EAST COAST
NRM CLUSTER

CLIMATE CHANGE IN AUSTRALIA

IMPACTS & ADAPTATION INFORMATION FOR AUSTRALIA'S NRM REGIONS

COASTAL VULNERABILITY

Background

This report has been produced as part of the Climate Change Adaptation for Natural Resource Management in East Coast Australia project. The project is being delivered by six consortium partners: University of Queensland (Consortium leader); Griffith University; University of the Sunshine Coast; CSIRO; New South Wales Office of Environment and Heritage; and Queensland Department of Science, IT, Innovation and the Arts (Queensland Herbarium) to foster and support an effective "community of practice" for climate adaptation within the East Coast Cluster regions that will increase the capacity for adaptation to climate and ocean change through enhancements in knowledge and skills, and through the establishment of long term collaborations.

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COASTAL VULNERABILITY

WHAT IS COASTAL VULNERABILITY?

Coastal vulnerability to climate change refers to the degree to which the coastal zone is unable to cope with adverse effects of climate change. It includes the exposure of the natural system to hazards, the impact on human systems and the adaptive capacity of the system. Climate impacts include sea-level rise, changes in sea-surface temperature, wave climate, rainfall and runoff, storm activity and ocean acidification. In some urbanised coastal areas, the social, economic and environmental consequences of these climate impacts can be exacerbated by ongoing population growth and development (Serrao-Neumann et al. 2014).

AUDIENCE

This information can be used by:

- **NRM agencies,** when adjusting their coastal policies and actions to help identify ecosystems that may shift or be lost, detect impacts of acidification on communities (e.g. shellfish), manage coastal impacts, and manage storm surges and subsequent inundation as a result of sea-level rise
- **Local and state governments,** to identify areas at risk of inundation (as a result of sea-level rise or storm surge), identify vulnerable communities or industries, target programs for building community capacity to respond to events, implement strategies such as dune restoration or sea walls to reduce potential impacts
- **Industry, business and the private sector,** to create their own programs for coastal adaptation, or adjust their current operations to accommodate for impacts from climate change, such as sea-level rise
- **Coastal communities,** to identify the vulnerability of their local area, build local capacity to hazards and participate in planning decisions relating to coastal adaptation to climate change.

PURPOSE OF THIS DOCUMENT

This document aims to:

- provide a brief introduction to coastal vulnerability to climate change and a more detailed introduction to sea-level rise
- discuss how coastal vulnerability and sea-level rise may be relevant to NRM planning
- provide links to resources and tools for NRM planning
- provide examples and case studies where coastal vulnerability or sea-level rise issues have been addressed in planning.

This document includes a background to approaches to conceptualising and assessing the vulnerability of people and coastal environments to climate change. The three pass approach to assessing vulnerability is described using examples from the East Coast Cluster. This includes a national and East Coast 1st pass assessment, 2nd pass assessments of the Hunter River (NSW) and Moreton Bay Region (QLD), and a 3rd pass assessment carried out in the Tweed River. Some resources and links to further case studies are also provided.

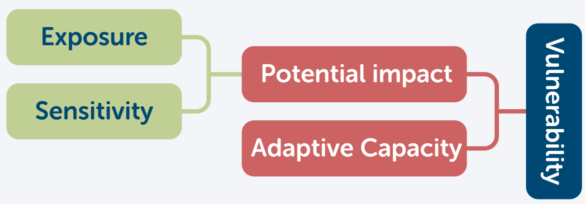


Figure 1. *Vulnerability is the result of the exposure to hazards, the sensitivity (degree to which it is affected) by hazards, the potential impact on the system, and the capacity of a system to adapt to these hazards*

SOCIO-ECOLOGICAL VULNERABILITY

VULNERABILITY OF PEOPLE AND ENVIRONMENTS

Coastal vulnerability to climate change can be assessed through examining exposure, sensitivity and adaptive capacity of people and coastal environments. Coastal populations, infrastructure and assets face risks from physical exposure to sea-level rise, coastal erosion, storm surge and ocean acidification.

