Climate change impacts on coastal freshwater ecosystems and biodiversity

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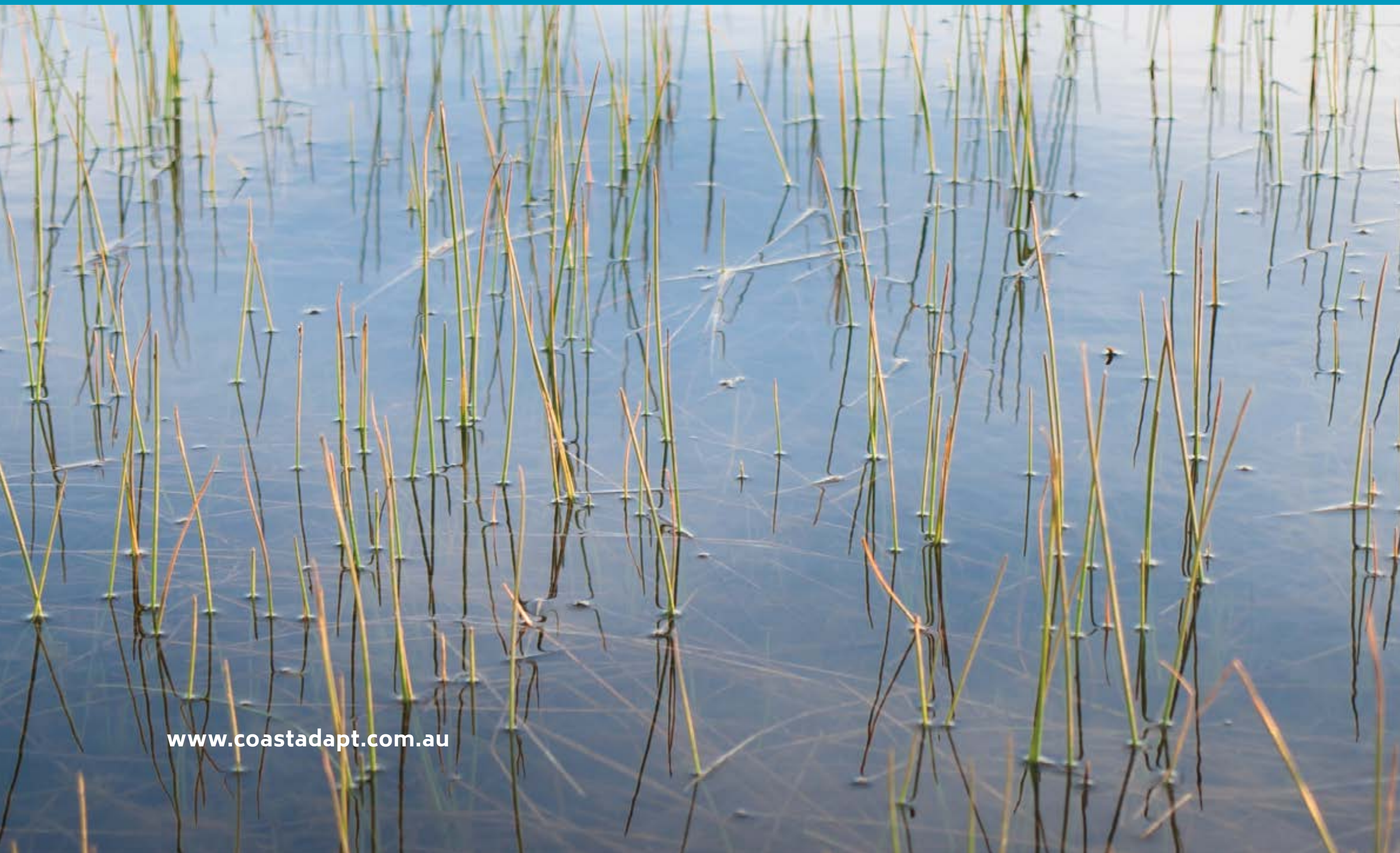
Impact Sheet 4



Contents

Australia's coastal freshwater ecosystems

Australia's coastal lands and islands contain a wide range of freshwater wetlands, which support a high diversity of plants and animals and provide many important ecosystem goods and services to people (Figure 1). Because of their location in the most densely populated parts of the continent, Australia's coastal freshwater wetlands are also amongst its most modified and degraded ecosystems. In many places, especially in south-eastern and south-western Australia, a large proportion of coastal freshwater wetlands have been completely lost as a result of drainage and infilling to provide land for development. Elsewhere, changes to landforms, hydrology, vegetation cover and land use associated with agriculture and urban settlements, have dramatically altered the ecological structure and function of coastal wetlands, both locally and with respect to their landscape context. Despite their ecological importance, and the degree of risk they face due to human activities, Australia's coastal freshwater ecosystems are relatively poorly described and understood compared with inland wetlands and other coastal ecosystems.

