**Precipitation Coldest Quarter**	166 mm	-15 %	-18 %	-34 %	-61 %

20	**Annual Mean Radiation**	17 J/m^2	2 %	2 %	2 %	3 %
21	**Highest Radiation Period (week)**	25 J/m^2	1 %	2 %	3 %	6 %
22	**Lowest Radiation Period (week)**	9 J/m^2	0 %	0 %	0 %	1 %
23	**Radiation Seasonality**	33.4	33.0	32.9	32.6	32.1
24	**Radiation Wettest Quarter**	20 J/m^2	0	0	1 %	2 %
25	**Radiation Driest Quarter**	12 J/m^2	8 %	10 %	16 %	23 %
26	**Radiation Warmest Quarter**	23 J/m^2	0 %	0 %	0 %	0 %
27	**Radiation Coldest Quarter**	10 J/m^2	1 %	1 %	3 %	5 %
28	**Annual Mean SMI**	0.64	-9 %	-11 %	-23 %	-41 %
29	**Highest Period (week) SMI**	0.86	-6 %	-8 %	-16 %	-26 %
30	**Lowest Period (week) SMI**	0.32	-11 %	-21 %	-57 %	-92 %
31	**SMI Seasonality**	26	26	27	31	49
32	**SMI Highest Quarter**	0.83	-7 %	-9 %	-20 %	-33 %
33	**SMI Lowest Quarter**	0.43	-5 %	-9 %	-25 %	-70 %
34	**SMI Warmest Quarter**	0.47	0 %	0 %	-3 %	-6 %
35	**SMI Coldest Quarter**	0.82	-8 %	-11 %	-25 %	-52 %

Coastal inundation

Of the three case study regions, IBRA 20 (Wet Tropics) has very low baseline inundation of coastal region (19km^2 of 7063km^2 or 0.3%). The inundated area is projected to rise to 162km^2 (2.3%) under 2100max. IBRA 20 (Sydney Basin) also has a relatively low baseline inundation (83km^2 of 5566km^2 or 1.5%) and this is projected to rise to 194km^2 or 3.5% under 2100max. IBRA 79 (Darwin Coastal) has the largest baseline inundation (360km^2 of 12,124km^2 or 3%) and this is projected to increase to 1,264km^2 or 10.4% under 2100max. The % inundation of each cell in a 5km coastal grid for the three case study regions was also plotted under the baseline 2009

scenarios and the three future scenarios (Fig. 14-16). For all regions, the extent inundated is greater by 2100 then 2030.
Previous analyses (Taranto 2009) of the projected inundations by priority ecosystems relevant to the three case study areas is given in Table 10. The inundated areas of Kakadu and the Wet Tropics of Queensland priority coastal hotspot, Ramsar wetlands and world heritage areas are projected to increase by 55% at least by 2030. Considerable increases in inundated areas (66% or greater) are projected by 2100 compared to 2009 inundation for all ecosystems (Fig. 17).