Weather and climate extremes can affect a wide range of economic activities supporting coastal communities. Industries that dependent on highly climate-sensitive natural resources may be especially vulnerable to climate change due to this sensitivity. Economic, biophysical, institutional, cultural and political circumstances and pressures can affect the adaptive capacity of people and industries to climate change impacts (Wong et al. 2014).

The vulnerability and resilience of coastal populations is connected to social, economic, and ecological systems. Coastal ecosystems are particularly vulnerable to biodiversity impacts from ocean warming and acidification, rising sea levels, increased frequency of storm surges, shoreline recession, saline intrusion to freshwater systems, and habitat shift and reduction (Steffen et al. 2009). It has been argued that marine governance arrangements need to address and anticipate this increasing ecological vulnerability, and build capacity to avoid irreversible adverse environmental impacts (Serrao-Neumann et al. 2016).

Social conditions can also influence vulnerabilities of coastal communities to climate-related stresses. Social relations that foster leadership, trust and vision, arguably assist the adaptive capacity of community members (Folke et al. 2005), while social relations that constrain access to resources for some groups or communities can decrease adaptive capacity (Marshall et al. 2014).

Additionally, exposure of coastal resources and infrastructure to climate change generates economic risks for coastal industries and essential services. These include transportation, minerals, fishing, tourism, and construction, as well as health, education, wastewater systems and telecommunications among others.

Natural coastlines and marine habitats such as the southern Great Barrier Reef, Harvey Bay-Fraser Island, Moreton Bay Marine Park, Cape Byron Marine Park, Myall Lakes, Hunter Estuary Wetlands and Sydney Harbour are major attractions for domestic and international visitors to the East Coast Cluster.

Coastal and nature-based tourism is dependent on these natural assets, yet they are vulnerable to climate change. Climate change impacts on coastal infrastructure across the East Coast Cluster will influence the types of tourism values that can be sustained and the viability of tourism operators in their current locations. In northern parts of the East Coast Cluster, high vulnerability to fluvial erosion may increase water quality impacts on downstream coastal environments. In southern parts of the region, valuable coastal wetlands may be threatened in areas like the Hunter River Estuary.

Responding to coastal vulnerability to climate change can be complex due to climate variability and uncertainty, spatial and temporal dynamics of coastal systems, and the breadth of stakeholders involved. This requires partnerships and cross-sectoral perspectives engaging a range of actors (Serrao-neumann et al. 2014).

State level tourism industry bodies and some regional networks are seeking to increase coastal tourism operators’ resilience to climate-related natural hazards through risk management and disaster preparedness. Opportunities also exist for regional tourism networks to align industry plans with regional NRM planning to identify shared assets to protect, assess possibilities of co-management of coastal resources, and coordinate disaster planning and recovery.

Tourism operators hold a strong environmental stewardship ethic. This provides a platform to explore future opportunities as co-managers of the coastal environment.

