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Silva Larson, Norman Duke, Petina Pert, April Reside, Natalie Stoeckl, Dagmar Meyer Steiger

CLIMATE CHANGE IN AUSTRALIA

IMPACTS & ADAPTATION INFORMATION FOR AUSTRALIA'S NRM REGIONS

An Australian Government Initiative

CLIMATE CHANGE ISSUES AND IMPACTS IN THE WET TROPICS NRM CLUSTER REGION

A PRODUCT OF THE PROJECT "KNOWLEDGE TO MANAGE LAND AND SEA: A FRAMEWORK FOR THE FUTURE", A COLLABORATION BETWEEN JAMES COOK UNIVERSITY AND THE CSIRO.

David W. Hilbert[a.b,c,1,3], Rosemary Hill[a,b,2,3], Catherine Moran[a,b,1,3], Stephen M. Turton[a,b,3], Iris C. Bohnet[b,2,3], Nadine A. Marshall[b,4], Petina L. Pert[b,2], Natalie Stoeckl[b,5,6], Helen T. Murphy[c,1], April E. Reside[c,7], Susan G. W. Laurance[c,8], Mohammed Alamgir[3], Rob Coles[9], Gabriel Crowley[6], Matt Curnock[4], Allan Dale[6], Norman C. Duke[9], Michelle Esparon[6], Marina Farr[5], Sarah Gillet[4],Margaret Gooch[9], Mariana Fuentes[7], Mark Hamman[7], Cassandra S. James[9], Frederieke J. Kroon[1], Silva Larson[5], Pethie Lyons[2], Helene Marsh[7], Dagmar Meyer Steiger[8] , Marcus Sheaves[10] & David A. Westcott[1,3]

a – report editor
b – chapter coordinator
c – section coordinator
1 – CSIRO Ecosystem Sciences, Tropical Forest Research Centre, Atherton, Queensland
2 – CSIRO Ecosystem Sciences, Cairns, Queensland
3 – School of Earth and Environmental Sciences, James Cook University, Cairns, Queensland
4 – CSIRO Ecosystem Sciences, Townsville, Queensland
5 – School of Business, James Cook University, Townsville, Queensland
6 – The Cairns Institute, James Cook University, Cairns Queensland
7 – School of Earth & Environmental Sciences, James Cook University Townsville, Queensland
8 – School of Marine & Tropical Biology, James Cook University, Cairns, Queensland
9 – Centre for Tropical Water and Aquatic Ecosystems Research, James Cook University, Townsville, Queensland
10 – School of Marine & Tropical Biology, James Cook University, Townsville, Queensland

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Rationale and scope

Stream 2 of the Regional NRM Planning for Climate Change Fund supports the project "Knowledge to manage land and sea: A framework for the future" run by a consortium of scientists from James Cook University (JCU) and CSIRO. This report is the first major product of the consortium project. It is not an in-depth review of the literature that already exists for some NRM sectors. Rather, it is syntheses of current knowledge through expert opinion about the threats and potential impacts of climate change in the Wet Tropics Cluster (WTC) region across all sectors. This report focuses on four geographically distinct NRM regions grouped in the WTC: Mackay-Whitsunday, Wet Tropics, Cape York, and the Torres Strait regions, which are managed by Reef Catchments NRM, Terrain NRM, Cape York NRM, and the Torres Strait Regional Authority respectively.

The report is framed by the specific topics and issues defined by the NRM groups in the WTC region, reflecting their planning processes and priorities of these groups as well as the characteristics of their regional communities.

The focus of this report is on possible impacts and threats, not adaptation options that will be discussed in a future report. Chapter 9 discusses the science of adaptation in a general sense and mitigation opportunities relating to carbon storage are discussed in a section of Chapter 6.

The report presents key messages around each topic and issue in bold type in each chapter. Key messages for NRM groups are also summarised at the beginning of each chapter. These key messages represent our syntheses of expected threats and impacts based on expert opinion but also substantiated by published sources. Each key message is followed by a brief explanation of the underlying scientific support with a small number of key citations to the relevant literature. In most cases there is a fair amount of uncertainty associated with the key messages and they should be understood as best estimates based on expert opinion.

Much of the uncertainty about potential impacts is due to the climate model uncertainty about changes in rainfall amount and timing that are critical variables that will influence many sectors in the WTC region. Another source of uncertainty for some topics and issues is limited or lack of direct research on climate change impacts across several of the key NRM sectors in the WTC region.

The main conclusions and summaries for each synthesis chapter (by NRM sector) are presented below with a final chapter on adaptation science.

Chapter 2: Climate change projections for the Wet Tropics cluster

- This chapter discusses the latest climate projections for key climate variables for the WTC region, including air and sea surface temperatures, annual and seasonal rainfall, changes in sea level, extreme events (e.g. cyclones, floods and droughts) and other climatic variables that are important for NRM (e.g. fire weather). Interim results from the new set of global coordinated climate modelling experiments, the *Climate Model Intercomparison* Project 5 (CMIP5), have been assessed by CSIRO and the Bureau of Meteorology and are presented here together with relevant climate change projections research from other published sources, including the Intergovernmental Panel for Climate Change (IPCC's) 4th and 5th Assessment Reports.

- Material presented in this chapter provides a climate science basis for the other chapters that focus on climate change issues and impacts across different NRM sectors in the WTC region, e.g. biodiversity, ecosystem services, infrastructure, industry, social issues and Indigenous communities.
- The WTC region may expect significant changes in its climate this century and NRM organisations will need to incorporate the latest climate science knowledge and data into their adaptive management and planning systems.

Chapter 3: Potential changes in biodiversity

- This chapter discusses the potential impacts of climate change on the biodiversity of the WTC region under a number of topics identified by the NRM groups: vegetation communities and ecosystems; freshwater and tidal wetlands; fringing reefs; abundance and distribution of key species (including cassowaries); freshwater biodiversity; marine turtles and dugongs; invasive species; infectious diseases and pathways; and biodiversity and disease.
- There will be substantial impacts on the region's ecosystems and biodiversity that will increase as climate changes continue into the future.
- Vegetation and ecosystems throughout the region are likely to be affected substantially by warming, changes in water balance and fire weather, increased cyclone intensities and sea level rise. There is a high degree of confidence that these stresses will change the landscape substantially in the future, although the rate of change and specific, regional vegetation changes are difficult to predict with certainty at this time. The appearance of environments unlike those of today could eventually result in new plant communities and vegetation structures.
- Many vertebrate species are predicted to lose suitable climate space from Cape York and the Wet Tropics bioregions, including amphibians, birds, mammals and reptiles. However, while some species will be losing climate space in these bioregions, other species will be moving in from elsewhere, particularly moving from the west towards the Wet Tropics and the Mackay-Whitsundays.
- Species vulnerability to climate change is likely to be determined by their ability to disperse to new areas of suitable climate. Endemic species are likely to have higher vulnerability to climate change due to high specificity for habitat requirements. Climate change will reduce the extent and the quality of cassowary habitat with consequent reductions in the distribution and size of cassowary populations.
- Across the WTC region, the diversity, distribution and abundance of invasive species is increasing independent of climate change; however, the direct and indirect effects of climate change are very likely to exacerbate the spread and impact of invasive species as well as allow opportunities for new species to invade. In combination with climate change,

invasive species are expected to contribute to interacting processes or ‘threat syndromes’ that could precipitate major environmental change and consequent impacts on biodiversity.

- The direct and indirect effects of climate change are very likely to exacerbate the spread and impact of invasive species as well as allowing opportunities for new species to invade. In combination with climate change, invasive species are expected to contribute to interacting processes or ‘threat syndromes’ that could precipitate major environmental change and consequent impacts on biodiversity.
- Emerging and existing diseases might be facilitated by climate change that causes an expansion of habitats and climate that favour vectors, change host-parasite ecology and increases disease outbreaks.
- The broad message from this chapter is that natural resource managers and their stakeholders cannot take for granted that the ecosystems and biodiversity in their regions will be the same in the future or that change can be entirely prevented. Future biodiversity management plans will need to allow for substantial changes in biodiversity despite the unpredictable nature of some of these changes.

Chapter 4: The impacts of climate change on key regional ecosystem services

- This chapter discusses insights about the impacts of climate change on regional ecosystem services for the WTC region. Climate change alters the functions of ecosystems and as a result, the provision of ecosystem services and wellbeing of people that rely on these services. The concept of ecosystem services is aimed at supporting this broad and open dialogue in ways that allow potential synergies and trade-offs among social, economic and ecological objectives to be identified and addressed with due reference to the multiple perceptions that people have about benefits and beneficiaries from the environment.
- Ecosystems, and the biodiversity and ecosystem service they support, are intrinsically dependent on climate. There has been a major set of international studies that have developed the concept of ecosystem services globally, which primarily have included the Millennium Ecosystem Assessment (MA), The Economics of Ecosystems and Biodiversity (TEEB), and now the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES).
- WTC region NRM managers need to build on past assessments and approaches of how climate change affects ecosystems in Australia, as well as around the world. An ecosystem services-based approach to NRM management should be adopted that takes into account the contribution of ecosystems to the livelihoods of primary stakeholders, resource users and local communities. NRM management plans should be based on principles of ecosystem service assessment that enables the combination of a biodiversity, economics and livelihoods analysis across different disciplines and sectors.
- Proponents of an ecosystem stewardship approach suggest that an ecosystem or species-only focus is not sufficient to prepare coupled ecological and social systems for climate change in the next few decades and beyond. Attention needs to be paid to the interactions between social and ecological systems, including governance and other institutional components.
- The primary role of the natural resource manager (in the WTC region) is to facilitate and engage stakeholder groups to respond to, and shape, socio-ecological change and nurture

resilience to impacts of climate change. It is not about whether ecosystems services are considered, but more about what processes are used to anticipate and prepare for future needs for services and future ability of ecosystems to meet those needs.

Chapter 5: The impacts of climate change on infrastructure

- This chapter discusses potential impacts of climate change on infrastructure that is critical to maintaining sustainable NRM systems: water supply, the generation and transmission of electric power, transport and freight distribution, telecommunications, the management of sewage, stormwater, solid and hazardous wastes, and access to housing, hospitals and schools.
- Vulnerability to the impacts of climate change on infrastructure is very high in the WTC region. In general, the biggest direct risk to infrastructure from climate change is likely to be from sea level rise in coastal areas, although other climate-induced changes (e.g. severe tropical cyclones, storm surges, heavy rain events, heat waves) will also be important. These impacts will compound an existing deficit in the provision and maintenance of infrastructure throughout the region, partly due to remoteness, low population densities and extremes of tropical climate and weather.
- The State Government has considerable responsibility for the provision and maintenance of large-scale public infrastructure, yet climate change impacts such as sea level rise are not mentioned in recent documents that discuss current or planned major infrastructure developments in the region. Dealing with the impacts of climate change on infrastructure will require the involvement of many different agencies and scales.

Chapter 6: Potential impacts of climate change on industries

- This chapter discusses the impacts of climate change on key NRM industries within the WTC region: tourism; grazing; cropping, horticulture and forestry; fishing; and mining. A section is also devoted to evaluating emerging NRM opportunities for the WTC region, e.g. payments for carbon abatement projects.
- The agriculture, tourism and mining industries – all of which are crucially dependent upon the region's natural resources – sustain the private sector in this area. Climate change is likely to have a profound effect upon the region's natural resources and may thus, by extension, have a profound effect upon these industries and the region's economy.
- The most significant changes are likely to be associated with extreme events – impacting the tourism, grazing, cropping, horticulture, fishing and mining industries. With the exception of mining, all of these industries are also susceptible to increased risk of diseases, pests and weeds. Increased temperatures, higher evaporation rates, more CO2 and altered rainfall patterns will all affect crop productivity thus impacting the grazing and horticulture industry, but they affect productivity in different ways, so the net impact of all three is not discernible *a priori*.
- Overall, business can expect more volatility in prices and in demand for products. We may also observe much wider variation in business outcomes across regions (e.g. those which are, or are not, affected by a particular extreme event). Average costs are likely to rise (with reduced access to finance, higher borrowing and insurance costs and possibly lower

productivity associated with altered pasture and crop growth, increased competition from pests and weeds, more disease and fire risk).
- There are emerging opportunities through carbon abatement opportunities, however:
    - The science, economics and policy of carbon are changing rapidly;
    - Current arrangement in Australia are highly dependent on government policy; and
    - Demonstrated co-benefits of increased agriculture productivity and profitability may be needed to increase adoption rates.

Chapter 7: Social impacts in the primary industries of the Wet Tropics Cluster

- This chapter discusses the social and economic impacts likely to be experienced by primary producers living and working within the WTC region and the industries to which they belong. Farmers, fishers and cattle producers in the WTC region are socially, economically and culturally dependent on natural resources. Resource condition can be affected by increases in temperature, changes in rainfall patterns and extreme weather events.
- Primary producers that are dependent on climate sensitive resources will be especially sensitive to increased climate variability, and are likely to experience a range of social and cultural impacts. The nature and extent of the dependency on natural resources will determine the nature and extent of the social, cultural and financial impacts experienced by producers and their industries.
- Psychological impacts are likely to be associated with extreme changes in resource condition that negatively affect the productivity of the land or sea. Primary producers that are unable to adapt to these changes and whose products become unviable will need to consider an alternative occupation. However, the occupational identity that can be created around primary production can be so significant that many producers will be unable to consider another occupation, and mental health issues will likely become apparent. In extreme cases mental health issues may result in elevated suicide rates and occurrences of domestic violence.
- Economic impacts are inevitable and likely to be severe in years of extreme climatic events. Economic opportunities may, however, be observable. Unemployment within rural regions may result from changes affecting the productivity of primary industries. Employment opportunities that do exist are in some cases likely to be secured by non-primary producers, where primary producers are less likely to have transferrable skill sets.
- Cultural impacts are likely to develop through a shift in the nature and sizes of primary production enterprises in the region. The tendency will be to move from lifestyle-based enterprises towards larger and more integrated corporate-style production enterprises.
- Climate adaptation planners within the WTC region will need to be aware of the likely impacts associated with climate change; however, while resource dependency (or sensitivity to change) may describe the likely impacts of climate change, adaptive capacity can be a major influence on what impacts actually eventuate. Recognising and enhancing adaptive capacity becomes increasingly important for resource-dependent industries facing significant climate change.

Chapter 8: Indigenous peoples: climate change impacts and issues

- This chapter focuses on three topics where particular characteristics of Indigenous societies warrant separate consideration of the climate change impacts and issues and is presented under three topics:
  1. Indigenous knowledge and climate change
  2. Indigenous communities and climate change
  3. Indigenous cultural practices and climate change.
- Australian Indigenous peoples have distinctive sources of both resilience and vulnerability to the impacts of climate change—resilience based on their unique knowledge, cultural practices and customary institutions, and vulnerability from their socio-economic and historical disadvantage. This vulnerability is heightened for some Indigenous due to their remoteness and the inhospitable and the fragile environments they occupy. Addressing climate change impacts and issues with Indigenous groups will necessarily engage the influence of colonial history on the present, the urgent socio-economic needs of contemporary communities and their aspirations for a better future.
- Indigenous ecological knowledge is important to strengthen understanding of climate change and provide the foundation for Indigenous adaptation strategies. Indigenous-driven knowledge recording that protects intellectual and cultural property rights is a key first step toward supporting Indigenous solutions for country. Many Indigenous groups are driving the development of innovative knowledge-recording approaches that reflect a trend towards hybridization, where traditional knowledge, practices, and beliefs are merged with novel technologies to create new knowledge systems that can negotiate interactions between scientific and Indigenous knowledge systems for bi-cultural adaptation strategies.
- Climate change will exacerbate current conditions of hardship experienced by Indigenous communities living on country. At the forefront are infrastructure related impacts on access to healthcare, fresh food, water and sanitation, and economic opportunities. Changed climate conditions such as heat waves will also exacerbate chronic health problems including asthma, diabetes, cardio-vascular and transferrable diseases.
- The impact of climate change will vary across Indigenous groups. Potentially climate change will introduce new opportunities for participation in local greenhouse gas mitigation projects such as carbon farming and pest and weed management. Others may find decreasing availability of resources such as bush tucker or ingredient materials for local economic enterprise. Indigenous engagement in natural resource management improves health and well-being outcomes, strengthening the argument for Indigenous management of country as a key part of NRM climate change adaptation. However, limited research has addressed consequences of changing climate for Indigenous societies, limiting the confidence in our understanding of the likely impacts on the physical, emotional, psycho-social and spiritual well-being of Indigenous communities.

Chapter 9: Adaptation science relevant to natural resource management practice

- This chapter provides a synthesis of key concepts and definitions related to adaptation planning for climate change. It does not include adaptation options or pathways for specific sectors or individuals; that information will be presented in a separate science report.

- The need for adaptation in the WTC region is urgent; in particular from local to regional scales, since climate and other drivers of change pose significant risks to people, industries and the environment in the region. Ideally, adaptation approaches should to be supported by concerted and cross-sectoral adaptation strategies that fit into a broader framework of sustainable development and fit in with the values associated with the region.
- Close collaboration of scientists, practitioners, decision-makers, policy analysts, and the people likely to experience climate change impacts and needing to adapt would be advantageous in the adaptation planning process.
- Participatory scenario planning is a method and process that has been identified to support collaboration, learning and building of adaptive capacity and community resilience. Building of adaptive capacity across scales and sectors will be critical for effective adaptation.

Chapter 1: Introduction

David W. Hilbert, Rosemary Hill, Catherine Moran and Stephen Turton

Stream 2 of the Regional NRM Planning for Climate Change Fund supports the project "Knowledge to manage land and sea: A framework for the future" run by a consortium of scientists from James Cook University (JCU) and CSIRO. This report is the first major product of the consortium project. It is not an in-depth review of the literature that already exists for some NRM sectors. Rather, it is a synthesis of current knowledge through expert opinion about the threats and potential impacts of climate change in the Wet Tropics Cluster (WTC) region (see below) across all sectors. The report is framed by the specific topics and issues defined by the NRM groups in the Wet Tropics Cluster (WTC) region, reflecting their planning processes and priorities of these groups as well as the characteristics of their regional communities.

The focus of this report is on possible impacts and threats, not adaptation options which will be discussed in a future report. Chapter 9 discusses the science of adaptation in a general sense and mitigation opportunities relating to carbon storage are discussed in a section of Chapter 6.

The report purposely emphasises direct climate change impacts in each sector. There are likely to be many second order effects where direct effects interact in complex ways within a sector and interactions between sectors are likely as well. We have not attempted to consider all these interactive effects since there are little or no published analysis available at this level of detail.

The report presents key messages around each topic and issue in bold type in each chapter. These key messages represent our syntheses of expected threats and impacts based on expert opinion but also substantiated by published sources. Each key message is followed by a brief explanation of the underlying scientific support with a small number of key citations to the relevant literature. In most cases there is a fair amount of uncertainty associated with the key messages and they should be understood as best estimates based on expert opinion. Much of the uncertainty about potential impacts is due to climate model uncertainty about changes in rainfall amount and timing that are critical variables that will influence many sectors in the cluster region. Another source of uncertainty for some topics and issues is limited or lack of direct research on climate change impacts across several of the key NRM sectors in the cluster region.

Geographic scope

Australia's 56 NRM regions have been grouped into eight clusters through which Element 2 of Stream 2 is delivered. The eight clusters are based on some broad common characteristics such as land use, climate and how these are anticipated to change (Figure 1). In total, Element 2 of Stream 2 is comprised of nine projects, one for each of the eight clusters, and a National Project delivering cross-boundary regional level information on issues that are national in scale, such as changes to biodiversity and invasive species resulting from climate change.

This report focuses on four geographically distinct NRM regions grouped in the Wet Tropics Cluster, shown in Figure 1. These are the Mackay-Whitsunday, Wet Tropics, Cape York, and the Torres Strait regions, which are managed by Reef Catchments NRM, Terrain NRM, Cape York NRM, and the Torres Strait Regional Authority respectively.

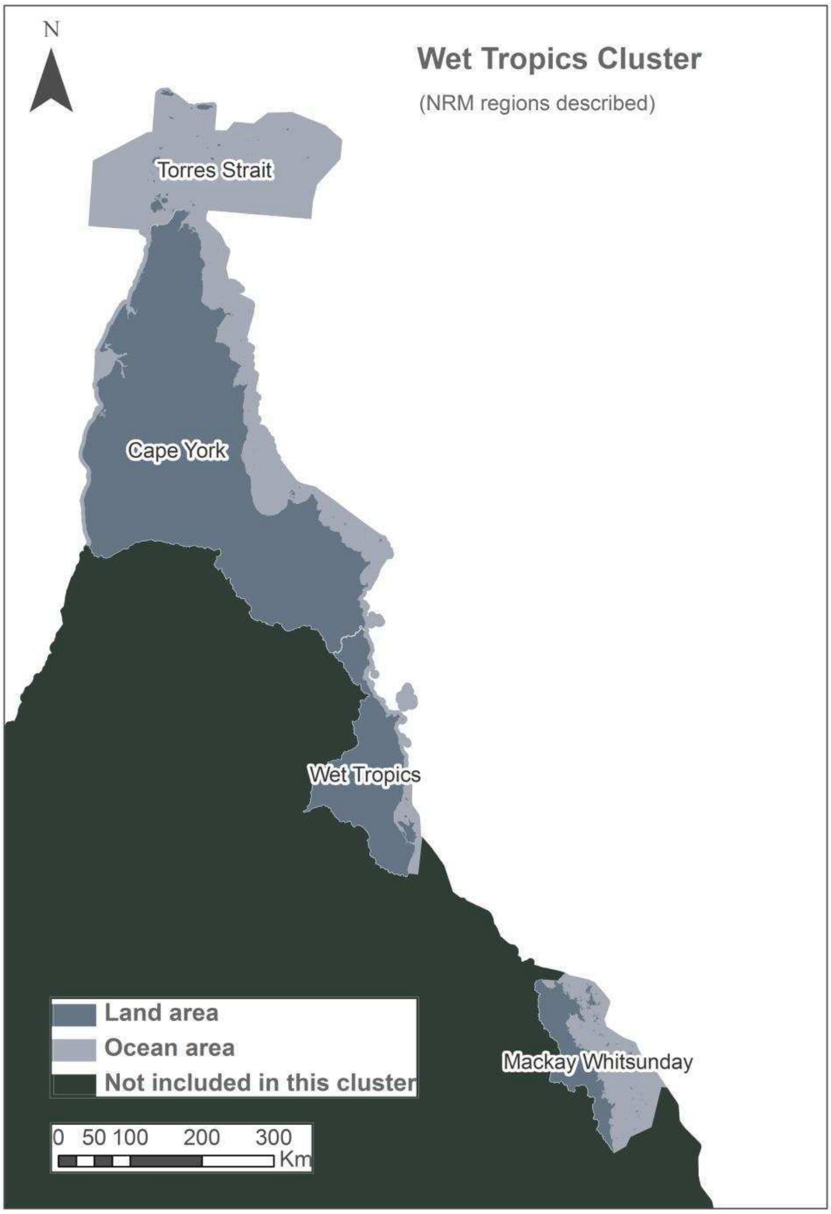

Figure 1. The Wet Tropics Cluster region (shaded).

Approach and method

A key component of the Stream 2 project was the adoption of a WTC 'Brokering Hub' to formally bring together the Stream 2 researchers and NRM organisations. The Brokering Hub acts as a steering committee for the project (Bohnet *et al*. 2013). This arrangement is intended to promote a collaborative approach to the research program and to facilitate communication between Streams 1 and 2.

The Stream 2 research component of the Brokering Hub is divided into three 'Science Nodes' (Figure 2). The production of the Science Synthesis Report has been co-ordinated by and is the major output from the 'Science Synthesis Research Node', although researchers from all three Science Nodes have contributed. NRM groups defined existing knowledge and priority information gaps through different processes. NRM groups from the WTC convened a meeting to articulate their 'Preferred processes and priorities' to inform the development of project bids by research consortia in the region when Stream 2 funding was announced in 2012. The key issues of concern identified in this document formed the foundation for the current Science Synthesis Report. During 2013, NRM groups in the WTC identified additional detail in relation to their information needs for NRM planning during two workshops, one a joint WTC-National Environmental Research Program (NERP) initiative and the other organised by the Participatory Scenarios Research Node. Finally, NRM groups were invited by email in late 2013 to clarify or add any further priority information needs. The list of NRM interests and concerns covered a wide range of issues in many sectors and experts in all of the fields identified were sought to contribute to the Science Synthesis Report.

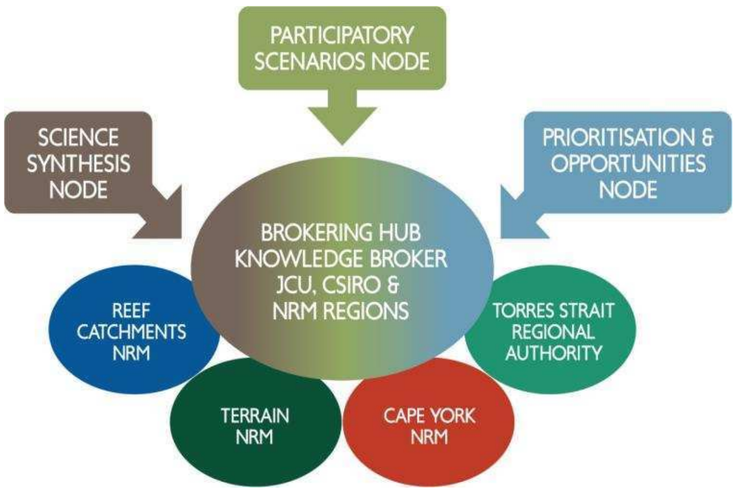

Figure 2. Co-research approach that promotes long-term system well-being and collective learning (Bohnet et al. 2013).

Two workshops were convened by the Science Synthesis Node with project scientists in late 2013 to agree on the structure of the report chapters, to draft key messages for each of the topics and issues raised by the NRM groups, and to identify additional contributing authors where necessary. One workshop focused on biodiversity issues and the other developed the cultural, social and economic chapters. The Science Synthesis Node co-ordinated the processes of writing, reviewing and editing the nine chapters for the final report.

Significance of the Wet Tropics Cluster and the climate change threat

This cluster contains a broad range of landscapes and seascapes including globally significant savannas, the vast majority of Australia's tropical rainforests, wetlands and low lying tropical islands. It also contains a high proportion of the Great Barrier Reef catchment. The region contains the Wet Tropics World Heritage Area and the Great Barrier Reef World Heritage Area with discussion for a third World Heritage Area nomination for parts of Cape York Peninsula. Arguably, this cluster supports more species overall than any other NRM cluster with many endemics. Only the South West of Western Australia is richer in plant species.

The climate change threat to biodiversity has been especially well documented for the Wet Tropics rainforests (Hilbert *et al*. 2001; Kanowski 2001; Williams *et al*. 2003; Hilbert *et al*. 2004; Williams *et al*. 2008). While much of the cluster's rainforest is in conservation reserves (especially the Wet Tropics World Heritage Area) some important areas are not, including many fragments and recovering forests on abandoned, previously cleared land. Management of off-reserve lands in response to climate change present both important opportunities and potential threats to biodiversity (Dunlop, Hilbert, Ferrier *et al*. 2012).

Along with very high biodiversity values, there are numerous and substantial economic and cultural values including extensive and intensive agriculture (McKeon *et al.* 2009a), tourism, mining, fisheries (Stoeckl and Stanley 2007) and large areas of Aboriginal lands. Much of the cluster's area is 'highly contested' with multiple and sometimes conflicting demands for the region's natural resources. Climate change is likely to exacerbate the issues and challenges. Climate change impacts and adaptation studies suggest significant changes in all sectors that will require factoring climate change into forward looking NRM planning across the cluster.

Both extensive and intensive primary production are likely to be challenged by climate change requiring adaptations in where, what and how food is produced in the region. The possible adaptation responses of this sector – as all others – will have important affects, positive or negative, on other sectors. There are opportunities provided by the Carbon Farming Initiative and the Biodiversity Fund (see chapter 6) that, if managed properly, could assist adaptation in this sector while also favouring biodiversity conservation.

Traditional owners are important inhabitants and land managers in many areas of the cluster who are likely to be highly affected by climate change in numerous ways (see Chapter 8). The approximate proportion of Aboriginal people is 50% in Cape York, more than 90% in the Torres Strait and 12% in the Wet Tropics. Indigenous people living in remote areas within this cluster have a high sensitivity to climate change induced ecosystem change because of the close connection for them between healthy 'country' and their physical and mental well-being and their cultural practices (Green 2006). Other issues affecting their community's welfare are urgent and pressing and these will require strategies and policies to strengthen adaptation capacity of communities for climate-change responses (Petheram *et al*. 2010). Communities located on the low-lying islands of Torres

Strait are particularly vulnerable to sea level rise and increasingly intense storm surges caused by more extreme weather (Green *et al*. 2009).

Natural resource management in the regions covered by this cluster has long been contentious due to its highly contested values in multiple sectors. The need for climate change adaptation in most of these sectors accentuates the challenge and requires an integrated approach.

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Chapter 2: Climate change projections for the Wet Tropics cluster

Stephen Turton

Executive summary

This chapter discusses the latest climate projections for key climate variables for the Wet Tropics cluster region. Climate change projections for the cluster region are synthesised from published sources, including the IPCC's 4th (2007) and 5th (2013) Assessment Reports.

Key climate change messages associated with each of the topics addressed in this chapter include:

Air and sea surface temperatures and heat waves	1. Average air temperatures are projected to increase in the future. 2. More hot days and fewer cold days will occur in the future. 3. Average sea surface temperatures are projected to increase throughout the year.
Changes in annual and seasonal rainfall	4. Projections of annual rainfall do not show a consistent tendency towards an increase or decrease; however, there is a large spread in model simulations with a tendency towards a decrease. 5. Wet season rainfall does not show a consistent tendency towards an increase or decrease; however, there is a large spread in model simulations. 6. Dry season rainfall, particularly during the monsoon retreat season (autumn), is more likely to decrease; however, there is a large spread in model simulations. 7. It is expected that the high natural rainfall variability will continue in future and may mask any trend in average rainfall for some decades to come, particularly in the wet season.
Extreme weather events	8. Extreme rainfall intensity will increase in the future. 9. The intensity of tropical cyclones is likely to increase in the future, while overall cyclone frequency may decrease.
Changes in sea level	10. Sea levels should continue to rise and may vary at the sub-regional level. 11. Frequency and height of storm surges are expected to increase.

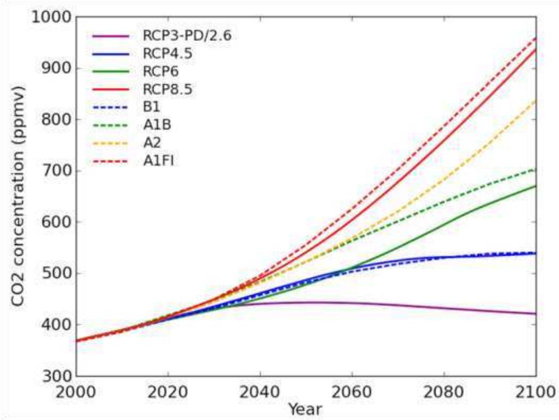
Other aspects of climate	12. Solar radiation is expected to decrease in winter (dry season) and spring (wet season build up), and increase in autumn (monsoon retreat season) under the highest RCP emission scenario; however, there is a large spread of model simulations. 13. Small decreases in relative humidity are favoured over increases during summer and autumn periods, with little change in winter and increases more likely in spring, especially under the highest RCP scenario. 14. Evapotranspiration is projected to increase in all seasons. 15. Wind speeds are expected to increase across eastern Australia. 16. Acidification of the oceans adjacent to the cluster region is projected to increase in line with changes in atmospheric CO_2. 17. Fire weather conditions are expected to worsen.

Introduction

This chapter discusses the latest climate projections for key climate variables for the Wet Tropics cluster region that will assist NRM groups with preparation of their new generation of NRM Plans. Climate change projections for the cluster region are synthesised from published sources, including the IPCC's 4th (2007) and 5th (2013) Assessment Reports. Box 1 shows the new emission scenarios and their representative concentration pathways (RCPs), utilised in the *Intergovernmental Panel on Climate Change's 5th Assessment Working Group I Report* (IPCC 2013). Material presented in this chapter provides a basis for the other chapters that will focus on climate change issues and impacts across different NRM sectors, e.g. biodiversity, ecosystem services, industry, infrastructure, social issues and Indigenous communities.

Box 1: New emission scenarios: Representative concentration pathways (RCPs)

- Four RCPs describe plausible trajectories of future greenhouse gas and aerosol concentrations to the year 2100.
- These are named RCP2.6, RCP4.5, RCP6, and RCP8.5 in accordance with the range of radiative forcing values (in W/m^2). Radiative forcing is a measure of the level of influence these gases have on Earth's energy balance.
- Each RCP is representative of a range of economic, technological, demographic, policy, and institutional futures.
- The intermediate scenario RCP4.5 could be considered as a trajectory with moderate mitigation, consistent with the B1 scenario of the SRES scenarios developed in 2001. The highest RCP scenario, RCP8.5, is similar to the A1FI, or highest concentrations case in the SRES scenarios. RCP4.5 and RCP8.5 concentration pathways are used for projections presented in this chapter.



Source :
Van Vuuren et al. (2011) The representative concentration pathways: an overview. *Climatic Change* 109: 5-31
IPCC (2001) Special Report on Emission Scenarios (https://www.ipcc.ch/pdf/special-reports/spm/sres-en.pdf)

When using these projections for decision-making in NRM plans users should consider that different models and RCPs generate a range of future climates. Tools and guidance material on the likelihood of the different projections will be offered through the *Climate Futures* software tool being developed by CSIRO.

Air and sea surface temperatures and heat waves

The latest IPCC models predict that all regions of Australia will warm significantly by 2090, including the Wet Tropics cluster region (IPCC 2013). There will be higher rates of warming in central (inland) regions and lower rates in coastal and near-coastal regions. Lower rates of warming may be expected in the Wet Tropics cluster region due to its proximity to the coast. Heat waves (number of days >35˚C) will become more common in a warming world and will also affect the Wet Tropics cluster region. In comparison, the number of cool days will decline. Sea surface temperatures will warm in concert with increases in atmospheric temperatures.

Increasing average air temperatures

Average air temperatures are projected to increase in the future.

Since historical records began (1850s), average temperatures in the Wet Tropics cluster region have increased at similar rates to the Australian average (~0.9˚C). Minimum temperatures have increased more than maximum temperatures during this time (BoM 2013). Year-to-year variability in temperatures is strongly driven by the El Niño Southern Oscillation (ENSO) phenomenon with warmer years generally associated with El Niño events (e.g. 1998).

Table 1 summarises projected changes in average temperatures (˚C) for Northern Australia utilising the CMIP5 global models for the RCP4.5 emission scenario (see Box 1). Projections are provided for the summer wet season (December–February), the winter dry season (June–August) and annual values and can be broadly applied to the Wet Tropics cluster region. All the models project an increase in average air temperatures, with the greatest increases expected during the summer wet season months.

Table 1: CMIP5 global models average temperature projections for Northern Australia for 2035 and 2065

The ranges of values are derived from 42 global models for the RCP4.5 scenario (see Box 1). Values are relative to the 1986–2005 baseline period.

Month	Year	Temperature range (˚C)
DJF (wet season)	2035	0.2 to 1.9
	2065	0.6 to 3.4
JJA (dry season)	2035	0.4 to 1.4
	2065	0.9 to 2.3
Annual	2035	0.3 to 1.6
	2065	0.7 to 2.6

(Source: IPCC 2013)

Increasing number of hot days

More hot days and fewer cold days will occur in the future.

Since historical temperature records began in Australia (1850s), the average number of hot days has increased while the number of cold days has decreased. A hot day is defined here as one with a daily maximum temperature exceeding 35˚C. Centred on 1995 (1986–2005 baseline), Cairns has experienced an average of four hot days each year. Based on the IPCC's Fourth Assessment Report model projections, Cairns can expect 4–8 hot days each year by 2030, increasing to 5–28 days per year by 2070, depending on the greenhouse gas emission scenarios (Hennessey *et al*. 2008). Projections are expected to be similar for the two new RCP scenarios (Box 1) but data was not available at the time of preparing this report. There is likely to be regional variability in the number of hot days across the Wet Tropics cluster region depending on distance from the coast and elevation above sea level. Frost events in upland areas, such as the Atherton Tablelands, will decline in the future.

Increasing average sea surface temperatures

Average sea surface temperatures are projected to increase throughout the year.

Since 1950, average sea surface temperatures have increased across the oceans adjacent to the Wet Tropics cluster region (BOM 2013); sea surface temperatures in Torres Strait and around northern

Cape York Peninsula have increased by about 1˚C in that time, compared with about 0.6˚C for the remainder of the cluster region. Future ocean warming will depend on the RCP scenarios (Box 1), but it would be reasonable to assume that sea surface temperatures will closely track changes in atmospheric warming.

Changes in annual and seasonal rainfall

Climate models, based on the latest IPCC emission scenarios (Box 1,) show that future projections for rainfall changes across Australia are much less certain than for temperature. This is because, unlike temperature, the projected direction of change in rainfall in different regions is not always consistent across climate models (IPCC 2013).

For Northern Australia (including the Wet Tropics cluster region), while it is appropriate to consider projected changes in annual rainfall, likely changes in seasonality (distribution) of rainfall is very important as the region experiences distinct wet and dry seasons. Rainfall variability is naturally very high across Northern Australia and this must also be considered when we examine future rainfall projections, particularly for the wet season.

Annual and seasonal rainfall

Projections of annual rainfall do not show a consistent tendency towards an increase or decrease; however, there is a large spread in model simulations with a tendency towards a decrease.

Wet season rainfall does not show a consistent tendency towards an increase or decrease; however, there is a large spread in model simulations.

Dry season rainfall, particularly during the monsoon retreat season (autumn), is more likely to decrease; however, there is a large spread in model simulations.

Table 2 summarises projected changes in rainfall (%) for Northern Australia utilising the CMIP5 global models for the RCP4.5 emission scenario (see Box 1). Projections are provided for the summer wet season (December–February), the winter dry season (June–August) and annual values. Unlike temperatures, which are expected to increase in all seasons, there is a very large spread in the models for rainfall across Northern Australia, with the greatest spread occurring during the winter dry season. However, it should be noted that dry season rainfall is very low across most of Northern Australia with the exception of parts of north-east Queensland.

Table 2: CMIP5 global models rainfall projections for Northern Australia for 2035 and 2065

The ranges of values are derived from 42 global models for the RCP4.5 scenario (see Box 1). Values are relative to the 1986–2005 baseline period.