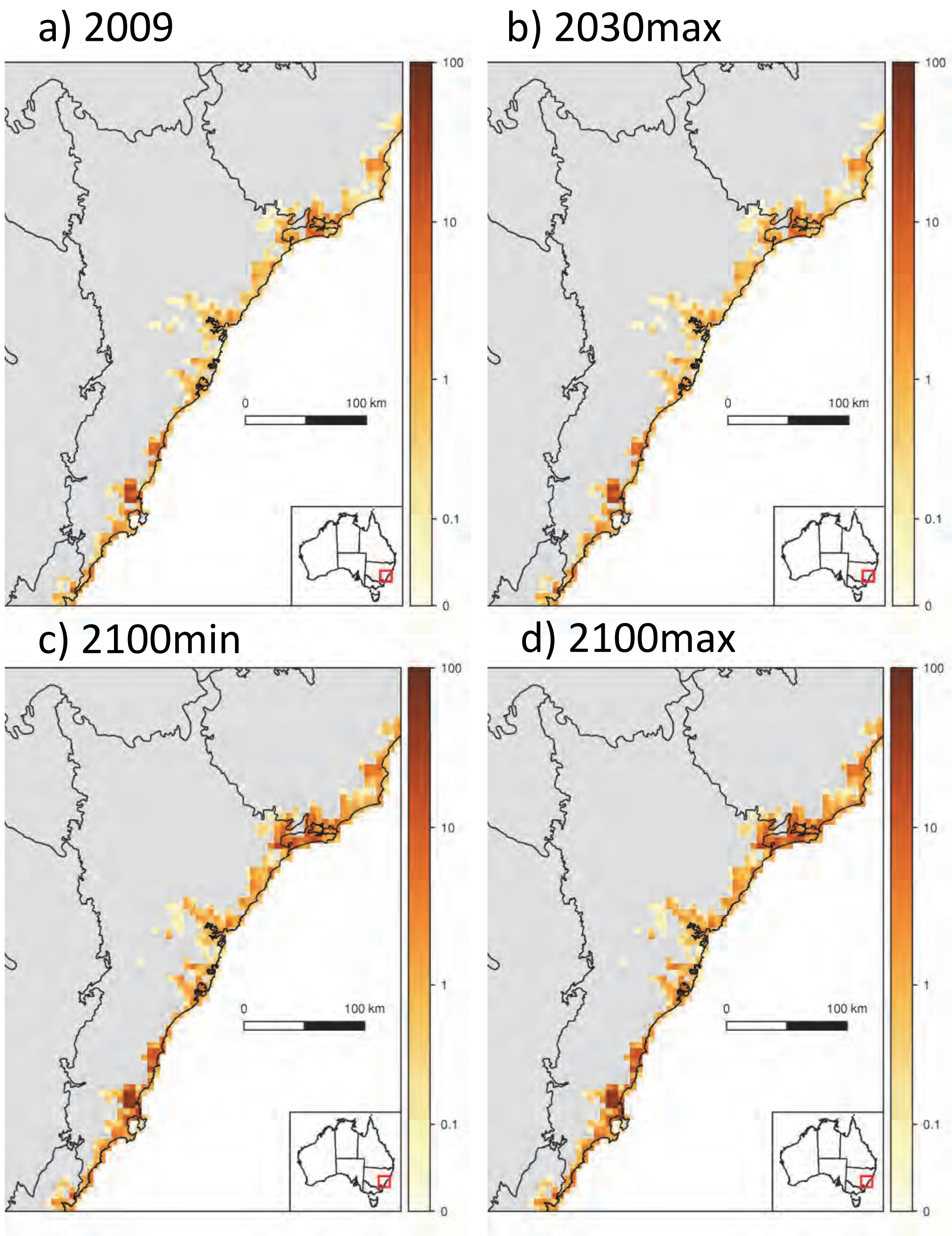


Figure 1 % inundation of each 5km coastal grid cell in IBRA region 20: Sydney Basin.