Coastal freshwater wetlands comprise a range of ecosystem types including those that are associated with estuaries and others that are more isolated, nestled in dune systems or contained within cave networks or craters supported by underground hydrological systems. Freshwater wetlands associated with estuaries occur within a matrix of wetland habitats including mangroves, sea grass beds and salt marshes. Typically occupying higher elevations than their more brackish counterparts, such freshwater estuarine wetlands include in-stream channel habitats and their riparian zones and floodplains. They also include a range of lacustrine (e.g. billabongs and lakes) and palustrine habitats (e.g. swamps and marshes) in low-lying, landward depressions that may be sporadically affected by marine influences (e.g. tides and storm surge) as well as stream flows. Coastal plains can also support marsh, swamp and wet heath wetlands that are not associated with estuaries but are instead filled by rainfall and/or groundwater. Similarly, non-estuarine coastal lakes may receive groundwater or be closed systems filled entirely by local rainfall and runoff (e.g. perched dune lakes).

Depending on their topographic position and hydrologic connectivity, coastal freshwater wetlands are influenced by terrestrial (e.g. runoff and groundwater seepage) and marine (e.g. tides, waves and storm surge) processes to different degrees. Coastal freshwater wetlands also vary with respect to the permanence and residence time of their waters and their bathymetry (i.e. physical shape). They may be permanent, semi-permanent or temporary, deep or shallow and with flowing water or still water that is regularly or rarely flushed. As a result, coastal freshwater wetlands differ considerably in terms of their water regimes and water quality, particularly their salinity and nutrient levels. These factors tend to be the major drivers of ecological structure and function in coastal freshwater wetlands. Wind exposure can also be important through its influence on nutrient dynamics as well as physical habitat stability.

Biodiversity

Coastal freshwater wetlands support a wide variety of vegetation types including a range of forested wetlands, shrublands, grasslands, sedgelands, reedbeds and forblands, all of which can occur as large patches or narrow bands fringing wetlands and watercourses. The distribution, composition and structure of major vegetation types tends to be governed predominantly by water regime and soil and water quality, especially salinity. Melaleuca (paperbark) swamp forests, for example, usually occupy lower elevations and, hence, more saline habitats, than Eucalyptus forests and woodlands. Herbaceous vegetation may be quite dynamic in some coastal wetlands reflecting shifts in water levels and salinity. Overall, vegetation in coastal freshwater wetlands typically comprises a complex mosaic of species that vary in their tolerance of flooding and drying, salinity, acidification and low nutrient levels, reflecting the heterogeneous and dynamic physical and chemical character of the landscapes they occupy.

A high diversity of aquatic and terrestrial fauna rely on coastal freshwater habitats for either their entire life histories or particular activities (e.g. feeding, refuge from heatwaves) or life history stages (e.g. spawning), including numerous endemic, rare or threatened species. Aquatic food webs vary amongst wetland types depending largely on their hydrology and water chemistry. Closed perched dune lakes, for example, which typically exhibit low salinity and nutrient levels, tend to support relatively simple and unproductive food webs. In contrast, permanent and semi-permanent coastal floodplain lakes often support diverse and highly productive aquatic food webs with a variety of primary producers (i.e. macrophytes and phytoplankton), herbivores (e.g. zooplankton, insects, crustaceans) and carnivores (e.g. fish); these provide important food sources for terrestrial fauna that traverse a range of coastal habitats, especially migratory birds. Coastal freshwater wetlands also provide important habitat for many amphibian, reptile and mammal species.