Month	Year	Change in rainfall (%)
DJF (wet season)	2035 2065	-20 to +8 -18 to +12
JJA (dry season)	2035 2065	-48 to +15 -53 to +17
Annual	2035 2065	-24 to +7 -21 to +11

(Source: IPCC 2013)

Overall, there is a tendency towards a decrease in annual average rainfall for Northern Australia, particularly for the dry season months. However, the lack of agreement among models is a major source of uncertainty about many impacts discussed in this report.

Rainfall variability

It is expected that the high natural rainfall variability will continue in future and may mask any trend in average rainfall for some decades to come, particularly in the wet season.

There is a high degree of natural variability in rainfall, particularly during summer, across the Wet Tropics cluster region. Rainfall variability tends to be lower in the northern areas of the cluster (Torres Strait and northern Cape York) and more variable in southern areas (southern Cape York, Wet Tropics and Mackay/Whitsunday). This variability is strongly influenced by El Niño Southern Oscillation (ENSO) events. El Niño episodes tend to produce drier wet seasons and La Niña episodes wetter wet seasons.

Extreme weather events

Extreme rainfall events

Extreme rainfall intensity will increase in the future.

In a warming climate, rainfall extremes are expected to increase in frequency and intensity, whereas changes in atmospheric circulation patterns will result in little overall change in total annual rainfall in the Wet Tropics Cluster Region. For example, the largest annual 1-day total rainfall for Northern Australia is projected to increase towards the end of the century with most climate models under both RCP4.5 and RCP8.5, despite a tendency towards decrease in annual average rainfall in the region (IPCC 2013).

Tropical cyclones

The intensity of tropical cyclones is likely to increase in the future, while overall cyclone frequency may decrease.

Globally, climate change and associated warming is predicted to increase the intensities of tropical cyclones in the future while having largely neutral effects on cyclone frequency (see review by Turton 2012). Walsh *et al*. (2004) found that under enhanced greenhouse conditions, simulated numbers (frequency) of tropical cyclones in the Australian region do not change very much compared with those simulated for the current climate. However, they noted a 56% increase in the number of simulated storms with maximum winds greater than 30 m s^{-1} (alternatively, a 26% increase in the number of severe storms with central pressures less than 970 hPa). More recent research by Knutson *et al*. (2010), based on theory and high-resolution dynamical models, consistently suggests that greenhouse warming will cause the globally averaged intensity of tropical cyclones to shift towards stronger storms, with intensity increases of 2–11% by 2100. However, existing modeling studies also consistently project decreases in the globally averaged frequency of tropical cyclones, by 6–34% depending on the oceanic basin under consideration (Knutson *et al*. 2010). Balanced against this, higher resolution modeling studies typically project substantial increases in the frequency of the most intense cyclones and increases of the order of 20% in the rainfall rate within 100 km of the storm centre (Knutson *et al*. 2010). Such changes have profound implications for tropical ecosystems and human communities in the global tropical cyclone belt, including the Wet Tropics Cluster Region.

Changes in sea level

Global mean sea level has risen by 0.19 [0.17 to 0.21] m, estimated from a linear trend over the period 1901–2010, based on tide gauge records and additionally on satellite data since 1993 (IPCC 2013). It is very likely that the mean rate of sea level rise was 1.7 [1.5 to 1.9] mm yr^{-1} between 1901 and 2010. Between 1993 and 2010, the rate was very likely higher at 3.2 [2.8 to 3.6] mm yr^{-1}; similarly high rates likely occurred between 1930 and 1950 (IPCC 2013).

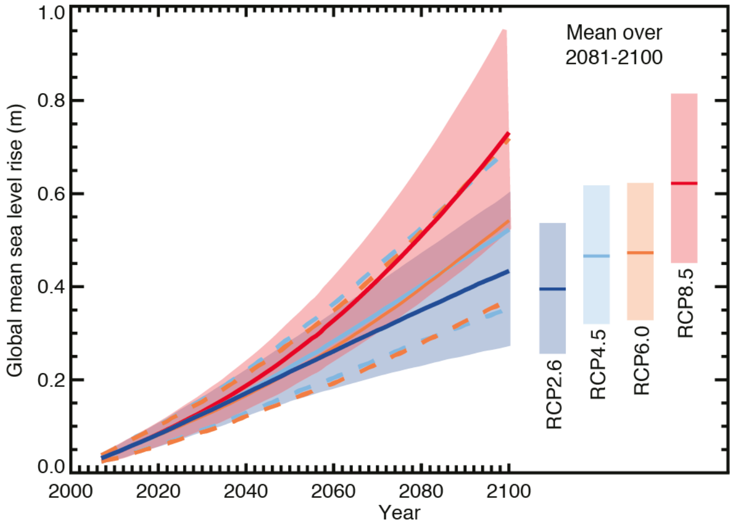
Sea level is projected to increase

Sea levels should continue to rise and may vary at the sub-regional level.

Box 2 summarises projections in global average sea level for the 21st Century for various RCP emission scenarios (IPCC 2013). It may be assumed that changes in sea level across the Wet Tropics cluster region will emulate global trends; hence by 2090 sea levels will increase between 30-60 cm and 45-85 cm for the RCP4.5 and RCP8.5, emission scenarios, respectively. At the time of preparing this report there was no data available for projected sea level changes for the Wet Tropics cluster region and for its various sub-regions (e.g. Torres Strait) but the data given here should be considered as indicative of what might be expected across the cluster region.

However, global circulation models indicate that average sea level rise on the east coast of Australia in the future may be greater than the global average sea level rise (OCC 2008). Moreover, the observed sea level rises in eastern Australia is tracking near the upper limit of the IPCC's Fourth Assessment Report's (2007) projections (Church *et al*. 2009). In summary, sea level rise is likely to be greater than the global average (Box 2) for coastal areas from the Torres Strait to Mackay/Whitsunday and similar to the global average for coasts along western Cape York Peninsula.

Box 2: Projections from process-based models of global mean sea level rise relative to 1986–2005 for the four emissions scenarios RCP2.6, RCP4.5, RCP6.0 and RCP8.5 (IPCC 2013)



Extreme sea level events

Frequency and height of storm surges are expected to increase.

The effects of rising average sea levels will be felt more severely during extreme storm conditions when strong winds coupled with falling barometric pressure bring about temporary and localised increases in sea level known as a storm surge.

According to Church *et al*. (2009) for every 10 cm increase in sea level, the frequency of extreme events increases by a factor of three. For many coastal locations in the Wet Tropics cluster region, sea level rise means that the present 1 in 100 year event could potentially occur more than once a year by 2100. In Queensland, scientists predict that storm surges will occur more frequently this century due to a combination of rising sea level and more severe tropical cyclones (OCC 2008).

McInnes *et al*. (2000) completed a detailed study of the impact of tropical cyclone storm surges in Cairns under the current climate (Year 2000) and around 2050 (corresponding with a doubling of pre-Industrial CO_2 levels). While this study is restricted to the greater Cairns area, it provides useful insights that have wider applicability. In their study, one thousand storm surge simulations were performed representing 5000 years of cyclone occurrence. Sea level heights in the present climate (Year 2000) for return periods of 50, 100, 500 and 1000 years were determined to be 2.0 m, 2.3 m, 3.0 m and 3.4 m respectively (McInnes *et al*. 2000). In an enhanced greenhouse climate (around 2050), these heights increase to 2.4 m, 2.8 m, 3.2 m, 3.8 m and 4.2 m respectively. Importantly, these sea level values are now superseded by research by the IPCC (2013) indicating higher sea levels by 2100 (Box 2).

Other aspects of climate

For NRM groups, there is an interest in projections for climate variables other than temperature, rainfall, sea level rise and extreme events that also influence processes in the landscape, like plant growth and the hydrological cycle.

Solar radiation

Solar radiation is expected to decrease in winter (dry season) and spring (wet season build up), and increase in autumn (monsoon retreat season) under the highest RCP emission scenario; however, there is a large spread of model simulations.

Changes in solar radiation may impact on a range of other climatic variables, notably evapotranspiration rates, and may also affect crop production rates.

Relative humidity

Small decreases in relative humidity are favoured over increases during summer and autumn periods, with little change in winter and increases more likely in spring, especially under the highest RCP scenario.

Relative humidity by itself is fairly meaningless and needs to be considered in relation to projected changes in air temperature for various RCP scenarios. Higher temperature, coupled with lower relative humidity, will increase evapotranspiration rates (water loss) for native vegetation, crops and pastures.

Potential evapotranspiration

Evapotranspiration is projected to increase in all seasons.

Annual potential evaporation, relative to the 1961–1990 baseline, is projected to increase by 2% by 2030 and 6–10% by 2070 (CSIRO & BOM 2007).

Wind speed

Wind speeds are expected to increase across eastern Australia.

Higher wind speeds have implications for a range of other climatic factors, including enhancing evapotranspiration loss from soils, water bodies and vegetation. Potentially, higher wind speeds during the dry season will also enhance the rates and spread of bushfires.

Ocean acidification

Acidification of the oceans adjacent to the cluster region is projected to increase in line with changes in atmospheric CO_2.

Oceans become more acidic as CO_2 emissions in the atmosphere dissolve in the ocean. This change is measured on the logarithmic pH scale, with lower vales being more acidic. The pH of the oceans has decreased by about 0.1 pH units since 1850, which is equivalent to a 25% increase in acidity. The pH levels of the oceans is projected to decrease even more by the end of the century as CO_2 concentrations are expected to increase for decades to come (IPCC 2013).

Bushfire events

Fire weather conditions are expected to worsen.

Climate change is likely to increase the frequency and intensity of extreme fire days and result in a longer fire season across the Wet Tropics cluster region (Lucas *et al*. 2009). Fire seasons may start earlier and end slightly later as well as being more intense.

Summary and conclusions

The IPCC (2013) are now 95% confident that human activities are changing Earth's climate even when allowances are made for natural variability. The Wet Tropics cluster region may expect significant changes in its climate this century and NRM organisations will need to incorporate the latest climate science knowledge and data into their adaptive management and planning systems. The main findings of this chapter in regard to the Wet Tropics cluster region are:

- Air and ocean temperatures are expected to increase in response to increasing Greenhouse Gas (GHG) emissions
- We can expect more hot days and fewer cold days in the future
- There is considerable uncertainty about how climate change may affect rainfall across the region due to naturally high rainfall variability but with higher GHG emissions there is evidence that the dry season will be longer and drier while the wet season will remain similar
- Extreme rainfall intensity may increase in the future
- The intensity of tropical cyclones is likely to increase in the future while overall cyclone frequency may decrease
- Sea levels should continue to rise but may vary at the sub-regional level
- Frequency and height of storm surges are expected to increase due a combination of rising sea levels and more intense tropical cyclones
- Fire weather conditions are expected to worsen with increased frequency or intensity of extreme fire days
- Solar radiation is expected to decrease in winter (dry season) and spring (wet season build up), and increase in autumn (monsoon retreat season) under the highest RCP emission scenario; however, there is a large spread of model simulations
- Small decreases in relative humidity are favoured over increases during summer and autumn periods, with little change in winter and increases more likely in spring, especially under the highest RCP scenario
- Evapotranspiration is projected to increase in all seasons
- Average wind speeds are expected to increase across eastern areas
- Ocean acidity will increase in line with increases in atmospheric CO_2.

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Chapter 3: Potential changes in biodiversity

David W. Hilbert, Susan Laurance, Helen Murphy, April Reside, Rob Coles, Norman C. Duke, Mark Hamann, Mariana Fuentes, Cassanda James, Frederieke Kroon, Helene Marsh, Marcus Sheaves, Dagmar Meyer Steiger, and David Westcott

Executive summary

The broad message from this chapter is that natural resource managers and their stakeholders cannot take for granted that the ecosystems and biodiversity in their regions will be the same in the future, or that change can be entirely prevented. So, future biodiversity management plans will need to allow for substantial, although somewhat unpredictable, changes and focus on maintaining viable, if different, ecosystems (Dunlop *et al.* 2012).

We have purposely focused on climate change threats, defined as changes to what is here now. Not all of these changes are necessarily disastrous or unmanageable, possibly aside from extinction of some endemic species which is possible or likely in the Wet Tropics Bioregion.

We largely assume that global carbon emissions will continue rise for some time so that climate change will follow the mid to worst case warming scenarios. The threats and impacts described here would be reduced if global carbon emissions and consequent climate change are reduced.

Key messages associated with the topics and issues addressed in this chapter are listed below:

Vegetation communities and ecosystems	1. Novel environments will occur that are outside the range now existing in the region and this may lead to new vegetation structures and communities. 2. Longer dry seasons and higher temperatures could cause a general opening up of vegetation. 3. Fire regimes will probably change, impacting vegetation in complex ways.
Freshwater and tidal wetlands	4. Freshwater wetlands will decrease in extent and become more isolated. 5. The expected outcome of rising temperatures will be the expansion of mangrove species into higher latitudes. 6. The expected outcome of rising sea levels will be mangrove dieback at lower intertidal elevations, with expansion of mangrove assemblage zones into higher elevations and upstream in estuaries.

	7.	The expected outcome of increasing rainfall will be greater biodiversity, biomass and abundance of mangrove plants in tidal wetland estuaries upstream and across the tidal profile. The expected outcome with decreasing rainfall will be reduced biodiversity, biomass and abundance of mangrove plants in tidal wetland estuaries upstream and across the tidal profile.
	8.	More severe storms and storm surges will result in significant losses in biodiversity, biomass and abundance of mangroves, with the real prospect of ecosystem collapse and loss of ecosystem functionality.
	9.	Increasing ocean acidity will impact key mangrove–fauna relationships.
	10.	Increases in sea level, temperature, heavy rainfall events and the intensity of tropical storms will have mostly negative impacts on seagrass meadows.
Fringing reefs	11.	Increased intensity of extreme events associated with climate change, such as increasing mean temperatures, frequencies of heat periods, ocean acidification, intensifying storms and rainfall variability, will decrease coral cover.
	12.	Increased rainfall variability associated with global warming is likely to affect runoff and pollutant transport into the Great Barrier Reef lagoon.
Abundance and distribution of key species	13.	Climate change is likely to impact on ecosystem processes such as dispersal, pollination and migration.
	14.	Climate change will lead to shifts to the locations of suitable climate space for many species.
	15.	Endemic species are likely to have higher vulnerability to climate change due to high habitat specificity.
	16.	Species vulnerability to climate change is likely to be determined by their ability to disperse to new areas of suitable climate.
Cassowaries	17.	Climate change will reduce the distribution and size of cassowary populations due to reduction in the extent and quality of their habitat.
	18.	Higher temperatures will reduce the capacity of cassowaries to utilise open vegetation types.
	19.	Cassowary populations will be reduced by the impact of more frequent extreme events on the quality and extent of their habitat.
	20.	Invasive plants have the potential to reduce quality of cassowary habitat and cassowary population sizes.
Freshwater biodiversity	21.	Climate change poses a high risk to the freshwater biodiversity of Cape York and the Wet Tropics Bioregion.

	22. Freshwater species with poor dispersal capacity and high specificity for habitat requirements are likely to have higher vulnerability to climate change.
Marine turtles and dugongs	23. Projected increases in sand temperature are likely to influence the reproductive output of marine turtles. 24. Sea level rise may impact marine turtle nesting grounds. 25. Extreme weather events can impact dugongs. 26. Warmer ocean temperature may expand the distribution of dugongs southward.
Invasive species	27. The suitable climatic space for most invasive species will shift towards the south and contract towards the east coast. However, the Wet Tropics cluster region will remain suitable for most tropical invasive plant species. 28. Cape York will have an increased biosecurity risk from countries to the north. 29. Climate change will create new opportunities for invasive species to recruit, spread and increase in abundance. 30. Increases in growth and recruitment of invasive weeds are likely to follow severe cyclones. 31. Dispersal opportunities for invasive species are likely to increase due to extreme rainfall events. 32. The degradation of coastal habitats by invasive species is likely to increase the impact of extreme events on human communities and infrastructure. 33. Spread of high biomass invasive grasses may transform savanna ecosystems into ones dominated by exotic grass. 34. Seasonally inundated waterholes in the dry tropics are likely to be increasingly impacted by invasive animals.
Infectious diseases	35. The abundance and diversity of mosquitoes will increase at higher elevations and latitudes, and during winter periods, increasing both the range and timing of disease risk.
Infection pathways	36. The spatial and temporal concentration of hosts, vectors and victims will be influenced by changes in water availability and distribution. When water is scarce disease risk will increase around water points where pigs, mosquitoes, other wildlife and people may concentrate. 37. Disease risk may increase with changing lifestyles and home design associated with changing climate. Open tropical homes with integrated gardens may increase human exposure to biting insects, increasing disease risk.
i. Hendra	38. Disease risk from Hendra virus is unlikely to change in response to climate change–driven changes in vegetation distribution. 39. Increased temperatures and longer dry seasons may reduce Hendra spillover risk.

ii. Dengue	40.	Extreme rainfall events and higher temperatures will increase mosquito populations and accelerate population dynamics, increasing the risk of dengue outbreaks.
	41.	Climate change may move dengue to higher elevations and southern latitudes.
iii. Japanese encephalitis	42.	Wild pigs may become hosts to Japanese encephalitis (JE), which was recorded in Torres Strait but is not known to occur in the Australian mainland at present.
Biodiversity and disease	43.	Climate change–driven changes in community structure may influence disease prevalence in wildlife and disease risk for humans.

Introduction

The Wet Tropics Cluster is exceptionally rich in biodiversity and contains expanses of largely intact, diverse ecosystems. There has been a comparatively large amount of research on potential climate impacts on biodiversity in this region, initially focusing in the Wet Tropics World Heritage Area but with substantial newer work in Cape York Peninsula. Because of these studies we are confident that climate change will drive significant ecological changes in the decades to come, although the rate, direction and magnitude of change are uncertain.

There are several recent reports that provide an overview of biodiversity impacts and adaptation for Queensland as a whole that are relevant to the Wet Tropics Cluster. Terrestrial ecosystems are discussed by Murphy *et al.* (2012), freshwater ecosystems by Kroon *et al.* (2012), coastal and marine systems by Bustamante *et al.* (2012), ecosystem services by Williams *et al.* (2012) and adaptation principles and options by Dunlop *et al.* (2012).

A major uncertainty in projecting many biodiversity impacts, especially at the ecosystem level, is due to the large uncertainty about regional changes in rainfall (See Chapter 2). Another uncertainty is how our ecosystems will respond to elevated atmospheric CO_2. It is often postulated that increased concentrations of CO_2 in the atmosphere will increase plant growth rates and subsequently biomass in ecosystems but there is no evidence that this is happening now in our region, and there is no experimental work of relevance to our ecosystems (Note that results of a study in tropical savanna near Townsville are yet to be published (Stokes *et al.* 2005).

This chapter is organised into four sections that represent the major issues relating to biodiversity that were highlighted by the NRM groups in the Wet Tropics Cluster Region.

The extent and distribution of vegetation communities and ecosystems

Vegetation throughout the region is likely to be affected substantially by warming, changes in water balance and fire weather, increased cyclone intensities and sea level rise. We are confident that these stresses will change the landscape substantially in the future, although the rate of change and specific, regional vegetation changes are difficult to predict with certainty at this time.

Forests and woodlands

Forests and woodlands in many places will be in disequilibrium with local climate, leading to changed structure and composition and eventually to transitions to other vegetation types. Modelling of vegetation types in the Wet Tropics (Hilbert 2010) and for Australia as a whole (Hilbert and Fletcher 2012) assessed how the distribution and extent of environments suitable to various structural vegetation types (e.g., rainforests, tall open forests, woodlands and grasslands) change under various climate change scenarios. The general pattern is a decline in the area of environments that now favour trees and an increase in more xeric environments that favour open woodlands, chenopod shrublands and grasslands. It is expected that vegetation changes would tend to mirror these environmental changes, but the rate and nature of actual future vegetation changes will depend on many factors. This research suggests very rapid changes in the spatial distributions of climatic environments that will exceed the responsive capacity of vegetation. As a result, much of the vegetation in our region will be increasingly in disequilibrium with climate and stressed. This will be especially apparent at ecotones such as the western edges of rainforest in the Wet Tropics Bioregion.

Numerous digital maps of projected shifts in vegetation environments were produced at fine resolution for the Wet Tropics Bioregion (Hilbert 2010) and at 2km^2 resolution for all of the cluster (Hilbert and Fletcher 2012) for various climate change scenarios. The latter will be made available by the National Project in the near future.

Novel environments will occur that are outside the range now existing in the region and this may lead to new vegetation structures and communities.

As climate change proceeds, large parts of Australia, including the Wet Tropics cluster region, will experience climates that are unlike those that exist now or have existed in the recent geological past. Continent wide analyses (Dunlop *et al.* 2012a) suggest that climate change may result in more than just a spatial reshuffling of currently familiar environments and species assemblages. We are likely to see the emergence of novel environments and the disappearance of many existing environments. These so called non-analogue environments may eventually result in species assemblages and vegetation communities that are unlike anything now existing in the region.

Longer dry seasons and higher temperatures could cause a general opening up of vegetation.

Modelling in the Wet Tropics (Hilbert 2012) and for Australia generally (Hilbert and Fletcher 2012) suggests that warming, especially when combined with lower rainfall or longer dry seasons, will create environments where tree cover may decline in stature and density. For example, tall open forests will change toward medium open forests with less tree cover. Similarly, more open, dry monsoonal forests are expected to become more open and grassy, more so if fire intensity and/or frequency increase.

Fire regimes will probably change, impacting vegetation in complex ways.

Fire regime is a major determinant of vegetation type and vice versa. Significant changes in fire regimes are likely to occur in the Wet Tropics Bioregion and Cape York but there are no specific projections as yet because of the complexity of climate-fire-vegetation interactions. Fire regimes are difficult to predict because they depend on complex interactions between climate (mean temperature and rainfall, length of the dry season and extreme weather events) and vegetation (determining the quantity and kind of fuel).More extreme fire weather and changes in the timing and/or quantity of rainfall (see Chapter 2) will affect fuel load and combustibility and will likely alter fire regimes. Invasive weeds are likely to interact with climate change to alter fire regimes as well (see below). Warming would be expected to increase fire frequency,, at least in the absence of altered rainfall. For, example, warming in previous decades has increased the area of savanna where fire is possible every year (Justin Perry, pers. com.) and this zone is expected to continue to expand toward the south with further warming. Decreased rainfall or a longer dry season would be expected to lower primary production of native grasses and consequently decrease fire frequency in grass-dominated systems due to reduced fuel loads (Krawchuk *et al.* 2009, Cary *et al.* 2012).

Higher fire frequencies tend to reduce tree cover in savannas by reducing tree recruitment and survival while lower fire frequencies increase the woody cover (D'Odorico *et al.* 2006, Beringer *et al.* 2007), however interactions with rainfall complicate this generality.

Substantial changes in forest cover in the Wet Tropics Bioregion, such as conversion of rainforest on its western boundary to wet sclerophyll or woodland, would require tree-killing fire that is unprecidented historically, although must have occured in the last glacial period when rainforest contracted due to lower rainfall (Hilbert *et al.* 2007). But a combination of higher temperatures, extreme heat waves, and lower rainfall after disturbance by more severe cyclones (See Chapter 2) could provide the conditions for stand replacing fire in rainforest.

Freshwater and tidal wetlands

Freshwater wetlands will decrease in extent and become more isolated.

Longer dry seasons and more severe droughts will decrease the extent of freshwater wetlands and reduce their connectivity leaving functionally isolated communities. Changes in the wetting and drying cycle will promote the loss of aquatic species (Mulhouse *et al*. 2005, Erwin 2009) and transitions to other vegetation types, such as through invasion by terrestrial species. These changes are likely to become permanent as seed banks of wetland species are depleted (Leck and Simpson 1987).

Longer dry periods and increasing sea level (See Chapter 2) will lead to increased salinisation of coastal freshwater wetlands and this will promote transitions to salt tolerant vegetation (e.g. saltmarsh, saltpan) (Visser *et al*. 2002). However, saltmarshes themselves are threatened by mangrove encroachment (Saintilan and Hashimoto1999, Rogers *et al*. 2005) as a consequence of extended droughts, leading to saltmarsh compaction, reducing surface elevation so allowing greater tidal penetration (Rogers *et al.* 2006).

Mangroves

Mangroves, as part of tidal wetlands worldwide, are critically endangered; they are strongly influenced by climate, geography and sea level as well as more direct human pressures, particularly land use change and pollution. The latter pressures decrease the resilience of mangroves and tidal wetlands reducing their capacity to effectively respond to changes in climate and sea level (Gilman *et al.* 2008). It is the interaction of climate change and other direct human impacts that will determine the survival of mangrove habitat in specific locations (Duke *et al.* 2007).

The expected outcome of rising temperatures will be the expansion of mangrove species into higher latitudes.

Global mangrove distributions are directly dependent on mean temperature ranges linked with both seawater and air temperatures, as well as cold and hot extreme events throughout each year (Duke *et al.* 2007). Cold extremes are quantified by numbers of days of frost when temperatures drop below zero. Hot extremes are mostly observed with a cessation in photosynthesis coupled with prolonged periods of high evapotranspiration (Sobrado 1999). Each of these extremes severely limit survival of mangrove species at notably different tolerances, manifest in the diverse range of latitudinal limits for respective species.

The expected outcome of rising sea levels will be mangrove dieback at lower intertidal elevations, with expansion of mangrove assemblage zones into higher elevations and upstream in estuaries.

Each of these responses will be highly dependent also on rainfall which is another primary determinant of mangrove distributions. Altered sea levels are mostly a direct consequence of temperature (See Chapter 2). But, this factor is considered separately because mangroves and tidal wetland vegetation are intimately dependent on mean sea level and tidal range. As with temperature, mangrove species have distinct ranges of tolerance manifest in their very distinct distributional patterns, seen as defined zones with distinctly different species assemblages across the tidal profile.

The expected outcome of increasing rainfall will be greater biodiversity, biomass and abundance of mangrove plants in tidal wetland estuaries upstream and across the tidal profile. The expected outcome with decreasing rainfall will be reduced biodiversity, biomass and abundance of mangrove plants in tidal wetland estuaries upstream and across the tidal profile.

As with temperature and sea level, mangrove species are distributed in distinct zones across both the tidal profile and up estuaries, depending on salinity. It is clear that longer term rainfall will increase in some places while it will decrease in others, but there is high uncertainty for this across the Wet Tropics Cluster region (See Chapter 2). Mangroves are highly dependent on salinity extremes and moisture conditions associated with inundation frequency (Duke 2006). Mangrove plant biodiversity and growth are highly dependent on salinity such that some species are only found in defined estuarine locations along the upstream gradient.

More severe storms and storm surges will result in significant losses in biodiversity, biomass and abundance of mangroves, with the real prospect of ecosystem collapse and loss of ecosystem functionality.

Mangroves are very sensitive to disturbance (Michener *et al.* 1997). Disturbance occurs in a variety of ways – as physical damage with broken limbs, uprooted trees, eroded substrate, burial; caused by lightning strikes, tsunami waves, storm waves, flooding, prolonged inundation, and migrating beach dunes and berms. It is clear that different mangrove species respond very differently to each of these effects. Overall, the key point is that mangrove forest replacement with recruitment and turnover all depends on the levels of disturbance (Gilman *et al.* 2008). Tropical cyclone intensity is projected to increase in the future and coupled with rising sea levels means mangrove ecosystems will be more vulnerable to storm surges (See Chapter 2).

Increasing ocean acidity will impact key mangrove–fauna relationships.

Water quality, including water acidity, affects both trees and mangrove-dependent fauna. Mangroves are highly dependent on their infauna and epifauna. An important example is the direct and indirect links between mangrove trees and grapsid crabs (Robertson *et al.* 1992). Mangrove crabs, which will be sensitive to increased acidity, recycle and retain essential nutrients within mangrove habitat such that mangrove plant growth is dependent on the crab activity. Mangrove crabs furthermore influence mangrove forest biodiversity and structure by their selective predation of mangrove propagules of particular species.

Seagrass

The Queensland coast and Great Barrier Reef Marine Park (GBR) have diverse and extensive seagrass meadows with an area of over 30,000 km^2 (Coles *et al*. 2002; Coles *et al*. 2009; Grech and Coles 2010). Seagrass meadows, along with algae and coral, provide key habitats that underpin the biodiversity and productivity of tropical ecosystems, including fisheries. The health of these habitats is closely linked with the health of the wider coral province (Unsworth and Cullen 2010).

Unlike the global trend, coastal seagrass meadows in the GBR remained relatively stable in distribution until late in 2009 (McKenzie *et al*. 2010) but since then have declined at some locations (Rasheed *et al*. 2013; McKenzie *et al.* 2012). Seagrasses in the GBR are simultaneously subjected to many natural and anthropogenic threats and the interrelationships between these stressors and changes in seagrass distribution are poorly understood (Duarte 2002).

Increases in sea level, temperature, heavy rainfall events and the intensity of tropical storms will have mostly negative impacts on seagrass meadows.

Separating out climate change signals from a background of complexity and variability is difficult (See Chapter 2). However, there is general consensus that the increases in sea level, temperature and likely increases in tropical storms and their intensity and more intense rainfall events will have a negative impact on seagrass meadows and add to the existing impacts from coastal development and land use (Connolly 2012; Grech *et al*. 2011). Over the long term it is likely that we would expect:

- Increasing local and possibly large-scale losses of seagrass due to storm erosion and decreased sunlight following floods. There have been recent losses of seagrass in North Queensland following Cyclone Yasi and recent floods (See Rasheed *et al*. 2013).
- Loss of seagrass from increased thermal stress in shallow water or where exposed at low tide. Seagrasses in north Queensland are already at times limited by high temperatures (Campbell *et al*. 2006).
- Distribution changes with the likely loss in some locations of the larger "foundation" species replaced with colonising species better able to establish, survive and reproduce quickly.
- Colonization by seagrass of new shorelines in undeveloped areas with suitable substrate. This is likely to be offset by loss of seagrass in deep water where light availability is limiting.
- Changes in productivity; potentially some increases due to warmer water and increased CO_2. Again these positive changes are likely to be offset by increased water depth and pulsed turbidity from more extreme rainfall and river runoff events reducing light availability.

Fringing reefs

Increased intensity of extreme events associated with climate change, such as increasing mean temperatures, frequencies of heat periods, ocean acidification, intensifying storms and rainfall variability, will decrease coral cover.

Declines in coral cover on the Great Barrier Reef (documented by De'ath *et al.* 2012) showed a change in average cover from 28 per cent to 14 per cent since 1985. The major drivers of the decline were identified as damage by tropical cyclones (48 per cent of the loss), coral predation by crown-of-thorns starfish (crown-of-thorns starfish; 42 per cent) and coral bleaching (10 per cent).
The projected increase in intensity of extreme events, such as cyclones and thermal stress events (See Chapter 2) will exacerbate chronic stressors like poor water quality on sensitive Great Barrier Reef ecosystems (coral reefs and seagrasses) (Waycott *et al.* 2007; Anthony *et al.* 2011).

Increased rainfall variability associated with global warming is likely to affect runoff and pollutant transport into the Great Barrier Reef lagoon.

The long-term average annual precipitation is expected to decrease over most of Queensland (although there is wide uncertainty among the climate models -See Chapter 2). As a result, mean annual stream flows are also expected to decline. However, intense periods of rainfall during La Niña events will continue to result in periodic extreme floods. For example, an annual increase of up to four percent in extreme rainfall is expected in the Cape York region (Whitfield *et al.* 2010). Such extreme rainfall events result in high stream flow, increasing the probability of river floods. High flows will increase flow velocity and bed erosion in the head waters, and lead to increased runoff and pollutant transport to the Great Barrier Reef lagoon. River flow regimes in the GBR catchment have been substantially altered already through surface water diversion, dam construction, and wetland drainage and deforestation (Great Barrier Reef Marine Park Authority 2009; Pena-Arancibia *et al.* 2012). Further changes in flow regime associated with global warming are likely to further exacerbate the detrimental impact of terrestrial runoff on coral reef health (Coles and Jokiel 1992; Berkelmans *et al.* 2012; Schaffelke *et al.* 2013).

The abundance and distribution of key species

General issues

Climate change is likely to impact on ecosystem processes such as dispersal, pollination and migration.

Habitat connectivity will be important for species needing to shift to track climate space. Some species will be vulnerable to climate change where climate niche shifts occur in situations where functional connectivity is fragmented (Shoo *et al.* 2011).

Climate change will lead to changes in the distribution of suitable climate space for many species and these species will either have to acclimate, adapt or move if they are to persist (Corlett and Westcott 2013). While many species will move they won't necessarily move together, at the same rate or in the same direction (Corlett and Westcott 2013). Because different species perform different roles in ecosystem processes, e.g. (Dennis and Westcott 2006) this will inevitably result in changes in the nature and the distribution of ecosystem processes and services. For example, changes in the projected distribution of plant and animal diversity across the Wet Tropics Bioregion (Mokany *et al.* in press) will result in changes in the distribution of seed dispersal services with a reduction in the range and abundance of dispersal services in the lowlands and an increase in the uplands (Mokany *et al.* in press).

Climate change will lead to shifts to the locations of suitable climate space for many species.

Many vertebrate species are predicted to lose suitable climate space from Cape York and the Wet Tropics Bioregion, including amphibians, birds, mammals and reptiles (Reside *et al.* 2013). However, while some species will be losing climate space in this region, other species will be moving in from elsewhere, particularly moving from the west towards the Wet Tropics and the Mackay-Whitsundays regions. The southern and western edges of the Wet Tropics Bioregion are predicted to have the highest number of species moving in, particularly mammals and reptiles (Reside *et al.* 2013).

For bird species that predominantly occur in the savanna on Cape York, large distributional losses are expected (Reside *et al.* 2012). However, their study showed that savanna birds that occurred broadly across the tropical biome were likely to increase in their range.

Within the Wet Tropics Bioregion, declines in distribution are predicted for almost all of the 43 flightless Carabid ground beetles (Staunton *et al.* in press). Lower elevations are predicted to become unsuitable, and these areas are predicted to face decreases in species richness. However the Carbine Uplands, Bellenden Ker Uplands and the Atherton Uplands are predicted to maintain relatively high species richness even under a high emissions scenario. For Schizophora flies, the high-elevation assemblage is expected to be at risk from climate change with 2–3 ^{o}C of warming; whereas an increase of 4–5 ^{o}C would put the mid-elevation assemblage at risk as well (Wilson *et al.* 2007).

Endemic species are likely to have higher vulnerability to climate change due to high habitat specificity.

Decreases in suitable area are predicted for most Australian endemic rainforest birds, including all 12 Wet Tropics endemics and the single Central Queensland Coast (CQC) bioregion endemic Eungella honeyeater (*Lichenostomus hindwoodi*), but species shared with Papua New Guinea showed mixed responses (Anderson *et al.* 2012). For nine out of 12 Wet Tropic Bioregion endemic bird species, total population size is expected to decline more rapidly than distribution area (Shoo *et al.* 2005b). The extinction risk for each bird species depends on the altitude at which the species is more abundant: upland species are the most vulnerable, whereas lowland species may increase in population size (Shoo *et al.* 2005a). The grey-headed robin (*Heteromyias albispecularis*) in particular is likely to experience population decline faster than suitable climate space, and abundance increases are predicted for high elevations (Li *et al.* 2009). The golden bowerbird is predicted to face severe range contractions with only moderate warming (Hilbert *et al.* 2004).

The endemic northern bettong (*Bettongia tropica*) is predicted to face a contraction in its optimal habitat, but a possible expansion of sub-optimal habitat (Bateman *et al.* 2012b). However, increasing drought is likely to result in local extinctions of the northern bettong (Bateman *et al.* 2012a).

Among beetles, flightless Carabid ground beetles endemic to more marginal mountain ranges are projected to be the most vulnerable to climate change impacts in the Wet Tropics (Staunton *et al.* in press).

Species vulnerability to climate change is likely to be determined by their ability to disperse to new areas of suitable climate.

The number of species of rainforest birds is predicted to increase in areas at elevations above 100 m for Cape York, and for elevations above 900 m for the Wet Tropics Bioregion, depending on the ability of the rainforest species to disperse across the Black Mountain Barrier (Anderson *et al.* 2012). If rainforest birds are unable to disperse across the Burdekin-Lynd Barrier, the Central Queensland Coast Bioregion (CQCB) is not predicted to face an increase in species richness. However, if dispersal were unconstrained, the CQCB is predicted to increase in the richness of rainforest birds across all elevations, particularly above 300 m. Without dispersal, some species , such as the Atherton scrubwren (*Sericornis keri*) are likely to be constrained to extremely limited upland refugia (Anderson *et al.* 2012).

Some analyses of vulnerability of vertebrates in the Wet Tropics Bioregion have been conducted on the basis of life-history characteristics rather than distribution. These analyses found that birds had the highest potential for recovery partly due to high potential for dispersal, as did some mammals;

whereas frogs were the most vulnerable due to their high habitat specificity and low dispersal ability (Isaac *et al.* 2009).

Cassowaries

Southern cassowaries (*Casuarius casuarius*) are currently listed as endangered in the Wet Tropics Region and, due to a lack of data, vulnerable on Cape York. Recognised threats to cassowaries include loss of habitat, predation by vehicles and dogs, extreme weather events (e.g. cyclones and droughts), weed invasion and potentially disease and pigs (Latch 2007). Climate change has the potential to amplify most of these threats but the greatest impact is likely to come through loss of habitat, declines in habitat quality and increased fragmentation.

Climate change will reduce the distribution and size of cassowary populations due to reduction in the extent and quality of their habitat.

Cassowaries utilise a broad range of vegetation types, from urban areas, banana plantations, to coastal dry forest, mangroves right through to rainforest (Latch 2007). Despite this, cassowaries are restricted to areas in close proximity to continuous rainforest and are dependent on rainforest for year-round availability of a diverse range of fruits (Bradford, *et al.* 2008). Consequently, the future of cassowaries in Cape York and the Wet Tropics Bioregion is dependent on how climate change and other factors impacts the quality and extent of rainforest.

A number of modelling studies forecast that under climate change the distribution of closed rainforests will follow the distributions of moister conditions. These conditions are expected to move towards higher altitudes resulting in a contraction and increased fragmentation of closed forest (Hilbert *et al.* 2001; VanDerWal *et al.* 2009). The consequence of this would be a similar loss and fragmentation of cassowary habitat and a decrease in habitat quality resulting in a consequent loss of carrying-capacity (i.e., a reduction in cassowary population size (Mokany *et al.* in press; Vanderwal 2013)).

Higher temperatures will reduce the capacity of cassowaries to utilise open vegetation types.

The southern cassowary occurs in areas with higher temperatures than those currently experienced in the Wet Tropics Bioregion, suggesting they should be able to cope with increased temperatures. Furthermore, it appears that Ratites are generally efficient thermoregulators, though cassowaries may have a lower tolerance for high temperature than other Ratites (Maloney 2008). Experience working with captive cassowaries suggests that they struggle with activity in high temperatures, particularly in direct sunlight (Westcott and Reid 2002) and this observation is supported by their interest in water, frequent bathing and drinking during periods of high temperature (DAW pers. obs.). This may reduce their activity under higher temperatures and reduce their ability to utilise open habitat.