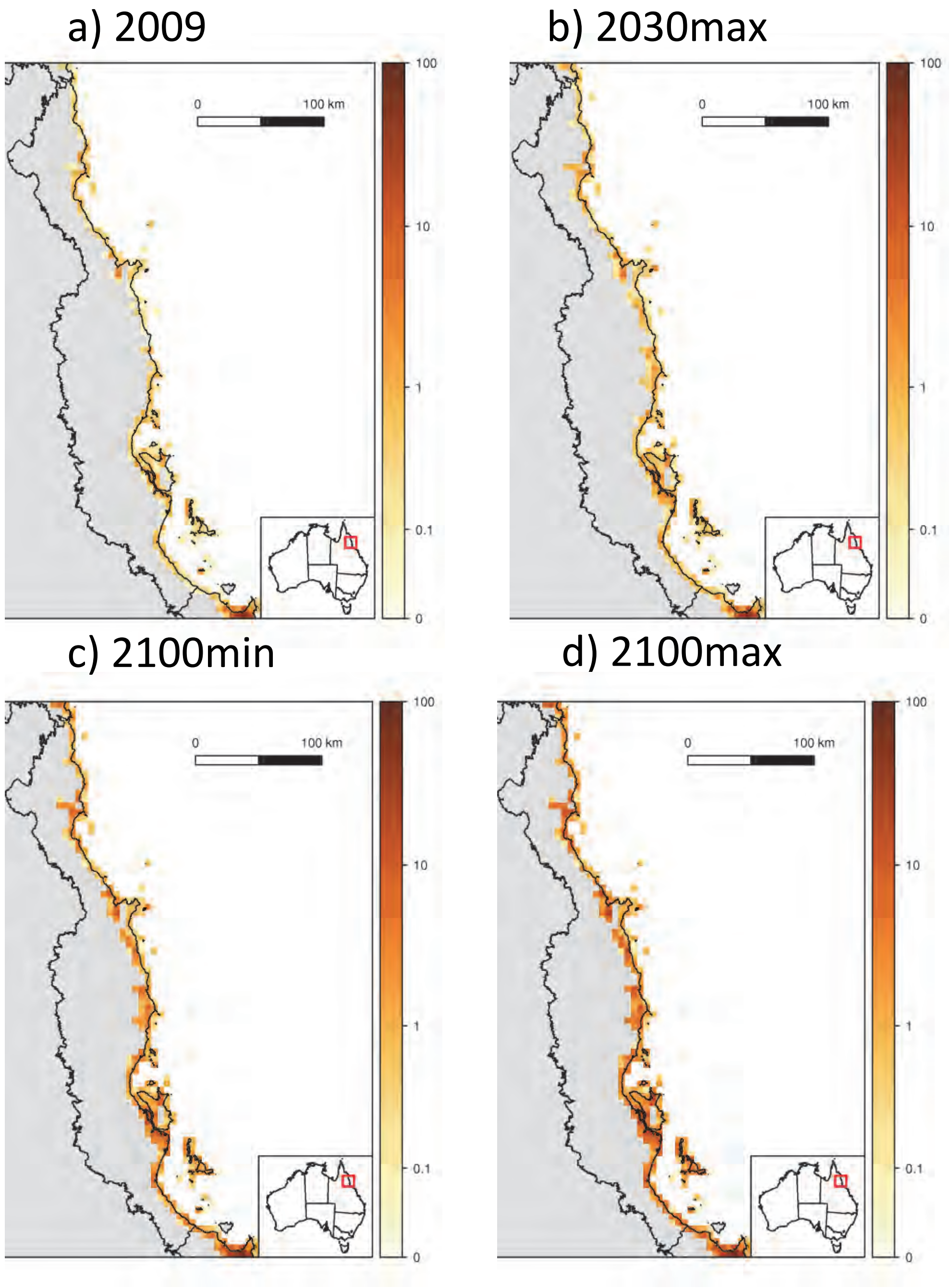


Figure 2 % inundation of each 5km coastal grid cell in IBRA region 42: Wet Tropics