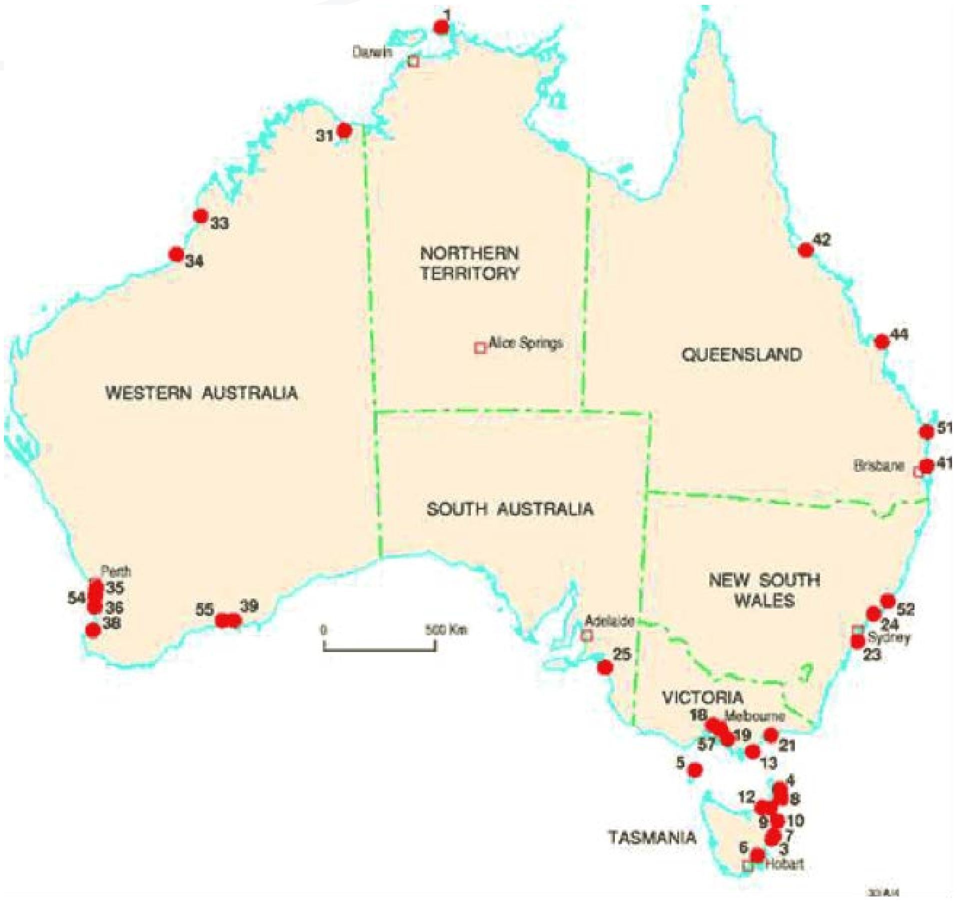


Figure 1: Australia's coastal Ramsar wetland sites:

1. Coburg Peninsula; 3. Moulting Lagoon; 4. Logan Lagoon; 5. Lavinia; 6. Pitt Water-Orielton Lagoon; 7. Apsley Marshes; 8. East Coast Cape Barren Island Lagoons; 9. Flood Plain Lower Ringarooma River; 10. Jocks Lagoon; 12. Little Waterhouse Lake; 13. Corner Inlet; 18. Port Phillip Bay (western shoreline); 19. Western Port; 21. Gippsland Lakes; 23. Towra Point Nature Reserve; 24. Kooragang Nature Reserve; 25. Coorong and Lakes Alexandrina and Albert; 31. Ord River Floodplain; 33. Roebuck Bay; 34. Eighty-Mile Beach; 35. Forrestdale and Thomsons Lakes; 36. Peel-Yalgorup System; 38. Vasse-Wonnerup System; 39. Lake Warden System; 41. Moreton Bay; 42. Bowling Green Bay; 44. Shoalwater and Corio Bays; 51. Great Sandy Strait; 52. Myall Lakes; 54. Becher Point Wetlands; 55. Lake Gore; and 57. Edithvale-Seaford Wetlands. Source: Geoscience Australia 2015 © OzCoasts.

Non-climatic threats

Coastal freshwater wetlands in Australia face a range of direct, local threats as a result of their human use (e.g. agriculture, tourism) including vegetation clearing, grazing and pollution. Hydrological regimes of many wetlands have been altered as a result of local topographic changes, river regulation and catchment-wide land use changes. In many cases, hydrological connectivity within and between wetlands and adjacent ecosystems has also been modified through the construction of barriers (e.g. levee banks, weirs) or structures that control estuarine opening to the ocean (e.g. barrages). In many places water quality has been adversely affected in many coastal wetlands by direct inputs and as a result of changes in catchments (e.g. broad-scale clearing) with increasing levels of eutrophication and acidification. Coastal freshwater wetlands are also prone to invasion by exotic species and disturbance by feral animals. Overall, human impacts on coastal freshwater wetlands in Australia have led to a significant loss of wetlands, severe degradation of others and a high level of fragmentation within and between those that remain.