Cassowary populations will be reduced by the impact of more frequent extreme events on the quality and extent of their habitat.

Cyclones will likely be an important driver of vegetation change in the Wet Tropics Cluster Region, with the damage they cause likely promoting more rapid vegetation change than would have occurred otherwise. Thus, greater cyclone severity (See Chapter 2) will likely result in more rapid loss of cassowary habitat. The effects of extreme weather events will also interact with human modification of the landscape reducing connectivity and making isolated patches and corridors more susceptible to desiccation (Laurance and Yensen 1991) and further damage by cyclones (Bruce *et al.* 2008; Metcalfe *et al.* 2008b) through reduction, removal and modification of vegetation.

While individual cyclones are unlikely to cause mortality across the species' entire range, they have the potential to severely impact and potentially eliminate local populations (Latch 2007).

Invasive plants have the potential to reduce quality of cassowary habitat and cassowary population sizes.

Climate change is predicted to result in increased storm intensity that is likely to favour invasive plants (see the section on invasive species below). Invasive plants such as miconia and pond apple pose very real threats to the cassowary to the extent that they can dominate intact and remnant rainforest vegetation. As the representation of such species increases in the local plant community, the diversity of fruits available and the proportion of the year in which they are available decreases. In extreme circumstances only the invasive species will be present with fruiting occurring for just a few months of the year replacing a more diverse species mix that provides fruit throughout the year (Westcott *et al.* 2008).

Freshwater biodiversity

Climate change poses a high risk to the freshwater biodiversity of Cape York and the Wet Tropics Bioregion.

Climate change is predicted to lead to shifts in the locations of suitable climate space in Cape York and the Wet Tropics Bioregion for freshwater fauna, including turtles, frogs and crayfish (James *et al.* 2013). For freshwater fish species, predictions are for richness to remain relatively similar to what they are now (James *et al.* 2013). The study by James *et al.* (2013) represents a first step towards understanding impacts of climate change on freshwater biodiversity at a continental scale. Further work is urgently needed to understand what this will mean for biodiversity at a more local level in the Wet Tropics Cluster Region particularly with respect to species turnover (changes in community assemblages), potential effects of sea level rise and barriers to movement that may prevent species moving into new areas even where future conditions are suitable.

Sea level rise and increased seasonality of rainfall into the future have implications for fish assemblages (Morrongiello *et al.* 2011). Coastal floodplain habitats of the Wet Tropics Bioregion and Cape York support the majority of the regional freshwater fish biodiversity (Pusey and Kennard 1996). Warmer waters, intrusion of saltwater and longer water residence times are likely to impact upon fish assemblages in these lowland habitats (Rayner *et al.* 2008). Furthermore, many endemic species of the region have specific habitat preferences, for example riffle specialists (Donaldson *et* *al.* 2013; Pusey *et al.* 2008) which are particularly at risk from more frequent drying of habitats resulting from increased flow variability and reduced dry season discharge (Januchowski-Hartley *et al.* 2011).

Understanding of climate- induced impacts on freshwater biodiversity in the Wet Tropics Bioregion and Cape York is in its infancy with little known in the other two subregions of the cluster. Exactly how air temperature will translate into water temperatures is unknown, or how this will be moderated by, for example, the topographic shading and riparian vegetation. Furthermore, water temperature preferences and physiological temperature tolerances are virtually unknown for the vast majority of freshwater species in the Wet Tropics Bioregion and Cape York.. Predicted changes in river flows will need to take into account alterations to the cloud base which significantly contributes to the water budget of the Wet Tropics Bioregion (Wallace and McJannet 2013). Water yields there could be significantly lower under increased temperatures, particularly during the dry season (See Chapter 2).

Freshwater species with poor dispersal capacity and high specificity for habitat requirements are likely to have higher vulnerability to climate change.

Freshwater species with limited dispersal capabilities and narrow habitat tolerances that are likely to be exceeded due to climate change are particularly at risk from climate change in the Wet Tropics Bioregion and Cape York. Many freshwater species are restricted in their capacity to disperse, requiring hydrological connectivity or close proximity to move between freshwater habitats. There are many thousands of in stream barriers in the Wet Tropics with estimates of over 5000 human-made interventions (e.g., dams, weirs, road crossings) (Lawson *et al.* 2010) that potentially obstruct the movement of freshwater fauna.

Spiny crayfish of the genus *Euastacus* found in the Wet Tropics Bioregion (e.g., Roberts crayfish, *Euastacus robertsi*, the red and blue spiny crayfish, *Euastacus fleckeri*, the Balan spiny crayfish, *Euastacus balanensis*, and the Cardwell hairy crayfish, *Euastacus yigara*) are restricted to cool mountain stream habitats above 700 m and are considered to be particularly at threat from climate change (Coughran and Furse 2010). James *et al.* (2013) predict that under the most likely future climate scenario (i.e., high emissions) the suitable climate space for many of the crayfish found along the east coast of Australia will contract further.

Other freshwater biota with similarly restricted habitats and poor dispersal capacity include frogs which are highly vulnerable due to high habitat specificity and low dispersal ability (Isaac *et al.* 2009). For example, *Litoria nannotis* has a high habitat specificity and sedentary nature, making it particularly vulnerable to disturbance and unlikely to persist under climate change (Rowley and Alford 2007).

Marine turtles and dugongs

Projected increases in sand temperature are likely to influence the reproductive output of marine turtles.

Incubation of marine turtle eggs is strongly influenced by sand temperature (Spotila and Standora 1985; Standora and Spotila 1985). Successful incubation of eggs occurs when nest temperatures are between 25 and ~34°C. The sex of hatchlings is determined by the nest temperature, with warmer temperatures producing more females (Mrosovsky and Yntema 1980). Therefore, warmer temperatures could skew marine turtle populations' sex ratios towards predominantly females, and may also decrease hatching success (Hamann *et al.* 2013; Hamann *et al.* 2007), especially on islands with no shade, or on beaches with darker sand.

It is predicted that the nesting grounds used by the northern Great Barrier Reef (nGBR) green turtle population, in the northern Great Barrier Reef and Torres Strait region, will produce a higher proportion of females by 2030 and will experience incubation temperature that constantly exceed the upper thermal incubating threshold by 2100; this will decrease hatching success unless the timing of nesting shifts (Fuentes *et al.* 2010a; Fuentes *et al.* 2009). Limited assessments have been conducted for other marine turtle populations however the Queensland Department of Environment and Heritage Protection is currently monitoring sand temperature at key marine turtle nesting grounds for each genetic stock of turtles in Australia to provide crucial data to understanding the impacts of increases in temperature on marine turtles. The full impact of predicted feminization of turtle nesting grounds is not fully understood (Hamann *et al.* 2013). Some nesting beaches have persisted with strong female biases over a few decades or even longer (Hays *et al.* 2003; Marcovaldi *et al.* 1997) and there is no evidence that a low production of male hatchlings has resulted in a low reproductive success within populations (Broderick *et al.* 2000), although it is possible that long-term population declines due to exploitation and other factors may mask such effects (Poloczanska *et al.* 2009). However, turtles may not be as vulnerable to warming temperatures and predicted feminization as first anticipated as male mating patterns may be able to buffer against the disruptive effects of climate change (Wright *et al.* 2012).

Higher sand temperatures may also decrease the duration of marine turtle egg incubation (Davenport 1997), decreasing hatchling body size and reducing hatchling performance and success (Booth and Astill 2001). The impacts of warmer temperatures are evident in Mon Repos, SE Qld, an important loggerhead turtle rookery, where sand temperatures at nest depth are regularly reaching as high as 36°C for weeks at a time during hatching season, causing increased debilitation and even death of eggs and hatchlings (C. Limpus, pers. comm.). Nevertheless, the 2010/2011 nesting season was one of the coolest years on record due to the above average rainfall that fell along the Bundaberg coastline throughout the summer (C. Limpus, pers. comm.).

Sea level rise may impact marine turtle nesting grounds.

Projected sea-level rise (SLR) is expected to cause shoreline erosion, saline intrusion into the water table and inundation and flooding of marine turtle nesting grounds (Fish *et al.* 2005; Fuentes *et al.*

2010b). These processes may increase egg mortality and eventually cause loss of nesting beaches (Fish *et al.* 2005). Reduction of available nesting area may amplify density-dependent population regulation at marine turtle nesting grounds, potentially increasing the risk of disease in nests and accidental destruction of nests by nesting females (Fish *et al.* 2008). Small, tropical low-lying islands, such as coral atolls, especially those that are not vegetated or that lie on exposed reefs in areas of high tidal range are likely to be the most vulnerable to SLR (Woodroffe *et al.* 1999). Nesting grounds below 2m used by the nGBR green turtle population are predicted to be more susceptible to SLR than nesting grounds with higher elevation since potential inundation is significantly and negatively correlated with maximum elevation (Fuentes *et al.* 2010b). Currently, concern exists regarding the impacts of SLR for several marine turtle rookeries in Torres Strait (e.g. Bramble Cay), the far northern Great Barrier Reef (e.g., Raine Island) and the Capricorn Bunker group (e.g., Heron Island) based on anecdotal and empirical reports of long-term changes to beach shape and sand volume at these places (Fuentes *et al.* 2010b). The impacts of sea level rise will probably be more notable over the longer-term (more than 50 years), however SLR may also help other coral cays to develop and/or stabilize and thus other areas may become available, or become better suited for marine turtles (Fuentes *et al.* 2012).

Extreme weather events can impact dugongs.

Extreme weather events can impact dugongs directly through stranding events or indirectly through impacts on seagrass (see above) that is their primary food source (Heinsohn and Spain 1974). The probability of direct stranding from extreme weather events is dependent on a range of factors (e.g., water depth where they are present and their proximity to shore); direct mortality is more likely if cyclones cross high dugong-density areas during high tide (Lawler *et al.* 2007). Consequently, direct mortality from extreme weather events is unlikely to be a significant threat to a population of dugongs. However, the impact that cyclones, storms and flooding can have on dugong food sources can be large and cause a greater disturbance to local dugong populations. Seagrass dieback results in reduced food availability, which will result in dugongs losing weight and fat stores (Marsh *et al.* 2011). This is likely to lead to delayed reproduction (causing a decline in calf numbers), distributional shifts (Marsh and Kwan 2008) and adult mortality (Schumann *et al.* 2013). A record number of dugong mortalities (181 compared to 85 for the same period in previous years) in the Great Barrier Reef in the summer of 2010/ 2011 has been attributed mainly to starvation associated with widespread loss of seagrass beds following Cyclone Yasi and intense rain and devastating floods in South East Queensland (Brodie and Waterhouse 2012; GBRMPA 2011; Sobtzick *et al.* 2012). Destruction of seagrass beds has also caused dugongs to emigrate from feeding areas and to travel greater distances in search of food (Heinsohn and Spain 1974; Preen and Marsh 1995; Sobtzick *et al.* 2012).

Warmer ocean temperature may expand the distribution of dugongs southward.

A simplified view of the effects climate change on sea level and water temperature is that they possibly may be beneficial to dugongs. Increased water temperature is likely to allow a southward extension of the range of dugongs in Australia (Lawler *et al.* 2007). Nonetheless, such potential expansion of habitat is likely to be offset by the narrowing of the Australian continental shelf at higher latitudes and the resultant limited availability of conditions suitable for the growth of large seagrass meadows.

The distribution and abundance of invasive species and emergent risks

Across the Wet Tropics Cluster Region, the diversity, distribution and abundance of invasive species is increasing independent of climate change; however, the direct and indirect effects of climate change are very likely to exacerbate the spread and impact of invasive species as well as allow opportunities for new species to invade. In combination with climate change, invasive species are expected to contribute to interacting processes or 'threat syndromes' that could precipitate major environmental change and consequent impacts on biodiversity (Murphy *et al.* 2012).

Shifts in distribution for existing species and new opportunities for invasion

The suitable climatic space for most invasive species will shift towards the south and contract towards the east coast. However, the Wet Tropics cluster region will remain suitable for most tropical invasive plant species.

As a general rule, suitable habitat for most tropical invasive species will shift towards the south and contract towards the east coast (Hughes *et al.* 2013; Kriticos *et al.* 2003; Kriticos *et al.* 2005; Murphy *et al.* 2009; Scott *et al.* 2008b; van Klinken *et al.* 2009) (Figure 1). For example, for some weed species currently restricted to tropical north-east climates this may mean an expanded distribution into southern Queensland. For other species (e.g., candyleaf – *Stevia ovata*), it likely means a contraction of the climatically suitable distribution in Queensland, and a shift into southern Austrslian states (Murphy *et al.* 2009). Scott *et al.* (2008b) modelled the potential future distribution of 41 sleeper and alert weed species which showed that under climate change scenarios for 2070, sleeper and alert weed species from the far north of Australia can be expected to be displaced southwards by over 1000 km.

However, while suitable climatic space shifts towards the south and contracts towards the east coast for many species, the Wet Tropics Cluster Regions generally remain suitable for tropical invasive species (Figure 2 a-d). For some species, suitable climatic space increases in the region, for example for Rubber Vine (*Cryptostegia grandiflora*) in the northern Cape York NRM region (Figure 2 e and f).

There is little data available on climate driven changes in distributions of tropical invasive species other than plants. For some other organisms potential shifts in distribution may be inferred based on thermal tolerances. For example, for invasive fish species, such as *Gambusia holbrooki* (Meffe 1991) and *Tilapia mariae* (Shafland and Pestrak 1982), their current distribution is most likely restricted by their lack of tolerance to low temperature. Increased water temperature may extend their distributional range into sub-tropical and elevated regions of Queensland.

Cape York will have an increased biosecurity risk from countries to the north.

The Wet Topics Cluster Region, particularly the Torres Strait and Cape York NRM regions, is predisposed to a unique set of biosecurity risks due to its close proximity to New Guinea and the Indonesian archipelago (Waterhouse and Mitchell 2012). The Northern Australian Quarantine Strategy (NAQS) maintains a list of high-risk exotic insect pests, plant diseases, weeds and animal diseases (http://www.daff.gov.au/biosecurity/quarantine/naqs). Targeted organisms are considered serious threats to Australia's agricultural productivity, export markets or the environment. The coastline of the Cape York NRM region in particular is considered by the NAQS to have a particularly high level of overall risk of invasion (Murray *et al.* 2012). Surprisingly, however, this list does not contain any aquatic vertebrates or invertebrates (NAQS, pers. comm.) despite there being a clear threat to fisheries and the environment due to risk of invasions in particular from Papua New Guinea (Department of Employment Economic Development and Innovation 2011).

More intense tropical cyclones and projected increases in wind speeds over northern Australia (See Chapter 2) may increase the likelihood of wind-borne assisted incursions by weeds, pests and pathogens from countries to the north (Eagles *et al.* 2013; Luck *et al.* 2014). A number of weed species on the NAQS list are wind-dispersed and therefore more likely to spread as a result of climate change. For example, the densely tussocked, perennial grass *Digitaria insularis* (Poaceae), produces large volumes of wind-dispersed seed. It is invasive throughout the Pacific as well as in Papua New Guinea. Several species of wind-dispersed Asteraceae are also included on the NAQS list including *Chromoleana odorata* (Siam weed) and *Mikania micrantha* (Mikania), both of which are already invasive in Queensland. Siam weed is currently limited to the Wet Tropics region south of Cairns. However, it is widespread in Papua New Guinea and is moving closer to the Torres Strait (Waterhouse 2013). In the future it poses a very significant risk of spreading by wind to the islands of the Torres Strait and Cape York Peninsula.

Climate change will create new opportunities for invasive species to recruit, spread and increase in abundance.

Climate change creates new opportunities for invasive species to recruit and spread. As discussed above, vegetation in the region will be increasingly in disequilibrium with climate and subject to multiple stressors related directly to climate, and indirectly, for example through changed biotic interactions. Wherever native species are particularly stressed (e.g. at ecotones, and see section on cyclones above), invasion by exotic species is more likely because of a reduction in resource use (nutrients, light, water) by the resident community.

Resource availability is also very likely to increase in tropical communities as native species shift their distributions in response to climate change. Communities are unlikely to migrate together, and the departure of a species from a community as its climatic tolerances are exceeded could result in increased levels of resources becoming available leading to enhanced opportunities for invasion (Ward and Masters 2007). Invasive species tend to have a broader range of tolerances than native species providing invaders with a wider array of suitable habitats (Walther *et al.* 2009).

The movement of invasive species to the south opens up a serious issue for north Queensland. A southwards shift of suitable habitat for existing species as well as species already considered invasive in Queensland, creates the opportunity for new invasive threats from as yet un-identified species. Under changed climatic conditions, emerging invasive species may come from: (a) species already present in Australia in low abundance for which climatic conditions become more favourable; (b) species native to, or known to be naturalised in, adjacent countries or countries that have similar climatic conditions to the predicted future climates of Queensland but which are not yet present in Australia; or (c) native Australian species that undergo significant changes in range or abundance in response to climate change or other anthropogenic stressors (invasive natives).

Emerging risks may also arise as a result of changes in land-use related to climate change or mitigation measures. For example, climate change and concerns about the sustainability of traditional sources of energy (and links between these drivers) are leading to the formulation of ambitious targets for renewable energy. In particular, tropical lignocellulosic crops (woody trees and grasses) have huge potential for use as feedstocks (Richardson 2013) and their feasibility for large-scale production of energy is currently being investigated for northern Australia.

Impacts of extreme events on invasive species

Increases in growth and recruitment of invasive weeds are likely to follow severe cyclones.

Intense tropical storms may facilitate weed invasion in tropical forests by increasing resource availability, reducing competition and increasing opportunities for propagule dispersal. Severe storms provide a large spatial and temporal window of opportunity for plant invasion and empirical research suggests that invasive species increase in growth and recruitment and spread readily following such events (Metcalfe *et al.* 2008a; Murphy *et al.* 2010; Murphy *et al.* 2008a; Murphy *et al.* 2008b). For tropical rainforests, vines and woody invasive species that are shade-tolerant and recruit from the seedling layer may constitute the greatest threat following severe storms. For example, growth rates of the small tree *Miconia calvescens* (a Class 1 weed in Queensland and the target of a national eradication strategy) more than doubled in the year following Cyclone Larry in 2006 and the species recruited readily and showed low mortality even five years post-cyclone (Murphy *et al.* 2010; Murphy *et al.* 2008a). Tropical forests persisting in fragmented landscapes are particularly at risk from invasion, potentially resulting in community homogenization and loss of ecosystem function (Laurance and Curran 2008).

With an increasing intensity of tropical cyclones we would expect to see significant structural and compositional changes to tropical landscapes as a result of weed invasion. These changes may include a decrease in diversity of native species and homogenization of communities at landscape and regional scales, slower rates of forest succession, increasing degradation of forest fragments, and ultimately a decrease in ecosystem function as these effects are compounded through interactions with other threats.

Dispersal opportunities for invasive species are likely to increase due to extreme rainfall events.

Flooding associated with extreme rainfall events (See Chapter 2) has the potential to move propagules of invasive species long distances across the landscape, downstream, across catchments, and via ocean currents. For example, pond apple (*Annona glabra*) is a major weed of riparian and coastal areas along the north-eastern coast of Australia. It produces seed during the late summer (February to April) which is peak cyclone season, and its seeds can float and remain viable in fresh and saltwater for over 12 months (Setter *et al.* 2008). Mason *et al.* (2008) modeled seed transport of pond apple in the Great Barrier Reef region from 1997-2002 and found that following Cyclone Justin in 1997, coastal rivers could potentially have transported seed over 1300 km to the Torres Strait and on to Papua New Guinea and beyond. Similarly, an increase of up to four percent in extreme rainfall is expected in the Cape York region throughout the year (Whitfield *et al.* 2010). Such extreme rainfall events result in high stream flow, increasing the probability of river floods and extended distribution of floodwaters which may increase spread of weed seeds and invasive aquatic organisms.

Aquatic invasive species such as Tilapia (*Tilapia mariae)* may also benefit from intensification of wet season rainfall allowing the fish to spread further westwards and into new catchments via overland water flow, and establish throughout Cape York rivers and across northern Australia (Garnett 2010). Tilapia can significantly change the composition of native fish faunas (Bradford *et al.* 2011) and degrade water quality (Garnett 2010).

The degradation of coastal habitats by invasive species is likely to increase the impact of extreme events on human communities and infrastructure.

Littoral forests and coastal vegetation play a key role in buffering and protecting communities and infrastructure from the effects of climate change (and are threatened by climate changes, see above), particularly those associated with sea level rise and severe storms. Research has shown that engineering solutions are not as cost-effective at providing these services as natural foreshore vegetation (Jones *et al.* 2012). Transformer weeds, such as Pond Apple (*Annona glabra*) and Singapore Daisy (*Sphagneticola trilobata*), are recognised as a serious threat to coastal vegetation in the Wet Tropics Cluster Region and seriously alter the structure and function of this community where they occur. Where invasive species have compromised the integrity of coastal vegetation it is very likely that the vulnerability of coastal communities to extreme events has been increased.

Other impacts

Spread of high biomass invasive grasses may transform savanna ecosystems into ones dominated by exotic grass.

Changes in plant species distributions and vegetation composition caused by climate will significantly affect fuel loads and fire regimes across northern Australia (see above, this chapter). Some research suggests a lengthening of the fire frequency interval for tropical dry forests across northern Australia due to increased dryness and elevated CO_2 decreasing grassy biomass (Cary *et al.* 2012). However, the expansion of exotic high biomass grasses is likely to lead to a shortening of the fire interval , i.e., tropical woodlands and savannas are likely to experience more frequent fire. In particular, gamba grass (*Andropogan gayanus*) and mission grass (*Pennisetum polystachion*) in the monsoonal zone, and buffel grass (*Pennisetum ciliare*) in sub-humid areas have dramatic effects on ecological function by developing fuel loads several times greater than produced by native species (Fensham 2012). For example, gamba grass has an extensive potential range across the savannas, and can produce up to 20 tonnes per hectare of biomass (Douglas and Setterfield 2005), resulting in significantly increased fire intensity and forward spread of fire (Setterfield *et al.* 2013). Such increases in fire intensity can increase tree mortality compared with savanna fires burning in native grass fuel loads and result in rapid ecosystem transformation to exotic grass-dominated structure (Rossiter *et al.* 2003). This transformation would have important implications for the grazing industry (See Chapter 6), carbon sequestration (See Chapter 4), ecosystem structure and biodiversity generally.

Seasonally inundated waterholes in the dry tropics are likely to be increasingly impacted by invasive animals.

Feral animal activity (e.g., pigs, cattle and horses) around waterholes increases significantly as the dry season progresses across northern Australia (Pettit *et al.* 2012). While, the impacts of this activity generally diminish after significant rains and seasonal flushing (Doupé *et al.* 2010), more prolonged dry seasons (See Chapter 2) are likely to result in more persistent impacts. For example, trampling and compaction of vegetation, harvesting of macrophytes and buried plant rhizomes and tubers, and enhancing dispersal opportunities for aquatic invasive plants are all impacts which are likely to have more significant persistent effects with more prolonged dry seasons (Pettit *et al.* 2012). Feral pigs already exert a heavy predation pressure on freshwater turtles around waterholes in northern Australia and increased pig predation may lead to severe population declines for these species (Fordham *et al.* 2008), as well as compromising cultural harvesting by Indigenous people.

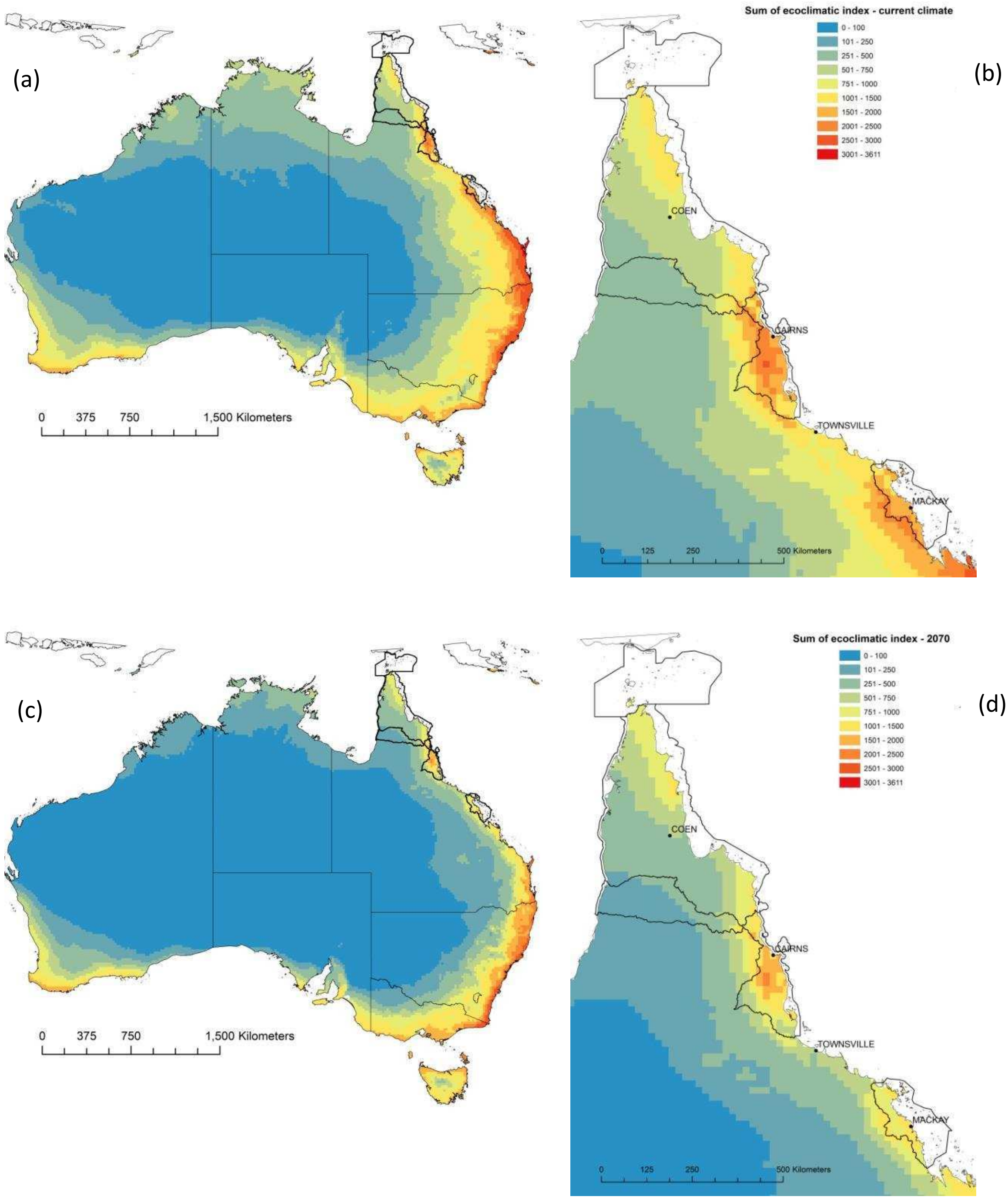

Figure 1. The summed results of Climex models for 54 existing or potential emerging weed species in (a) and (b) current climate conditions (centred on 1975) and in (c) and (d) future conditions (2070). For each species an "Ecoclimatic Index" on a scale of 1-100 is generated which gives an overall measure of how favourable the climate is for permanent occupation by a species. Higher scores indicated higher climatic suitability.

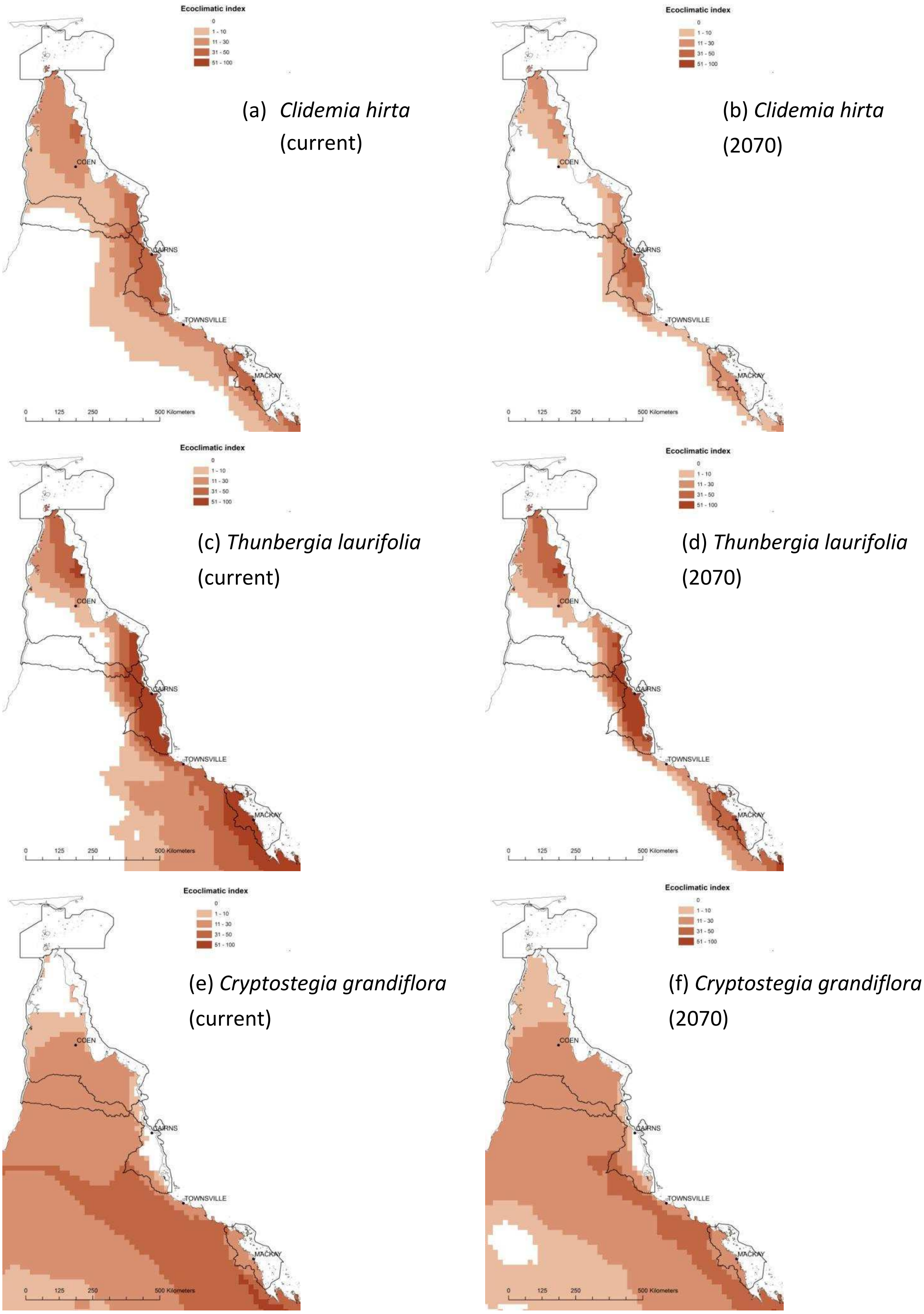

Figure 2. Modelled climate suitability (Ecoclimatic index) for *Clidemia hirta* (Clidemia), *Thunbergia laurifolia* (Thunbergia) and *Cryptostegia grandiflora* (Rubber vine) in current climate (left column) and 2070 (right column) (Breadon *et al*. 2012; Kriticos *et al*. 2003; Scott *et al*. 2008a).

Emerging infectious diseases in northern Australia

Emerging infectious diseases are considered to be a growing threat to human and wildlife health. Such diseases might be facilitated by climate change that causes an expansion of habitats and climate that favour disease vectors, changes host-parasite ecology and increases disease outbreaks. Relatively little research has been done on potential climate change impacts on disease in the Wet Tropics Cluster Region.

Emerging infectious diseases are a growing global concern due to the significant impacts they can have on wildlife and human populations (Jones *et al.* 2008; Taylor *et al.* 2001). By definition, such diseases have recently moved from an existing host to a new host, increased in prevalence or range, are newly discovered, or are recently evolved (Daszak *et al.* 2000; Lederberg *et al.* 1992; Morse 1993). Predominantly, emerging diseases are from zoonotic pathogens (pathogens transmissible between animals and humans) with mosquito-borne diseases causing the greatest number of human infections and deaths annually (Reisen 2010). Climate change is an important determinant of disease emergence because it constrains the overall distribution of infectious disease, while weather affects the timing and magnitude of outbreaks (Epstein 2001).

As many of the emerging infectious diseases are from tropical localities, the tropical and subtropical regions of Australia should be considered at greatest risk for disease establishment. For example, malaria was only recently declared absent from Australia in 1981, yet northern Australia is still at risk from malaria and other diseases such as dengue and Chikungunya because suitable mosquito vectors for these diseases are common and infected people from overseas frequently visit these areas (Longbottom 1996, Hanna *et al.* 1999). Outbreaks of infections such as dengue, Ross River fever, Barmah Forest virus, Japanese encephalitis (JE), and Murray Valley encephalitis have occurred annually or sporadically (JE) in northern Australia for many years (Mackenzie *et al.* 1998, Russell & Kay 2004).

The expansion and increased dynamics of vector communities

Vector communities throughout the region are likely to be affected substantially by warming, changes in water availability due to extreme rainfall events and increased cyclone intensity (See Chapter 2). We are confident that these climate changes will change the vector community substantially in the future, although the rate of change and local details are difficult to predict with certainty.

The abundance and diversity of mosquitoes will increase at higher elevations and latitudes, and during winter periods, increasing both the range and timing of disease risk.

Long-term warming may influence the geographic expansion of infections because warmer temperatures increase the development rate of mosquito larvae and parasites (Epstein *et al.* 1998). For example, annual minimum temperatures of 16^{o}C and 10^{o}C respectively limit the distribution of malaria and dengue (Martens *et al.* 1997). Given predicted temperature increases, this suggests that the tropical uplands of Atherton and Evelyn Tablelands and south east Queensland may become suitable for these diseases in the future. The abundance and diversity of mosquitoes in the Wet Tropics Bioregion is positively correlated with mean annual temperature, suggesting that warming will increase mosquitoes at higher elevations (Hilbert 2010). In 1996, Bryan *et al.* predicted that *Anopheles farauti*, an important malaria vector, would most likely extend its distribution in 2030 by 800km southwards (from Townsville to Gladstone). However, only a short time later van den Hurk *et al.* (1998) captured *An. farauti* in Mackay (ca. 400km south of Townsville) suggesting that this range expansion is already underway.

The abundance and diversity of mosquitoes will increase with extreme rainfall events as a result of an increased extent of temporary surface water and vector breeding habitat. Disease outbreaks are facilitated by extreme weather events (McMichael *et al.* 2006), which can increase vector-breeding habitat. Human-mosquito exposure may rise if increasing cyclone severity damages homes (See Chapter 5), proliferating mosquito breeding habitat through greater extent and duration of flooding, and the possible restriction of access to health care.

Mosquito abundance and diversity may decline in dry seasons as a result of increased rainfall seasonality which would reduce surface water and the availability of mosquito breeding habitat. However, some mosquito species are capable of persisting even during the dry season. For example, in the Cairns area *Culex annulirostris* and *Aedes vigilax*, both very common and competent vectors for a number of viruses, are able to persist year round, regardless of season (Meyer Steiger, unpublished data).

Wind is an important disperser of vectors, e.g. midges (vectors for blue-tongue) and mosquitoes. Climate will influence wind patterns in northern Australia (see Chapter 2) and may result in changed dispersal patterns of these vectors.

For example, monsoonal lows and tropical cyclones in the Gulf of Carpentaria sustain strong north westerly winds. Computer simulations demonstrated that tropical low-pressure systems west of Cape York are able to transport mosquitoes from Papua New Guinea into Cape York Peninsula (Ritchie and Rochester 2001). Similar results have been obtained for midges (Eagles *et al.* 2013) and may also hold for a range of other insect vectors and wind dispersing pathogens, e.g., agricultural diseases such as black sigatoka.

Infection pathways may alter due to changing climate and human lifestyles

The spatial and temporal concentration of hosts, vectors and victims will be influenced by changes in water availability and distribution. When water is scarce disease risk will increase around water points where pigs, mosquitoes, other wildlife and people may concentrate.

Disease risk may increase with changing lifestyles and home design associated with changing climate. Open tropical homes with integrated gardens may increase human exposure to biting insects, increasing disease risk.

The distribution and risk of disease

i. Hendra

Disease risk from Hendra is unlikely to change in response to climate change–driven changes in vegetation distribution.

Changes in the distribution of vegetation are likely to result in shifts in the distribution of the different flying-fox species, however, these changes are most likely to involve species replacing each other rather than the loss of all flying-foxes. As a consequence, the distributions of diseases for which flying-foxes are a vector are unlikely to change.

Increased temperatures and longer dry seasons may reduce Hendra spillover risk.

Despite Hendra occurring in flying fox populations throughout the tropics in Australia, spill-over events, instances where Hendra is passed from flying-foxes to another species, have been recorded largely from moister tropical and subtropical environments (McFarlane *et al.* 2011). This possibly reflects reduced virus survival in the environment in hotter and drier habitats, suggesting that longer dry seasons may reduce the probability of spill-over events.

Like many tropical species, tropical flying-foxes occur close to their maximum thermal tolerances and therefore are subject to heat stress and mass mortality during extreme temperature events (Welbergen *et al.* 2008). Stress has been hypothesised to drive Hendra susceptibility, infection or shedding in flying-foxes (Plowright *et al.* 2008). More common extreme temperature events may increase stress and increase the probability of shedding and spillover.

ii. Dengue

Extreme rainfall events and higher temperatures will increase mosquito populations and accelerate population dynamics, increasing the risk of dengue outbreaks.

Climate change may move dengue to higher elevations and southern latitudes.

Higher temperatures decrease the larval development time of *Aedes aegypti*, the main vector of dengue in Australia; for example larvae hatched five times faster at 30°C than at 15°C (Tun-Lin *et al.* 2000). However, human lifestyles govern the distribution of the vector and the infection risk. Climate-related changes in lifestyles may influence Dengue risk, e.g., dengue-friendly gardens etc.

iii. Japanese encephalitis

Wild pigs may become hosts to Japanese encephalitis (JE), which was recorded in Torres Strait but is not known to occur in the Australian mainland at present.

At least one suitable vector of JE (*Culex annulirostris*) is already widespread on the mainland and in 2006 van den Hurk *et al.* retrieved the JE virus for the first time on the Australian mainland. Russell (1998) points out that the JE virus has the capability to survive not only in tropical parts of Australia but also in more temperate regions.

Biodiversity and disease

Climate change–driven changes in community structure may influence disease prevalence in wildlife and disease risk for humans.