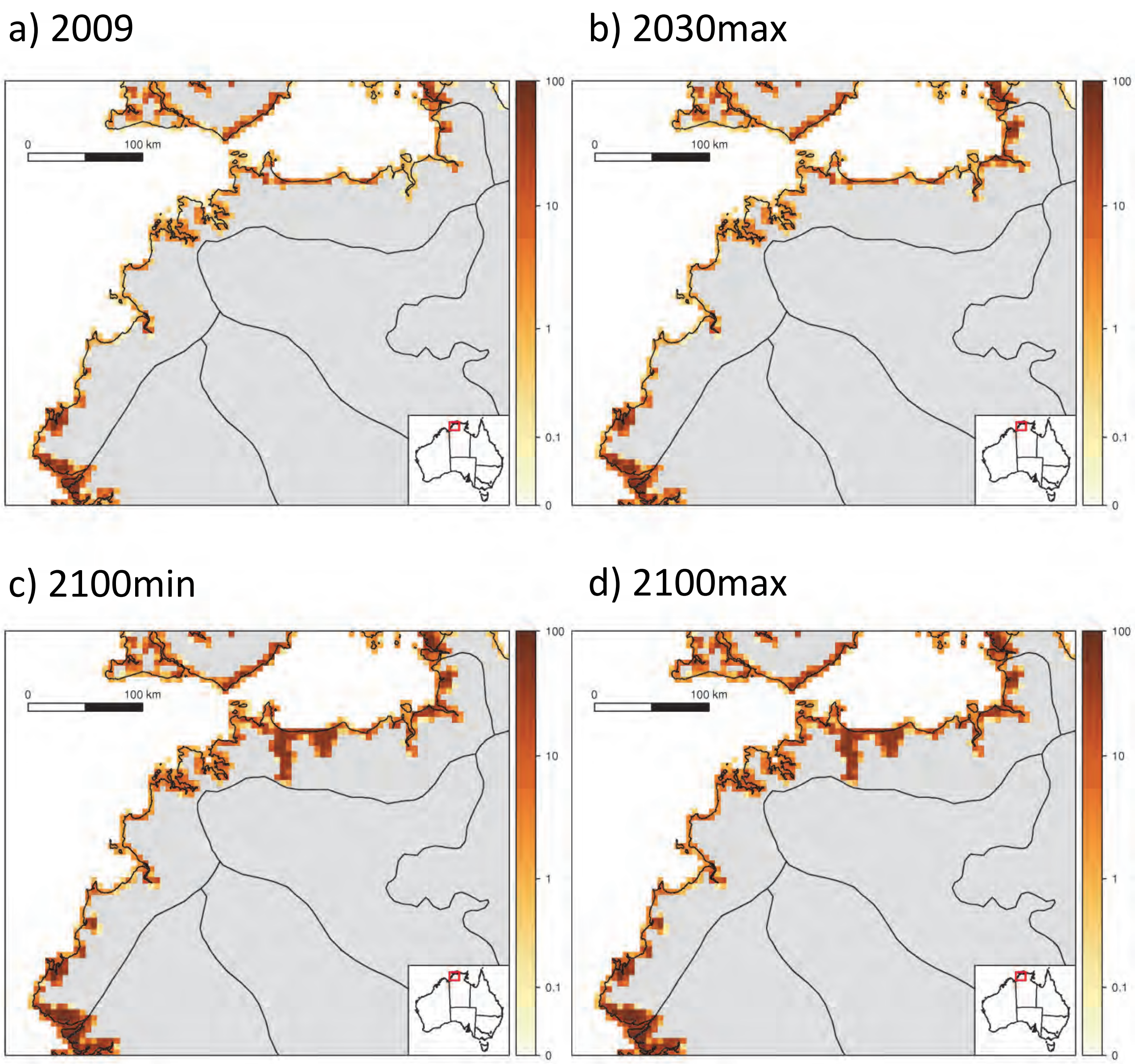


Figure 3 % inundation of each 5km coastal grid cell in IBRA region 79: Darwin Coastal

Table 4. Size of priority coastal ecosystems in the three case study regions (Hunter estuary, Kakadu and Cairns), baseline (2009) inundation and projected inundation (size and % change from baseline inundation) under three future scenarios. pci = priority coastal hotspot, Ramsar = Ramsar wetland, wh = world heritage area.

			Inundation			
Name	Priority designation	Area km^2	2009 km^2	2030 max km^2	2100min km^2	2100max km^2
Hunter Estuary	pci	21445.50	6.02	6.08 (1%)	33.00 (82%)	33.73 (83%)
Hunter Estuary Wetlands	ramsar	33.92	1.36	1.36 (0%)	3.98 (66%)	4.01 (67%)

Kakadu National Park	wh 19125.70		12.51	61.21 (80%)	108.52 (88%)	114.34 (89%)
Kakadu National Park (Stage II)	ramsar 6385.34		9.60	40.95 (77%)	82.49 (88%)	87.83 (89%)
Kakadu National Park (stage I) including wetland components of Stage III	ramsar 12559.83		2.68	19.88 (87%)	25.65 (89%)	26.13 (90%)
Wet tropics of Queensland	wh 8938.29		3.54	7.83 (55%)	22.21 (84%)	42.09 (92%)