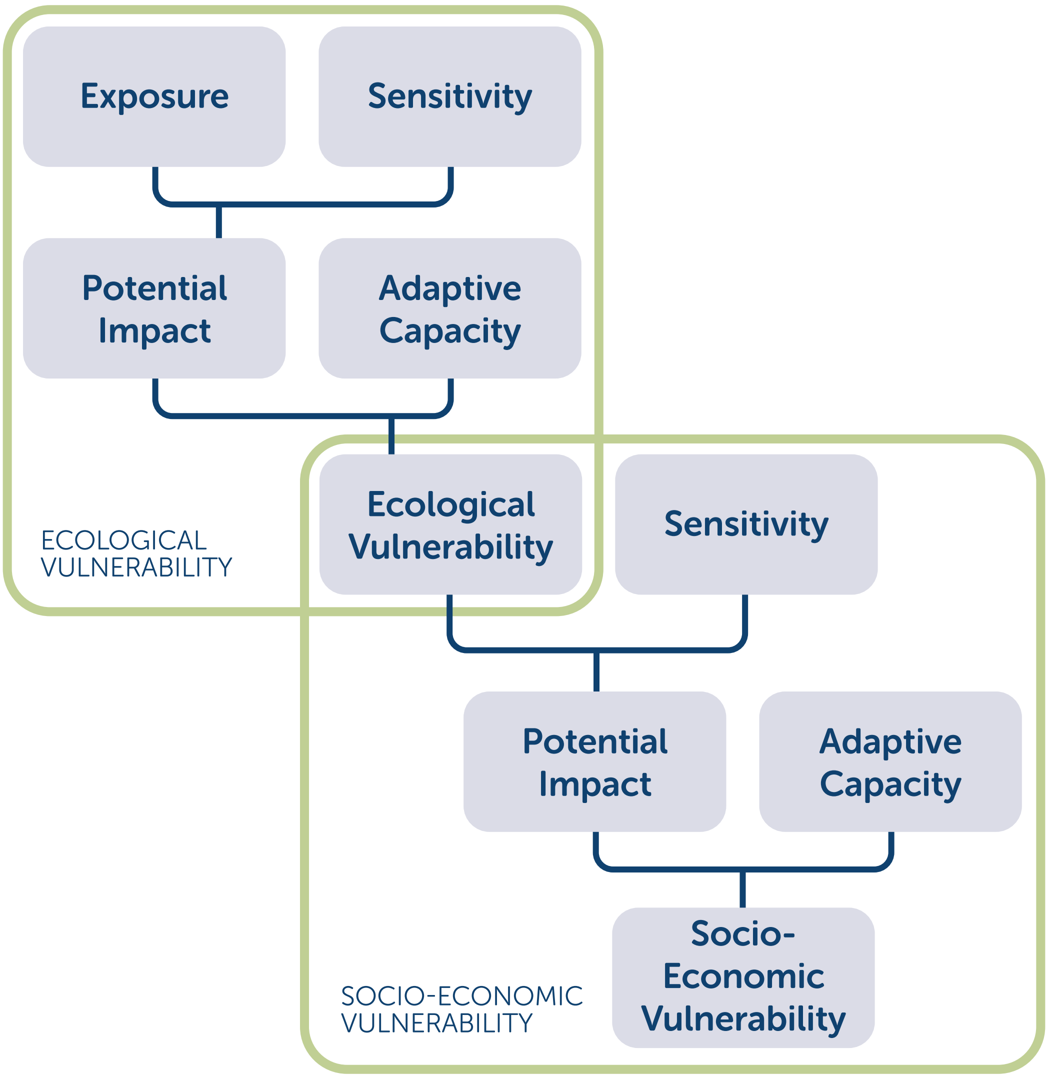


Figure 2. *The combined vulnerability of the linked socio-ecological system includes ecological and socio-economic vulnerability. The exposure and sensitivity of the ecosystem determine the potential impact, which combines with the adaptive capacity of the ecosystem to determine the ecological vulnerability. The sensitivity of a socio-economic system to ecological vulnerability (i.e. its degree of resource-dependence) determines the potential impact, which combines with the adaptive capacity of the human system to determine the socio-economic vulnerability (Marshall et al. 2014: 87)*

COASTAL VULNERABILITY TO SEA-LEVEL RISE

SEA-LEVEL RISE PROJECTIONS

Between 1966 and 2009, the average rate of sea-level rise in Australia was 1.4mm per year. The most recent climate change projections identified with a very high degree of confidence that sea levels will continue to rise. Compared with 1986-2005, sea-level rise is projected to be about 0.13 – 0.14m by 2030. By 2090, sea-level rise is projected to be between 0.38m under the low emission scenario, to 0.66m under the high emission scenario. However, if sections of the Antarctic ice sheet collapse, sea levels could rise by an additional several tenths of a metre. In addition, sea levels will not stabilise by 2100, but will continue to rise for centuries regardless of future emissions, due to continuing thermal expansion of the oceans.