The transmission dynamics of zoonotic diseases are subject to the ecology and behaviour of their hosts and vectors and by the structure of the communities in which those hosts and vectors occur. Disease prevalence can be high in communities with abundant competent hosts but low in those with few competent hosts. It has been suggested that disease prevalence may be lower in diverse communities due to dilution effects, i.e., the more species present the fewer competent hosts are likely to be present. Support for this hypothesis is equivocal (Laurance *et al.* 2013; Salkeld *et al.* 2013), however, changes in community structure will likely impact the abundance of competent hosts and therefore have the potential to influence the prevalence and risk posed to wildlife and humans by zoonotic disease.

Summary and conclusions

We expect that there will be substantial impacts on the region's ecosystems and biodiversity that will increase as climate changes continue.

Terrestrial vegetation and ecosystems throughout the region are likely to be affected substantially by warming, changes in water balance and fire weather, increased cyclone intensities and sea level rise. We are confident that these stresses will change the landscape substantially in the future, although the rate of change and specific, regional vegetation changes are difficult to predict with certainty at this time. The appearance of environments unlike those of today could eventually result in new plant communities and vegetation structures.

Longer dry seasons and more severe droughts will decrease the extent of freshwater wetlands and reduce their connectivity leaving functionally isolated communities. Mangroves will be affected in complex ways due to the interaction of warming, altered rainfall, sea level rise, ocean acidification and direct human impacts. Increases in sea level, temperature and likely increases in tropical storm intensity and more intense rainfall events will have a negative impact on seagrass meadows and add to the existing impacts from coastal development and land use. Increased intensity of extreme events, such as cyclones and thermal stress events will exacerbate chronic stressors like poor water quality on sensitive Great Barrier Reef ecosystems.

Many terrestrial vertebrate species are predicted to lose suitable climate space from Cape York and the Wet Tropics Bioregion, including amphibians, birds, mammals and reptiles. However, while some species will be losing climate space in this region, other species will be moving in from elsewhere, particularly moving from the west towards the Wet Tropics and the Mackay-Whitsundays. Species vulnerability to climate change is likely to be determined by their ability to disperse to new areas of suitable climate. Endemic species are likely to have higher vulnerability to climate change due to high specificity for habitat requirements. Climate change will reduce the extent and the quality of cassowary habitat with consequent reductions in the distribution and size of cassowary populations.

Freshwater species with limited dispersal capabilities and narrow habitat tolerances that are likely to be exceeded due to climate change are particularly at risk from climate change in the Wet Tropics Bioregion and Cape York.

The important marine vertebrates, turtles and dugongs will be affected by climate change. Marine turtle populations may be impacted negatively through increased nest temperatures affecting their reproduction and the loss of nesting grounds due to sea level rise. Dugongs will be directly and negatively affected by more extreme weather events and indirectly by loss of their seagrass habitat. However, warmer ocean temperatures may allow their expansion southward.

Across the Wet Tropics cluster region, the diversity, distribution and abundance of invasive species is increasing independently of climate change; however, the direct and indirect effects of climate change are very likely to exacerbate the spread and impact of invasive species as well as allow opportunities for new species to invade. In combination with climate change, invasive species are expected to contribute to interacting processes or 'threat syndromes' that could precipitate major environmental change and consequent impacts on biodiversity.

Emerging and existing diseases might be facilitated by an expansion of habitats and climate that favour vectors, changes host-parasite ecology and increases disease outbreaks.

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Chapter 4: The impacts of climate change on key regional ecosystem services

Petina L. Pert, Mohammed Alamgir, Gabriel Crowley, Allan Dale, Michelle Esparon, Marina Farr, April Reside, Natalie Stoeckl

Executive summary

Climate change alters the functions of ecosystems and as a result, the provision of ecosystem services and wellbeing of people that rely on these services. The concept of ecosystem services is aimed at supporting this broad and open dialogue in ways that allow potential synergies and tradeoffs among social, economic and ecological objectives to be identified and addressed with due reference to the multiple perceptions that people have about benefits and beneficiaries from the environment. In this chapter we discuss insights about the impacts of climate change on regional ecosystem services for the Wet Tropics. Syntheses of published ideas and approaches are presented with key climate change messages for NRM groups to enable them to incorporate into their new regional plans for the Wet Tropics Cluster Region.

Applying an ecosystem services framework relevant for regional NRMs	1. Since the Millennium Ecosystem Assessment framework was developed, there have been various modified versions as well as some new ecosystem services frameworks developed. 2. An ecosystem services framework for NRMs (based on established science) is required to describe the linkages between ecosystems, ecosystem functions, ecosystem services and the community's wellbeing (such as the SEQ Catchments ES framework).
Adding value to regional NRM ecosystem services	3. Ecosystems contribute to the wellbeing of people in a multitude of ways. Most of these 'contributions' are not captured in the marketplace and are thus unpriced. But absence of price does not mean absence of value. 4. There are many different economic valuation techniques that seek to highlight the importance of those non-priced values – often by attaching a 'price' to nature. 5. These techniques are exceedingly complex and not well-understood by non-economists. One size does not fit all. So extreme care must be taken when using and interpreting results from those studies.
Impacts of climate change on ecosystem services	6. Climate change is projected to have a significant adverse impact on Australia's agricultural products and exports.

	7. Adopting a diversified approach will enable farmers to farm longer and more sustainably in an environment of greater uncertainty, in the face of climate change. 8. Classifying ES according to their spatial characteristics might assist NRM regions' assessments and planning at the appropriate scale. 9. Future food, fodder and fibre production and ecosystem services will be under additional risk and uncertainty from climate change. 10. Increased attacks of pests and diseases related to changes in the abundance and distribution of insects, many of which are vectors for disease. 11. Increased exposure of soils leads to further soil degradation and erosion that reduces water infiltration and soil moisture content. 12. Climate change will drastically impact the critical habitat provision for biodiversity. 13. Economic significance of the emerging carbon economy, if all the potential opportunities are realised, could also generate environmental livelihood benefits. 14. Ecosystem degradation threatens water availability, quality and regulation. 15. There is a need to address the underestimation of ecosystem services in farmlands. 16. Establishing mechanisms such as Payments for Ecosystem Services (PES) can support the transition to more sustainable farming systems. 17. Growing human pressures, including climate change, are having profound and diverse consequences for coastal/marine ecosystems and ES.
Climate change impacts to coasts and communities	18. Recognition of the carbon sequestration value of vegetated coastal ecosystems provides a strong argument for their protection and restoration. 19. Seagrass ecosystems have been recognised as a significant carbon stock. 20. Communities will need to have strategies in place for extreme events.

Introduction

Definitions

The benefits that we as humans derive from ecosystems, such as timber, food, water and climate regulation, are referred to collectively as ecosystem services (MA 2005). The Millennium Ecosystem Assessment (MA 2003; 2005) was the first international dynamic and integrated document that reported on ecosystem services (ES) research globally. More recently a global review on ES studies evaluated the current trend, spatial distribution, weakness and future direction of ES research (Seppelt *et al.* 2011). To avoid confusion and double-counting of ecosystem services the latest definitions distinguish between ecosystem services that can be turned directly into benefits (commonly called '*final ecosystem services*') (Australia 21 2012). A further extension to that is to identify the specific beneficiary of the benefit to assist with its valuation and the avoidance of double counting. Although, there are unresolved issues on the opinion and use of terminology in ecosystem services frameworks, the concept of intermediate and final ecosystem services has been adopted in the most recent large scale application of ecosystem services analysis, the UK National Ecosystem Assessment (UK National Ecosystem Assessment 2011).

Box 1. Types of ecosystem services

Numerous schemes have categorized and classified the variety of ecosystem services (Boyd and Banzhaf 2007; Costanza 2008; Costanza *et al*. 1997; de Groot *et al*. 2002; de Groot *et al*. 2010; Fisher B 2009; TEEB 2010a; Wallace 2007). Here, we primarily use the commonly applied based on the MEA (MA 2005) to describe and categorize the relationship between ecosystem and society, as follows:

Provisioning services: are essentially the tangible products (or goods) that are used directly by humans for nutrition, shelter and safety (e.g. food, fresh water).

Regulatory (or 'regulating') services: are the benefits that ecosystems provide in terms of regulating ecosystem-dependent processes (e.g. climate regulation, water purification).

Cultural services: include the spiritual and inspirational, religious, recreational, aesthetic and educational benefits that people derive directly or indirectly from ecosystems (e.g. aesthetic, spiritual, recreational and ecotourism experiences).

Habitat or Supporting services: are those that underpin broader ecosystem functioning and hence contribute to sustaining other services, and usually are more intermediate services (e.g. nutrient cycling, soil formation). Some services can be final in some situations and to some beneficiaries but intermediate in other situations.

Scope of chapter

In this chapter we will describe an ecosystem services framework relevant for regional NRMs, impacts of climate change at a regional level, and associated challenges and potential opportunities. Among the many direct drivers and indirect pressures that exist or are emerging in the Wet Tropics cluster region, the discussion in this chapter focuses primarily on climate change and associated impacts on ecosystem services.

Applying an ecosystem services framework relevant for regional NRMs

Since the Millennium Ecosystem Assessment framework was developed, there have been various modified versions as well as some new ecosystem services frameworks developed.

An ecosystem services framework for NRMs (based on established science) is required to describe the linkages between ecosystems, ecosystem functions, ecosystem services and the community's wellbeing (such as the SEQ Catchments ES framework).

Ecosystem service frameworks

Since the Millennium Ecosystem Assessment framework (Millenium Ecosystem Assessment 2005) was developed, there have been various modified versions as well as some new ecosystem services frameworks (Bastian *et al.* 2012; Carpenter *et al.* 2009; Daily and Matson 2008; de Groot *et al.* 2010; Müller and Burkhard 2012; Potschin and Haines-Young 2011; Tallis *et al.* 2008; Turner and Daily 2007). For example, in Europe the 2010 report on the economics of ecosystems and biodiversity (TEEB) acknowledges the plurality of ecosystem values and has presented a tiered approach for recognizing, demonstrating, and capturing the value of ES for policy making (TEEB 2010a). More recently, the MEA work has continued under a recently formed "Intergovernmental Platform on Biodiversity and Ecosystem Services" (IPBES) http://www.ipbes.net/ in 2010, modeled on the Nobel-prize-winning Intergovernmental Panel on Climate Change (IPCC) (Duraiappah *et al.* 2013; Larigauderie and Mooney 2010). IPBES will be a mechanism that addresses gaps in the science policy interface on biodiversity and ecosystem services globally. To date, Australia (Australian Government Department of the Environment 2010) continues to be involved in the establishment and process, and CSIRO is also actively engaged (Bohnet *et al.* in prep.).

Recommended regional ecosystem services framework

The ecosystem services concept reduces the complexity of natural systems to a manageable (comprehendible) number of services that people get from ecosystems as a way to focus on human dependence on the environment and to engage stakeholders and the community in dialogue about what services are needed where, when and by whom. To apply the concept of ecosystem services in NRM regional planning and management practices, tools need to be relevant and understandable for their stakeholders (e.g. local government, industry, business, researchers, non-government organizations and land managers). Within Australia a well-tested consistent framework already exists which has been applied at the NRM regional level successfully (Maynard *et al.* 2010; 2011). The South East Queensland (SEQ) Ecosystem Services Framework clearly describes the linkages between ecosystems, ecosystem functions, ecosystem services and the community's wellbeing. It provided a practical means (via matrices and maps) for identifying and prioritizing geographic areas within the region according to their ecological attributes and importance. Through spatial visualization, areas have been mapped to show where most ecosystem services are generated, as well as identifying valuable natural assets of the region, deserving appropriate protection measures or anticipate losses in services resulting from development activities, or changes in climate.

Adding value to regional NRM ecosystem services

Ecosystems contribute to the wellbeing of people in a multitude of ways. Most of these 'contributions' are not captured in the marketplace and are thus unpriced. But absence of price does not mean absence of value.

There are many different economic valuation techniques that seek to highlight the importance of those non-priced values – often by attaching a 'price' to nature.

These techniques are exceedingly complex and not well-understood by non-economists. One size does not fit all. So extreme care must be taken when using and interpreting results from those studies.

The many 'values' associated with our natural environment and the ecosystem services it provides

There are many different ways of thinking about 'value' but most economists assume that something is of value if it makes people happy or increases overall life satisfaction (Frey and Stutzer 2002). The price provides some (but not all) information about the 'value' of market goods, but absence of price does not mean absence of value. More than 150 years ago the economists Dupuit in 1861, and later Marshall in 1881, noted that people may derive great benefit (or 'value') from the use of particular goods (e.g. drinking water) but may not always need to pay for those goods. Moreover, people do not even need to 'use' natural resources to benefit from them. Many feel there is much benefit to be had by preserving the environment *in case* they wish to use it in the future (Weisbrod, (1964) and even people who do not currently 'use' the environment and have no intention of ever using it in the future, can still benefit from simply knowing it is there (Krutilla, (1967).

From these ideas, grew the Total Economic Value (TEV) framework which economists often use to categorize different types of environmental values – formally use values and non-use values. Although the TEV and the MEA use different terms, both frameworks highlight the fact that 'the environment has value far above and beyond that which is reflected in the marketplace' (Stoeckl *et al.* 2013b, p. 6). As such, the environment (and the ecosystem services it provides) will be undervalued by those who look only at market prices (Dearden *et al.* 2005; Protected Areas Development 2014; Tallis *et al.* 2009).

Techniques for assessing the 'value' of the environment and its ecosystem services

> *While there may be no "right" way to value a forest or a river, there is a wrong way, which is to give it no value at all.*
>
> Paul Hawken in the foreword to Prugh *et al.* (1999)

Environmental economists have devised numerous 'valuation' techniques that seek to redress this oversight – often attaching dollar signs to environmental values as a way of highlighting their importance. Indeed the idea of putting a 'price' on nature to highlight its importance is gaining acceptance in many areas – evidenced by The Economics of Ecosystem and Biodiversity (TEEB)'s slogan: *Making Nature's Values Visible* (TEEB 2010b). Moreover, the practice of comparing monetary estimates of the value (price) of the environment with other dollar estimates such as projected revenues from a mine, is accepted by governments throughout the world as a legitimate process for evaluating environment/development trade-offs. These evaluations are often done using cost benefit analysis (CBA). The use of CBA by government departments (in conjunction with non-market valuation studies) is legislated in some countries (e.g. the US Flood Control Act of 1936, the US 1981 Executive order 12291), and actively encouraged in many agencies through the publication of guidelines and/or handbooks (Commonwealth of Australia 2006; H.M. Treasury 2003).

There are so many different ways in which the environment benefits people, that there also means that there are many different things that can be 'measured' to highlight those benefits, and there are numerous different techniques for attempting to attach dollar signs to those benefits, for use in CBA or otherwise. Good references for economists include: Getzner *et al.* (2005), Bateman *et al.* (2002), Rietbergen-McCracken & Abaza (2000), Garrod & Willis (1999), and Willis *et al.* (1999). A very good 'layman's' overview of these techniques can be found at Protected Areas Development (2014). To name but a few of these techniques: input-output analysis and general equilibrium models allow economists to estimate the regional economic impact/benefit of tourism, or agriculture that relies upon the natural environment (Driml 1987; Stoeckl *et al.* 2010). Travel cost models allow one to estimate recreational benefits (Driml 2002; Kragt *et al.* 2009). Hedonic pricing allows economist to assess the 'premium' attached to normal market prices that is associated with environmental amenities (determining, for example, how much extra one must pay for a house with a river view - (Castorina 2006). Contingent valuation allows one to determine how much people are willing to pay to prevent the degradation of the environment (Farr *et al.* 2014; Stoeckl *et al.* 2012) and choice models enable researchers to assess the rate at which people are willing to trade one good (e.g. clearer water) for another (e.g. more fish or more money) (Rolfe and Bennett 2003).

Care should, however, be taken when using dollar denominated valuation techniques in regions where there are significant disparities between the rich and the poor (such as the Wet Tropics Cluster Region, given the gap between Indigenous and non-Indigenous incomes – Stoeckl *et al.* 2013a). This is because dollar denominated valuation techniques generally measure how much people are willing to pay. A rich person will be ABLE (and thus WILLING) to pay more for the goods and services, which they enjoy than the poor. So dollar-based valuation techniques will give greater voice to the preferences of the wealthy than to the preferences of the poor unless deliberate attempts are made to redress that issue' (Baker 1975; Blackorby and Donaldson 1990; Stoeckl *et al.* 2013b). Fortunately, there are also non-monetary methods for assessing the importance of a range of different 'values' – some of which have been successfully trialled in and around Northern Australia (see Delisle *et al.* 2009; Larson 2009; Larson *et al.* 2013; Stoeckl *et al.* 2013a; Stoeckl *et al.* 2012 for published examples). Moreover, there is a growing body of literature on subjective wellbeing and overall life satisfaction (LS) which provides yet another way of looking at the 'value' of the environment – a good review of which can be found in Kristoffersen (2010).

The complexity of valuation studies and the consequent need to use with caution

No single valuation technique is without fault and none is suited to all situations (Pagiola *et al.* 2004). Indeed 'most are surrounded with at least some controversy vis-à-vis the 'accuracy' of final estimates, each requires different types of information as an input; and each produces (sometimes subtly) different information as output' (Stoeckl *et al.* 2013b, p. 7). These details are well understood by the valuation specialists, but few non-economists fully understand the assumptions underlying many of these valuation techniques, and may thus be in danger of using results from such studies inappropriately.

For example, (most) valuation studies generate estimates of 'value' that are denominated in dollars. But this does not mean that those estimates can be validly compared. Some valuation studies generate estimates that reflect prices (for example, the *hedonic* valuation techniques) (Boardman *et al.* 2010; Carter and Liese 2010). Other valuation studies generate estimates that reflect expenditures (for example, *the defensive expenditure technique*) (Rogers *et al.* 1997; Tiezzi 2002). To compare these estimates would be to compare lines (prices) and rectangles (price times quantity); much like comparing apples and oranges. As a general rule, people should thus avoid making cross-study comparisons unless much care has been taken to ensure the techniques generate estimates that are truly comparable.

It is also not uncommon for people to add values that have been generated from different studies; another practice that should be avoided unless done with considerable care. This is because many of the 'values' identified in the MEA and the TEV frameworks overlap (e.g. the enjoyment an angler derives from fishing, and the enjoyment that same person derives from spending a day on the water with friends/family). So adding separate 'values' to generate an estimate of TEV is akin to adding sets in a simple Venn-diagram: TEV will not equal the value of set A plus the value of set B if these values overlap (see Hoehn and Randall 1989 for a formal treatment of the problem). The message here is that one should always check for overlap before adding.

The story gets even more complicated.

Some valuation methods generate estimates of the 'total' value of a region (e.g. total tourism revenues). These 'total' values are particularly useful if seeking to describe the current state of affairs (for example, determining that tourism brings in more money to the region than manufacturing), or if trying to work out what might happen to the region, if the entire wet tropics rainforest ceased to exist. But managers are rarely faced with all or nothing questions (e.g. rainforest, versus no rainforest), and are instead more likely to be required to address questions such as: what losses would the region suffer if the environment values in the region were to change, or be eroded? Information about the 'total' value of a region is not useful in such situations – what is needed is information about the 'value' (or cost) of a change, termed *marginal values* by economists. Those interested in assessing the impacts of climate change, are likely to need information about *marginal values* (as opposed to total values).

If one wants to generate estimates of the marginal value of environmental change, one must firstly work out what environmental change is likely to occur (e.g. 10% loss in soil productivity; 50% increase in sediment loads). Only then can one go on to estimate the likely economic consequences of that carefully specified change (DeFries *et al*. 2005). These things are highly context specific (See Chapter 6), and will vary over time, space, and with scale (National Research Council of the National Academies 2004), so one cannot simply 'borrow' information from another context and apply it to the wet topics (a practice called benefit transfer). Not only are the socioeconomic conditions and thus 'values' likely to differ across regions (Rolfe and Bennett 2003), but so too will the biophysical conditions and associated 'changes'. Benefit transfer should thus only be used cautiously, with a full recognition and acknowledgement of the potential implications of the extrapolation that these methods require' (National Research Council of the National Academies 2004, p. 216).

Impacts of climate change on ecosystem services

Climate change is projected to have a significant adverse impact on Australia's agricultural products and exports.

Adopting a diversified approach will enable farmers to farm longer and more sustainably in an environment of greater uncertainty, in the face of climate change.

Classifying ES according to their spatial characteristics might assist NRM regions' assessments and planning at the appropriate scale.

Future food, fodder and fibre production and ecosystem services will be under additional risk and uncertainty from climate change.

Increased attacks of pests and diseases related to changes in the abundance and distribution of insects, many of which are vectors for disease.

Increased exposure of soils leads to further soil degradation and erosion that reduces water infiltration and soil moisture content.

Climate change will drastically impact the critical habitat provision for biodiversity.

Economic significance of the emerging carbon economy, if all the potential opportunities are realised, could also generate environmental livelihood benefits.

Ecosystem degradation threatens water availability, quality and regulation.

There is a need to address the underestimation of ecosystem services in farmlands.

Consequences and uncertainties of climate change at the regional level

Environmental factors are the major determinant of ecosystem services production and supply. It is predicted that climate change will affect ecosystem services (Schröter *et al*. 2005; Shaw *et al*. 2011). Agricultural production involves a wide range of ecosystem services and processes that use water, soil and biological components of the agricultural ecosystem, such as: nitrogen cycling, climate regulation, soil formation, pest and disease regulation and pollination, in addition to the obvious food production (Coates *et al.* 2013; Fleiner *et al.* 2013; Jarvis *et al.* 2013; Pert *et al.* 2013) (see also Chapter 6). Sustainable use and management of water and biodiversity resources in agroecosystems play a decisive role in providing food and income for a growing population (Nellemann *et al.* 2009; PAR 2011). Climate change is clearly a driver that will affect food and water security for the foreseeable future, albeit with a high degree of uncertainty in the precise way in which the impact will be felt for specific locations and crop and crop–livestock systems. As agriculture is particularly dependent on the hydrological cycle, food production will obviously be greatly affected by changes in precipitation, streamflow, soil moisture and evapotranspiration (See Chapter 2). Local agricultural production may increase or decrease under conditions of climate change (and agriculture itself has well-established positive and negative feedbacks to climate change, see Chapter 6). Conversely, many agricultural and natural ecosystems serve as carbon sinks, absorbing atmospheric CO_2 and thereby potentially slowing down climate change. A summary of ecosystem services and their impacts from climate change are summarised in Table 1, with key references for further information. In this table, we have continued to use the MA practice of referring to a fourth category of service i.e. Supporting services but tried to also incorporate the typology of de Groot *et al.* (2010). Furthermore a type of classification that might assist landscape scale assessments and NRM planning, that classifies ecosystem services according to their spatial characteristics is provided in Table 2 and Figure 1.

Table 1. Examples of ecosystem services (based on the MA typology which includes a fourth category of services – Supporting services) impacted on by climate change.

Ecosystem Service	Examples	Ecosystem	Impact Positive (+) negative (-)	References
PROVISIONING SERVICES				
Food	*Losses in cropping:* Crop yields may fall and no longer offer conditions for some agricultural sectors.	Terrestrial	-	See Chapter 6 Chapman *et al.* 2012; CSIRO 2013; Forsius *et al.* 2013
	Losses in fish provision: Decline in commercial fishing industry attributed to decreased primary production due to alteration of nutrient supply, as an effect of rising surface temperature.	Freshwater Marine	-	Quiggin 2010 Nellemann *et al.* 2009 Brander 2007; Prayaga *et al.* 2010; Stokes and Howden 2010; Sumaila and Cheung 2010
	Losses in fisheries revenues: due to temperature increase	Freshwater Marine	-	Sumaila and Cheung 2010
	Shifts in the distribution of fish: species move and effect levels of permissible commercial catches	Freshwater Marine	-	Cheung *et al.* 2012
Freshwater	*Declines in streamflow*: due to increased irrigation pressures	Freshwater	-	Chisholm 2010; Terrado *et al.* 2013; Sullivan and Huntingford 2009
Fibre and fuel & other raw materials	*Declining forage provision:* due to the reduced availability of fodder for livestock. *Decline in sources of fuel for energy*: The risk of fossil-fuel supply limitation should be included when considering the uncertainties of future climate change.	Terrestrial	-	Howden *et al.* 2008; Shaw *et al.* 2011; Chaplin-Kramer and George 2013; McKeon *et al.* 1998; McKeon *et al.* 2009; Murray and King 2012; Bauer *et al.* 2013
Genetic Materials: genes for resistance to plant pathogens	*Changes in forest ecosystem structure and species composition:* Due to changes in fire regimes and land temperature increasing changes in forest ecosystem structure will occur affecting the genetic material of species with (potentially) useful genetic material.	Terrestrial Freshwater Marine	- +	UK National Ecosystem Assessment 2011
Biochemicals, natural medicines, and pharmaceuticals	Changes effecting ecosystems will have an impact on the many medicines, biocides, food additives such as alginates, and biological materials that are derived from ecosystems. As new disease threats emerge, substantially higher pharmaceutical use appears inevitable, especially of pharmaceuticals not commonly employed at present (e.g., antiprotozoals). The use of medications for the treatment of general symptoms (e.g., analgesics) will also rise.	Terrestrial Freshwater Marine	-	Redshaw *et al.* 2013

Ecosystem Service	Examples	Ecosystem	Impact Positive (+) negative (-)	References
Ornamental resources	*A decrease in availability and access to ornamental resources*: may also occur in areas where the climate has changed or sea level risen. Animal products, such as skins and shells, and flowers that are used as ornaments, may no longer be available if species go extinct. The value of these resources is often culturally determined. Ornamentals for the aquarium trade will also be impacted.	Terrestrial Freshwater Marine	-	Geyer *et al.* 2011; Costanza *et al.* 2011b
REGULATING SERVICES				
Climate regulation	*Reforestation for carbon sequestration:* In Australia implementation costs have been valued at $1150-6000/ha and transaction and maintenance costs of $40-100/ha per year. Opportunity costs in agriculture are clearly compensated only if carbon prices increase to USD 55/tCO_2e. Mangrove ecosystems play an important role particularly in carbon sequestration in coastal ecosystems. Previous studies aimed at the marine gas and climate regulation service have used primary productivity as an indicator of the magnitude of this service. These studies have used proxy measurements, such as, satellite ocean colour data or measured photosynthetic rates of microalgae and macrophytes in order to give a quantitative estimate of carbon sequestration.	Terrestrial	- +	See Chapter 6 Paterson and Bryan 2012; Beaumont *et al.* 2007; Costanza *et al.* 1997; Mangi *et al.* 2011
Air quality regulation	*Decrease in air quality due to global warming and change in atmosphere:* Ecosystems both contribute chemicals to and extract chemicals from the atmosphere, influencing many aspects of air quality. Climate change will impact on the capacity of ecosystems to extract aerosols & chemical from the atmosphere.	Terrestrial	-	Cárcamo and Gaymer 2013; Beckett *et al.* 2000; van Oudenhoven *et al.* 2012; Beckett *et al.* 2000
Erosion control	*Coastal erosion:* Increased coastal erosion from storm surge events. *Terrestrial:* A decrease in vegetative cover effects soil retention and the prevention of landslides. More droughts, lower summer rainfall, higher evaporation and temperature, more wildfires and higher peak wind speeds are likely to drive greater exposure of the soil surface. Low surface cover exposes the soil to water and wind erosion and reduces water infiltration and soil moisture content. Loss of topsoil reduces vegetation growth and increases sediment loads in watercourses.	Coastal Terrestrial	-	Barbier *et al.* 2011; Bohnet and Pert 2010; Department of Climate Change 2009; Cobon *et al.* 2009; Baldock *et al.* 2012; and Pert *et al.* 2010a
Natural hazard protection	*Change in forest fire regulation:* Increased forest risk to fire and greater expenditure required on fire prevention and fire fighting. Low-elevation coastal zones are particularly vulnerable to cyclones, tsunamis, floods and storm surges. Marshes, mangroves, wetlands, seagrasses, coral reefs and barrier islands have the potential to attenuate waves, buffer the impacts of storms and provide coastal protection.	Terrestrial	-	Staudinger *et al.* 2012; Munang *et al.* 2013; Costanza *et al.* 2008; Martinez *et al.* 2011

Ecosystem Service	Examples	Ecosystem	Impact Positive (+) negative (-)	References
Biological regulation	*Increased prevalence of attacks by pests, disease and weeds*: Farmers will need to respond using more agrochemicals. There are likely to be many direct and indirect impacts. For example, increased attacks by pests, diseases and weeds are anticipated as a result of climate change, resulting in an increase in the use of pesticides and effects on natural pollinators. Furthermore the potential exists for livestock to be additionally affected by climate due to an anticipated increase in the incidence of pests and diseases. Much of this will be related to changes in the abundance and distribution of insects, many of which act as vectors for disease. For example the cattle tick may spread further as temperatures increase which then results in losses in liveweight gain.	Terrestrial	- +	Enete *et al.* 2012; Newsome 1990; Ward *et al.* 2003; Glen *et al.* 2007; Howden *et al*. 2008; Enete *et al*. 2012; Garibaldi *et al*. 2013; Sandhu *et al*. 2012
Water regulation	*Alterations to water regimes:* The timing and magnitude of runoff, flooding, and aquifer recharge can be strongly influenced by changes in land cover, including, in particular, alterations that change the water storage potential of the system, such as the conversion of wetlands or the replacement of forests with croplands or croplands with urban areas. Climate change impacts on hydrological ecosystem services and threatens water availability, quality, and the delivery of regulation and provisioning ecosystem services. Additionally, water scarcity from the decrease of freshwater resources, due to climate change threatens food security and health through several pathways, particularly in developing countries.	Terrestrial	-	Baral *et al.* 2013; Bryan *et al.* 2011; Cork *et al.* 2007; Pert *et al.* 2010b; Sandhu *et al.* 2012; Terrado *et al.* 2013; Sullivan and Huntingford 2009
Pollination	Climate changes affect the distribution, abundance, and effectiveness of pollinators.	Terrestrial	- +	Blanche *et al.* 2002, 2006a, 2006b; Blanche and Cunningham 2005; Cunningham *et al.* 2002; Cunningham and Blanche 2009
Regulation of human disease	*Increase in insects and diseases:* Climate change is expected to impact widely upon human health, including changes in the geographic distribution of vectors that carry severe diseases such as malaria, Dengue fever, and others. Changes in ecosystems through climate change can directly change the abundance of human pathogens, such as Dengue fever, and can alter the abundance of disease vectors, such as mosquitoes. Many prevalent human diseases are linked to climate fluctuations, from cardiovascular mortality and respiratory illnesses due to heatwaves, to altered transmission of infectious diseases and malnutrition from crop failures.	Terrestrial	-	Hanna *et al.* 2012; Patz *et al.* 2005; Waldock *et al.* 2013; McMichael 2014

Ecosystem Service	Examples	Ecosystem	Impact Positive (+) negative (-)	References
CULTURAL SERVICES				
Cultural diversity	*Altered composition of heritage biotas:* The diversity of ecosystems is one factor influencing the diversity of cultures. Changes in microbes and lower plants contribute to biodeterioration (disintegration of heritage structures) or bioprotection. Biodeterioration risk is argued in the case of some World Heritage Area sites (e.g. rock art sites). Declines in traditional hunting species may decline in some areas or increase in others.	Terrestrial Freshwater Marine	-	See Chapter 8 Viles and Cutler 2012; Hill *et al.* 2012
Recreation and ecotourism	*Loss of recreational fish:* Decreased growth rate of recreational fishes, valued as an economic, recreational and cultural resource for communities throughout the Wet Tropics, due to declining lake levels and higher water temperature.	Freshwater Marine	-	Andersson 2007; Biggs *et al.* 2012; Cárcamo and Gaymer 2013; Driml 2002; Kragt *et al.* 2009; Prayaga *et al.* 2010; Prideaux *et al.* 2010
	Changes in estimated value of protected areas: People often choose where to spend their leisure time based in part on the characteristics of the natural or cultivated landscapes in a particular area. Ecotourism-related ecosystem services may decrease if landscapes are altered by climate change.	Terrestrial Freshwater Marine	-	See Chapter 6 Velarde *et al.* 2005
Aesthetics	*Loss of coral reefs:* Due to increased coral bleaching, coral reefs are not values as aesthetic leading to a decrease in tourism. *Limits on beach front housing & development in storm surge areas:* Many people find beauty or aesthetic value in various aspects of ecosystems, as reflected in the support for parks, "scenic drives," and the selection of housing locations.	Marine Terrestrial	-	See Chapter 6 Andersson 2007; Bohnet and Pert 2010
Knowledge systems (traditional & formal)	*Utilizing knowledge systems:* Ecosystems influence the types of knowledge systems developed by different cultures and can assist in climate change mitigation.	Terrestrial Marine	+	Hill *et al.* 2012; Wyatt *et al.* 2010
Cultural heritage values	*Cultural heritage values impacted on:* Many societies place high value on the maintenance of either historically important landscapes ("cultural landscapes") or culturally significant species.	Terrestrial Marine	-	Chan *et al.* 2012a; Chan *et al.* 2012b; Hill *et al.* 2011, 2012; Plieninger *et al.* 2013; Wyatt *et al.* 2010
Sense of place	*Sense of place altered or impacted on through climate change:* Many people value the "sense of place" that is associated with recognized features of their environment, including aspects of the ecosystem. Values and meanings differ across cultural and socio-demographic categories, such as ethnicity, race, age, gender, and class or among various cultural groups, tribes, user groups, landowners, or stakeholders.	Terrestrial Marine	-	McLain *et al.* 2013

Ecosystem Service	Examples	Ecosystem	Impact Positive (+) negative (-)	References
HABITAT or SUPPORTING SERVICES				
Habitat	Changes in forest ecosystem structure and species composition: Due to changes in fire regimes and land temperature increasing changes in forest ecosystem structure will occur. The provision of habitat for some species increases while that of other tropics species declines. As geographical ranges and environmental envelopes of species shift and contract in response to climate change so does the habitat provision for biodiversity (Meynecke 2004). Flora and fauna that currently live and grow in a very narrow band of climatic requirements, will subsequently find habitat unsuitable and possibly face extinction.	Terrestrial	- +	See Chapter 3 Hilbert *et al*. 2001; Thoma 2004; Williams *et al*. 2003; Meynecke 2004
Gene pool protection	Maintenance of a given ecological balance and evolutionary processes, (especially endemic species and species already restricted to refugias).	Terrestrial Freshwater Marine	-	See Chapter 3 Hilbert *et al*. 2001; Thoma 2004; Williams *et al*. 2003; Meynecke 2004
Nutrient cycling	Higher ecosystem maintenance cost and reduced productivity of the forest ecosystems	Terrestrial	-	Altieri 1999; Staudinger *et al*. 2012; Wallace 2007
Pollination	Phenological asynchrony may lead to decline or extinction of local pollinators' population.	Terrestrial	-	Kuldna *et al*. 2009; Gallai *et al*. 2009; Lautenbach *et al*. 2012
Primary production	Changes in soil cover and exposure: Low surface cover exposes the soil to water and wind erosion and reduces water infiltration and soil moisture content. Loss of topsoil reduces vegetation growth and increases sediment loads in watercourses.	Terrestrial	-	See Chapter 6 Cobon *et al*. 2009; Baldock *et al*. 2012; Pert *et al*. 2010a

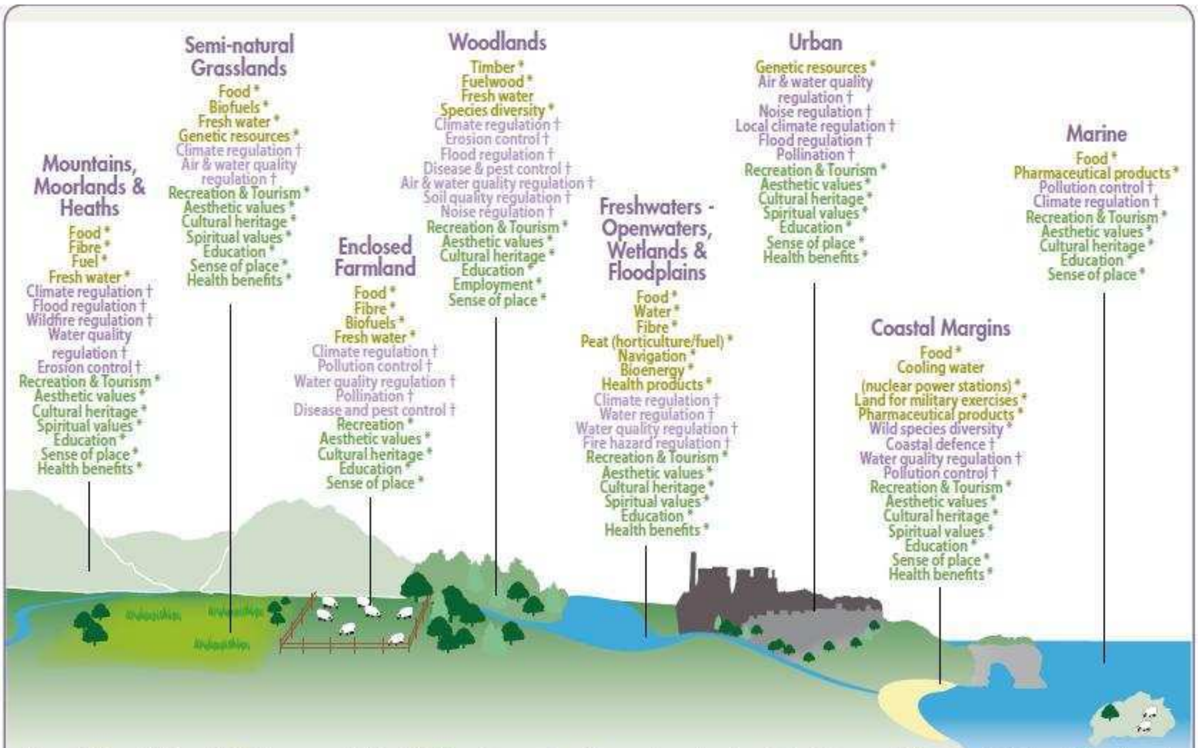

Figure 11 The eight Broad Habitats assessed in the UK NEA and examples of the goods and services derived from each. Items marked with an * denote goods, those with † denote services. Items in yellow are considered to be from provisioning services, purple from regulating and green from cultural. The supporting services, including amongst others primary production and nutrient cycling, are not listed against individual habitats as they are considered necessary for the production of all other ecosystem services. Source: adapted from the Millennium Ecosystem Assessment (MA 2005).

Figure 1. The eight broad habitats in the UK NEA and examples of goods and services derived from each (UK National Ecosystem Assessment 2011)

Table 2. Ecosystem services classified according to their spatial characteristics (a type of classification that might assist landscape scale assessments and planning). Source: (Costanza 2008).