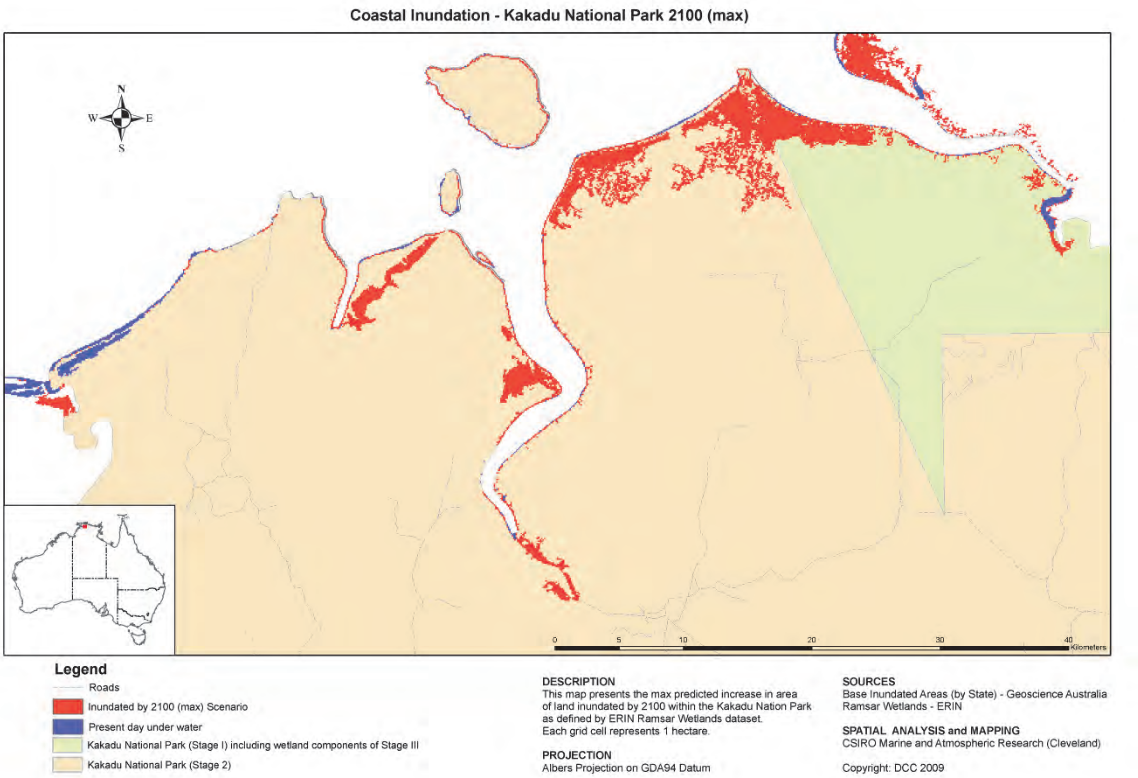


Figure 4 Area of Kakadu Ramsar wetlands inundated under baseline inundation scenario (2009; blue regions) and additional inundation projected under inundation scenario 2100max (red areas) from Taranto 2009.

Sea surface temperature, salinity and pH

Kakadu and Darwin region

Sea surface temperatures are projected to warm by 0.6-0.9°C by 2030 and 1.5-2.9°C by 2070 under scenarios A1B and A1FI (Table 19 and 20).

Table 5 Change in mean annual sea surface temperatures (°C) and mean spring, summer, autumn and winter sea surface temperatures (°C) compared to 1990 baseline for Kakadu and Darwin marine waters. 10th, 50th and 90th percentiles output from 11 general circulation models under scenario A1B and A1FI projected to 2030 and 2070 given.

	2030			2070		
Scenario	10th	50th	90th	10th	50th	90th
Sea Surface Temperature A1B						
Annual	0.6	0.7 0.9 1.5	1.7 2.1			
Spring	06	0.7 0.8 1.4	1.6 2.0			
Summer	0.6	0.7 0.8 1.6	1.7 2.4			
Autumn	0.7	0.7 1.0 1.6	1.7 2.4			
Winter	0.6	0.7 0.8 1.4	1.6 2.0			
Sea Surface Temperature A1FI						
Annual	0.6	0.7 0.9 2.0	2.3 2.9			
Spring	06	0.7 0.8 1.9	2.2 2.7			
Summer	0.6	0.7 1.0 2.1	2.2 3.2			
Autumn	0.7	0.7 1.0 2.1	2.3 3.2			
Winter	0.6	0.7 0.8 1.9	2.2 2.7			

Table 6 Change in mean annual sea surface salinity (g/l) and mean spring, summer, autumn and winter sea surface salinities (g/l) compared to 1990 baseline for Kakadu and Darwin marine waters from 3 general circulation models under scenario A1B and A1FI projected to 2030 and 2070.

	2030			2070		
	GISS	Miroc H	Miroc M	GISS	Miroc H	Miroc M
Sea Surface Salinity A1B						
Annual	-0.23	0.06 0.06 -0.54			0.15 0.15	
Summer	-0.21	0.09 0.03 -0.50			0.21 0.08	
Winter	-0.24	0.04 0.09 -0.56			0.09 0.22	
Sea Surface Salinity A1FI						
Annual	-0.22	0.06 0.06 -0.74			0.21 0.20	
Summer	-0.20	0.08 0.03 -0.68			0.28 0.10	
Winter	-0.23	0.04 0.09 -0.77			0.12 0.29	

Wet Tropics

Sea surface temperatures are projected to warm by 0.5-0.9°C by 2030 and 1.1-2.8°C by 2070 under scenarios A1B and A1FI (Table 13).