Exposure to climate change

Coastal freshwater wetlands are subject to high levels of exposure to changes in climatic drivers due to their position in the landscape. As low-lying ecosystems at the interface of terrestrial, marine and freshwater realms, these wetlands experience changes both directly and via the effects of changes in other connected ecosystems. Freshwater wetlands are also typically exposed to a wide range of extreme events, including floods, droughts and fires, all of which are expected to change in frequency and intensity.

Temperature

Land surface temperatures around Australia have risen by almost 1°C over the last century and although mean temperatures tend to be cooler in coastal areas than those inland, a similar warming trend has occurred. There has also been a decline in the frequency of extreme cold weather during this period.

Global climate models consistently project an increase in mean annual temperatures around Australia over the next century, predominantly in response to rising carbon dioxide (CO_2) levels. More frequent and warmer hot days and warmer cold extremes are anticipated. The degree of warming will depend on the emissions scenario (Representative Concentration Pathway – RCP) that eventuates. Under RCP4.5, in which emissions peak in 2040 then fall, average annual temperature around Australia is likely to increase by 1.4 to 2.7°C by 2090. Under a more optimistic scenario (represented by RCP2.6 in which global emissions peak before 2020 and then decline substantially) an increase of 0.6 to 1.7°C is projected by 2090. The greatest increase in mean annual temperature is likely to occur in the North Western Plateau drainage division (Figure 2), where an increase of 4.5°C is projected by 2085 under RCP 8.5, in which global emissions continue to rise throughout the 21st century, followed by the Indian Ocean drainage division with a projected increase of 4.4 °C. The least change is expected in Tasmania with a projected rise of 2.4°C under RCP8.5 by 2085. Warming is expected to be lower in coastal regions, especially during winter in southern Australia. Many regions, however, are likely to experience temperatures beyond their current range of variability. Mean annual temperatures in the South East Coast and Indian Ocean drainage divisions (Figure 2), for example, are projected to be around 8.3 standard deviations from their current range under RCP8.5 by 2085. The least change is projected for the Timor Sea drainage division but even here mean annual temperatures are projected to be around six standard deviations from the current.

Rainfall

Rainfall around Australia's coast is highly variable both spatially and temporally, with substantial variation both within and between years. Nevertheless, rainfall has declined significantly since 1950 in much of eastern and south-western Australia but increased in northern Australia. Projections for future rainfall vary considerably between global climate models and are therefore very uncertain. Most models suggest a decline in rainfall is likely in much of southern Australia, especially in the South West Coast drainage division. In northern Australia, most models project no change or a slight increase in annual rainfall. Even under the most extreme emissions scenario (RCP8.5), however, projected changes in rainfall do not substantially exceed the historic range of variability, with changes projected to remain within a single standard deviation of current variation. The greatest changes relative to current patterns are projected for the South West Coast, Gulf of Carpentaria and Tasmania drainage divisions.

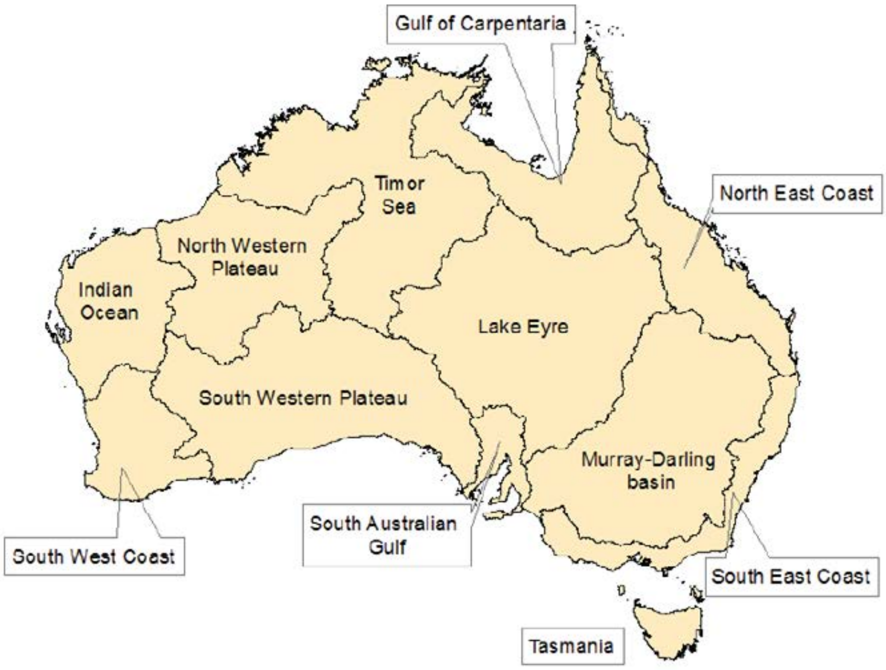


Figure 2: Coastal drainage divisions of Australia referred to in text. Source: James et al. 2013.