Spatial characteristic	**Ecosystem services**
Global non-proximal (does not depend on proximity)	Climate regulation Carbon sequestration (NEP) Carbon storage Cultural/existence value
Local proximal (depends on proximity)	Disturbance regulation/ storm protection Waste treatment Pollination Biological control Habitat/refugia
Directional flow related: flow from point of production to point of use	Water regulation/flood protection Water supply Sediment regulation/erosion control Nutrient regulation
In situ (point of use)	Soil formation Food production/non-timber forest products Raw materials
User movement related: flow of people to unique natural features	Genetic resources Recreation potential Cultural/aesthetic

Government investments in ecosystem services

Establishing mechanisms such as Payments for Ecosystem Services (PES) can support the transition to more sustainable farming systems.

Payments for ecosystem services (PES) is a concept that emerged in the mid-2000s. It can be defined as: 'a voluntary transaction whereby a well-defined ecosystem service, or a land-use likely to secure that service, is being "bought" by at least one buyer from at least one provider – if, and only if, the provider secures the provision of the service' (United Nations Environment Programme & International Union for Conservation of Nature 2008; Wunder 2005). Incentive systems such as payments for ecosystem services (PES) can support the transition to more sustainable farming systems. Studies which have looked at payment for ecosystem services more recently include: (Adhikari and Boag 2013; Greiner *et al.* 2008; Hein *et al.* 2013; Wendland *et al.* 2010). On the biophysical side, carbon storage indicates the mass of carbon in an ecosystem at any given point in time. Sequestration is the change in storage in an ecosystem over time. Valuations of how much that sequestration is worth has been considered by Sanderman and Baldock (2010) and in Australia by Lam *et al.* (2013). A major study of the potential for payments for ecosystem services in China concluded that:

> While the valuation of ecosystem services is an important ongoing part of developing ecosystem service markets, PES, and eco-compensation programs, policy makers focus less on calculating these values, and more on designing the mechanisms necessary to allow stakeholder negotiations to effectively arrive at eco-compensation subsidy rates. (Zhang et al. 2010)

Further details on payments from carbon abatement projects and potential opportunities are discussed in Chapter 6.

Climate change impacts to coast and communities

Drivers (stressors) of coastal change

Globalization has been reported as one of the major drivers of change and degradation of coastal ecosystems and associated diminishing services (MA 2005). NRM bodies will also need to take into consideration the climate change impacts to coastal communities and the already associated drivers of coastal change.

Growing human pressures, including climate change, are having profound and diverse consequences for coastal/marine ecosystems and ES.

There have been few systematic reviews of the impacts of rising CO_2 and climate change on marine ecosystems and ES (See Chapter 3). Concerns about reefs are heightened by the fact that most coral reefs today are also severely impacted by multiple stressors such as overfishing, destructive fishing, pollution, sedimentation, nutrient overenrichment, and invasive species. Key studies which have specifically looked at the climate change impacts on marine ecosystems include Beaumont *et al.* (2007); Cárcamo and Gaymer (2013); Carter-Silk (2013); Doney *et al.* (2012); Hoegh-Guldberg and

Bruno (2010); Mangi *et al.* (2011) and Ruiz-Frau *et al.* (2011). The remaining marine ecosystems are experiencing accelerating loss of populations and species, with largely unknown consequences (Worm *et al.* 2006). Increased ocean temperatures will lead to increases in coral bleaching and ocean acidification, which may reduce coral calcification (Scavia *et al.* 2002). This will make it difficult for corals to recover from disturbances. Moderate bleaching results in stress that causes reduced growth rates and reproductive output, whereas severe bleaching results in coral death. Bleaching also appears to make corals more vulnerable to disease, so that some death occurs after a time lag (Muller *et al.* 2007). Climate-driven impacts on keystone and foundation species may be especially important. Some critical habitat-forming marine benthic species, such as oysters or corals, appear sensitive to CO_2 and climate change both directly and through pathogens.

Carbon sequestration value of vegetated coastal ecosystems

Recognition of the carbon sequestration value of vegetated coastal ecosystems provides a strong argument for their protection and restoration.

Seagrass ecosystems have been recognised as a significant carbon stock.

The carbon (C) sequestered in vegetated coastal ecosystems, specifically mangrove forests, seagrass beds, and salt marshes, has been termed "blue carbon". Coastal and marine ecosystems play a valuable role in sequestering carbon dioxide (CO_2) (McLeod *et al.* 2011; Pendleton *et al.* 2012). Mangroves and seagrass beds interrupt freshwater discharge, are sinks for organic and inorganic materials as well as pollutants (Figure 2). Seagrass ecosystems have been recognized as a globally significant carbon stock (Fourqurean *et al.* 2012) and can accumulate a substantial quantity of carbon each year (up to up to 0.3 $kgCm^{-2}year^{-1}$) (Hyndes *et al.* 2014; Hemminga *et al.* 1991). Seagrass beds transfer carbon to the adjacent ecosystems (such as mangroves and deep sea) (Suchanek *et al.* 1985; Bouillon and Connolly 2009; Hyndes *et al.* 2014). Climate change could increase or decrease the productivity and distribution of seagrasses depending on species (Adam 2002; Duarte *et al.* 2008). A decrease in seagrass productivity will result in a decrease in carbon sequestration.

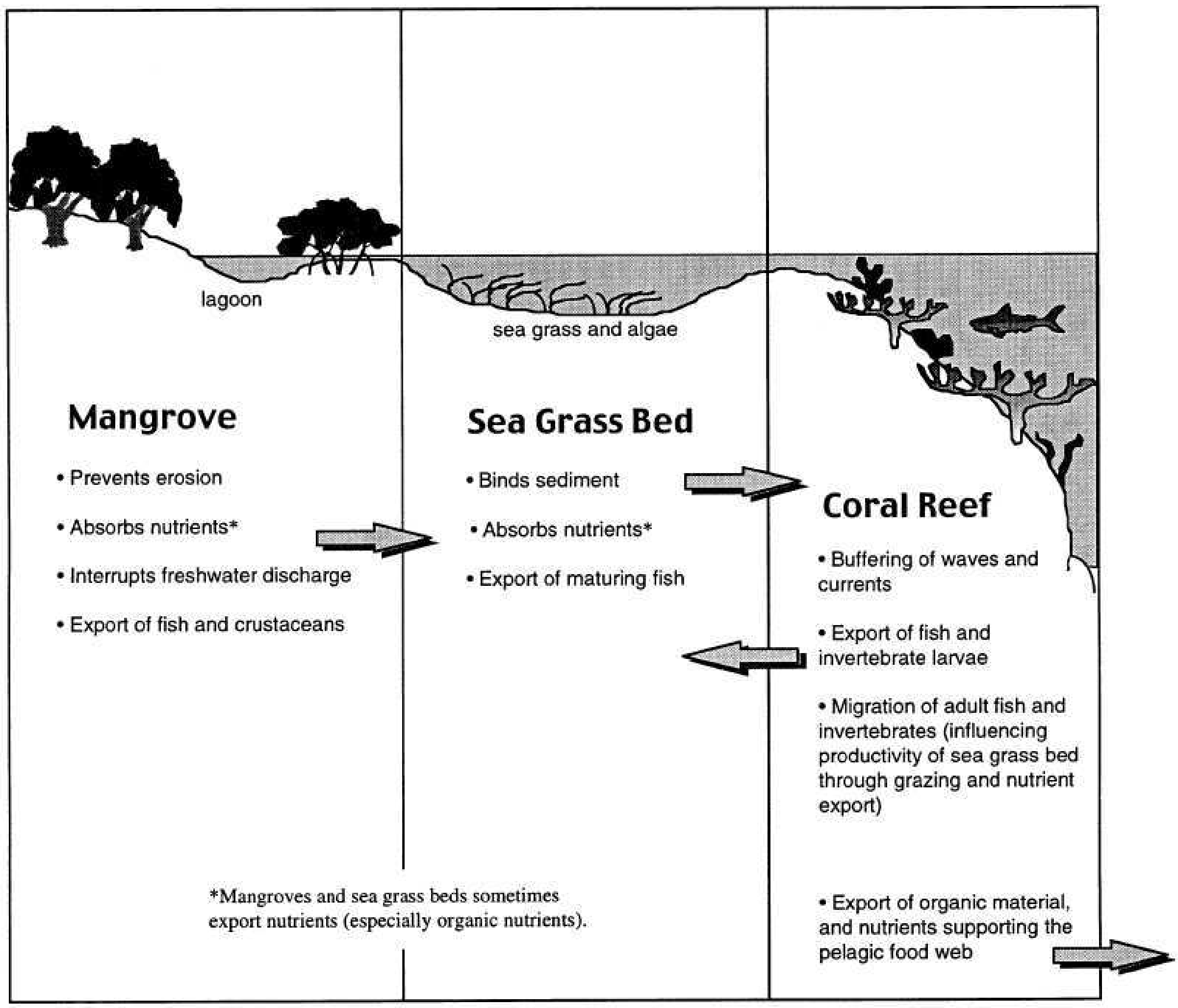

Figure 2. Interactions with the tropical seascape, showing the connection between mangroves, seagrass beds and coral reefs. Source: Moberg and Folke (1999)

How will communities and infrastructure be impacted?

Communities will need to have strategies in place for extreme events.

Warming ocean temperature can cause shifts in a range of commercial valuable species (Hughes 2000; 2003), and also alter their reproductive capacity (Donelson *et al*. 2010), with a likely economic impact on coastal communities (Metcalf *et al*. 2013). It is predicted that due to climate change, intensities of tropical cyclones may increase (Turton 2012), which will add further to the economic loss in coastal communities. Sea level rise and extreme events may increase the cost of maintenance and repair of coastal infrastructure (Elrick-Barra *et al*. 2013), and bring about a shift in population and altered community structure (Arkema and Samhouri 2012; Chaplin-Kramer and George 2013; Costanza *et al*. 2011a; Department of Climate Change 2009; Doney *et al*. 2012; Garibaldi *et al*. 2013; Guerry *et al*. 2012; Kennedy *et al*. 2013; Koch *et al*. 2009; Munang *et al*. 2013; Poloczanksa *et al*. 2008; Staudinger *et al*. 2012; Terrado *et al*. 2013).

Summary

Ecosystems, and the biodiversity and ecosystem service they support, are intrinsically dependent on climate. There has been a major set of international studies that have developed the concept of ecosystem services globally, which primarily have included the Millennium Ecosystem Assessment (MA), The Economics of Ecosystems and Biodiversity (TEEB), and now the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES).

Wet Tropics Cluster Region NRM managers need to build on past assessments and approaches of how climate change affects ecosystems in Australia, as well as around the world. An ecosystem services-based approach to NRM management should be adopted that takes into account the contribution of ecosystems to the livelihoods of primary stakeholders, resource users and local communities. NRM management plans should be based on principles of ecosystem service assessment that enables the combination of a biodiversity, economics and livelihoods analysis across different disciplines and sectors.

Proponents of an ecosystem stewardship approach suggest that an ecosystem or species-only focus is not sufficient to prepare coupled ecological and social systems for climate change in the next few decades and beyond (Chapin III *et al.* 2009). Attention needs to be paid to the interactions between social and ecological systems, including governance and other institutional components. The primary role of the natural resource manager (in the Wet Tropics cluster region) is to facilitate and engage stakeholder groups to respond to, and shape, socio-ecological change and nurture resilience to impacts of climate change. It is not about whether ecosystems services are considered, but more about what processes are used to anticipate and prepare for future needs for services and future ability of ecosystems to meet those needs.

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Chapter 5: The impacts of climate change on infrastructure

Catherine Moran and Stephen Turton

Executive summary

There are likely to be many negative impacts on infrastructure in the Wet Tropics Cluster as a consequence of climate change and more extreme weather events. The key messages associated with each of the topics addressed in this chapter are:

Sea level rise	1. The most immediate threats are to islands. 2. There will be more frequent and extensive inundation of existing and planned infrastructure in coastal areas. 3. There will be saltwater contamination of water supply for domestic, agricultural and industrial uses in coastal areas. 4. Inundation by seawater will likely lead to more rapid deterioration of coastal infrastructure. 5. Sea level rise may raise water tables and lead to increased freshwater flooding of coastal infrastructure. 6. Sea level rise will lead to increased coastal erosion.
More extreme weather events	7. Infrastructure will be damaged more often by increases in the magnitude, extent and duration of river and flash flooding, landslips, erosion and transport of sediment and debris.
Increased number of 'hottest' days and heat waves	8. There will be increased interruption to industry operations, especially power transmission.
More intense tropical cyclones	9. There will be increased damage to and destruction of infrastructure from strong winds, storm surges and heavy rainfall associated with more intense tropical cyclones.
Changes in rainfall patterns	10. There will be more uncertainty around water availability.
Changed fire regimes	11. More intense and frequent bush fires will damage and destroy infrastructure, including in areas not currently subject to bushfire threat.
Population shifts in response to climate change	12. Higher temperatures, sea level rise and more intense extreme events will substantially reduce liveability, particularly in low-lying islands and coastal locations, in remote regions and parts of Cape York.

Introduction

Infrastructure provides the basic physical and organisational framework and services that support human communities, be they urban, peri-urban, rural or remote. Infrastructure includes large-scale public systems and services, as well as those operated privately on individual properties. Many elements of infrastructure are linked and impacts on one type of infrastructure often have secondary impacts on others.

In this chapter, we consider potential impacts of climate change on water supply, the generation and transmission of electric power, transport and freight distribution, telecommunications, the management of sewage, stormwater, solid and hazardous wastes, and access to housing, hospitals and schools. There is limited published work on the potential impacts on infrastructure in the Wet Tropics Cluster Region specifically; most previous work has focussed on coastal areas in urban centres in southern Australia.

Dealing with the impacts of climate change on infrastructure will involve many different agencies working at different scales (Beer *et al.* 2013). In this discussion of potential climate change impacts on infrastructure, it is recognised that the electricity and mining industries provide and depend on critical infrastructure but are also major greenhouse gas emitters in Australia, and the implications of climate change for these sectors will include measures aimed at mitigation as well as adaptation. These issues will be discussed in a future report on adaptation options.

Impacts of sea level rise

The most immediate threats are to islands.

The most concerning immediate physical impacts likely to result from sea level rise relate to inundation affecting the infrastructure, vegetation and water sources on islands, as well as impacts of coastal erosion on infrastructure and sites of cultural significance in these areas (Duce *et al.* 2010). The exact nature of these impacts will vary from island to island. In some cases, sea level rise could potentially increase the transport of sediment from reef flats to islands, causing them to grow. However, in general, these impacts will decrease the amount of viable land on islands and, unless managed well, will cause decline in the quality of life for island communities, especially those in the Torres Strait (Duce *et al.* 2010).

Seawater inundation

There will be more frequent and extensive inundation of existing and planned infrastructure in coastal areas.

There is a high level of confidence in the broad projections for sea level rise, although there will be substantial variation between locations in the magnitude of sea level rise (See Chapter 2). For example, sea level rise is likely to be higher than the global average along the east coast of Queensland and Torres Strait than on the west coast of Cape York Peninsula (Office of Climate Change (OCC) 2008). Sub-regions with high tidal ranges, such as Mackay-Whitsunday will be particularly exposed to tidal and storm surge events compared with the other sub-regions in the Wet Tropics Cluster region. There is also uncertainty around the extent of realised inundation that will occur given that managers may choose to install a range of protection measures, such as sea walls and tidal gates. It is not possible to know the extent to which managers will implement these options, nor the extent to which they will be effective in reducing inundation.

Certainty about the specific impacts of sea level rise in the region will increase over the near future. Although it is no longer a State requirement for Local Planning Schemes, many Local Authorities continue to develop spatially explicit maps of the predicted consequences of sea level rise for inundation. For example, the Cairns Regional Council has recently developed 'Coastal processes and Flood overlays' for their new Planning Scheme (See http://www.cairns.qld.gov.au/building-planning-and-infrastructure/planning-schemes/cairns-region-planning-scheme/draft-scheme-mapping).

Sea level rise will eventually lead to the permanent inundation of low-lying coastal areas and an increased frequency and extent of temporary inundation events (Church *et al*. 2009; IPCC 2013). The risk is highest for low-lying areas of the coastal mainland and islands, as well as along watercourses that may be impacted by increased tidal reach. Even a modest increase in sea level height will substantially increase the frequency of high sea level events, which will occur with high tides, storm surges and heavy rainfall events (OCC 2008; Wang *et al.* 2010b; Commonwealth of Australia 2011; King *et al.* 2013, Chapter 2 this report). For example, McInnes *et al.* (2003) estimated for the Cairns region that sea level rise will increase the height of 1 in 100-year inundation events from 2.3 m to 2.8 m by the year 2100. The return period for 2.8 m inundation events in the current climate is 300 years, but is projected to decline to 100 years with sea level rise. Under these projected changes, the average area of Cairns that would be inundated by a 1 in 100-year event will more than double (McInnes *et al*. 2003).

There is likely to be more extensive inundation of coastal roads, including several major roads, especially during storm tides (OCC 2008). This will affect access to extensive areas, including those that are not directly impacted by inundation. All ports in the region are highly vulnerable to inundation from sea level rise. Cairns and Mackay ports are important for the supply of goods, including petroleum and food, to the region and their disruption as a consequence of inundation will have multiple secondary impacts. Many of the smaller ports in Cape York and the Torres Strait are critical for goods supply to communities that are isolated by road during the wet season. Boat ramps are vulnerable to inundation as a consequence of sea level rises.

Many of the airports in the region are located on low-lying land near to the coast and are at risk of inundation with sea level rise, especially during storm tides. For example, the Cairns International Airport is particularly low-lying and may need to be re-located in several decades (IPCC 2013).

Low-lying parts of rail networks will be more often inundated, affecting the transport of passengers and freight on the main rail line, as well as the transport of cane from farms to mills and the transport of coal and other export materials to ports in Cairns, Mackay, Weipa and Hay Point.

Coastally located sewerage treatment works will potentially be inundated during storm tides, resulting in serious risks to public and environmental health (OCC 2008). Stormwater systems may also be inundated by seawater, exacerbating flooding if storm tides coincide with heavy rainfall events. Sea level rise will cause the upstream extension of tidal reach in coastal waterways. Increased tidal reach will be likely to impede agricultural drainage in floodplain systems, potentially impacting agriculture in these areas. This will interact with high flow events to cause inundation of land along these watercourses.

Under projected conditions of higher sea levels (See Chapter 2) there is a high risk of leachate from a ruptured cap or walls of the Cairns landfill, especially in interaction with more intense cyclonic activity (Church *et al.* 2009; Commonwealth of Australia 2009).

Sea level rise is likely to result in the inundation of extensive areas of coastal housing. Even when they are not inundated themselves, inundation of road networks will prevent access to housing, hospitals, schools and other services. Several of the islands in the Torres Strait already experience higher tidal inundation and are extremely vulnerable to sea level rise. On the mainland, areas such as Cardwell are especially susceptible.

Tourism infrastructure in coastal areas near Cairns, Mission Beach and Port Douglas and offshore islands, e.g. Whitsundays and Green Island will also be highly vulnerable to projected increases in sea level over coming decades (Wilson & Turton 2011).

There will be saltwater contamination of water supply for domestic, agricultural and industrial uses in coastal areas.

Projected sea level rises are likely to lead to saltwater contamination of freshwater supplies through seawater intrusion and increased tidal reach, impacting the availability of water for domestic use, as well as for agriculture and industrial activities such as electricity generation and wastewater management (OCC 2008). Saltwater contamination of only 5% is sufficient to make water unsuitable for these uses (Commonwealth of Australia 2009). Furthermore, saltwater contamination of freshwater will increase rates of corrosion of pipes and other water distribution infrastructure (e.g., irrigation equipment).

Inundation by seawater will likely lead to more rapid deterioration of coastal infrastructure.

In addition to direct effects, inundation by seawater is likely to lead to the more rapid deterioration of coastal infrastructure. Concrete, for example, which is the main construction material used in infrastructure, is likely to experience increased exposure and higher rates of deterioration, especially due to sea level rise in coastal areas but also because of increased atmospheric carbon dioxide concentrations, ocean acidification, higher temperatures and humidity (Wang *et al.* 2010a). Sea level rise will increase exposure of coastal infrastructure to salt water via spray, splash and inundation and also potentially enable the greater penetration of wave energy into these areas (McEvoy *et al.* 2013). This will impact major infrastructure such as electricity transmission, which may experience more flashovers and higher rates of corrosion as a result of increased salt-spray deposits on conductors (Commonwealth of Australia 2009).

Freshwater inundation

Sea level rise may raise water tables and lead to increased freshwater flooding of coastal infrastructure.

Sea level rise will potentially raise the water table in coastal areas, leading to freshwater flooding of basements and other subsurface structures, as well as damaging underground cables such as the telephone landlines and the broadband network, especially where copper cables remain in use.

Erosion

Sea level rise will lead to increased coastal erosion.

Sea level rise will cause increased erosion, especially of soft shorelines and features such as sand cays in the Great Barrier Reef (Wilson & Turton 2011). Coastlines and coastal systems (e.g., mangroves) will be unstable as a consequence of a more frequent cycle of erosion and deposition of sediments (See Chapter 3). Increased erosion has the potential to expose acid sulphate soils, with negative consequences for multiple industries (e.g., fishing, aquaculture, agriculture) and other land uses along watercourses. Increased exposure to acid sulphate soils will further elevate rates of corrosion of infrastructure. Erosion will lead to the loss of land areas associated infrastructure, such as coastal roads. A large proportion of infrastructure facilities are located near to the coast in the Wet Tropics Cluster region, especially around major population centres such as Cairns and Mackay.

Impacts of more extreme weather events

Increased magnitude and frequency of heavy rainfall events

Infrastructure will be damaged more often by increases in the magnitude, extent and duration of river and flash flooding, landslips, erosion and transport of sediment and debris.

Heavy rainfall events will be more frequent as the climate continues to warm in the future (See Chapter 2; IPCC 2013). This will increase the extent, magnitude and duration of river and flash flooding in low-lying areas. Many of the impacts of flooding due to heavy rainfall events will be similar to those described above for inundation as a consequence of sea level rise.

It is likely that the increased frequency and magnitude of high rainfall events will more rapidly fill water supply reservoirs, although increased evaporation may offset this benefit. Furthermore, it is possible that high rainfall events may cause damage to water storage facilities, as well as leading to increased sedimentation in dams and other water reservoirs on floodplains and at river mouths (OCC 2008; Commonwealth of Australia 2009).

In addition to causing temporary flooding and impassability of roads, more frequent inundation will damage road infrastructure more than it already does. This may have especially serious consequences for accessibility in Cape York, where the largely unsealed road network experiences considerable damage every year from inundation.

Port infrastructure may be impacted by higher rainfall events, particularly through increased transport of sediment and debris that may damage or interfere with port infrastructure or operations (Commonwealth of Australia 2009). Furthermore, flooding of supply-chain infrastructure and processes (e.g., mine shut-down due to flood; flooding of rail-lines) will likely result in a backlog of ships, and the need to increase dredging in port areas (McEvoy *et al.* 2013).

The likelihood of flooding of subsurface infrastructure will increase with more frequent heavy rainfall events. For example, underground cables such as telephone landlines and the broadband network are vulnerable, especially where copper cables remain in use as these are less durable than fibre optic cables.

Stormwater systems are likely to be overwhelmed more frequently, which will lead to flooding of other low-lying infrastructure as well as exacerbating upstream flooding. Flooding of sewerage treatment plants will have potentially serious impacts on public health and disease outbreaks (Commonwealth of Australia 2009).

Extensive areas of housing are likely to be affected by flooding from heavy rainfall events, including areas that have not previously been inundated (OCC 2008). Development on slopes or at the base of hillsides (e.g., in the west of Cairns) is potentially vulnerable to landslips. Flooding is already an issue in communities throughout the region, for example around Wujal Wujal, Kowanyama, Pormpuraw and Napranum (State of Queensland 2013b) and is likely to be exacerbated by increases to the intensity and frequency of heavy rainfall events.

Longer periods of freshwater flooding will lead to the more rapid deterioration of infrastructure materials, including concrete and wooden structures (McEvoy *et al.* 2013).

Increased number of 'hottest' days and heat waves

There will be increased interruption to industry operations, especially power transmission.

Very hot days and heat waves are associated with an increased demand for electricity to cool buildings. As demand for electricity increases, so does the electrical current in transmission networks. Both high temperatures and increased current increase the resistance in conductors, resulting in increased loss of power from transmission networks and a reduced reliability of supply (Nguyen *et al.* 2011). Increased power failure will reduce the comfort, productivity and health of residents, as well as the capacity to maintain industrial processes.

Other industry impacts of high temperatures will include the shut down of industrial facilities in line with occupational safety practices, potentially resulting in extended closure of ports and other facilities (Commonwealth of Australia 2009). Periods of high temperature may lead to buckling in steel structures due to thermal expansion (Nguyen *et al.* 2011), as well as the more rapid deterioration of the concrete, steel, asphalt, coatings, sealant and timber components of infrastructure (McEvoy *et al.* 2013). Additionally, industrial water use may be impacted by high temperatures, e.g., if the temperature of water used for cooling in power generation or mining operations exceeds a certain threshold (Commonwealth of Australia 2009).

Parts of the region that are not on the national power supply grid (e.g., much of Cape York and parts of the Daintree lowlands) are less susceptible to the predicted interruption of centralised power generation and transmission during heat waves. However, many of these areas already experience high temperatures and an increased frequency of hot days and heatwaves, combined with a limited ability to provide cooling, may make these areas less liveable.

More intense tropical cyclones

There will be increased damage to and destruction of infrastructure from strong winds, storm surges and heavy rainfall associated with more intense tropical cyclones.

In this section, we mostly deal with the impacts of strong winds, as the impacts of storm surge is described in an earlier section on 'Sea level rise', and the impacts of heavy rainfall have been outlined in the section on 'Increased magnitude and frequency of heavy rainfall events'. More intense tropical cyclones will be associated with higher winds, including extreme cyclonic wind gusts (Stewart and Wang 2011). It is worth noting that non-cyclonic wind speeds are also predicted to increase by up to 20% in north eastern Australia by 2100 (Stewart and Wang 2011).

Residents of the Wet Tropics Cluster Region are used to dealing with tropical cyclones and strong emergency service systems have been developed. However, more intense tropical cyclones in the future (See Chapter 2) may result in increased damage to infrastructure across the Wet Tropics Cluster and this is likely to be compounded in remote areas where there is already a lack of infrastructure and where there is often already a significant lag time in post-cyclone recovery of basic infrastructure.

More intense cyclones pose more of a threat to buildings, especially older or more exposed buildings. There is variation in the susceptibility of buildings to damage during cyclones based on their age and location. For example, the risk to pre-1980 buildings in foreshore locations will be an order of magnitude higher than to buildings constructed post-1980 (Stewart and Wang 2011). Also, the risk of damage is generally highest in foreshore locations, and is modified by the amount of shielding provided by topography and other buildings, interacting with wind directions.

It is likely that the number of people seeking cyclone shelters will increase if more intense cyclones cross the coast in the region. Access to cyclone shelters is limited in the region, especially in remote areas. For example, there is only one cyclone shelter in the entire Cook Shire, in Cooktown. Even where cyclone shelters have been constructed, access can be prevented by presence of poor and flooded roads or a lack of transport.

Electricity transmission and distribution are likely to be negatively impacted by more intense cyclones. In the Wet Tropics Cluster Region, aged wooden power poles are most common, and are highly susceptible to damage from tropical cyclones (Foster *et al.* 2013). It is possible that increased interruption and damage to power generation and transmission will inspire greater support for the development of renewable or local methods of energy generation in the region, especially in more remote parts.

Cyclones usually result in closures of ports for occupational safety reasons, but also because of the impacts of strong wind, wave action, storm surge and flash flooding on shipping (Commonwealth of Australia 2009; McEvoy *et al.* 2013; Stewart and Wang 2011). Additionally, schools, workplaces and many services shut down before and after intense cyclones. Because the damage caused by intense cyclones is often serious and widespread, periods of closure may be longer.

Impacts of changes in rainfall patterns

There will be more uncertainty around water availability.

While there is uncertainty about future changes in rainfall, patterns of rainfall are likely to change in the future, including seasonality (see Chapter 2). Increased and less predictable variability in rainfall will make it difficult for industrial operations that require large amounts of cooling water and for agricultural production (Foster *et al.* 2013). In times of prolonged low rainfall, current water storages (i.e., large dams) are already inadequate. Agriculture in marginal areas that depend on irrigation from large dams (e.g., dry regions west of the Atherton Tablelands) may become unviable in this climate of uncertain water availability.

There is currently substantial seasonal and inter-annual variation in rainfall throughout much of the region, although areas such as the Atherton Tablelands and far northern Cape York Peninsula receive fairly reliable rainfall. This large variation in water availability has led to mechanisms to increase reliability, such as a preference for groundwater rather than a dependence on surface water in areas such as Cape York. However, this will no longer be a solution if groundwater supplies become contaminated by saltwater.

Impacts of changed fire regimes on infrastructure

Projected longer, warmer dry seasons (see Chapter 2) will provide conditions more conducive to fire across the Wet Tropics Cluster region particularly in the more seasonally dry areas (e.g. western Cape York and western parts of the Mackay/Whitsunday and the Wet Tropics areas). This is likely to extend the fire season and also lead to more bushfires in these areas. More frequent heat waves that lead to a build-up of heat will also create bushfire conditions. The interaction between drier dry seasons and more severe and persistent damage to vegetation from more intense tropical cyclones may further increase fire risk, including in areas that are not currently considered fire-prone, e.g. wetter parts of the Wet Tropics, Cape York and Mackay/Whitsunday areas (see Chapter 3).

More intense and frequent bush fires will damage and destroy infrastructure, including in areas not currently subject to bushfire threat.

Bushfire and more intense, extensive fires will impact water supplies if pipes, pumps, tanks and other water storage and distribution infrastructure are damaged. Interrupted power transmission is a likely consequence of bushfires in the region; wooden power poles are very vulnerable to burning and are the most common power pole material used in the Cluster region, although even steel poles are susceptible to bushfires (Foster *et al.* 2013). It has been suggested that the burial of transmission lines would mitigate this problem (Foster *et al.* 2013), although risks from sea level rise, higher water tables and salt water intrusion may offset this benefit. There are similar risks to telecommunications infrastructure.

Houses and other buildings, hospitals and other services will vulnerable to damage as a result of bushfires, particularly given projected increases in human population in peri-urban and rural areas in the Wet Tropics Cluster region. Fences and other infrastructure associated with rural production are likely to be damaged by bushfire, as well as livestock and crops.

Population shifts in response to climate change impacts on infrastructure

Higher temperatures, sea level rise and more intense extreme events will substantially reduce liveability, particularly in low-lying islands and coastal locations, in remote regions and parts of Cape York.

Changes in climate and weather extremes will both directly (e.g., by becoming too hot and causing health problems or by lack of a reliable water supply) and indirectly (e.g., through impacts on infrastructure, specific sectors, and factors such as bushfire risk) impact on the liveability of the region. Low-lying communities on the mainland, in the Torres Strait (Duce *et al.* 2010) and on Cape York are likely to be particularly vulnerable.

In terms of the consequences for infrastructure, population shifts away from areas that are severely impacted may relieve pressure on existing infrastructure in the short term, but is likely to lead to declined cost-effectiveness and reduced investment in infrastructure in these areas over the longer term. This problem will be compounded by the remoteness of many of these areas.

Some areas of the Cluster region are likely to attract populations from elsewhere in the Cluster and from other regions. Elevated areas such as the Atherton Tablelands will be buffered from the direct impacts of many projected changes (e.g., sea level rise), and will likely maintain tolerable temperatures with fertile soils and adequate levels of rainfall. Government policy will also strongly influence population patterns in the region. For example, if mining develops as projected in the area around the Mackay-Whitsundays (State of Queensland 2013c), the regional population is likely to increase substantially, along with the development of major infrastructure projects.

There is an existing trend of increasing population in the region as the result of shifts from southern regions of Australia to areas such as the Mackay-Whitsundays and Cairns and surrounds. This trend is reflected in plans for urban expansion around existing population centres. Current and planned settlement patterns and infrastructure projects contain only limited consideration of the impacts of climate change, although the planning schemes of several Local Governments do incorporate sea level rise projections. Planned state-run projects typically lack explicit consideration of potential climate change impacts.

Population growth in certain areas of the region may lead to increased investment in infrastructure in those areas, but there is likely to be a significant lag time, where demand will exceed capacity of critical infrastructure.

Summary and conclusions

Vulnerability to the impacts of climate change on infrastructure is high in the Wet Tropics Cluster. In general, the biggest direct risk to infrastructure from climate change is likely to be from sea level rise in coastal areas, although other climate-induced changes (e.g. severe tropical cyclones and heavy rain events) will also be important. These impacts will compound an existing deficit in the provision and maintenance of infrastructure throughout the region, partly due to remoteness, low population densities and extremes of tropical climate and weather.

The State Government has considerable responsibility for the provision and maintenance of large-scale public infrastructure, yet climate change impacts such as sea level rise are not mentioned in recent documents that discuss current or planned major infrastructure developments in the region (e.g., State of Queensland, 2013a,b,c).

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Chapter 6: Potential impacts of climate change on industries

Natalie Stoeckl, Marina Farr, April Reside, Matt Curnock, Silva Larson, Gabriel Crowley, Stephen Turton, Bruce Prideaux, Nadine Marshall and Sarah Gillet

Executive summary

Climate change is likely to make it harder for most businesses to cope financially, but there are some emerging opportunities. The key messages associated with each of the topics addressed in this chapter are listed below:

Vulnerability of dominant industry sectors in NRM cluster	1. The private sector in this region is heavily dependent upon just a small handful of industries (agriculture, fishing, mining, tourism, and to a lesser extent, forestry) for income, employment and livelihoods.
	2. These industries are reliant upon the natural environment, and thus are vulnerable to the potential impacts of climate change.
	3. This is particularly so in remote areas; the regional centres have generally more diversified economies and may be in a somewhat less vulnerable position (except from damage to built infrastructures through extreme weather events or sea level rise).
	4. Possible increases in geopolitical instability mean that export-oriented businesses (agriculture, mining and tourism) are likely to see greater fluctuations in revenue streams, irrespective of local climate impacts.
	5. To the extent that climate change causes more extreme weather events, it will contribute to variability in business profitability across time and across space. Some businesses will see increases in costs and marked reductions in production (for example, from asset damage); others may see higher prices and/or more demand for their services (e.g. road repair, health professionals).
Tourism	6. Extreme events, particularly those that damage important areas of the Great Barrier Reef or rainforest, may generate severe and long-lasting reductions in visitation.
	7. The media's portrayal of extreme weather events will negatively influence visitor perceptions and may exacerbate the negative economic consequences on the tourism industry.

	8. Gradual changes to the natural environment may not have discernible impacts on visitation, but tour operator costs may increase if they need to travel further to find undamaged sites. 9. There is likely to be change in seasonal visitation patterns with more tourists in the dry season (winter) and fewer in summer when there is higher rainfall and temperatures, and an increased risk of extreme weather events. 10. Perceptions (real or imagined) of increased human health risks from climate-related diseases such as dengue, malaria or heat stress could affect visitation.
Grazing	11. Most graziers can expect to have to deal with new (and possibly more) pests, weeds and diseases. 12. Higher temperatures, more CO_2 and less rainfall mean that pastures may grow more quickly, but they could be less nutritious. 13. Climate change may increase the frequency and intensity of extreme fire days, but this will not necessarily translate into higher fire risk – that will also be influenced by rainfall and ground cover. 14. Higher temperatures, higher evaporation rates and reduced rainfall (if it occurs) will reduce surface water. 15. Droughts adversely affect pasture growth and availability, raising costs and reducing margins in the short term. 16. More frequent and more severe droughts will exacerbate existing problems and contribute to land degradation, lowering productivity in the long term. 17. Associated losses of land cover will make the land more susceptible to erosion, impacting downstream users and ecosystems. 18. The cost of fuel and insurance is likely to increase and the future of government assistance to cope with exceptional circumstances is uncertain.
Cropping, horticulture and forestry	19. The cropping, horticultural and forestry industries are particularly vulnerable to extreme events. 20. The combined effect of increased temperatures, higher evaporation rates, possibly lower rainfall and higher concentrations of CO_2 on crop productivity is uncertain. 21. Rising sea levels may impact underground water resources in low-lying areas.
Fishing	22. Higher sea temperatures and ocean acidification may affect the biological process of fish reproduction, growth and behaviour. 23. Extreme weather events may damage important coastal ecosystems that support fisheries.

	24. Sea level rise will fundamentally alter coastlines, as the inter-tidal zone moves inland. If mangroves, salt marshes and seagrass beds are unable to colonise these new areas, the impacts on fisheries could be substantial and permanent. 25. Loss of seagrass habitats could also further endanger dugong and sea turtle, key species in the non-commercial but culturally crucial traditional fisheries.
Mining	26. The mining industry is most vulnerable to extreme events (particularly cyclones and flooding), but generally copes well with such disasters. 27. The industry provides a potentially valuable resource to help others in recovery efforts.
Emerging opportunities: Payments from carbon abatement projects	28. The science, economics and policy of the carbon price are changing rapidly. 29. Current arrangements in Australia are highly dependent on government policy. 30. Abatement opportunities exist through vegetation management. 31. Land prices, lost opportunity cost, establishment cost and discount rate hamper profitability. 32. Threats to carbon sequestration in the area include disturbances from fires, cyclones, wild pigs or termites. 33. Abatement opportunities exist in reducing emissions from savanna burning. 34. The main method is shifting of burning from the late dry season (approximately October–November) towards the early dry season (March–April). 35. One savanna burning project has been established so far in the cluster region. 36. Abatement opportunities exist through reduction of methane emissions from livestock. 37. Methods include change in diet for domestic animals and humane management of feral animals. 38. Abatement opportunities also exist through landfill waste management and diversion of some materials from landfills. 39. Composting waste, such as technology implemented by the Cairns Advanced Resource Recovery Technology Facilities project, also reduces emissions. 40. Future opportunities may exist through improved fertiliser management for industries such as sugar; however, likely economic return from such methods is estimated to be low.

Introduction

The private sector in this region is heavily dependent upon just a small handful of industries (agriculture, fishing, mining, tourism, and to a lesser extent, forestry) for income, employment and livelihoods.

These industries are reliant upon the natural environment, and thus are vulnerable to the potential impacts of climate change.

This is particularly so in remote areas; the regional centres have generally more diversified economies and may be in a somewhat less vulnerable position (except from damage to built infrastructures through extreme events or sea level rise).

Unlike the more urbanised economies of south eastern Australia, northern Australia is heavily dependent upon a handful of industries for income and employment: government (federal, state and local); agriculture, horticulture, fishing, mining and tourism (Stoeckl & Stanley 2007). In the Wet Tropics Cluster Region, the public sector (here, including government, health and education) is 'core', providing 59%, 40%, 28% and 18% of all jobs respectively in the Torres Strait, Cape York, Wet Tropics and Mackay/Whitsundays NRM regions (ABS 2011). But it is agriculture, fishing, tourism, mining, and to a lesser extent forestry, that sustains the private sector in rural and remote areas. Moreover, agriculture is the single most significant user of land outside regional centres.