Table 7 Change in mean annual sea surface temperatures (°C) and mean spring, summer, autumn and winter sea surface temperatures compared to 1990 baseline for Cairns marine waters. 10th, 50th and 90th percentiles output from 11 general circulation models under scenario A1B and A1FI projected to 2030 and 2070 given.

	2030			2070		
Scenario	10th	50th	90th	10th	50th	90th
Sea Surface Temperature A1B						
Annual	0.5	0.7 0.9 1.2	1.6 2.0			
Spring	0.5	0.7 0.8 1.1	1.6 1.9			
Summer	0.6	0.7 0.8 1.4	1.6 2.0			
Autumn	0.5	0.6 0.9 1.4	1.7 2.0			
Winter	0.5	0.6 0.9 1.1	1.5 2.1			

Sea Surface Temperature A1FI						
Annual	0.5	0.6 0.8 1.7	2.2 2.8			
Spring	0.5	0.7 0.8 1.5	2.2 2.6			
Summer	0.6	0.7 0.8 1.8	2.3 2.8			
Autumn	0.6	0.7 0.8 1.9	2.2 2.8			
Winter	0.4	0.6 0.9 1.5	2.1 2.8			

Table 8 Change in mean annual sea surface salinity (g/l) and mean spring, summer, autumn and winter sea surface salinities (g/l) compared to 1990 baseline for Cairns marine waters from 3 general circulation models under scenario A1B and A1FI projected to 2030 and 2070.

2030				2070		
	GISS	Miroc H	Miroc M	GISS	Miroc H	Miroc M
Sea surface salinity A1B						
Annual	-0.09	-0.06 0.07		-0.22	-0.14 0.16	
Summer	-0.10	-0.04 0.10		-0.23	-0.10 0.23	
Winter	-0.08	-0.07 0.04		-0.20	-0.16 0.11	
Sea surface salinity A1FI						
Annual	-0.09	-0.06 0.07		-0.31	-0.19 0.22	
Summer	-0.10	-0.04 0.10		-0.32	-0.13 0.32	
Winter	-0.08	-0.07 0.04		-0.27	-0.22 0.15	

Hunter Estuary Region

Sea surface temperatures are projected to warm by 0.5-0.9°C by 2030 and 1.1-2.8°C by 2070 under scenarios A1B and A1FI (Table 15).

Table 9. Change in mean annual sea surface temperatures and mean spring, summer, autumn and winter sea surface temperatures compared to 1990 baseline for marine coastal waters in the Hunter estuary region. 10th, 50th and 90th percentiles output from 11 general circulation models under scenario A1B and A1FI projected to 2030 and 2070 given.

2030				2070		
Scenario 10	th 50	th 90	th 10	th 50	th 90	th
Sea Surface Temperature A1B						
Annual	0.7	0.8 0.9 1.7	1.9 2.2			
Spring	0.7	0.8 0.9 1.7	1.9 2.2			
Summer	0.7	0.8 0.9 1.4	2.0 2.3			
Autumn	0.7	0.8 0.9 1.7	1.9 2.0			
Winter	0.7	0.8 0.9 1.6	1.8 2.2			
Sea Surface Temperature A1FI						
Annual	0.7	0.8 0.9 2.3	2.6 3.0			
Spring	0.7	0.8 0.9 2.3	2.6 3.0			
Summer	0.6	0.8 0.9 1.8	2.6 3.1			
Autumn	0.7	0.8 0.9 2.3	2.6 2.8			
Winter	0.7	0.7 0.9 2.2	2.5 3.0			

Table 10 Change in mean annual sea surface salinity (g/l) and mean spring, summer, autumn and winter sea surface salinities (g/l) compared to 1990 baseline for marine waters around the Hunter Estuary from 3 general circulation models under scenario A1B and A1FI projected to 2030 and 2070.

2030				2070		
	GISS	Miroc H	Miroc M	GISS	Miroc H	Miroc M
Sea Surface Salinity A1B						
Annual	0.01	-0.01 0.10		0.02	-0.03 0.23	
Summer	0.01	-0.02 0.09		0.02	-0.06 0.21	
Winter	0.01	0.00 0.10 0.02			0.00 0.25	
Sea Surface Salinity A1FI						
Annual	0.01	-0.01 0.10		0.02	-0.04 0.32	
Summer	0.01	-0.02 0.08		0.03	-0.08 0.28	
Winter	0.01	0.00 0.10 0.02			-0.01	0.34

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