BRISBANE		
Scenarios	**2030**	**2090**
RCP 2.6	0.13 (0.09 to 0.17)	0.39 (0.23 to 0.55)
RCP 4.5	0.13 (0.09 to 0.18)	0.47 (0.31 to 0.65)
RCP 8.5	0.14 (0.09 to 0.18)	0.65 (0.45 to 0.87)
SYDNEY		
Scenarios	**2030**	**2090**
RCP 2.6	0.13 (0.09 to 0.18)	0.38 (0.22 to 0.54)
RCP 4.5	0.13 (0.09 to 0.18)	0.47 (0.30 to 0.65)
RCP 8.5	0.14 (0.10 to 0.19)	0.66 (0.45 to 0.88)

Table 1. *Projected sea-level rise for Brisbane and Sydney under three emission scenarios: RCP 2.6 (low), RCP 4.5 (intermediate), and RCP 8.5 (high) for 2030 and 2090. Values shown are the median change across the models, with the range of model results in brackets (Dowdy 2015)*

IMPACTS AND RISKS

There are two basic risks to coastal areas from sea-level rise and extreme events:

- inundation
- coastal erosion.

Impacts from inundation include:

- permanent inundation from long-term changes to the mean sea level
- more frequent or severe storm surge and king tide events causing short-term impacts
- saltwater intrusion upstream in estuaries and in groundwater.

Coastal erosion will depend on topography, mean sea level, extreme events, waves, and supply and loss of sediments to the coast. A particular concern for coastal management is that beaches that are currently stable or accreting (accumulating, e.g. due to sufficient sediment supply) may flip to become receding beaches as sea levels rise.

Both inundation and erosion threaten coastal ecosystems and infrastructure and houses.

Sea-level rise impacts coastal ecosystems through saline intrusion to freshwater systems, habitat shift and habitat reduction (Steffen et al. 2009). These impacts may be compounded by non-climatic changes such as invasive species and landuse change or modification (Nicholls et al. 2007).

HOW IS IT USED IN NRM PLANNING

NRM planning focuses on the effects of sea-level rise on coastal ecosystems, and particularly on possible shifts in the distribution of coastal species or ecosystems. The first priority is to identify areas or ecosystems that are particularly vulnerable to sea-level rise; for example, using a three pass assessment approach. Management options for coastal systems may include changing the flow regime to accommodate rising sea levels or influxes of saline water (e.g. removing existing tidal barriers). A problem for local and regional planning is 'coastal squeeze', where ecosystems are not able to shift landward due to existing coastal development, possibly resulting in the local elimination of some ecosystems.

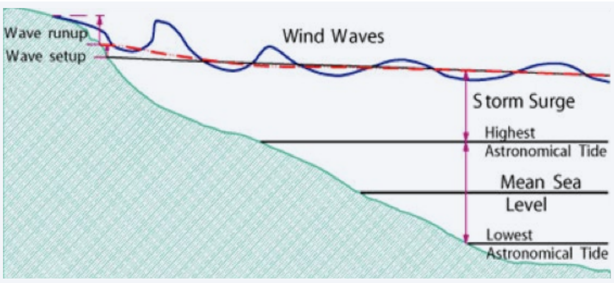


Figure 3. *Sea level = mean sea level +/- tide + wave set-up + wind response. Mean sea level changes slowly and increases in sea level can lead to permanent inundation. Extreme events such as extreme tides, storm surge and storm tides interact with sea level and sediments and produce greater risks (Oz Coasts 2010)*

A THREE PASS APPROACH TO VULNERABILITY

A three pass approach to assessing coastal vulnerability to sea-level rise provides vulnerability assessments at spatial scales from national to regional and local based on increasingly detailed data and modelling (Sharples et al. 2008). When combined with socio-economic information, these assessments can provide a more comprehensive assessment of the vulnerability of these areas to sea-level rise, and identify populations that are highly exposed and lack adaptive capacity.