Shifts in seasonal rainfall patterns are also projected and, although similarly uncertain, most climate models suggest that rainfall is likely to become more variable with more abrupt wet seasons and longer dry seasons that start later in the year. It is highly likely that the intensity of extreme rainfall events will increase around Australia although this trend may be weaker in the south-west. Droughts are also projected to become longer and more severe.

Wind, storms and cyclones

The frequency and intensity of tropical cyclones in Australia have not increased in recent decades. Changes can be expected in the future, however these are relatively uncertain. Overall, tropical cyclones are expected to become less frequent but more intense and may extend further south. Mid-latitude weather systems are also likely to shift south during winter. Median and extreme winds are projected to increase in northern Australia and Tasmania but are likely to decline or remain stable in other areas.

Sea level

Between 1900 and 2010, sea levels around Australia have risen by an average of 1.7 mm per year. Sea levels are expected to rise throughout the 21st century at even faster rates, even under the lowest emission scenario (RCP2.6). By 2100, global sea levels are projected to be between 20 to 60 cm above 1990 levels although a further rise of 10 to 20 cm or more may occur depending on the contribution of melting ice sheets. Coastal inundation due to sea-level rise is expected to be greatest in the Gulf and estuarine systems of northern Australia. Sea-level rise will be further exacerbated in coastal regions by storm surges associated with more frequent and intense extreme weather events. For example, a current 1-in-100-year coastal inundation event caused by storm tides may occur twice as often by 2030 due to sea-level rise and even more frequently as the century progresses (Figure 3).