In Torres Strait, for example, nearly one third of all registered business are in agriculture, fishing or forestry (ABS 2013), and the prawn fishery landed an estimated $6.1 million of product during the 2009 fishing season (Torres Strait Protected Zone Joint Authority 2010; Wilson *et al.* 2010). These fisheries help supplement dietary protein for low-income households, and maintain culturally significant practices (Delisle 2013).

More than 97% of land in the Cape York NRM region is used for cattle grazing; and almost 65% of land in the Wet Tropics and Mackay/Whitsundays comprises native pastures and rangelands (McKeon *et al.* 2009a). In the Mackay/Whitsunday region, sugar accounts for more than 99% of all cropping (Biggs *et al.* 2013). Almost 20 % of land in the Mackay/Whitsundays and 10% of land in the Wet Tropics region used to grow sugar, fruit, vegetables, and other horticultural products (van Oosterzee *et al.* in press) and mining provides more than 14% and 10% of jobs in the Cape York and Mackay/Whitsunday NRMs (ABS 2011). Tourism is also a significant part the Wet Tropics and Mackay/Whitsunday economies (Deloitte Access Economics 2013).

As discussed in Chapter 2, climate change will have a profound effect on this region's natural resources and ecosystems. In addition to the physical destruction caused by extreme events, floods, drought, higher temperatures, and longer dry seasons will increase evaporation rates (CSIRO, 2009), affecting soil water balances and reducing stream flows (Krockenberger *et al.* 2003; Whetton 2001). Resultant impacts on water storage impoundments and ground water will affect the availability of water for irrigation, and changes in water table levels could result in dry-land salinity and acid sulphate soils (Barron *et al.* 2011). Climate change may also alter fire regimes (NCCARF 2013), will affect plant growth rates (Chapman *et al.* 2012; Cobon *et al.* 2009; Inman-Bamber 2007; McKeon *et al.* 1998; Wilson & Mannetje 1978) and the speed with which weeds, pests and diseases spread across the region and the globe (Patz *et al.* 2003). Ecosystems in this region will be degraded by the gradual increase in baseline air and sea surface temperatures and occasional heat waves (See Chapter 3), resulting in a loss of biodiversity (Garnaut 2008; Meyer *et al.* 1999; Turton in press; Turton *et al.* 2010), and in some habitats, complete shifts in ecological communities may occur, and may be long-lasting and/or irreversible (Hughes *et al.* 2003; Hughes *et al.* 2007; Reside *et al.* 2013; Williams *et al.* 2003b). Because industries in the region are dependent on climate-sensitive resources, climate change will have a significant impact upon these industries.

That the agriculture, fishing and forestry sectors are dependent upon the natural environment is self-evident. But Australian tourism and tourism in north Queensland – particularly in the Wet Tropics and Mackay/Whitsunday regions– is similarly dependent, as it relies heavily on nature-based experiences (STCRC 2009; Sun *et al.* 2011; Turton *et al.* 2010). Curnock *et al.* (2013) for example, found that for 70% of tourists to the Great Barrier Reef (GBR) coastal region, the GBR was an important part of their decision to visit, and for 10% of these tourists, seeing the GBR was the main reason for their visit to the region. Tourists to this region have also noted that the existence of healthy coral reefs, healthy reef fish, iconic marine species and clear water are more important factors influencing decisions about whether to come to this region than the having high quality accommodation and prices to match budgets (Stoeckl *et al.* 2012). Similarly, the rainforest of the Wet Tropics World Heritage Area has been identified as an important driver of tourism expenditure in the region (Prideaux & Sibtain 2012).

Climate change is likely to have a long-term trajectory of increased temperatures and shifts in rainfall patterns (See Chapter 2); industries that are dependent upon natural resources will be affected by this and are particularly sensitive to the greater amplitude of fluctuations in rainfall, and the expected increase in severity of cyclones, heatwaves, floods and droughts. But climate change may have a significant impact on physical infrastructure (See Chapter 5) – largely associated with the damage caused by extreme events and/or sea level rise. As such climate change may also affect businesses in a variety of other industries including, but by no means limited to, those associated with transport (affected when roads, ports and/or airports are damaged), retail and wholesale (as when, for example, flooding prevents customers from accessing shopfronts), construction (when required to help repair infrastructure) and health (required to deal with physical or mental side effects of damage).

Climate change thus has the potential to significantly impact the 'core' industries on which this region depends (particularly in remote areas). This chapter outlines some of those impacts, the key messages being that climate change is likely to make it harder for most businesses to cope financially (section 2); there are some industry-specific impacts to be aware of (section 3); and there are some emerging opportunities of which land and sea managers may be able to avail themselves (section 4).

Possible increases in geopolitical instability mean that export-oriented businesses (agriculture, mining and tourism) are likely to see greater fluctuations in revenue streams, irrespective of local climate impacts.

To the extent that climate change causes more extreme weather events, it will contribute to variability in business profitability across time and across space. Some businesses will see increases in costs and marked reductions in production (for example, from asset damage); others may see higher prices and/or more demand for their services (e.g. road repair, health professionals).

Regions vulnerable to the degradation of natural resources, sea level rise and extreme weather events are at risk of increasing political instability, large scale migration and violent conflict (Reuveny 2007). As such, geo-political instability and associated acts of terrorism may be exacerbated by climate change indirectly affecting businesses in this region. The full extent of flow-on effects from a future climate-related international conflict are difficult to determine, however the risks of such conflicts to international travel patterns and tourism are very real (Frey *et al.* 2007). Moreover, better economic integration serves to reduce commodity price volatility (Jacks *et al.* 2011); more conflict is thus likely to increase price volatility exacerbating existing fluctuations in agricultural and mining incomes irrespective of actual climate events in this region.

This volatility is likely to be exacerbated by more frequent, or intense, extreme weather events in the Wet Tropics Cluster Region (See Chapter 2). Tropical cyclones and floods can cause significant damage to a region's resources – both built and natural (e.g. forests and reefs; tourist and agricultural infrastructure). Such events are usually followed by increased insurance premiums in affected areas (Carter 2012; Real Estate Investor 2014), thus raising costs for businesses (or increasing risk for those unable to accommodate these higher premiums). Businesses that rely on resources that recover (or are restored) quickly may see their operations return to normal relatively soon after such events. Others may suffer long periods with little to no income, or incur increasing debt (rebuilding dams, laser-levelling washed out fields, feeding livestock, repairing boats and buildings, etc.). In contrast, some types of businesses (e.g. construction companies or health professionals assisting after extreme events) may have increased revenues/demand after extreme events; these companies may come from the affected area, or (more common) may come from other regions. Extreme events thus have different impacts (both positive and negative) on the profitability, and by extension share prices of (listed) firms in different regions and different industries (Li 2013). As such, extreme events contribute to both spatial and temporal variability in business profits (by increasing variability in costs, price and demand). This applies to industries in general and natural resource based industries in particular.

In the agricultural sector, the loss of stock or crops in one area may increase prices; generating unanticipated but potentially significant surges in revenues for unaffected producers (Quiggin 2007). Likewise, when graziers de-stock during drought years, the supply of meat rises and price falls (sometimes to such a degree that it costs graziers more to get cattle to market than they receive for the meat (Kleinhardt Business Consultants 2007) making it difficult to destock), but when the drought breaks and growers rebuild herds, supply is reduced and prices rise (Quiggin 2007). Extreme events thus contribute to temporal price variability.

In the tourism sector, there is evidence to suggest that the Wet Tropics Cluster Region we will see fewer visitors in the wet (summer) season and more in the dry (winter) months, particularly at terrestrial nature-based attractions (Turton in press). Moreover, some tourism activities may also suffer shortened seasons, including those dependent on freshwater streams and rivers (e.g. white water rafting) as base flows are reduced during the dry season due to longer drier dry seasons (Turton in press).

Government assistance to support post-extreme event recovery– traditionally provided as drought or disaster relief funding – is liable to be replaced by programs to increase resilience to climate variability (Nelson *et al.* 2008; Productivity Commission 2009). Whether or not this helps to reduce extreme-event related income volatility remains to be seen.

Industry-specific impacts

Tourism

Extreme events, particularly those that damage important areas of the Great Barrier Reef or rainforest, may generate severe and long-lasting reductions in visitation.

The media's portrayal of extreme weather events will negatively influence visitor perceptions and may exacerbate the negative economic consequences on the tourism industry.

Gradual changes to the natural environment may not have discernible impacts on visitation, but tour operator costs may increase if they need to travel further to find undamaged sites.

There is likely to be change in seasonal visitation patterns with more tourists in the dry season (winter) and fewer in summer when there is higher rainfall and temperatures, and an increased risk of extreme weather events.

Perceptions (real or imagined) of increased human health risks from climate-related diseases such as dengue, malaria or heat stress could affect visitation.

Climate change will affect natural resources that the tourism industry is dependent upon. Drought and other changes in rainfall patterns can cause the slow degradation of tourism sites which may or may not recover. Extreme weather events such as cyclones and floods can cause severe damage to tourism infrastructure, rainforests, wetlands and mangroves (Australian Greenhouse Office Department of Environment and Heritage 2005; Becken 2005; Williams *et al.* 2003a). Floods also increase sediment loads in rivers (Chaiechi *et al.* in review; Fabricius *et al.* 2008), and this increases water turbidity in the GBR lagoon (Fabricius *et al.* 2013) which contributes to the overall degradation of the GBR (Bartley *et al.* 2014; Brodie *et al.* 2012) manifested by reductions in live coral cover

(De'ath *et al.* 2012). Moreover, higher sea temperatures have been associated with coral bleaching events from which coral reefs of high tourism value may take many years to recover (Bureau of Meteorology 2014). Crown-of thorn starfish outbreaks have been linked to flood events, and these too significantly affect the ecosystem health and attractiveness of coral reefs (GBRMPA 2014).

Changes to the natural environment that are associated with events such as these may have severe and long-lasting consequences for tourism destinations. Reef visitation by divers and snorkelers could decline by up to 80% in response to a hypothetical decline in coral and fish biodiversity (Kragt *et al.* 2009). Miller (2005) notes that many recreational specialists (scuba divers in particular) are attracted to the Great Barrier Reef for its diversity of marine species, and such specialists are likely to recognise and avoid sites that are degraded. More than 80% of visitors to the GBR coast say they would have either reduced the length of their visits to the area, or not come at all if ocean waters changed from clear to murky; 70% would have responded similarly if there was a 50% reduction in coral cover (Stoeckl *et al.* 2013). Environmental impacts do not have to be widespread: degradation of the perceived values for one major natural attraction at a tourist destination can have flow-on effects that impact visitation to other regional attractions, and to the destination as a whole (Coghlan & Prideaux 2009; Prideaux *et al.* 2010; STCRC 2009).

Recovery of habitats affected by extreme events (rainforest as well as coral reefs) can take many years, even if the impact is spatially restricted. Tourism businesses and infrastructure based around the Mission Beach and Cardwell region have still not fully recovered two years after being heavily impacted by Severe Tropical Cyclone Yasi in 2011. Indeed, the lack of tourists to the region for months after the event were perceived to be more harmful to the industry than the direct impact of the cyclone itself (Marshall *et al.* 2013). Moreover, the media's portrayal of extreme weather events can influence visitor perceptions of a destination and result in sudden and long-term changes in travel behaviour (Scott *et al.* 2012). Even single events have been shown to have long-term negative consequences on tourist perceptions and travel choices, with several European cases of changed visitor patterns (Scott *et al.* 2012), and examples affecting Caribbean destinations reported by Hübner and Gössling (2012). Impacts to tourism visitation associated with Severe Tropical Cyclone Larry (2006) in the wet tropics region included a short-term reduction in visitor numbers, however a significant tourism marketing investment associated with regional recovery efforts is considered likely for a rapid return to healthy visitation (Prideaux *et al.* 2007; Prideaux & Falco-Mannome 2010).

In contrast to extreme events, the gradual degradation of a natural attraction associated with the predicted declines in biodiversity likely to accompany climate change (Cobon *et al.* 2009; Orr & O'Reagain 2011; Williams *et al.* 2001) may not have a discernible impact on a destination's total tourism visitation – although different tourism markets are likely to respond in different ways. A study of reef tourists in the Caribbean (Uyarra *et al.* 2009), found that most tourists are only able to perceive certain aspects of changes in a reef's ecological condition and many are still willing to visit degraded reefs, and a similar situation has been documented in GBR tourism (Ramis & Prideaux 2013). This suggests that if change is gradual, tourism markets may not suffer rapid declines, depending on how natural resources are presented, promoted and managed.

Industry responses to the localised impacts of either extreme weather events or the gradual degradation of a tourism location, can increase operational costs for tourism businesses. High overhead costs associated with vessel operations, infrastructure and staffing requirements contribute to relatively small profit margins for many GBR tourism businesses and consequently can increase their vulnerability to fluctuations in visitation (Curnock *et al.* 2013). Damaged or degraded reefs in proximity to major tourism hubs (e.g. Cairns, Port Douglas, Whitsundays) are likely to cause operators to increase their transit distance to reach suitable alternative sites, and further increase overhead costs.

Finally, it is important to note that increased climatic variability may affect the spatial range and transmission patterns of diseases, parasites and pathogens (Patz *et al.* 2003). Tourism is highly sensitive to global shocks affecting international travel patterns; including terrorism (e.g. events of 11th September 2001), financial crises (e.g. the 2008/09 Global Financial Crisis) and disease (e.g the SARS outbreak; Biggs *et al.* 2012). As a long-haul international destination, Australian tourism is thus particularly vulnerable; the risks need not be real, misperceptions of risk may alone, be enough to significantly affect visitation.

Grazing

Most graziers can expect to have to deal with new (and possibly more) pests, weeds and diseases.

Higher temperatures, more CO_2 and less rainfall mean that pastures may grow more quickly, but they could be less nutritious.

Climate change may increase the frequency and intensity of extreme fire days, but this will not necessarily translate into higher fire risk – that will also be influenced by rainfall and ground cover.

Higher temperatures, higher evaporation rates and reduced rainfall (if it occurs) will reduce surface water.

Droughts adversely affect pasture growth and availability, raising costs and reducing margins in the short term.

More frequent and more severe droughts will exacerbate existing problems and contribute to land degradation, lowering productivity in the long term.

Associated losses of land cover will make the land more susceptible to erosion, impacting downstream users and ecosystems.

The cost of fuel and insurance is likely to increase and the future of government assistance to cope with exceptional circumstances is uncertain.

Climate change is likely to impact the financial viability of the grazing industry in a variety of ways. Increased climatic variability will affect the spatial range and transmission patterns of diseases, parasites and pathogens (Patz *et al.* 2003): it may increase the spread of some diseases but reduce the spread of others. Locally, higher temperatures are likely to increase the probability of domestic diseases spreading (Cobon *et al.* 2009) and pests (Howden *et al.* 2008; Pearson & Langridge 2008; White *et al.* 2003). So whilst some graziers may be lucky enough to see less of some familiar diseases, pests and weeds, most can expect to have to deal with new ones, and this could impose significant costs on the industry. White *et al.* (2003), for example, assessed the potential impact of more cattle ticks (brought about by higher temperatures) on the beef industry in Australia, estimating losses for Queensland at approximately 21% of average farm income.

Changes in temperature, evapotranspiration rates, CO_2 and rainfall patterns will impact pasture growth. Each will affect pasture in different ways, so the net impact of all three changes is uncertain. There is evidence that increases in temperature may improve the nutritional quality of pasture (McKeon *et al.* 1998; Wilson & Mannetje 1978), and increase carbon dioxide concentrations may increase pasture growth, but reduced rainfall and increased temperatures and evaporation rates may cause a reduction in non-structural carbohydrate concentrations and digestibility in tropical grasses (Cobon *et al.* 2009, p.32; IPCC 2007).

Climate change is likely to increase the frequency and intensity of extreme fire days and result in a longer fire season across the Wet Tropics cluster region (Lucas *et al*. 2009; See Chapter 2). But this does not necessarily translate into higher fire risk; a complex issue, which depends on weather, ignitions, and fuel loads that are in turn depend on climate – rainfall patterns and temperature (Bradstock 2010). Woody thickening has been associated with heaving grazing (Archer 2002 cited in Sharp & Whittaker 2003) and with infrequent fires in the past, so one cannot determine whether more frequent and extreme fire days will translate into higher fire risk without also knowing something about recent grazing practices and fire histories. The compounding influence of rain on fire risk is also complex (Fensham *et al.* 2005): if it rains in normally dry areas during peak growth seasons this could increase fire risk (since it will increase fuel loads); but more rain in normally wet areas could serve to decrease fire risk. Morefore, rainfall projections are uncertain. As such, the effect of climate change on fire risk is uncertain (See Chapters 2 & 3).

Higher temperatures, more frequent droughts and reduced rainfall also means that less surface water will be available (CSIRO 2009). This may increase operational costs for those required to install more water infrastructure, or may reduce productivity of operations where water is a binding constraint.

More droughts and reduced summer rainfall may reduce pasture growth and availability (Cobon *et al.* 2009). The immediate effect is to decrease production per head, increase costs (particularly if supplementary feeding is required) and reduce gross margins (Cobon *et al.* 2009). Arguably, larger corporations – particularly those with multiple land holdings who can move stock from degraded to healthy pastures – will be at a relative advantage compared to smaller operations (Undersander *et al.* 1992).

There are also longer-term knock-on effects of drought. Reduced pasture growth can lead to increased soil loss (as much as 40%; see Peterson *et al.* 2010), and the extent to which this land degradation occurs will depend upon the intensity and frequency of droughts; overstocking will exacerbate the problem (McKeon *et al.* 2004; McKeon *et al.* 2009b). Researchers have already noted a decline in land and pasture condition in north Queensland in terms of reduced ground cover and a decline in perennial grass species (DeCorte *et al.* 1991; O'Reagain *et al.* 2009; Tothill & Gillies 1992). If climate change precipitates more frequent and more intense droughts then land and pasture condition may deteriorate even more rapidly. This can be avoided to some extent by adjusting stock numbers. However, mass de-stock during drought years results in price falls (Quiggin 2007), making it unprofitable for pastoralists in more remote areas (with high transport costs (Kleinhardt Business Consultants 2007) to destock. Cattle sales may also be affected by an increase in road closures as a result of flood and flood damage, already an issue in the region (Kleinhardt Business Consultants 2007).

The 'average' producer in the northern grazing industry is spending more than they earn and has also been accumulating debt (McCosker *et al.* 2010). Drought has been shown to increase that financial hardship further (Edwards *et al.* 2009), which makes it unlikely that natural resource management will be a high priority for pastoralists. The industry is also sensitive to fuel prices, which are currently subsidised (Gleeson *et al.* 2012). While pastoralists are likely to be protected from any carbon taxes in the short term, they will be exposed to increases in global fuel prices (Gleeson *et al.* 2012). If climate change results in more, or more intense droughts and extreme events (See Chapter 2), then these financial pressures will be exacerbated, and some pastoralists may thus also find it more difficult and/or more expensive to access finance (since higher risk generally drives the cost of finance up (Cummins & Phillips 1999; Zanjani 2002).

Finally, loss of ground cover can make the land more susceptible to erosion. There are complex interactions here, but research in Australia and elsewhere (including Chaiechi *et al.* in review; Mackenzie & Armstrong 2002; McJannet *et al.* 2007; Yu & Neil 2000) indicates that sediment loads respond to changes in the flows from the river systems, climate (rainfall volume and intensity, temperatures and evaporation) and geographic features (soil type, hill slope etc.). The combined effect of higher temperatures and evaporation rates, more intense rainfall events and less ground cover will thus be to adversely affect water quality locally, and in downstream systems including the GBR (Furnas 2003; O'Reagain *et al.* 2011; O'Reagain & Scanlan 2013). As discussed earlier, reduced water quality in the GBR lagoon may be detrimental to the tourism industry, given the importance of 'clear water' as a regional drawcard (Stoeckl *et al.* 2013).

Cropping, horticulture and forestry

The cropping, horticultural and forestry industries are particularly vulnerable to extreme events.

The combined effect of increased temperatures, higher evaporation rates, possibly lower rainfall and higher concentrations of CO_2 on crop productivity is uncertain.

Rising sea levels may impact underground water resources in low-lying areas.

The cropping, horticultural and forestry industries are particularly vulnerable to droughts, floods and cyclones. The sugar industry, for example, is estimated to have lost millions during the 1998 harvest because the early (and significant) wet season rains lowered the sugar content of crops, prevented some growers from harvesting their entire crop, prevented some crop plantings and compacted soils in some areas thus lowering productivity (Antony *et al.* 2002; Everingham *et al.* 2012). Additionally, up to 90% of banana crop in the Tully / Innisfail region were destroyed by Cyclone Larry in 2006 (The Sydney Morning Herald 2006), and just five years later – in the same region – at least 85% of the banana crop (Lindsay & Comiskey 2012; Packham 2011) and up to 75% of sugarcane crops (Woods *et al.* 2012) were destroyed by Cyclone Yasi (Turton 2012). Where an entire crop is vulnerable to a single event, primary producers face increased financial incentives to grow annual (or even shorter term) crops, hastening the speed with which they can recover from extreme events (Diczbalis & Chay 2006). This may at least partially explain the observed declines in forestry in this region (although weak timber markets are also discouraging investment in this area – Harrison and Herbohn 2006).

Changes in temperature, rainfall and CO_2 also have the potential to affect crop production (Chapman *et al.* 2012) and hence horticultural profits – but it is not clear if the effects will be good or bad. Preliminary modelling predictions suggest that an increase in temperature may speed the growth of sugar cane. But higher temperatures also increase water stress (CSIRO 2013) – the cost of which has been estimated to be more than $200 million AUD per year (Inman-Bamber 2007). Moreover, increased concentrations of CO_2 may increase the efficiency with which sugarcane uses light, water and nitrogen resulting in higher biomass accumulation (Biggs *et al.* 2013). It seems that the jury is still out about what the combined effects will be.

Many growers rely upon underground aquifers during the dry season. Whilst the largest threat to these is over-use by industry, those along the coast with low hydraulic gradients are, however, particularly vulnerable to sea-level rise (See Chapter 2): the aquifers may fill with sea water (Ferguson & Gleeson 2012). Inland, dry-land salinity may result when flooded aquifers are raised by flooding (Webb *et al.* 2005).

Fishing

Higher sea temperatures and ocean acidification may affect the biological process of fish reproduction, growth and behaviour.

Extreme weather events may damage important coastal ecosystems that support fisheries.

Sea level rise will fundamentally alter coastlines, as the inter-tidal zone moves inland. If mangroves, salt marshes and seagrass beds are unable to colonise these new areas, the impacts on fisheries could be substantial and permanent.

Loss of seagrass habitats could also further endanger dugong and sea turtle, key species in the non-commercial but culturally crucial traditional fisheries.

The fishing industry is likely to be impacted by climate change in several significant ways. Increased ocean acidification and increased sea temperatures (See Chapter 2) are likely to affect the biological process of fish reproduction, growth and behaviour (See Chapter 3). Some species respond well to temperature increases with shorted incubation times, higher growth rates and improved juvenile swimming ability, but these benefits are associated with relatively minor temperature increases (GBRMPA 2013). Ocean acidification affects fish reproduction (particularly cold water fish) and reduces the ability of fish larvae to find suitable habitat and find their breeding habitat (GBRMPA 2013).

Climate change is likely to degrade mangroves, saltmarshes and seagrass beds (See Chapter 3) which are vital to the productivity and food webs of coastal waters and which provide critical nursery areas for many fish and crustaceans (GBRMPA 2013; Goudkamp & Chin 2006; Manson *et al.* 2005). These ecosystems are vulnerable to extreme events, all due to the direct damage of winds and waves; seagrass is also vulnerable to increased ocean turbidity associated with flood waters from the catchments. Moreover, rising sea levels will fundamentally alter coastlines. In time, the inter-tidal zone will move inland, but mangroves, saltmarshes and seagrass beds may not be able to colonise these areas if confronted with natural or man-made barriers such as levee banks, roads or buildings (Goudkamp & Chin 2006).

Climatic degradation of our mangroves (See Chapter 3) may significantly impact commercial fishers. Fish populations, including commercially important fish such as snapper and sweetlip, are both more diverse and abundant when reefs are connected to mangroves (Goudkamp & Chin 2006; Mumby *et al.* 2004); indeed Mumby *et al.* (2004) report that such connections can double fish biomass. Moreover, expenditure associated with the recreational fishing sector is non-trivial (Deloitte Access Economics 2013; Prayaga *et al.* 2010) so a contraction in this sector could create economic losses in associated businesses (e.g. fishing, boating and tackle supply shops).

Finally, seagrass beds are also a vitally important for dugong and turtle (See Chapter 3). Loss of seagrass thus puts at risk two traditional fisheries that have no commercial value, but are of extreme cultural importance to the Aboriginal and Torres Strait Islanders of the region (Delisle 2013). Marine turtles are also vulnerable to climate change because extreme events and rising sea levels are degrading nesting sites, and higher temperatures are altering the sex-ratio of hatchlings (GBRMPA 2013).

Mining

The mining industry is most vulnerable to extreme events (particularly cyclones and flooding), but generally copes well with such disasters.

The industry provides a potentially valuable resource to help others in recovery efforts.

Mining activities, including underground and open cut extraction; production; maintenance of pits; and transportation of resources and equipment, are vulnerable to cyclones and river flooding, and thus to climate change (Pearce *et al.* 2009). The main costs are related to limited production, costs of dewatering pits, and repair of mine infrastructure, road or rail, and ports (Sharma *et al.* 2013). Accidental spills and tailing dam breakages during such events would cause water and ground pollution in the region, including marine environments.

Although the mining industry has been negatively affected by flooding and cyclones in the past, they have provided support to the region during such events. For example, the mining industry provided additional State Emergency Service (SES) volunteers, helicopters, fodder drops for livestock in isolated communities, evacuation centres and helped with road infrastructure reconstruction – to affected communities and local governments, thereby provided valuable resources and contributing to an improved response to floods and cyclones (Sharma *et al.* 2013).

Emerging opportunities: Payments from carbon abatement projects

The Emissions Reduction Fund will build upon the Carbon Farming Initiative (CFI), presenting many options for sequestering carbon and mitigating greenhouse gas emissions in North Queensland, with corresponding economic gain (Eady *et al.* 2009). Under the Emissions Reduction Fund, opportunities for the NRM sector are likely to be limited to reforestation and revegetation of marginal lands; improving Australia's agricultural soils; and managing fires in savanna grasslands (Department of Environment 2014). Here we focus on the opportunities available and relevant to the cluster region, with some mention of future potential opportunities (Anon. 2012; Eady *et al.* 2009; Whittle *et al.* 2013). These opportunities have the potential to generate co-benefits by reducing emissions while also providing alternative income streams.

The science, economics and policy of the carbon price

The science, economics and policy of the carbon price are changing rapidly.

Current arrangements in Australia are highly dependent on government policy.

New methodologies are being developed and approved, and there are currently many research projects investigating new methods for carbon sequestration. This research is likely to result in verifiable methodologies in the near future. However, the economic viability of emission reduction projects are dependent on the price of carbon (Polglase *et al.* 2013). In July 2012, a fixed price of AUD$23 per tonne for carbon dioxide equivalent ($/ t CO_2 -e) was set, rising at 2.5 % a year in real terms (Australian Government 2008), but changing government priorities may result in a shift in this price – or indeed in the entire scheme. Many Emissions Trading Schemes (ETS) are opening up internationally. Currently Australian Carbon Credit Units cannot be exported, but opportunities may open up in the future for selling carbon credits in an international ETS. Barriers to the implementation of many emission reduction projects include the establishment costs and the low income gained for abated carbon over the short to medium term (Whittle *et al.* 2013). Demonstrated co-benefits, particularly for increased agriculture productivity and profitability, are likely to greatly increase adoption rates.

Abatement opportunities through vegetation management

Abatement opportunities exist through vegetation management.

Land prices, lost opportunity cost, establishment cost and discount rate hamper profitability.

Threats to carbon sequestration in the area include disturbances from fires, cyclones, wild pigs or termites.

Vegetation management options to improve the carbon balance include afforestation, environmental plantings, restoration, and native forest protection (avoided deforestation). Those likely to apply under the Emission Reduction Fund are likely to be limited to reforestation and revegetation of marginal lands; improving Australia's agricultural soils; and managing fires in savanna grasslands. The Wet Tropics Bioregion is among the highest in Australia for sequestration through hardwood and "environmental" plantings (Polglase *et al.* 2013). In regions with >600 mm rainfall, the annual average rate of sequestration over 40 years is 9-12 to CO_2/ha/year, depending on the risk buffer (Polglase 2009). However, the profitability might be hampered through high land prices, lost opportunity cost, establishment cost, and discount rate. Costs of planting establishment vary widely depending on site conditions and methods, such as direct seeding, tube stock, restricted grazing or natural regeneration (Polglase *et al.* 2013). Opportunities for indigenous participation in emission reduction projects have the potential to address land management issues and provide economic opportunity (Salvin 2012). However, for many of the assessed regions (the area held by Jabalbina Yalanji Land Trust between Mossman and Cooktown; and the Umpila Land Trust area on the eastern side of Cape York Peninsula), land available for emission reduction reforestation is limited (Adshead & Salvin 2012; Salvin 2012). There are currently three established environmental planting projects in the cluster region, all in the Atherton Tablelands.

The methodology according to the Carbon Farming Initiative states that the plantations must adhere to a 100-year permanence rule. However, this condition may be revised under the Emissions Reduction Fund. Threats to carbon sequestration in the area include disturbances from fires, cyclones, wild pigs or termites. However, the owners of environmental planting projects will not be penalised for losing carbon through no fault of their own; but the landholder must take reasonable action to re-establish carbon stores. Co-benefits from revegetation of cleared land will result in improved nutrient cycling, water regulation and provision of habitat for biodiversity. There is conflicting evidence for whether monoculture plantings will be more profitable and will store more carbon than environmental plantings (Crossman *et al.* 2011; Kanowski & Catterall 2010). The biodiversity co-benefits are greater with environmental plantings, and more carbon may be stored due to greater structural complexity. Biodiversity payments may be required to encourage environmental plantings to maximise the co-benefits (Bekessy & Wintle 2008; Crossman *et al.* 2011).

Abatement opportunities through reduced emissions from savanna burning

Abatement opportunities exist in reducing emissions from savanna burning.

The main method is shifting of burning from the late dry season (approximately October–November) towards the early dry season (March–April).

One savanna burning project has been established so far in the cluster region.

Fire in the savannas contributes around 1-2% of Australia's total greenhouse gas emissions. The goals of the savanna burning methodology are to reduce these emissions by shifting burning from the late dry season (approximately October-November) towards the early dry season (approximately March-April), and to reduce the area that is burnt each year. Reducing late dry season fires can be done by managed early dry season burning (CSIRO 2011). The project owners must develop a vegetation map for their project area, and determine the fire history of the area for the 10 years prior to the project commencement. Emissions abatement is calculated as the difference between the baseline and project emissions. Fires cannot be controlled by introducing cattle or by increasing fire outside the project area. Currently this approved Savanna Burning methodology applies to savanna regions with high rainfall (>1000 mm p.a.), which includes most of Cape York, but has potential to be extended to lower rainfall conditions (600-1000 mm p.a.). Only one savanna burning project in the cluster region has been established so far. Co-benefits of reducing late dry season fire include the retention of long-unburnt areas that are likely to benefit biodiversity. Additionally, the savanna burning methodology has the potential to provide livelihood opportunities to Indigenous communities (Andersen & Heckbert 2009).

Abatement opportunities through reduction of emissions from livestock and landfill

Abatement opportunities exist through reduction of methane emissions from livestock.

Methods include change in diet for domestic animals and humane management of feral animals.

Abatement opportunities also exist through landfill waste management and diversion of some materials from landfills.

Composting waste, such as technology implemented by the Cairns Advanced Resource Recovery Technology Facilities project, also reduces emissions.

The methodology approved under the CFI include options for reducing methane emissions from livestock are for piggeries, and for dietary additives to milking cows. Improvements in livestock diets include the following dietary additions: tannins, *Eremophila* spp, and fats and oils to dairy cattle that are pasture grazed for more than nine months each year. Co-benefits may include improvements in productivity (Charmley 2009). Proposals for future methodologies include improved diet for beef cattle, but also the humane management of feral goats, deer, pigs and camels. Barriers to implementation of this methodology result from the difficulty of quantifying the greenhouse gas emissions from livestock, making auditing problematic. A co-benefit of reduced numbers of feral herbivores is a reduction of grazing pressure, which will increase landscape health and reduce food competition for native species.

Avoided emissions methodologies for landfills include diverting waste from landfill into purpose-built alternative fuel manufacturing facilities where the materials are processed into a variety of product streams, including processed engineered fuel. The waste suitable for this methodology includes mixed loads of construction and demolition waste, and mixed loads of commercial and industrial waste. A second avoided emissions methodology is diverting putrescibles eligible waste from landfill to a composting waste treatment technology, as implemented by the Cairns Advanced Resource Recovery Technology Facilities Project. The co-benefits of this methodology include reducing water, sediment and nutrient migration into local waterways. There are also methodologies for the capture and combustion of landfill gas, in particular methane, involving collecting the gas, combusting the methane component or an electricity generation system to convert it to carbon dioxide. The electricity can be sold back to the electricity grid.

Potential opportunities through improved fertiliser management

Future opportunities may exist through improved fertiliser management for industries such as sugar; however, likely economic return from such methods is estimated to be low.

Fertiliser management options include reduced application rates, split applications, subsurface applications, and improved soil testing to better match fertiliser application with the crop's requirements (Knudsen & Putland 2012). Other options include the use of nitrification inhibitors. Applying nitrification inhibitors to the soil slows the process of ammonium conversion to nitrate, and therefore to nitrous oxide which is then released into the atmosphere. Research has shown reductions in nitrous oxide up to 40%, with large variation. However, the likely economic return from fertiliser management is low, but research is continuing for improved methodologies (Knudsen & Putland 2012). A co-benefit of the reduction in fertiliser use is an improvement of water quality downstream.

Summary and conclusions

The agriculture, tourism and mining industries – all of which are crucially dependent upon the region's natural resources – sustain the private sector in the Wet Tropics Cluster Region. Climate change is likely to have a profound effect upon the region's natural resources and may thus, by extension, have a profound effect upon these industries and the region's economy.

The most significant changes are likely to be associated with extreme weather events – impacting the tourism, grazing, cropping, agriculture, horticulture, fishing and mining industries. With the exception of mining, all of these industries are also susceptible to increased risk of diseases, pests and weeds. Increased temperatures, higher evaporation rates, more CO_2 and altered rainfall patterns will all affect crop productivity thus impacting the grazing and horticulture industry, but they affect productivity in different ways, so the net impact of all three is not discernible *a priori.*

Overall, business can expect more volatility in prices and in demand for products. We may also observe much wider variation in business outcomes across regions (e.g. those which are, or are not, affected by a particular extreme weather event). Average costs are likely to rise (with reduced access to finance, higher borrowing and insurance costs and possibly lower productivity associated with altered pasture and crop growth, increased competition from pests and weeds, more disease and fire risk).

There are emerging environmental and economic opportunities through carbon abatement schemes, however:

- The science, economics and policy of carbon are changing rapidly.
- Current arrangement in Australia are highly dependent on government policy.
- Demonstrated co-benefits of increased agriculture productivity and profitability may be needed to increase adoption rates.

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Chapter 7: Social impacts in the primary industries of the Wet Tropics Cluster

Nadine Marshall, Iris Bohnet, Gaye Crowley, Matt Curnock, Allan Dale and Margaret Gooch

Executive summary

This chapter discusses the social and economic impacts likely to be experienced by primary producers living and working within the Wet Tropics cluster region and the industries and rural communities to which they belong. Farmers, foresters, fishers and cattle producers in the Wet Tropics Cluster are socially, economically and culturally dependent on natural resources. Resource condition can be affected by increases in temperature, changes in rainfall patterns and extreme weather events. Primary producers that are dependent on climate sensitive resources will be especially sensitive to increased climate variability, and are likely to experience a range of social and cultural impacts. The nature and extent of the dependency on natural resources and the climate patterns that drive their use and management will determine the nature and extent of the social, cultural and financial impacts experienced by producers and their industries.

Psychological and allied health impacts are likely to be associated with extreme changes in resource condition that negatively affect the productivity of the land or sea. Primary producers that are, for a variety of reasons, unable to adapt to these changes and whose products become unviable will need to consider alternative products or occupations. However, the personal and occupational identity that can be created around primary production can be so significant that many producers will be unable to consider other product options and occupation, and the resultant mental health and allied health issues will likely become apparent. In extreme cases mental health issues may result in elevated suicide rates and domestic violence.

Economic and operational impacts are inevitable and likely to be severe in years of extreme climactic events. Economic opportunities may, however, be observable. Unemployment and rapidly changing employment profiles within rural regions may result from changes affecting the productivity of primary industries. Employment opportunities that do exist are in some cases likely to be secured by non-primary producers, where primary producers may not have transferrable skill sets.

Other social and cultural impacts are likely to develop through a shift in the nature and sizes of primary production enterprises in the region. The tendency will be to move from lifestyle-based enterprises towards larger and more integrated corporate-style production enterprises, and an increase in non-productive rural properties and consequent land management issues.

The key messages from this chapter are listed below:

Psychological impacts	1.	Psychological impacts are likely to be severe, especially when producers can no longer remain viable within their industry.
Health risks	2.	Future physical health risks to people living in the wet tropic clusters may include those associated with heat exhaustion and dehydration during heatwaves; and there may be increased cases of some vector-borne diseases.
Family impacts	3.	Family impacts are likely to be associated with climate changes that decrease the viability of the land, making primary production a less enticing venture for younger family members and women.
Unemployment	4.	Unemployment and employment transience within rural sectors may result from climate changes that threaten the viability of primary industries and producers.
Rural communities	5.	Persistence of rural communities despite limited viability.
Shifts in enterprise type	6.	A tendency towards larger, corporate-style production enterprises rather than lifestyle-based enterprises, affecting the cultural basis of rural regions.
	7.	Economic impacts are likely to be severe but could bring opportunities.
Recovery from extreme events	8.	Impacts of floods, extensive bushfires, droughts and cyclones are experienced by primary producers for months or even years after the events.