THE FIRST PASS – POTENTIAL RISK

First pass assessments are applied at a broad spatial scale (national to state) to identify areas that may be susceptible to sea-level rise, and which could benefit from further detailed assessment. The simplest type of first pass assessment would use a bathtub model to estimate inundation based on sea-level rise values and coastal elevation. A first pass assessment of erosion risk can be carried out using basic geomorphic data on shoreline type to identify unstable shores. First pass assessments are not suitable for use at more detailed spatial scales, as they do not include key ecosystem or hydrological processes. For example, first pass assessments may overestimate coastal ecosystem losses as they do not include responses such as vertical accretion. The main use of first pass assessments is to determine relative risk and identify areas that require further analysis. Data required includes bedrock and coastal geology, digital elevation models, sea-level rise values, modelled high water level and storm tides.

THE SECOND PASS – LIKELY RISK

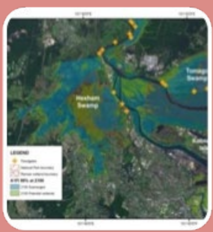
In second pass assessments, the vulnerability of coastal river systems is modelled at a regional scale using data such as: elevation (Surface Elevation Tables), digital elevation models, tidal data, rates of accretion, erosion, spatial distribution of vegetation, and regional sea-level rise projections. Models include elevation deficit models, Sea Level Affecting Marshes Models (SLAMM), and spatially applied empirically-based elevation models. Assessments at this scale are most suitable for landscape or catchment management applications. A second pass assessment can provide coarse-scale mapping to identify coastal regions exposed to impacts and drivers resulting from coastal hazards at a strategic level.

THE THIRD PASS – DETAILED RISK

The third pass approach can be applied at a local level using site-specific data to model local ecosystem processes and responses. This approach uses a range of biophysical information, such as inundation data, plant productivity, sedimentation and groundwater levels, and organic matter decomposition rates. The models can be used at a local scale for a detailed assessment of risk, or can be used to inform regional second pass assessments. Third pass mapping and assessments can indicate the style and magnitude of impacts and coastal hazards likely to occur, the likely behaviour of a specific site or shoreline in response, and indicate the degree of uncertainty inherent in such an assessment.

FIRST PASS ASSESSMENT

- Applies at a broad spatial scale (national to regional)
- Identifes areas susceptible to sea-level rise that may require further investigation
- Uses geological data to determine sensitivity to coastal impacts



SECOND PASS ASSESSMENT

- Focuses on the regional scale
- Identifies exposure to sea-level rise
- Uses information on ecosystem responses, as well as different modelling approaches to determine level of exposure to sea-level rise

THIRD PASS ASSESSMENT

- Focuses on a local or site scale
- Requires localised, site-specific data on biophyscial elements like innudation, groundwater levels, sedimentation, plant species characteristics and responses, as well as soil type
- Provides information on site specific ecosystem responses and local coastal processes

Figure 4. *A three pass approach to assessing coastal vulnerability to sea-level rise includes a broad, national scale first pass approach, a regionally focused second pass approach and a site-specific third pass approach. Each pass requires more focused and precise data, with broad geological and digital elevation data for a first pass assessment, more refined geological information as well as ecosystem processes and responses needed for the second pass assessment, and a range of biophysical data and detailed information on environmental processes required for third pass assessments*

COASTAL VULNERABILITY IN THE EAST COAST CLUSTER

ECOSYSTEM RESPONSES

There are 3 possible responses of coastal ecosystems to rising sea levels:

- submergence, where plant species adapt to changes in salinity or additional time under water
- horizontal migration, where species gradually colonise higher ground
- vertical elevation gain, where plants retain more soil and organic matter to raise the ground level.