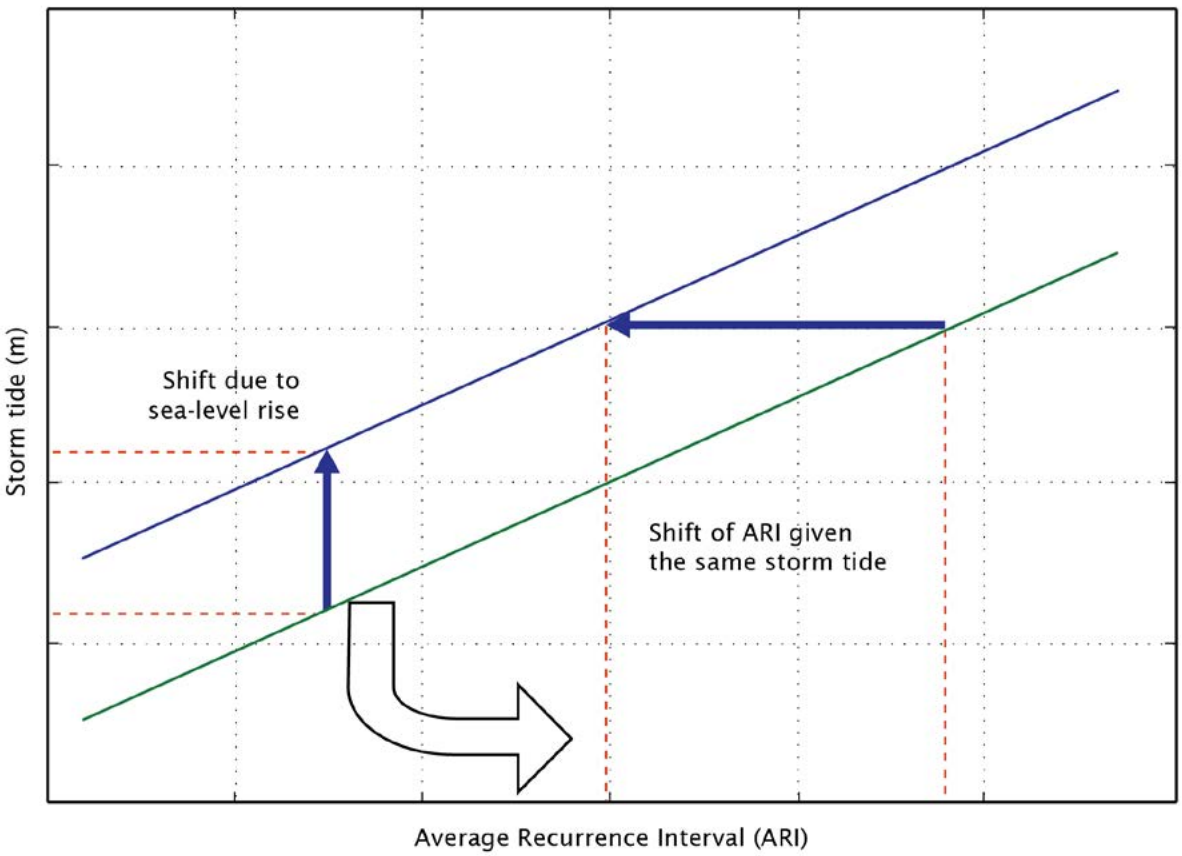


Figure 3: Diagram illustrating reduction of average recurrence interval of same height of storm tide due to sea-level rise. Source: Reproduced from Wang and McAllister 2011, with permission from CSIRO Publishing.

Marine climate

In addition to changes in sea level, climate change is associated with a range of direct changes to other aspects of the ocean climate that may affect coastal freshwater wetlands subject to marine influences.

Greater frequency and intensity of large wave events, for example, has occurred along Australia's southern coast. Sea surface temperatures are also expected to rise by around 2-4 °C by 2090 under RCP8.5.

Sea surface salinity will also change with Australia's southern and north-eastern waters projected to become slightly fresher (-0.1g/l by 2030) and those in the west, north-west and south-east to become slightly saltier (+0.1g/l by 2030). The ocean is very likely to become more acidic too, with the degree of acidification reflecting emissions scenarios. The greatest decline in pH is expected for waters in north-eastern Australia.

Sensitivity to climate change

Coastal freshwater ecosystems and their biota are likely to be highly sensitive to changes in climate because these tend to influence their key ecological drivers (i.e. water regime and soil and water quality). The sensitivity of coastal freshwater ecosystems is further affected by the many non-climatic stressors to which they are subject. Damage to coastal barriers by water buffalo or cattle, for instance, may exacerbate saltwater inundation of coastal freshwater wetlands due to sea-level rise (Figure 4). Similarly, the sensitivity of coastal freshwater ecosystems to non-climatic stressors will be influenced by climate change. The concentration of pollutants in some wetlands, for example, may increase if inflows are reduced due to a drying climate.

Figure 4a: Water buffalo in Kakadu National Park. Source: © Tourism NT.

Figure 4b: Cattle grazing on the Clarence River floodplain. Source: © State of New South Wales, Department of Industry, 2016.

Ecosystems

Hydrological regimes of coastal freshwater ecosystems are particularly sensitive to climate change and are influenced by warming, altered rainfall, increased evapotranspiration rates, sea-level rise and changes to extreme events. The sensitivity of wetland water regimes to climate change depends on their position in the landscape (e.g. proximity to the ocean) and hydrological connectivity.

Changes in rainfall result in much higher changes in runoff and stream flow proportionately which, in turn, affect patterns of groundwater recharge, flow and discharge. Soil moisture is also sensitive to warming, altered rainfall and increased evapotranspiration, particularly in drier catchments. Models indicate that mean annual runoff over the 21st century is likely to decline significantly in the South West Coast drainage division (Figure 2) but remain relatively stable in the Indian Ocean, South Western Plateau and North Western Plateau drainage divisions. An increase in mean annual runoff may occur in catchments of northern Australia while a reduction is projected for south-eastern Australia, although this is small in comparison with current levels of variability.

Wetland geomorphic processes will be sensitive to climate change both directly and as a result of hydrological changes. More frequent and intense rainfall events in upper reaches of catchments cause more erosion and re-suspension of sediments that can eventually reach coastal wetlands. Greater storm surge will also increase erosion rates of coastlines and coastal wetlands. Similarly, more frequent flooding can promote channel widening in watercourses.

Water quality of coastal freshwater wetlands is highly sensitive to climate change, both directly and indirectly as a result of effects on biogeochemical processes. Direct changes include probable rises in salinity in both surface and ground waters due to sea level rise and increased marine incursions via storm surge. In places where rainfall and runoff also decline, a reduction in flushing and dilution flows can be expected to further contribute to rises in salinity as well as the concentration of other contaminants (e.g. fertiliser). Most biogeochemical processes influencing wetland water chemistry are strongly affected by climate change and tend to be faster under higher temperatures. Rates of decomposition, for example, can double with rises of 10°C. Salt-water intrusion can also alter microbial processes, further stimulating decomposition. Additionally, many coastal wetlands, especially floodplains, swamps and brackish lakes, are associated with acid sulphate soils which when exposed can result in the release of harmful substances (e.g. sulphuric acid, metals). Such processes may be exacerbated by climate change, especially drought.