Introduction

Primary industries and producers, which include the sectors of agriculture, forestry, and fisheries, are especially vulnerable to climate change because they are socially, culturally and economically dependent on resources that are highly climate-sensitive (Fleming and Vanclay 2010; Greiner *et al.* 2003; Howden and Stokes 2010; Stokes and Howden 2010). Increases in temperature, changes in rainfall patterns and extreme weather events (See Chapter 2) can alter the quality or quantity of resources that can be harvested (Howden and Stokes 2010), and in the case of commercial fishing, can alter the location of where the natural resource resides (Hobday and Evans 2013; Hobday *et al.* 2013; McLeod *et al.* 2012). Primary producers will be sensitive to changes that occur in natural resources depending on the nature and extent of their dependency on those resources. The more dependent primary producers are on a natural resource and associated ecosystem services, the more sensitive they are to changes in condition or access to the resource. Producers that are more dependent on the resource are likely to have less psychological, financial, social and cultural flexibility with which to experiment with their options for the future and hence resource dependency can make such producers especially vulnerable to climate change (Marshall 2010; 2011).

The aim of this chapter is to help climate adaptation planners within the Wet Tropics Cluster region consider the main social and cultural impacts that are likely to result from climatic changes in the region. We develop a list of likely social and economic impacts through our understanding of how primary producers are dependent on natural resources, and we do this with as much reference as possible to local case-studies (Marshall *et al.* 2013a; Marshall *et al.* 2007; Marshall *et al.* 2013b; Marshall *et al.* 2012). Resource dependency is a useful indicator of climate sensitivity and can help to predict the likely social, cultural and economic impacts that will be experienced by producers within the region through understanding the likely consequences of altering the relationship between primary producers and the natural resource (Marshall 2011; Marshall *et al*. 2011). The basis of this list is presented in Table 1.

Table 1. Predicted individual and community impacts of changing relationships with agricultural resources

Dependency on the agricultural resource	Predicted individual impacts	Predicted community impacts
Identity	Psychological impacts associated with having to change identity, family impacts	Higher suicide rates, higher divorce rates, higher levels of domestic violence, increased levels of depression, less contribution made by individuals to community cohesion
Place attachment	Psychological impacts, financial impacts incurred through loss of productivity or increasing costs associated with agriculture	producers not leaving their land even though climate change has rendered the land untenable, unemployment, loss of community vitality,
Lack of employability (age, transferability of skills, attitude to working elsewhere)	Limited employment options available in the event that climate changes reduce the productivity of the land, lack of employment	Limited employment options available to primary producers who tend to have limited transferable skill sets, unemployment, loss of community vitality
Family	Reduced viability of the land may make the family farm unattractive for younger family members and especially younger women whom attain an education	Rural decline with population migrating to larger regional centres for education and employment
Corporate/ Lifestyle business approach	Financial un-viability of smaller family-owned farms	Economic viability of the region declines

Impacts on primary industries in the Wet Tropics NRM cluster

Psychological impacts are likely to be severe, especially when producers can no longer remain viable within their industry.

Primary-producers such as cattle producers, farmers, fishers, and foresters can be individually sensitive to impacts of climate change because of their attachment to their occupation and to the identity that they have created for themselves around their occupation (Lankester in Prep; Marshall *et al.* in press-a; Marshall *et al.* 2012; See Chapter 6). Producers working in resource-extraction industries can develop a strong attachment and identity based on their resource-based occupation and can become psychologically dependent upon continuing within their occupation. When a person who has a strong attachment to their occupation is suddenly faced with the prospect that they are no longer able to continue in that occupation, for example as a result of climate changes rendering a primary production enterprise unviable, they lose not only a means of earning an income, they lose an important part of their identity (Lankester 2012).

Identity is an important component of psychological well-being and important to maintain at favourable levels if mental health issues are to be avoided (Hitch *et al.* 2013). Marshall and Stokes (in press) described the identity created around the cattle industry in Northern Australia in terms of their attachment to the industry, the lifestyle it offers, the willingness to consider another occupation, tenure within the occupation, and the numbers of past and current family members also within the industry whom help to reinforce their identity within the industry (Table 1)(Marshall and Stokes in press) . Table 2 suggests that cattle producers in northern Australia (including within the Wet Tropics NRM Cluster) have developed a strong identity around their occupation.

A well developed occupational identity is important for maintaining and developing rural industries, however during times of crisis, maintaining a strong identity can be a source of extreme stress and mental health concerns (e.g.” identity crises”). Climate change represents a potential source of mental stress if conditions become too difficult for primary producers to remain viable. Work by Lankester (2012) has shown that male cattle producers tend to identify with an average of two to three roles in life whereas females tend to identify with an average of four to five roles. Lankester (2012) suggests that when identity is threatened in crises situations , people need to be able to ‘switch’ between identities, and when producers relate only to a limited number of roles in life, they are more likely to experience severe mental stress and this may explain why males in particular are more likely to suicide than females (Gunn *et al.* 2012; Page and Fragar 2002). In rural Australia, suicide remains the single greatest killer of men, while domestic violence is the greatest killer of women (Alston 2012; Andersen *et al.* 2010; Berry *et al.* 2011; Fraser *et al.* 2005)). Berry *et al*. (2011) have attributed these findings to coinciding periods of intense drought. They also suggest that other weather-related disasters may also erode the social and economic bases on which farming communities depend.

A recent study within the cattle industry across Northern Australia found that 86% of cattle producers were highly vulnerable to the impacts of climate change and this was partly attributed to their strong level of identity as a ‘cattle producer’ (Marshall *et al.* in press-b).

With the onset of longer and more intensive periods of drought within the Wet Tropics NRM Cluster Region (Salinger *et al.* 2005; Sivakumar *et al.* 2005; See Chapter 2) an increasing proportion of primary producers with a strong attachment to their ‘producer’ identity will be at risk of mental health issues. Climate adaptation planners may wish to consider supporting producers to remain within the industry during ‘bad’ periods, much like the pharaohs of ancient Egypt did (Allen 1997;

Rathbone 2009). Primary producers are likely to require financial support to remain within their industry during such periods, and if such periods become extended and primary occupations are deemed unviable, then these primary producers may have no option but to change occupations. If such primary producers are to continue in their occupation they will require emotional and psychological support in addition to financial assistance.

Table 2. Components of identity within a member of a primary industry (Marshall and Stokes 2014).

Factors of resource dependency	Survey statement	% Strongly agreed	% Agreed & strongly agreed
Identity	I love being a cattle producer	62.4%	92.6%
	Being a producer is a lifestyle – it is not just my job	51.9%	80.5%
	I would happily consider another occupation if the need arose	25.9%	39.1%
	How long have you been grazing cattle? (years)	Mean= 36.76, SE = 1.17	
	How many generations of your family have worked as producers?	Mean= 3.26, SE = 0.09	
	How many of your family members are cattle producers	Mean= 3.28 SE = 0.28	

Future physical health risks to people living in the wet tropic clusters may include those associated with heat exhaustion and dehydration during heatwaves; and there may be increased cases of some vector-borne diseases.

Heat waves in the wet tropics are likely to increase in frequency due to climate change (See Chapter 2). These events, characterised by consecutive hot days and nights, are associated with heat-related mortality (Akompab *et al*. 2013a; b). The impact of climate change on vector-borne pathogens such as dengue is still unclear, however, it is likely that the spread of some pathogens will likely increase across the wet tropics, while others may decrease (See Chapter 3). Diseases associated with contaminated water supplies due to major flood events are likely to increase (Altizer *et al*. 2013). The impact of disease will exacerbate other social impacts triggered by crop failure, damage to equipment, damage to transport infrastructure and contamination of water supplies caused by flooding (See Chapter 5).

Family impacts are likely to be associated with climate changes that decrease the viability of the land, making primary production a less enticing venture for younger family members and women.

Rural and regional parts of Australia have consistently faced the challenges of small-scale agriculture as a basis for family farms and livelihoods, climate variability and an increasingly globalising economic environment (Hogan and Young 2013). The combined effect has been rural decline that has corresponded with a shift in policy towards the economic self-sufficiency of communities.

Consequently, younger members of rural families have tended to migrate to larger regional centres or main cities for higher education and career opportunities. Educated women in particular are less likely to return to the land to continue in 'taken-for-granted labour' (Alston 2006). Women are more likely to be accorded secondary status despite their contributions to the economic and social survival of farm families, whereas a career in a large regional or coastal centre is more attractive (Alston 2006). With the onset of climate changes, the impacts likely to be experienced by families within the region include further reductions in labour (familial and external) and problems with succession planning.

Unemployment and employment transience within rural sectors may result from climate changes that threaten the viability of primary industries and producers.

Producers living and working in resource dependent communities often have limited experience in other occupations (Krannich and Zollinger 1997). As a result, they often lack transferable skills and, consequently, become 'locked' into their occupation (Bohnet *et al.* 2011; Freudenberg 1992). Producers who are older, have little education or are uninterested in working elsewhere are likely to be especially sensitive to changes such as climate change since they are usually least equipped to take advantage of other employment opportunities (Allison and Hobbs 2004). Useful proxies for employability include age, education, level of transferrable skills sets and attitude to working elsewhere (e.g. Bohnet *et al*. 2011).

Persistence of rural communities despite limited viability.

Attachment to place is a concept that describes the level of connection that individuals have with their physical community. It concerns the identity created around locality geographic area, the sense of pride associated with belonging to a particular place, the friendships and networks that exist within it, and/or connections to ancestors from that place (Gustafson 2001). Attachment to a place can often lead to producers preferring the stability associated with remaining in the one community, rather than moving locations, and this can increase their dependency on the natural resource (Stedman 1999) and decrease their capacity to effectively respond to climate change (Marshall *et al.* 2011). More severe climate events such as drought, floods and more intense cyclones may render primary industries untenable (See Chapter 6), yet the level of attachment to place that primary producers may possess can allow communities to persist, even if they are no longer productive.

A tendency towards larger, corporate-style production enterprises rather than lifestyle-based enterprises, affecting the cultural basis of rural regions.

The business skills that producers possess can be good indicators of their competitive advantage within a resource-based industry and their level of transferable skills outside of the industry (Marshall, 2011). Typically, the extent of business skills that an individual primary producer has is correlated with the size of business that they operate (Allison and Hobbs, 2004). Generally, larger businesses are more likely to buffer themselves from unpredictable problems such as mechanical breakdowns, difficulties with employees and climactic fluctuations since they can take bigger risks and experiment with their options for the future. Business owners with larger operations are more likely to be strategic, have the capacity to motivate, plan, organise and act, and are more likely to be driven by economic incentives to harvest the resource. Capital investments, however, can limit flexibility and stifle innovation (Bohnet, 2008) particularly in the face of extreme events such as cyclones and flooding (Marshall *et al*. 2013).

It is, however, equally important to consider a significant level of land abandonment following major events, with previously productive farms or land areas being abandoned. This change has major natural resource management implications, but also presents opportunities for good NRM. There is no published work regarding this issue and it warrants further investigation. Anecdotal information suggests that it is a significant issue in the post Larry/Yasi landscape.

Economic impacts are likely to be severe but could bring opportunities.

Economic impacts are inevitable in most cases and are likely to be severe in extreme years. In particular, a high frequency of extreme events can bring particular sectors or production areas (e.g. tree crops, particular mill districts or banana growing districts) to the edge of viability. Economic impacts can be incurred through two main avenues, i) direct damage to resources and infrastructure associated with cyclones and floods, and ii) loss of production and long-term ecological values through drought, fire, flood and associated environmental degradation.

The impacts of floods and cyclones in recent years have reduced the economic viability of primary producers. For example, within the local commercial fishing industry many Reef fishers indicated that they experienced economic hardship for several months after Cyclone Yasi (Marshall *et al.* 2013c). In all cases, financial stress can result in a suite of social impacts from mental health issues to divorce and breakdown of relationships (Smith *et al.* 2003). Tracey (1995) in her study of the logging industry in New South Wales found that financial stress combined with the uncertainty over the future of livelihoods put significant stress on families. This was especially true for those who had large debts and where the family home was used for collateral on bank loans. Many were suffering from stress-related health problems and were on medication such as anti-depressants and sleeping pills, while others drank alcohol more heavily than before. Other symptoms of stress included increased frequency of arguments among many couples (Tracey 1995).

There are also possible economic opportunities for local primary producers in some instances (See Chapter 6). For example, some barramundi fishers and some prawn trawler operators spoke of a 'bumper season' following the extremely wet weather of 2010-2011 (Gooch *et al*. 2012). Other potentially positive effects of changing weather have been noted by fishers on the Sunshine Coast, just north of Brisbane, who frequently report catches of coral trout, previously restricted to the warm tropical waters of the Great Barrier Reef (GBRMPA 2012).

Important positive outcomes of extreme weather are opportunities for community renewal, social networking and capacity-building. For example, after the extreme weather events of 2010-2011, individuals worked together to restore private and public property in several coastal towns across Queensland. This created new social bonds, galvanised community spirit, and helped heal trauma associated with the events. For some individuals, the reconstruction activities helped boost their personal income for a short period, as their particular skills were in short supply (Gooch *et al*. 2012).

Impacts of floods, extensive bushfires, droughts and cyclones are experienced by primary producers for months or even years after the events.

Extensive damage occurred to Queensland's infrastructure during the summer of 2010-2011 when the State experienced high levels of flooding and was exposed to several cyclones, including Tropical Cyclone Anthony and Severe Tropical Cyclone Yasi. The wild weather resulted in widespread damage to road and rail networks, together with eleven port closures and four airport closures. As a result, farmers and commercial fishers faced difficulties in getting their produce to market, for some time after the events. As well, power black-outs resulted in loss of produce due to lack of refrigeration. Commercial fishers in the Cassowary Coast area spent months repairing damage to private property including houses, boats and other fishing equipment, and were disadvantaged by damage to public infrastructure including roads, jetties and boat ramps. Some were without power for over two months (Gooch *et al.* 2012).

A survey of 145 commercial fishers after Severe Tropical Cyclone Yasi crossed the coast at Mission Beach in 2011 showed the most significant impacts across the industry were the three to four months of lost operations after the extreme weather. Many fishers were unable to fish because of the large amounts of debris and sediment remaining in the water and the reduced catchability of some Reef-associated target species (Marshall *et al.* 2013c).

On-going poor weather, damage to property and infrastructure for several months after the event left many Reef-based fishers feeling uncertain about their capacity to fully recover, as they had only just recovered from Cyclone Larry in 2006 (Gooch *et al.* 2012).

Summary and conclusions

Climate change is likely to have a profound impact upon the social and cultural lives of the primary producers and industries of the Wet Tropics cluster region. The most significant changes are likely to be associated with extreme events in which the condition (quality or quantity) of the natural resource is affected and productivity is lowered. Other impacts may be associated with secondary impacts through economic volatility, infrastructure damage, increasing costs and increased problems associated with pests and weeds, disease and fire risk (see chapter on economic impacts).

Large changes in resource condition threatens the viability of agricultural and fishing businesses. Because of the dependency that primary producers have on the natural resource, impacts are likely to include psychological impacts, family impacts, cultural impacts and economic impacts. Unemployment and rural decline are likely community impacts. Some economic opportunities as a result of changes in resource condition or employment in repairing the region may be experienced.

Overall, climate adaptation planners within the Wet Tropic cluster will need to be aware of the likely impacts associated with climate change, however, while resource dependency (or sensitivity to change) may describe the likely impacts of climate change, adaptive capacity can be a major influence on what impacts actually eventuate (Marshall *et al*. 2012). Recognising and enhancing adaptive capacity becomes increasingly important for resource-dependent industries facing significant climate change.

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Chapter 8: Indigenous peoples: climate change impacts and issues

Rosemary Hill and Pethie Lyons

Executive summary

Australian Indigenous peoples' culture, history and geography underpin simultaneous high resilience and high vulnerability to climate change impacts. The key messages associated with each topic addressed in this chapter are listed below:

Indigenous knowledge and climate change	1. Australian Indigenous peoples' culture, history and geography underpin simultaneous high resilience and high vulnerability to climate change impacts. 2. Supporting Indigenous peoples to document and share their Indigenous knowledge is a necessary first step to the bigger challenge of engaging with Indigenous processes of knowing about environmental change. 3. Indigenous-led innovations in multimedia platforms for environmental and cultural knowledge systems offer good prospects for documenting climate change impacts. 4. Indigenous peoples' management and observations of their environment accumulated over time can contribute to overall understanding of climate change. 5. Local environments have recently become less predictable and readable for some groups, impacting their livelihood. 6. Indigenous groups frame and perceive climate change based on their unique world view and socio-economic context while also engaging with western science and societies.
Indigenous communities and climate change	7. Liveability in Indigenous communities is likely to worsen. The existing poor state of infrastructure in Indigenous communities such as housing, water, energy, sewerage, and roads is likely to further deteriorate. Attracting educators, health workers and other skilled people to work in Indigenous communities is likely to become harder. 8. Indigenous health and wellbeing is likely to be adversely affected by climate change. Chronic health disabilities, including asthma, cardiovascular illness and infections, are likely to be exacerbated by climate conditions (particularly through heat stress); extended distributions and prevalence of several vector-, water-, food- and air-borne diseases; and by declining access to health services. 9. Indigenous engagement in natural resource management for climate adaptation, mitigation and other outcomes is likely to improve health and wellbeing.

	10. Indigenous peoples in remote (and some regional) contexts face a double disadvantage burden of high prices and low incomes that is likely to be exacerbated as climate extremes pressure transport infrastructure, costs and availability of bush foods and resources. 11. Climate change intersects with and is likely to exacerbate significant social-economic-institutional barriers to sustainable development in remote/regional Indigenous economies. 12. Climate change potentially offers new economic opportunities for Indigenous communities, for example in energy production, carbon sequestration and GHG abatement, co-benefits and aquaculture.
Cultural practices and climate change	13. Indigenous peoples' cultural practices, including customary harvesting, rely on access to a range of resources that are likely to be impacted negatively by climate-induced changes, including cyclones, storm surge, sea level rise, changed water availability, changes to vegetation patterns and reduction in species availability. 14. Indigenous peoples' fire management practices are likely to be negatively impacted by climate change, for example through damage from frequent bush fires and phase shifts in vegetation patterns. 15. Indigenous peoples need to have access to land and sea country to maintain cultural practices and associated Indigenous knowledge, and have the opportunities to respond to climate variability and change.

Introduction

Indigenous peoples in Australia engage in Natural Resource Management (NRM), widely referred to as 'caring for country', through diverse activities that have their origins in holistic relationships with their customary land and sea estates (or 'country') that have evolved over at least 50,000 years (Hill *et al.* 2013; State of the Environment Committee 2011). Indigenous peoples are experiencing multiple natural phenomena associated with climate change impacts on their country, including extreme weather events, climate variability, natural hazards and sea level change (Green *et al.* 2010; McIntyre-Tamwoy *et al.* 2013). Nevertheless, climate change is not the immediate concern for many Indigenous peoples whose lives are impacted by other environmental, health and social issues, or native title processes, that have more immediate consequences (Green *et al.* 2009a; McIntyre-Tamwoy *et al.* 2013; Nuttall 2007; Toussaint 2008). On the other hand, the Torres Strait is an example where the impacts of climate change and increasing weather variability are visible and directly experienced requiring immediate attention (TSRA 2011a; b; 2012). On mainland far northern Cape York Indigenous groups are fearful of in-migration of climate refugees and government relocation programs for Torres Strait Islanders onto traditional lands (Green and Raygorodetsky 2010; McIntyre-Tamwoy *et al.* 2013; O'Neill *et al.* 2012). Work undertaken with Indigenous groups needs to recognise this diversity of contexts that influence climate change impacts and issues (Green *et al.* 2009a).

The unique cultural connections that Indigenous peoples have to country, and associated systems of kinship and customary law underpinned by Indigenous knowledge systems, are recognised as important sources of resilience to the impacts of climate change (Green *et al.* 2010). Nevertheless, Indigenous Australians have also been identified as highly vulnerable to negative impacts from climate change which compound over-arching issues of socio-economic disadvantage, chronic poor health, and the burdens of the colonial history of dispossession and hostile policy settings (Howitt *et al.* 2012; Veland *et al.* 2013). Globally, many Indigenous peoples live in 'isolated, fragile, and harsh environments' areas that will be particularly "vulnerable to environmental change due to their latitude, topography, distance from the sea, soil's quality" (Macchi *et al.* 2008, p.21).

A systems approach that recognises both high vulnerability and high resilience as alternate feedback loops can help resolve this apparent paradox and provide an effective basis for understanding adaptation and building adaptive capacity (Maru *et al.* in review 2013) . Figure 1 presents a schematic of such a vulnerability-resilience approach, which highlights how unique characteristics of Indigenous societies mediate their adaptive capacity and therefore the impacts and issues associated with climate change perturbations.

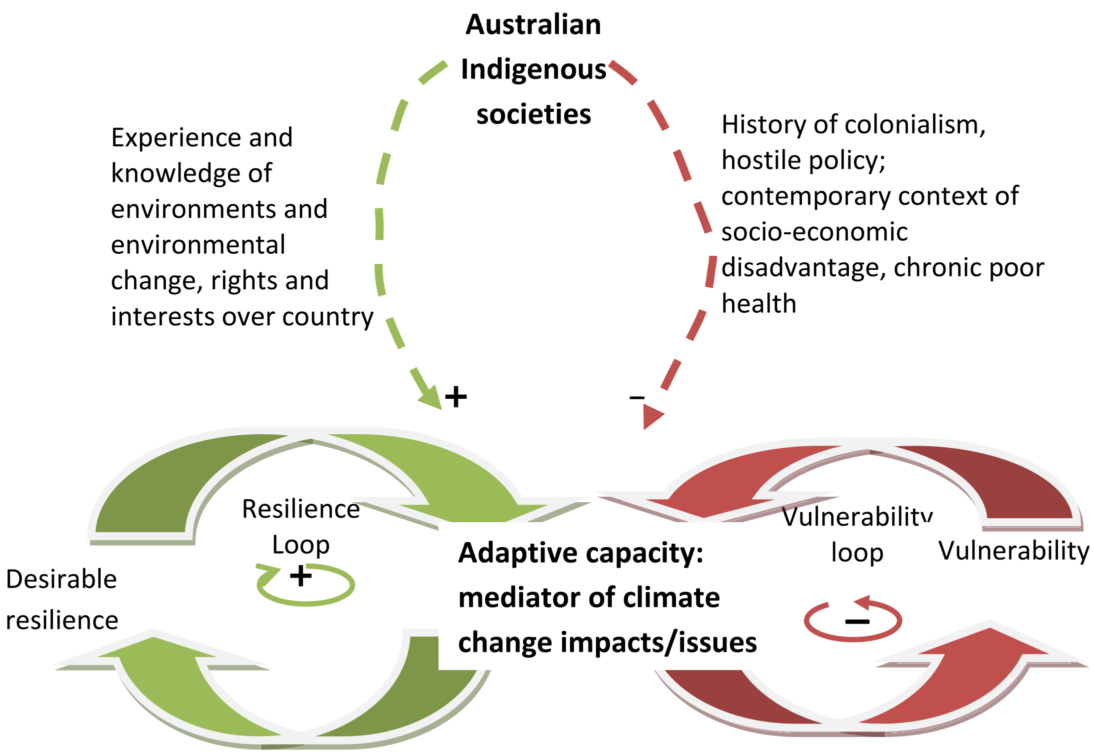

Figure 1. Australian Indigenous societies and vulnerability-resilience to climate change. Adapted from Maru et al. 2013

Australian Indigenous peoples' culture, history and geography underpin simultaneous high resilience and high vulnerability to climate change impacts.

This resilience is sourced through accumulated knowledge, practices, experiences and customary institutions attuned to particular environments and environmental change. Historical vulnerability results from colonial disruption, political marginalisation, socio-economic disadvantage and associated poor chronic poor health. Geographical vulnerability results from Indigenous peoples frequently being the majority of human populations in harsh environments that are susceptible to high impact due to latitude, topography, aridity, distance from or proximity to sea and other factors.

This model underpins the need for a chapter targeted to Indigenous peoples in this synthesis report. The chapter focuses on three topics where particular characteristics of Indigenous societies warrant separate consideration of the climate change impacts and issues under three topics:

- Indigenous knowledge and climate change
- Indigenous communities and climate change
- Indigenous cultural practices and climate change.

Indigenous knowledge and climate change

Supporting Indigenous peoples' documentation of knowledge

Supporting Indigenous peoples to document and share their Indigenous knowledge is a necessary first step to the bigger challenge of engaging with Indigenous processes of knowing about environmental change.

Indigenous-led innovations in multimedia platforms for environmental and cultural knowledge systems offer good prospects for documenting climate change impacts.

Indigenous knowledge systems are widely recognised as reservoirs of experience and practice that can provide important insights for the design of adaptation and mitigation strategies to cope with global environmental change (Gómez-Baggethun *et al.* 2013; See forthcoming Adaptation Pathways and Options Report). Connections between ownership of knowledge and ownership of country in Australian Indigenous societies triggers significant responsibilities for maintaining control of knowledge (Rose 1996). While erosion and loss of Indigenous knowledge is a key concern for many Indigenous peoples, protection of cultural and intellectual property rights takes priority in any consideration of processes for documentation to strengthen knowledge (Holcombe 2009; Janke 2009). Indigenous-driven knowledge-recording programs ensure adherence to values and cultural integrity in knowledge transfer (Green and Raygorodetsky 2010; Lefale 2010; NCCARF 2012; O'Neill *et al.* 2012). Areas of concern to traditional owners and remote Indigenous communities should be prioritised in such programs (NAILSMA 2010). Resourcing programs to strengthen Indigenous knowledge will be particularly important where it is the only source of historic climate information; this is particularly the case for local scale knowledge on ecosystem change and where alternative perspectives on sustainable development can be explored (Berkes 2008; Berkes 2009; NAILSMA 2010). These initiatives can strengthen the capacity of groups to express their concerns and engage with the scientific community (NAILSMA 2010).

Many Australian Indigenous groups are using multi-media platforms to record their environmental and cultural knowledge as well as promote their work on country (see websites NAILSMA, Mandingalbay Yidinji Corporation, Yawuru Aboriginal Corporation, Yorta Yorta National Aboriginal

Corporation). These initiatives reflect a common trend globally towards hybridization, where traditional knowledge, practices, and beliefs are merged with novel forms of knowledge and technologies to create new knowledge systems (Gómez-Baggethun *et al.* 2013). Boundary objects such as multi-media platforms play a key role in mediating interactions between scientific and Indigenous knowledge (IK) systems to negotiated bi-cultural management of social-ecological systems (Robinson and Wallington 2012). The Yorta Yorta group uses a knowledge recording and storage framework based on a GIS database that can store stories, images and sound. The cultural knowledge repository is a key resource in building the skills of the youth and recording knowledge of country. I-Tracker, acronym for 'Indigenous Tracker', uses state-of-the-art technology to advance land management practice with north Australia Indigenous communities by enabling land managers 'to record, analyse and map their own data' on country. The development of the I-Tracker application involved deep engagement with Indigenous land managers ensuring their objectives were met and that the science behind its use is rigorous (NAILSMA 2012).

The Bureau of Meteorology web-based Indigenous Weather Knowledge project has made nine seasonal calendars available online. The UNSW Sharing Knowledge project explores the link between health and climate in Indigenous communities. This work includes filming of Traditional Owners and elders talking about change on their country. Web-based information systems such as North Australian Fire Information (NAFI) are also being usefully incorporated into Indigenous land management practice. The website supports strategic fire management planning and monitoring, enabling users to locate recently burnt fires daily. The site has been described as "the single most important improvement in fire management technology in the NT in the past 10 years" (North Australian Fire Information http://savanna.cdu.edu.au/savanna_web/information/downloads/NAFI-Doco.pdf accessed 26 Nov 2013). Maps are a powerful translation tool for Indigenous people to present their land management practice, change in land condition as well as targeted cultural programs (Griggs *et al.* 2013).

Together these diverse initiatives under Indigenous governance offer good prospects for documenting climate change in ways that respect and reinforce the intellectual and cultural property rights of Indigenous peoples (Hill *et al.* 2012).

Indigenous knowledge about climate and climate change

Indigenous peoples' management and observations of their environment accumulated over time can contribute to overall understanding of climate change.

Local environments have recently become less predictable and readable for some groups, impacting their livelihood.

Australia's Indigenous peoples have a long history of observing climate change. Green *et al*. (2009a, p.105) writes the "Coastal Aboriginal people of the Northern Territory are amongst the first of the world's inhabitants to make observations about, and be affected by climate change". The Maningrida people's description of their country, of sea-level rise over thousands of years, align with geomorphology studies (Green *et al.* 2009a).

Indigenous people living on country use signs and signals from their physical environment, such as changing seasons, abundance of animals, unusual patterns and extremes, condition and quality of animals, to read and predict change in their country (Berkes 2008; Berkes 2009; Berkes *et al.* 2007; Green *et al.* 2009a; Herman-Mercer *et al.* 2011; Lebel 2013). Climate sensitive Indigenous bio-indicators offer a potential contribution of local knowledge to climate change discussions (Green *et al.* 2010; Lebel 2013). Significantly, they are also linked to the cultural and subsistence indicators and practice for those Indigenous groups (Green *et al.* 2010; Lefale 2010).

Reports from Indigenous groups across the world are voicing increasing incidents and accounts of changing environmental patterns that are impacting on their livelihoods (Berkes 2008; Lebel 2013; Lefale 2010; McIntyre-Tamwoy *et al.* 2013; NAILSMA 2010). In northern Australia Indigenous people living on country are observing and living with changes to their environment. The Yolngu and Miriuwung – Gajerrong Peoples found their seasonal calendar less predictable as harvests times have changed, as outlined in the Box 1, below. The Yolngu people have also observed that the seasonal flowering and fruiting of the green plum with the sting ray life cycle no longer coincide and their food gathering times are a month out from their seasonal calendar (NAILSMA 2010). The Maningrida Indigenous people in the northern territory are also observing warmer seasons, especially in the winter months (Green *et al.* 2009a)

Box 1. Miriuwung – Gajerrong – East Kimberley, Western Australia (NAILSMA 2010)

The Miriuwung – Gajerrong people observed changes in the timing of a bird call and the fruiting of the green plum (Daloong), incidents that usually coincide. They also found that the black plum, Mejerren, fruited a month early, but without harvest. Hunting season for the Miriuwung – Gajerrong people is also occurring a month out from the usual appearance of prey. The traditional owners observed that the arrival of the last of the wet season's heavy rain occurred a month later.

In the Wet Tropics Cluster Region several studies highlight changed seasonal patterns, the people of Injinoo linked climate change to new observations of increased incidence of soft-shelled crayfish, "green jelly" on rocks and beaches, and warmer waters where divers are going deeper to reach fish in cool waters (McIntyre-Tamwoy *et al.* 2013). Increasing storm surge activity has also resulted in loss of coastal camping spots for the Injinoo people. In Kowanyama community leaders are discussing the need to understand changes they are observing on their country and expressed interest to gain access to future climate projections for their region (Green *et al.* 2009a). Kuku-Yalanji people in south-east Cape York Peninsula use plants and animals seasonal indicators to manage changes to fire practices, carbohydrate and other resources (Hill and Baird 2003; Hill *et al.* 2004; Hill *et al.* 1999; NAILSMA 2010). Girringun community report plants fruiting and flowering out of season (McIntyre-Tamwoy *et al.* 2013). Torres Strait community observed changes in the population and location of totem marine animals as well as increased erosion activity that is impacting culturally significant sites (O'Neill *et al.* 2012).

While there is increasing support and interest for Indigenous peoples, industry, government and science to engage in processes to use and build on their relevant knowledge base to improve overall understanding of climate change and its impacts, recognition of the potential contribution of Indigenous knowledge to environmental management in Australia has been slow (Berkes 2008; Green *et al.* 2010; McIntyre-Tamwoy *et al.* 2013; NAILSMA 2010).

Indigenous world views and interactions with western science

Indigenous groups frame and perceive climate change based on their unique world view and socio-economic context while also engaging with western science and societies.

Indigenous observations and perspectives of their local environment are defined by their worldview, values and culture, and institutions which form the basis of their relationship to their environment (Berkes 2008; Green *et al.* 2009a; Petheram *et al.* 2010). The uniqueness of the Indigenous perspective is the connection and association of the land and sea country to the spirits of creation, the deceased and to those in the present time (Green *et al.* 2012).

Indigenous knowledge and observations of environmental change do not make a distinction between biological, physical and human variables (Berkes 2008; Boillat *et al.* 2013; Green *et al.* 2010; Houde 2007; Leonard *et al.* 2013). Change can be attributed to other activities on country, such as colonialism, mining and people breaking customary law/Lore (Green *et al.* 2012; Leonard *et al.* 2013; Petheram *et al.* 2010). The Yakanarra people in the Kimberley region "interpret unusual (i.e., extreme) weather events (hazards) as a result of a lapse or wrongdoing in their relationship with ancestral beings – it is a form of disharmony... Extreme weather events and degradation of the land and waters signify a rupture in this relationship which is often attributed to the actions, or neglect, of a particular individual or group" Green *et al*. (2009a, p.105). This perspective will bring some difficult issues to bear for these Indigenous groups when changes in human practice do not bring about the environmental change sought (Green *et al.* 2009a; Green *et al.* 2012).

From the Indigenous perspective, the environment has its own agency and capacity to respond to human action in a reciprocal relationship where actions in accordance with customary lore can bring balance back with the environment (Berkes 2008; Boillat *et al.* 2013; Cruikshank 2001; Houde 2007; McIntyre-Tamwoy *et al.* 2013; O'Neill *et al.* 2012). This worldview supports the belief that the health of the people and their country is deeply connected (NAILSMA 2010). Consequently, the Indigenous sense of obligation and reciprocal relationship to country will have a psychosocial health impact as climate change takes greater effect (Green *et al.* 2009a; O'Neill *et al.* 2012).

Uncertainty about climate change is a significant issue in Indigenous communities. Studies across Indigenous groups demonstrate diverse levels of understanding, perspectives and capacities to respond to and manage the impacts of climate change (Cruikshank 2001; Lebel 2013; McIntyre-Tamwoy *et al.* 2013; NAILSMA 2010). In the Northern Territory the Kakadu community is thought to have a generally higher understanding of climate change relative to others (Green *et al.* 2009a). Scientific information and further research about climate change is a priority for Indigenous peoples across the Wet Tropics region (Hill *et al.* 2011). This would require mindful engagement where there are considerable cross cultural and paradigm differences between western and Indigenous knowledge (Green *et al.* 2010). The complexity of discourse by governments and scientists on climate change is distancing community groups. In Kowanyama the issue of climate change is called "whitefulla mumbo jumbo" because of the perceived complexity of science and government debates on the topic (Green *et al*. 2010).

Indigenous communities and climate change

Climate change impacts and issues for liveability

Liveability in Indigenous communities is likely to worsen. The existing poor state of infrastructure in Indigenous communities such as housing, water, energy, sewerage, and roads is likely to further deteriorate. Attracting educators, health workers and other skilled people to work in Indigenous communities is likely to become harder.

For Indigenous peoples in regional and remote Australia, likely increases in intensity and/or frequency of extreme events including cyclones, intense rainfall, droughts and heatwaves will impact heavily on infrastructure (Maru *et al.* 2012a; See Chapter 5). Damage to transport infrastructure increases disruption to the provision of goods and services and increases the rates of depreciation of transport and other basic settlement infrastructure. Remoteness, and limited alternative routes, may result in significant delays and failures of emergency, rescue and relief efforts. Food supplies rely on a long chain of access from external sources that is disrupted by extreme events (Petheram *et al.* 2013). Such increased hardships reduce the attractiveness of Indigenous communities to educators, health workers, other professionals and businesses (Maru *et al.* 2012a).

Few studies focus directly on liveability impacts and issues in the Wet Tropics NRM Cluster (WTC). A case study with Wujal Wujal Aboriginal community in south-east Cape York identified a likelihood of further out-migration of people in response to climate extremes (Bird *et al.* 2013). Case studies in the Gilbert River district of western Queensland have shown that Aboriginal people spend more time indoors, living in houses, looking after children, in employment, such as office work compared to 1960s when people had very basic housing and were commonly living outdoors in hunting and gathering and droving lifestyles(Memmott *et al.* 2013) . This change of practices in turn exacerbates the negative impacts of poor infrastructure—staying inside on hot days requires air-conditioning, which may overload electricity systems already struggling to supply sufficient power for cooking, washing, lighting and appliances (Horne *et al.* 2013)

Uncertainty in this context is understood as a measure of confidence in the validity of a finding, based on the type, amount, quality, and consistency of evidence (Mastrandrea *et al.* 2010). While there is limited research specifically with Indigenous peoples and communities including in remote, regional, peri-urban settings, the agreement about likely negative impacts on liveability is high (Low-Choy *et al.* 2013; Maru *et al.* 2012a).

Climate change impacts and issues for health

Indigenous health and wellbeing is likely to be adversely affected by climate change. Chronic health disabilities, including asthma, cardiovascular illness and infections, are likely to be exacerbated by climate conditions (particularly through heat stress); extended distributions and prevalence of several vector-, water-, food- and air-borne diseases; and by declining access to health services.

Indigenous engagement in natural resource management for climate adaptation, mitigation and other outcomes is likely to improve health and wellbeing.

Indigenous people in Australia face chronic health disabilities including, for example, being three times more likely than non-Indigenous people to suffer asthma and diabetes, and more than twice as likely to attempt self-harm (Australian Bureau of Statistics 2013; MacRae *et al.* 2013). Many enduring problems are recognised as being associated with poor nutrition, overcrowded housing, lack of good water and sewerage systems, poor hygiene as well as psycho-social stress from a history of dispossession, breakdown of traditional family relationships, loss of capacity to care for traditional lands, and life histories complicated by domestic violence (Green *et al.* 2009a; Green *et al.* 2009b; Memmott *et al.* 2013). Other risk factors include rates of tobacco smoking, illicit substance abuse, obesity, and low exercise levels in urban settings (Australian Bureau of Statistics 2013). A recent study in the Northern Territory concluded that approximately 25-30% of the Indigenous health disparity may be explained by socioeconomic disadvantage (Zhao *et al*. 2013).

The northern Australia scoping study (Green *et al.* 2009a; Green *et al.* 2009b) identified that climate change is likely to bring elevated heat stress and consequential higher rates of skin and gastrointestinal infections and conditions that increase risks of asthma, cardio-vascular and transferable diseases such as melioidosis (See also human diseases in Chapter 3). In northern Australia, more than three quarters of communities travel over 100 kilometres to access hospital; 147 of 1035 communities reported having access to an airstrip. Climate-induced disruptions to transport will lower accessibility of already inadequate health services (See Chapter 5). Indirect impacts such as reduction in bush food yields and disruption to fisheries may also cause negative impacts (See Chapter 3).