Other disturbance regimes shaping coastal freshwater ecosystems are also sensitive to climate change effects. In particular, fire regimes are expected to change, especially in areas that become drier, whereas more hot days are likely to result in more frequent and intense fires. Changes to fire regimes can subsequently alter water quality. Greater nutrient loads might occur, for example, as a result of floods that follow major fires.

Biodiversity

The biota of coastal freshwater ecosystems are sensitive to the direct effects of climate change and the hydrological, physical and chemical effects these produce, as well as their complex interactions. Plants will be particularly sensitive to increased atmospheric CO_2 which is expected to favour woody plants over herbaceous plants as well as plants with C4 photosynthetic pathways (many salt marsh plants) over C3 species (most other plants). Higher temperatures will trigger a wide range of physiological and life history changes amongst many taxa. Growth rates of primary producers (e.g. phytoplankton and macrophytes), for instance, are controlled by temperature, and productivity of cyanobacteria is especially likely to rise under warmer conditions (Figure 5). Life history processes in many plants and animals are similarly influenced by temperature, e.g. flowering, emergence of invertebrates, sex determination of hatching reptiles and amphibians, and migration of many fish and birds.

Coastal freshwater biodiversity is especially sensitive to altered water regimes. Changes to rainfall, surface and ground water levels and soil moisture can have a dramatic effect

Figure 5: Photo of blue-green algae bloom in Swan-Canning Estuary, Western Australia. Photo: © Tom Rose.

on plant growth and reproduction as well as plant interactions (i.e. competition and facilitation). Fauna relying on freshwater coastal ecosystems will also be directly influenced by altered hydrology, especially aquatic species such as macroinvertebrates and fish that depend on specific water regimes and hydrological connectivity to complete their life cycles. Amphibious and terrestrial animals will be affected as rainfall is often a critical driver of juvenile recruitment success and survival. Direct effects of climate change will be exacerbated by habitat changes that occur as a result of climate change effects on wetland geomorphology, water quality and vegetation, e.g. through altering the availability of food sources or the accessibility of breeding habitat.

Altered water quality is likely to be another major driver of climate change impacts on coastal freshwater ecosystems, especially changes in salinity but also nutrient levels and pH. Primary producers (i.e. algae, macrophytes and plants) will be particularly sensitive to such chemical changes as illustrated by well-documented shifts in lake flora from macrophytes to phytoplankton in response to increased nutrient levels (Figure 6). Wetland vegetation is sensitive to soil, as well as water quality with most species in freshwater systems intolerant of salt during at least some life history stages. Melaleuca seedlings, for example, are more sensitive to saline conditions than adult paperbark trees. Riparian and wetland vegetation in coastal regions is also sensitive to wind damage; the effects of tropical cyclones are often worse for riparian ecosystems than for those in adjacent upland areas. Vegetation is highly responsive to altered fire regimes, with increased frequency and intensity of fires leading to changes in composition and structure, e.g. shifts to grassy understoreys. Fauna are likely to be directly and indirectly affected by altered fire regimes, such as through effects on food supply (Figure 7).

Figure 6: Altered water quality will result in changes in freshwater systems.

a) A clear water state, with macrophytes. Source: David Rissik.

b) A turbid state, with phytoplankton of a coastal lake. Photo: © Ballina Shire Council.

Many indirect effects of climate change on the biodiversity of coastal freshwater ecosystems are likely as a result of changes in other connected coastal and terrestrial ecosystems, as well as effects on connectivity itself. For example, diadromous fish (i.e. species that move through a range of marine and freshwater habitats throughout their life cycles, such as Australian bass, *Macquaria novemaculeata*), might be especially sensitive to climate change impacts as they will be affected directly as well as through changes in the different habitats they occupy.

Figure 7: Fire in freshwater wetlands at Kakadu National Park. Source: © Commonwealth of Australia, Department of Environment.

Adaptive capacity

Many of Australia's coastal freshwater ecosystems and their biodiversity have evolved in the face of a relatively high degree of climatic variability, including changes in sea level and hydrologic regimes. As a result they exhibit a wide range of traits that afford some degree of resilience to many of the extreme events expected to increase in frequency and intensity in response to climate change. Some coastal wetlands, for example, can exhibit changes in elevation relative to sea level as a result of deposition patterns facilitated by vegetation. Similarly, many riparian and floodplain plants can tolerate changes in water level or possess life history strategies that enable them to escape from unfavourable conditions (e.g. fire) and re-establish at a later time (e.g. soil seed banks). Such processes and adaptations, however, are expected to be outpaced by the rate of current climate change. In some cases, complex interactions may promote adaptive capacity, for example sediment trapping may be enhanced by greater plant productivity caused by elevated CO_2 and nutrient levels. For the most part, however, the adaptive capacity of coastal freshwater ecosystems and biodiversity will be significantly hampered by the concurrence of multiple stressors relating directly to climate change as well as the many non-climatic pressures to which they are already subject. Especially limiting is 'coastal squeeze', which describes constraints on the ability of coastal ecosystems to move in space due to the ocean on one side and human development on the other. Similarly, the high level of fragmentation in coastal landscapes resulting from human infrastructure (e.g. dams and weirs) and land use, may prohibit the migration of some biota (e.g. fish) to new habitats with suitable climates.

Probable impacts

Predicting ecological impacts of climate change is extremely difficult due to the increasing levels of uncertainty involved in considering exposure to sensitivity and then potential adaptive capacity. Complex and unpredictable interactions between climatic and non-climatic stressors, as well as human responses to these, further complicate the task. Additionally, there are great knowledge gaps concerning coastal freshwater ecosystems and their biodiversity in Australia, climate change impacts notwithstanding. Nevertheless, some broad probable impacts can be inferred from current trends. Furthermore, existing non-climatic pressures (e.g. pollution, overfishing) are usually expected to be aggravated by climate change.

In regions subject to a drying climate for example (e.g. south-western Western Australia), it is likely that coastal freshwater wetland areas will shrink or, in some cases (e.g. perched dune lakes), be completely lost under more severe scenarios. Freshwater wetland losses may occur as coastal areas become more terrestrial as rainfall, runoff and stream flow decline, or there is encroachment by more brackish or saline systems in response to sea-level rise and saline intrusion of groundwater. Declines in water quality are highly probable in many coastal freshwater wetlands as a result of rising salinity as well as a greater potential for eutrophication and acidification. Exposure of potentially toxic acid sulphate soils, for example, may be greater under a drying climate. Larger and more frequent harmful blue green algae blooms are also anticipated in response to warming, drying and reduced flushing by marine or freshwater flows.

Changes in water regime and water quality will result in shifts in the composition and structure of wetland vegetation as well as the faunal communities they support (Figures 8 and 9). Encroachment of freshwater coastal wetlands by more salt-tolerant plant species (i.e. salt marsh plants or mangroves) is widely anticipated all around Australia, both in response to sea level rise and CO_2 fertilisation. CO_2 fertilisation may also promote woody thickening of coastal swamp forests on floodplains further inland.

Some freshwater coastal biota may become locally or completely extinct as a result of climate change effects, while others may adapt in situ or migrate to new habitats with suitable climate and other conditions. Stream frogs are expected to be particularly vulnerable and to decline in diversity in most regions, especially the North East Coast (Figure 2). The species richness of freshwater fishes is also forecast to decrease in many regions but particularly in the South Western Plateau and coastal northern Western Australia. Aquatic biota of closed coastal freshwater wetlands (e.g. perched dune lakes) are likely to be particular vulnerable to climate change. Significant declines in the abundance and diversity of migratory birds are anticipated due to losses in coastal habitats due to sea-level rise. In general, species with specialist habitat requirements are expected to be more vulnerable to climate change while hardy generalists are often predicted to be climate change 'winners' that may even expand their distributions. Invasion by exotic species is thought to be likely in many ecosystems as a result of climate change and there are also likely to be novel ecosystems, i.e. communities with combinations of species that have never previously occurred.

Overall, it is highly probable that there will be a significant change in the number, extent, distribution, diversity and connectivity of coastal freshwater wetlands in Australia in the future due to climate change and other pressures. In those freshwater wetlands that do persist, changes in the composition and structure of biological communities are very likely and these, in turn, will affect ecosystem functions and services. Many coastal wetlands, for example, may be transformed from carbon sinks to sources. Coastal freshwater biota are likely to be especially vulnerable to climate change impacts due to their high likelihood of exposure and sensitivity to the key drivers expected to change, as well as the high level of non-climatic pressures which they face.

Figure 8: Dry coastal wetland with acid scald. Source: Simone Haigh, WetlandCare Australia.

Figure 9: Dead *Melalecua* trees on a coastal floodplain near Cairns caused by sea water inundation. Source: Better management (http://better-management.org/).

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