Indigenous engagement in land and natural resource management and climate change adaptation has been identified to have significant positive impacts on diabetes and cardiovascular diseases (Berry *et al.* 2010; Burgess *et al.* 2009). Systematic review of the evidence has found psycho-social factors as key moderators of this positive impact, alongside changes in diet, nutrition and physical activity (Davies *et al.* 2011). These identified psycho-social factors have direct impacts through changing the biochemistry of stress, and through people developing a greater sense of mastery over their lives. Inequities in mental health between Indigenous and non-Indigenous Australians are currently very high throughout all life stages (Jorm *et al.* 2012)

Confidence in statements about status and changes in health of Indigenous Australians remains limited by data availability (MacRae *et al.* 2013; Schouten *et al.* 2013) but initiatives such as the 2012-13 national survey (Australian Bureau of Statistics 2013) and the application of systematic review techniques (Davies *et al.* 2011) are gradually improving this. However, few studies of climate impacts are specifically directed to the Wet Tropics Cluster.

Climate change impacts and issues for livelihoods

Indigenous peoples in remote (and some regional) contexts face a double disadvantage burden of high prices and low incomes that is likely to be exacerbated as climate extremes pressure transport infrastructure, costs and availability of bush foods and resources.

Climate change intersects with and is likely to exacerbate significant social-economic-institutional barriers to sustainable development in remote/regional Indigenous economies.

Climate change potentially offers new economic opportunities for Indigenous communities, for example in energy production, carbon sequestration and GHG abatement, co-benefits and aquaculture.

Indigenous people have many day to day concerns about costs of living, such as for food, power and fuel and aspirations for improved economic conditions that are seen as fundamental survival strategies for their communities (Low-Choy *et al.* 2013; Memmott *et al.* 2013). In remote and rural contexts, these concerns are exacerbated by the combined effects of high prices and low incomes (Stoeckl *et al.* 2013; See Chapter 6). Customary bush foods are important for nutrition (Jackson *et al.* 2012) and other resources are used in art, crafts generating market returns (Koenig *et al.* 2011a; Koenig *et al.* 2011b). Climate change may reduce the availability of these local resources, while at the same time preventing importation of external resources due to disruption of transport services (See Chapter 5).

Livelihood dimensions of climate change are contextualised within the challenge for Indigenous communities of both immediate risks to livelihoods and long-term challenges of sustainable development. (Bardsley and Wiseman 2012). Development in many Indigenous communities is constrained by factors such as remoteness, and low levels of human, built, financial, social and institutional capital (Taylor *et al.* 2011; See Chapter 6). Analysis of different types of development pathways to overcome these constraints in northern Australia, based on a Daly River case study, show low returns to Indigenous people result everywhere partially due to relatively weak connections to production in the market economy represented in lower rates of employment, lower average wages and lower rates of business ownership. Some of the barriers also relate to institutional arrangements that prevent Indigenous ownership of entitlements such as to water (Stoeckl *et al.* 2013). Endogenous development, based on investing in local knowledge, institutions and place-based services like carbon farming (See Chapter 4) may offer a better development path for Indigenous peoples in this context (Stoeckl *et al.* 2013; Taylor *et al.* 2011)

Greenhouse gas mitigation can enhance some existing, and provide new livelihood and enterprise opportunities through management of land, soil, fire, feral animals and weeds enabling people to build on their knowledge, skills and customary practices of caring for country, thereby providing an expanded opportunity to be and do what they value (Maru *et al.* 2012a; See Chapter 4). Current efforts on ranger programs and work by West Arnhem Land Fire Abatement (WALFA) and Centrefarm to engage with carbon economies are encouraging examples. Scaled-up renewable energy production and transmission from remote Australia could provide significant opportunity for employment, livelihoods and development in remote Australia. Supporting aquaculture development on Goulburn Island has been identified as beneficial to both adaptation and livelihood options through enhancing collection and local consumption of bushfoods. However, logistics of implementation will be complicated, and will need to be part of a wider set of options (Petheram *et al.* 2013). Capturing these opportunities would require research and implementation support on technical, institutional, legal, financial, cultural and behavioural barriers to production, transmission and adoption of new enterprises and opportunities.

Uncertainty about livelihoods impacts of climate change is quite high as studies of the factors that underpin entrenched Indigenous economic disadvantage are few and integrated models capable of taking account of the multiple variables at play are at an early stage of development (Maru *et al.* 2012b; Stoeckl *et al.* 2013).

Cultural practices and climate change

Indigenous peoples' cultural practices, including customary harvesting, rely on access to a range of resources that are likely to be impacted negatively by climate-induced changes, including cyclones, storm surge, sea level rise, changed water availability, changes to vegetation patterns and reduction in species availability.

Indigenous peoples' fire management practices are likely to be negatively impacted by climate change, for example through damage from frequent bush fires and phase shifts in vegetation patterns.

Indigenous peoples need to have access to land and sea country to maintain cultural practices and associated Indigenous knowledge, and have the opportunities to respond to climate variability and change.

Cyclones impact immediately and for some time afterwards on the availability of native fruits and wildlife; in the longer term there is a risk of phase-shift towards more disturbance-tolerant vegetation with associated loss of cultural values and impacts on fire practices (Turton 2008; 2012). Likely negative impacts from storm surge and sea level rise (See Chapter 2) include reduction in bush tucker and bush resources from erosion, salt-water intrusion and flooding (Bird *et al.* 2013). Likely changes to quality, availability and localised excesses or depletion of water will impact on culturally-significant sites including mound springs, water holes, and story places, and resources that depend on seasonal water supplies such as turtles (Jackson *et al.* 2012; Nursey-Bray *et al.* 2013). Likely impacts of climate-change related changes to vegetation patterns include reductions in quantities and access to bush tucker, bush medicine, and resources used for particular practices such as bark for painting, and grasses for weaving (Bird *et al.* 2013; (McIntyre-Tamwoy *et al.* 2013). Climate change appears to have already impacted on timing and conditions of hunting and gathering, and the availability of and access to cultural keystone species e.g. through increased incidence of soft-shelled crayfish, and changing hibernation patterns of goannas ((McIntyre-Tamwoy *et al.* 2013; Memmott *et al.* 2013). Climate change is likely to impact on Indigenous fire practices that are highly attuned to seasonal indicators (Hill and Baird 2003; Hill *et al.* 2004; Hill *et al.* 1999).

Connections between ownership of knowledge and ownership of country in Australian Indigenous societies triggers significant responsibilities for maintaining control of knowledge, and for ensuring its transmission occurs in the right context (Hill *et al.* 2012; Rose 1996). Some knowledge can only be transmitted on particular places; getting out on country with people is recognised as opening up knowledge-sharing and educational activities (Hill 2011). Climate related Indigenous knowledge is most strongly held by the older generation, where this *knowledge is related to and understood relative to the elders' roles and activities on their country* (Anik and Khan 2012; Berkes 2008). Access to country that supports deep engagement of youth and elders in recording and sharing ecological and cultural knowledge is an important foundation for developing community understanding of climate change (Griggs *et al.* 2013).

The level of confidence in findings about impacts on important cultural resources is low as few studies (among them Jackson *et al.* 2012; McIntyre-Tamwoy *et al.* 2013; Nursey-Bray *et al.* 2013) address the particular elements of the environment that are important for Indigenous peoples. Confidence in the importance of access to land and sea country is high and supported by many studies (Hill *et al.* 2013).

Summary and conclusions

Australian Indigenous peoples have distinctive sources of both resilience and vulnerability to the impacts of climate change—resilience based on their unique knowledge, cultural practices and customary institutions, and vulnerability from their socio-economic and historical disadvantage. This vulnerability is heightened for some Indigenous due to their remoteness and the inhospitable and the fragile environments they occupy. Addressing climate change impacts and issues with Indigenous groups will necessarily engage the influence of colonial history on the present, the urgent socio-economic needs of contemporary communities and their aspirations for a better future.

Indigenous ecological knowledge is important to strengthen understanding of climate change and provide the foundation for Indigenous adaptation strategies. Indigenous-driven knowledge recording that protects intellectual and cultural property rights is a key first step toward supporting Indigenous solutions for country. Many Indigenous groups are driving the development of innovative knowledge-recording approaches that reflect a trend towards hybridization, where traditional knowledge, practices, and beliefs are merged with novel technologies to create new knowledge systems that can negotiate interactions between scientific and Indigenous knowledge systems for bi-cultural adaptation strategies.

Climate change will exacerbate current conditions of hardship experienced by Indigenous communities living on country. At the forefront are infrastructure related impacts on access to healthcare, fresh food, water and sanitation, and economic opportunities. Changed climate conditions such as heat waves will also exacerbate chronic health problems including asthma, diabetes, cardio-vascular and transferrable diseases.

The impact of climate change will vary across Indigenous groups. Potentially climate change will introduce new opportunities for participation in local greenhouse gas mitigation projects such as carbon farming and pest and weed management. Others may find decreasing availability of resources such as bush tucker or ingredient materials for local economic enterprise. Indigenous engagement in natural resource management improves health and well-being outcomes, strengthening the argument for Indigenous management of country as a key part of NRM climate change adaptation. However, limited research has addressed consequences of changing climate for Indigenous societies, limiting the confidence in our understanding of the likely impacts on the physical, emotional, psycho-social and spiritual well-being of Indigenous communities.

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Chapter 9: Adaptation science relevant to natural resource management practice

Iris C. Bohnet, Allan Dale, Margaret Gooch, Nadine A. Marshall and Matt Curnock

Executive summary

This chapter provides a synthesis of key concepts and definitions related to adaptation planning for climate change. It does not include adaptation options or pathways for specific sectors or individuals; that information will be developed and presented in a separate report.

Key messages associated with the topics addressed in this chapter are listed below:

Preparing for and adapting to change	1. While the future will always be uncertain, the need for adaptation from local to regional scales is vital. 2. Understanding the likely interactions between proposed adaptation options is critical to assess their strengths and weaknesses, prevent undesirable outcomes and to inform development of integrative policies. 3. Societies are increasingly vulnerable to the impacts of climate change, due to reasons other than climate change. 4. Effective adaptation to climate change requires sufficient adaptive capacity across scales.
Adaptation approaches	5. Adaptation approaches need cross-sectoral strategies that fit into a broader framework of regional sustainable development and address the entire cascade of climate change impacts to avoid unintended negative side effects. 6. Adaptation to climate change is highly context-specific as it depends on the specific environmental, social, economic, cultural and political conditions in the target region or sector.
Adaptation planning	7. Adaptation planning requires close collaboration of scientists, practitioners, managers, decision-makers, policy analysts and the people likely to experience climate change impacts. 8. Participatory scenario planning is a method and process allowing identification, deliberation and agreement on ‘no regrets’ or ‘low regrets’ strategies and programs.

Introduction

Climate change poses significant risks to people and the environment (See Chapters 3-8). Informing policy and on-ground preparations needed to manage climate risks, avoid harm, and to capitalise on emerging opportunities poses a great challenge, not only for climate scientists (Moss *et al.* 2013), but also for planners and managers within the Wet Tropics Cluster (Bohnet *et al.* 2013; Lyons *et al.* 2013). Planned, proactive adaptation to climate change improves preparedness and can moderate harm, through targeted strategic actions directed towards the vulnerable systems, in response to actual or expected climate-related risks. Another fundamental societal response to reducing these risks, besides adaptation to climate change, is mitigation of climate change. Mitigation implies "limiting global climate change by reducing the emissions of greenhouse gases or enhancing their sinks" (Fussel 2007, p. 265). Although mitigation has received much greater attention in the past, by both, the scientific community and policy makers, there are good and urgent reasons for considering possible adaptation pathways (e.g. Pielke *et al.* 2007). For example, adaptation measures can be targeted and implemented at the local or regional scale, and their efficacy is less dependent on actions undertaken by others. Table 1 summaries key characteristics of climate change mitigation and adaptation.

Table 1: Characteristics of climate change mitigation and adaptation (Source: adapted from Fussel & Klein 2006; Fussel 2007).

	Mitigation of climate change	**Adaptation to climate change**
Target systems	All systems	Selected systems
Scale of effect	Global to local	Local to regional
Lifetime	Centuries	Years to centuries
Lead time	Decades	Immediate to decades
Effectiveness	Certain	Generally less certain
Monitoring	Relatively easy	More difficult

In other words, people influence the impacts of climate change in two fundamental ways. The first is mitigation: by reducing global emissions of greenhouse gasses society can deal with the root cause of the issue and limit the magnitude of human-induced global climate change (Howden *et al.* 2007). The second, and the focus of this chapter, is adaptation: by building the capacity of people to adjust climate-sensitive activities to plausible future climate scenarios, society can limit its vulnerability to the climate change that does occur (Wreford & Adger 2010). The two are linked in that the more effort that is put into mitigation, the less effort will be required for adapting to climate changes (Verchot & Cooper 2008). While strong arguments exist to stabilise greenhouse gas concentrations before the climate system passes irreversible thresholds, we can also accelerate efforts to prepare for those changes that are inevitable (Marshall *et al.* in press).

Mitigation and adaptation are not mutually exclusive responses to climate change. However, mitigation and adaptation responses can work against each other. For example, increasing air-conditioning as a local adaptation strategy to cope with increasing temperatures counteracts global efforts to mitigate climate change, if these air-conditioners are powered by fossil fuels and not alternative energy sources. On the other hand, responses can indeed be complementary and reinforce each other; for example, planting of trees to provide shade as a local adaptation response to warming *and* in a global effort to mitigate greenhouse gas emissions.

The remainder of this chapter summarises thinking on planned adaption to climate change focusing on key concepts, assessment approaches and key lessons applicable to regional NRM organisations.

Adapting to the impacts of climate change – who, what, when and how?

Despite the growing body of scientific literature on adaptation to climate change (Arnell 2010), it is not a well-defined set of activities that one can undertake to adapt to climate change. Adaptation is relevant to all systems or sectors including governance, agriculture, forestry, natural ecosystems, water and energy supply, coastal communities, public health, housing, infrastructure and tourism (e.g. Smit *et al.* 1999; Fussel 2007; Stafford Smith & Ash 2011; Taylor & McAllister 2013). Consequently, any analysis of adaptation needs to define the system or sector and the system's boundary, which relates to scale, on the one hand, and interplay between sectors, on the other.

While the future will always be uncertain, the need for adaptation from local to regional scales is vital.

This key message has been taken up among trawler operators in the Great Barrier Reef Marine Park, who are beginning to realise the importance of planning for an uncertain future. During 2011-2012, the Great Barrier Reef Marine Park Authority (GBRMPA) in collaboration with the Queensland Seafood Industry Association (QSIA), the Department of Agriculture, Fisheries and Forestry Queensland (DAFF), Queensland's Climate Change Centre of Excellence and other organisations, held a series of adaptation planning workshops for trawler operators along the coast of Queensland. Through structured discussions between managers, scientists, trawl operators, processors and marketers, the workshops identified the impacts, adaptive responses, risks and vulnerabilities associated with climate change. The recent extreme weather events in north Queensland helped participants to visualise and prepare for changes in long-term weather patterns (GBRMPA 2012).

> The workshops "were my awakening", said the QSIA's former trawl-fishing president, Geoff Tilton. "I went there probably with an empty head about climate change, (but) came away thinking you better put your thinking cap on here, this is not just a debate between people in the media … Let's have a look at some of the science, let's talk about some of the impacts, let's think about some of the things that are going to, or could possibly be going to, happen."
>
> "The science tells us changes are coming," Mr Tilton says. "While we may not be able to completely understand them now, it makes sense to prepare our businesses. And we can be good stewards of the marine environment at the same time." (GBRMPA 2012, p. 53)

While this collaborative effort is an important first step in an adaptation planning process, it does not represent tangible adaptation actions. It remains unclear how the different sectors individually or collaboratively plan for potential climate risks.

A significant adaptation action taken by individual banana farmers in the high risk coastal belt around Innisfail, for example, has been to physically acquire access to land and water in other districts to reduce the risk of total crop loss in cyclones. Another adaptation action-oriented example that links scales and sectors is, tree plantings established by farmers on their land and incentive programs provided by regional NRM organisations via state or national governments.

Figure 1 provides an example of the interplay between different scales and sectors involved in adaptation to climate change. Figure 1 also illustrates that adaptation responses driven by individual sectors or policy goals are generally overlapping with other sectors (e.g. Leitch *et al.* 2010). These overlaps may lead to potential synergies but securing these require dialogue between sectors, different districts and those researching sectoral adaptation options to ensure that adaptation in one sector does not have a negative effect on another sector.

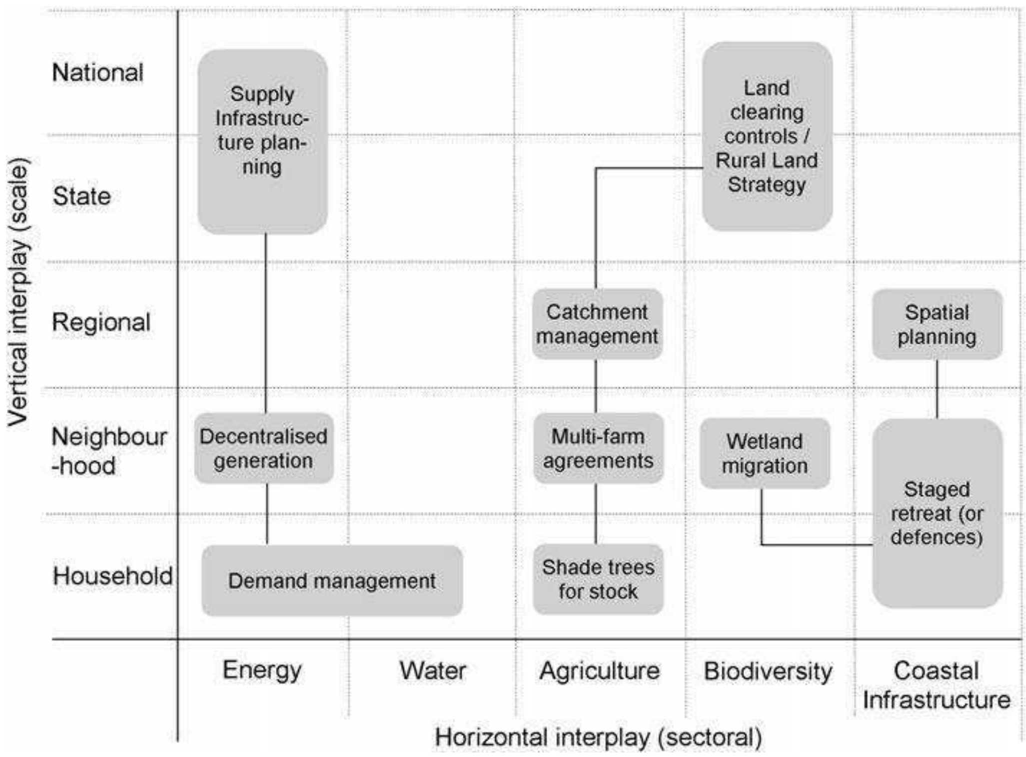

Figure 1: Example of adaptation options for a region illustrating interplay between scale and sector (Source: Taylor & McAllister 2013)

Understanding the likely interactions between proposed adaptation options is critical to assess their strengths and weaknesses, prevent undesirable outcomes and to inform development of integrative policies.

To improve our understanding and integrative thinking about adaptation, Reyer *et al.* (2012) constructed a simple conceptual model for analysing conflicts and synergies of adaptation measures

(Figure 2). Conflicts may cover interactions from 'low regrets' (Wilby & Dessai 2010) to conflicts that outweigh the expected positive effects. Identifying conflicts and low regrets options may benefit from researcher dialogue (Taylor & McAllister 2013) and from participation of the whole suite of stakeholders involved in adaptation planning (Fussel 2007). This co-creation of knowledge may improve overall integration and learning about complex environmental policy processes.

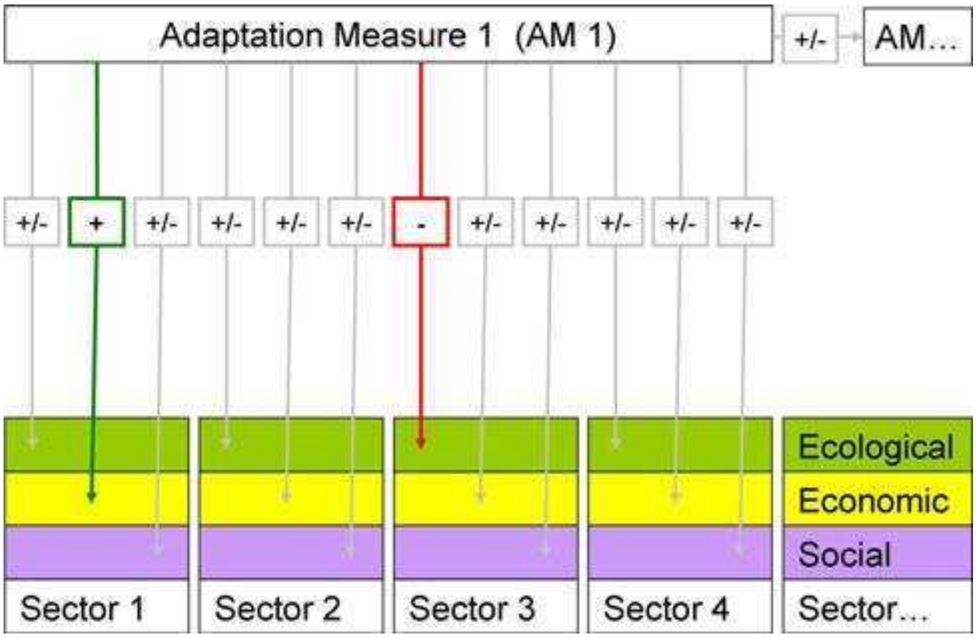

Figure 2: Conceptual model of conflicts and synergies of adaptation measures. The arrows depict possible positive or negative effects an adaptation measure may have on ecological, economic or social aspects of a sector. In the figure, the particular example of adaptation measure 1 having a positive effect on economic aspects of sector 1 (i.e., the ''wanted effect'') while having a negative effect on ecological aspects of sector 3 highlights a conflict. (Source: Reyer *et al*. 2012)

Societies are increasingly vulnerable to the impacts of climate change, due to reasons other than climate change.

Adaptation often arises from extreme events, climate hazards or other non-climate related conditions such as environmental, economic, political and cultural conditions (Marshall *et al.* 2013). Adaptation can be conceptualised as either reactive, i.e. after impacts have been experienced, or proactive, i.e. before major damage has occurred (Fussel 2007). In practice, adaptation to climate change and other non-climate conditions is a continuous process (Park *et al.* 2012). Adaptation options may include technical, institutional, legal, educational and behavioural measures (Figure 1 provides a wide range of examples) and depend on the vulnerability of the social groups and/or sectors and their adaptive capacity in a region or in the context of a linked social-ecological system.

Benchmarking of resilience, first trialled in the Wet Tropics in 2011, is demonstrating the impact that broader resilience issues have on the capacity of regions, communities, sectors and individuals to adapt to climate change (Dale *et al.* 2011).This work has now progressed into a second phase of resilience benchmarking and adaptation strategy-making across the wider Far North Queensland and Torres Strait region.

Effective adaptation to climate change requires sufficient adaptive capacity across scales.

A key challenge for industries that choose, collectively and proactively, to adapt to climate change is to ensure that sufficient capacity exists across scales (e.g. across individuals, communities, regions, nations). Adaptive capacity is a description of the potential or preconditions necessary to cope with novel situations and enable adaptation without overly losing options for the future (Brooks & Adger 2004; Nelson *et al.* 2007). It describes the capacity to convert current resources (financial, physical, human, social or natural capitals) into successful adaptation strategies (Adger *et al.* 2003). Characteristics that contribute to adaptive capacity reflect learning, the flexibility to experiment and adopt novel solutions, and the ability to respond generally to a broad range of challenges (Gunderson 2000; Olsson *et al.* 2004; Armitage 2005; Darnhofer *et al.* 2010). At the individual (resource-user) scale, adaptive capacity has been comprehensively operationalised according to four measurable attributes reflecting the individual's skills, circumstances, perceptions and willingness to change. These four dimensions are described below.

(i) *Perceptions of risk and uncertainty:* Not all individuals are equally capable of dealing with uncertainty (Knight 1927). Yet, positively managing the risks associated with change and uncertainty are fundamental aspects for coping and adapting to change. How risk is perceived and managed reflects individual and cultural differences in experiences, knowledge, beliefs, values, attitudes and judgements as well as differences in abilities to plan and execute plans (Taylor 2003; Ritchie *et al.* 2004). Some people recognise and accept that potential rewards may be highest when uncertainty is highest. A risk-averse individual, in contrast, will select strategies with more certain outcomes, even if the benefits are lower. They will tend to use imitation rather than innovation in solving environmental challenges (Kuhn 2000; Anderson 2003; Kostov & Lingard 2003; Taylor 2003).

(ii) *Skills for planning, experimenting, learning and reorganizing:* This component reflects the capacity to anticipate and prepare for the future. The capacity to plan, experiment, learn and reorganise in the face of change is dependent on novelty, creativity, sharing experiences and possessing the skills to make the most of opportunities (Colding *et al.* 2004; Olsson *et al.* 2004). Without it, any response to climate changes will be reactive.

(iii) *The ability to cope with change:* Climate change will affect the security of individuals and populations as well as the security of states (Adger 2010). In social systems, the ability to cope is a measure of the proximity to emotional and financial thresholds (Marshall 2008). Individuals with emotional and/or financial buffers are better able to absorb the costs of change and adapt (Lawes & Kingwell 2012; Marshall *et al.* 2012). Health issues will typically influence the capacity of older resource users to cope and adapt, and mental health issues will influence the capacity of resource users already experiencing financial hardship (Berry *et al.* 2011).

(iv) *The level of interest in change:* This dimension of adaptive capacity corresponds with the degree to which the system is capable of 'self-organisation'. Individuals that have a higher level of interest in adapting to the requirements of the future usually have a higher financial, social and/or emotional flexibility. The level of interest in climate change adaptation can be influenced by climate education and access to climate technology, expertise and information (Steinfeld 2001; Marshall *et al.* 2011). People interested in adaptation to change can identify the consequences, impacts and possible responses ("adaptation options") to climate change (Howden *et al.* 2007).

Adaptation at the individual scale is likely to influence adaptation processes at other scales (Adger *et al.* 2013). For example, individual characteristics may be important in determining the success of an NRM-led or industry-led initiative; such initiatives may depend on the support and capacity of individuals (Marshall *et al.* 2012). Individuals or resource-users within the Wet Tropics Cluster, for example, who have a higher capacity to incorporate change into their working lives are more likely to effectively trade-off the costs between short-term efforts to undertake change and their future limitations to be productive (Marshall *et al.* 2011). For these people, change will no longer be seen as a disturbance, but as a trigger for the reorganisation of resources, and for the renewal of the farm organisation and activities (Darnhofer *et al.* 2010). Individuals that possess this capacity will not only ensure their own ability to cope and adapt to the impacts of climate change, but will contribute towards the success of their industry in coping and adapting to climate change.

Fussel (2007) provides a list of preconditions for effective planned adaptation. He argues that if these preconditions are fulfilled, the adaptive capacity of those required to change their practices or behaviour will be enhanced. These preconditions are:

- *Awareness of the problem*: Assessing and communicating vulnerability to climate change
- *Availability of effective adaptation measures*: Triggering research that may lead to the development of new adaptation options
- *Information about these measures:* Identifying and assessing effective adaptation measures
- *Availability of resources for implementing these measures*: Evaluating co-benefits of adaptation (thus increasing perceived benefits); identifying ways for the most efficient use of resources, e.g. by mainstreaming adaptation in existing activity (thus reducing costs); and motivating the provision of additional resources, either domestically or internationally
- *Cultural acceptability of these measures*: Educating people about risks and response options to increase the acceptability of unfamiliar measures
- *Incentives for implementing these measures*: Identifying obstacles for implementation of effective measures and suggesting options to overcome them (Fussel 2007, p. 270).

Adaptation approaches need cross-sectoral strategies that fit into a broader framework of regional sustainable development and address the entire cascade of climate change impacts to avoid unintended negative side effects.

In the past, adaptation needs were conceptualised as linear cause-effect chains in which climate scenarios were the basis for estimating future climate impacts, which then defined adaptation needs (Figure 3 a). More recent adaptation assessments take a more integrative and complex approach to determine adaptation needs (Figure 3 b).

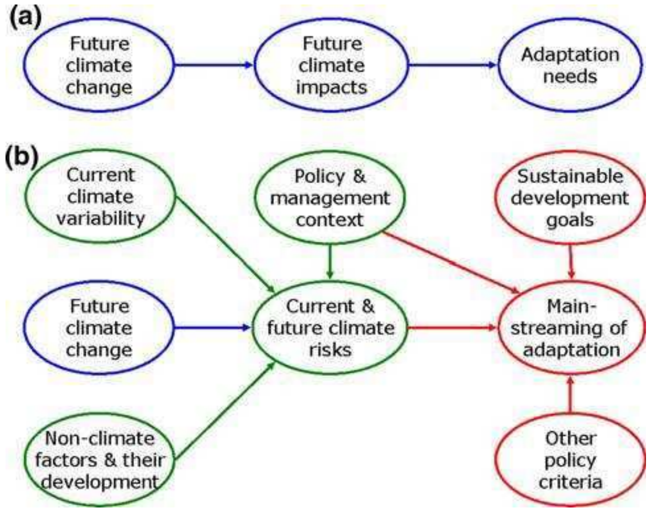

Figure 3: Evolution of approaches for determining adaptation needs: (a) linear hazard-based approach; (b) complex integrative approach (Source: Fussel 2007).

In this approach adaptation is 'mainstreamed' and arrives at a more comprehensive description of climate and other non-climate related risks. In this conceptualisation, adaptation to climate change is considered in a much broader context and aimed at achieving synergies with other policy objectives such as sustainable development goals. Smith & Wandel (2006) suggest that adaptation is more likely to be successful when linked to sustainable development. Specifically, adaptation is more successful if it focuses on reducing vulnerability and building adaptive capacity instead of adjusting to the impacts of climate change alone (Schipper 2007). This also means that adaptation can include a much broader range of actions that make societies and individuals more robust to change, including, but not limited to, those caused by climate change (Pielke *et al.* 2007).

Reyer *et al.* (2012, p. 537) argue that "adaptation should be fully integrated into regional sustainable development policies (and not only into sectoral development) to mediate conflicts and synergies between sections and to reconcile comprehensive strategies with local realities" (Figure 4).

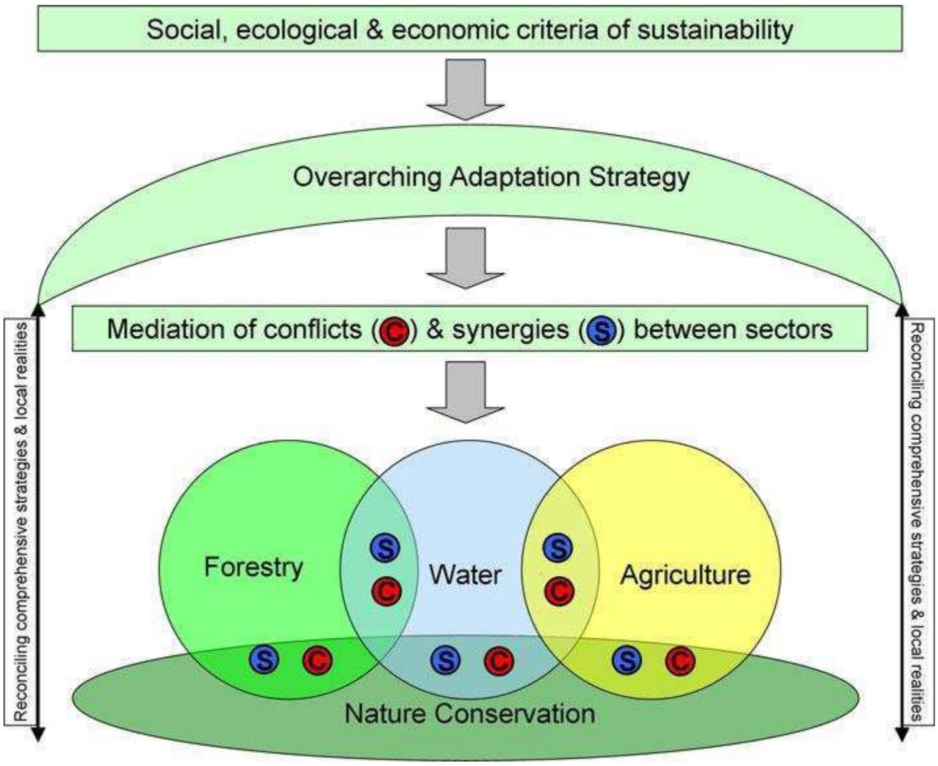

Figure 4: Conceptualisation of the integration of an overarching adaptation strategy into a broader context of sustainability. The overarching adaptation strategy supports the mediation of conflicts and synergies between sectors (these could be other sectors as well) and strives to reconcile local realities with comprehensive higher order strategic issues. (Source: Reyer *et al.* 2012).

Adaptation to climate change is highly context-specific as it depends on the specific environmental, social, economic, cultural and political conditions in the target region or sector.

For Far North Queensland (FNQ) and the Torres Strait (TS) (excluding the Mackay Whitsunday region), Regional Development Australia is undertaking a wider Roadmap-development and review process aimed at exploring the bigger strategic issues facing this region as a whole. This process has identified 12 Strategic Priority Packages of importance to the future of this region. Regional adaptation to climate change is one of the 12 major strategic issues of importance. A range of broad strategic adaptation initiatives have been identified, including insurance reform, disaster response reforms and the opportunity for major strategic Carbon Farming initiatives.

This Roadmap work is supported by the benchmarking of social resilience at the sub-regional scale carried out in collaboration with Northern Gulf NRM, Wet Tropics NRM, Cape York NRM and Torres Strait Regional Authority (Dale *et al.* 2011). These benchmarks, together with other research carried out across FNQ (including the Mackay Whitsunday region) and the TS are aimed at informing regional NRM planning (e.g. Bohnet *et al.* 2013; Butler *et al.* 2013; Lyons *et al.* 2013). Bohnet *et al.* (2013) in their co-research, carried out across the four Wet Tropics Cluster regions, found that each region faces region-specific issues and challenges that each NRM organisation needs to address in progressing their NRM plans. These issues, for example, include addressing the barriers that prevent dialogue about behavioural change required to address the impacts of climate change. Echoing this view, Dale *et al.* (2013) also suggest that capacity building is likely to be a major focus in the next generation of NRM plans.

Adaptation planning requires close collaboration of scientists, practitioners, managers, decision-makers, policy analysts and the people likely to experience climate change impacts.

Linking adaptation and sustainability points towards building resilience; resilience is the concept for understanding and managing change in social-ecological systems (Folke 2006). The following example illustrates how resilience can be fostered through cooperation between industry and government working together.

The coastal area between Tully and Innisfail produces about 90% of Australia's banana crop. In February 1986, Severe Tropical Cyclone Winifred crossed the coast at Mission Beach causing widespread destruction leading to a severe immediate shortage of bananas, followed by an oversupply the following year. The cycle of under-supply then over-supply lasted for about two years after the cyclone. The Australian Banana Grower's Council (ABGC) together with the Queensland Department of Primary Industries developed plans for a staggered crop cycle to prevent the situation from arising again, but there was little up-take among growers. After Cyclone Larry in 2006, the staggered crop cycle was again promoted by the ABGC and the Queensland government, but once again, adoption levels were not sufficient to avoid periods of over-supply and under-supply in the aftermath of Severe Tropical Cyclone (TC) Yasi, which crossed the coast at Mission Beach in 2011. The impact of TC Yasi on the Australian banana industry was catastrophic, destroying almost 100% of the banana crop in the coastal production areas.

The financial and social impacts on the region were significant, especially coming only five years after similar regional damage caused by Severe TC Larry that crossed the coast at Innisfail in March 2006. After TC Larry, the ABGC commissioned a new study to investigate both pre- and post-cyclone management practices to mitigate the impacts of cyclone damage. A field trial of pre-cyclone preparation involved the partial or total removal of banana leaves to reduce wind damage to the crop. Results showed that canopy removal reduced bunch weights by 40%-50%. However, in trees where fruit production had not yet commenced, trees returned to fruit production earlier than un-treated trees, after a cyclone. Thus, the study showed that growers who undertake pre-cyclone preparation will benefit financially compared with those who take no precautions. However, there is risk associated with canopy removal if a cyclone does not impact a crop, as crop volumes per hectare will be low (Lindsay & Comiskey 2012).

Although up-take of new ideas has been slow among banana growers, this example shows that partnerships between industry, scientists and government can help build resilience among the Wet Tropics primary producers.

Participatory scenario planning is a method and process allowing identification, deliberation and agreement on 'no regrets' or 'low regrets' strategies and programs.

Participatory scenario planning at the regional scale and with local communities has been advocated as a suitable approach to foster learning and building of adaptive capacity and community resilience to manage change (e.g. Bizikova *et al.* 2009; Gidley *et al.* 2009; Brown *et al.* 2010). In the Great Barrier Reef region scenario planning has been used to address issues and challenges the region is facing from the 'rainforest to the reef' (e.g. Bohnet *et al.* 2008a; Bohensky *et al.* 2011). In the Wet Tropics Cluster region scenario planning has supported water quality improvement planning and implementation in the Terrain NRM region (Bohnet *et al.* 2008b; Bohnet 2010; Bohnet *et al.* 2010, 2011). In the Torres Strait scenario planning is currently underway to support building resilient communities (Butler *et al.* 2012, 2013). Further scenario planning activities are carried out in the Reef Catchments NRM region at the local and regional scale, involving the broader community and regional representative sectoral stakeholders respectively (Bohnet & Bell 2014). This work aims to support the different sectors in the region as well as the regional NRM organisations in their adaptation planning based on the multiple types of knowledge and science that is brought 'to the table'.

In addition to building of adaptive capacity across scales and sectors it is also important to address potential barriers to adaptation (Moser & Ekstrom 2010; Lyons *et al.* 2013). A framework to detecting barriers in an adaptation process, based on diagnostic questions to ascertain how actors, context, and the systems of concern may contribute to the existence of potential barriers may be useful (Moser & Ekstrom 2010). Using such a diagnostic tool seems to provide, in addition to the tools developed in the national project called 'AdaptNRM' and through the 'Participatory Scenarios and Knowledge Integration Node' of the Wet Tropics Cluster (e.g. Bohnet & Bell 2014), another option to address some of the key messages described above.

Summary and conclusions

The need for adaptation is urgent; in particular from local to regional scales, since climate and other drivers of change pose significant risks to people, industries and the environment in the Wet Tropics Cluster region. Ideally, adaptation approaches should to be supported by concerted and cross-sectoral adaptation strategies that fit into a broader framework of sustainable development and fit in with the values associated with the region. Close collaboration of scientists, practitioners, decision-makers, policy analysts, and the people likely to experience climate change impacts and needing to adapt would be advantageous in the adaptation planning process. Participatory scenario planning is a method and process that has been identified to support collaboration, learning and building of adaptive capacity and community resilience. Building of adaptive capacity across scales and sectors will be critical for effective adaptation.

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