Some plants are able to adapt more readily to sea-level rise; for example, mangroves can migrate shoreward and retain soil and organic matter in their extensive root system. Any management strategies need to incorporate likely ecosystem responses.

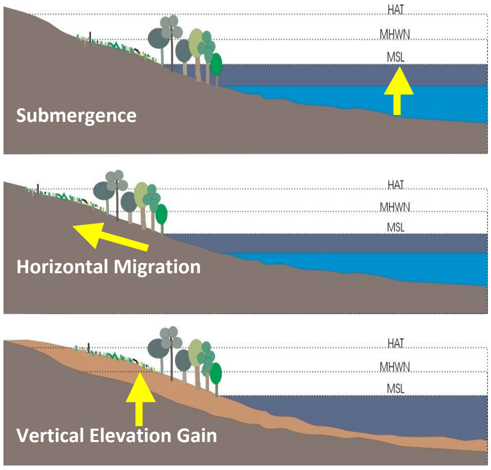
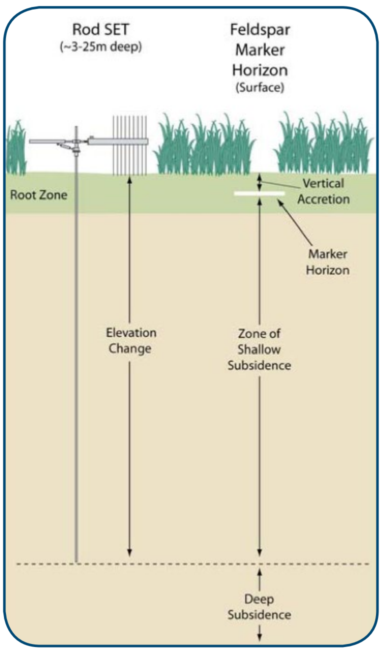


Figure 5. *Coastal ecosystem responses to sea-level rise include submergence, landward migration and vertical elevation gain (Rogers et al. 2014)*

Figure 6. *A Surface Elevation Table (SET) can be used to measure rates of vertical accretion in wetlands (USGS 2010)*



MEASURING SURFACE ELEVATION

Third pass assessments require detailed information on processes such as erosion, accretion and longshore drift. One tool to measure wetland response to sea-level rise is the Surface Elevation Table (SET), which can be used to measure elevation changes. The SET can be used to measure long-term changes in elevation, or short-term impacts from events over time-scales from years to decades (USGS 2010).

The SET includes a long rod that is inserted into the ground to a deep benchmark to provide a constant reference point. Surface elevation is measured using pins lowered to the sediment surface. To distinguish between vertical accretion and other sub-surface processes that affect sediment elevation, a 'marker horizon' is also laid on the wetland surface. Vertical accretion is measured as sediment accumulation over the horizon in core samples. Sub-surface changes such as sediment shrink or swell or vegetation accretion or subsidence, can then be calculated as the difference between the measured elevation change and vertical accretion.

SEA-LEVEL RISE AND VULNERABLE SPECIES – THE WATER MOUSE

The Water Mouse (false water rat) is a native mammal listed as vulnerable by the IUCN Red List. It occupies wetlands across northern and eastern Australia and is almost entirely dependent on mangrove habitats where it preys on crustaceans, insects and molluscs (Van Dyck 1995). Primary threats to the Water Mouse are predation and habitat degradation by invasive species (cats and feral pigs), and pollution and habitat loss from urban development (Woinarski et al. 2000).

Models of the effects of sea-level rise on coastal vegetation in Moreton Bay suggest the area of mangroves is likely to increase as mangroves migrate into low lying undeveloped areas. However, this may not translate into an increased Water Mouse population. Models also indicate an expansion of urban areas, bringing the Water Mouse's mangrove habitat closer to threats associated with urban environments such as predation by cats and foxes. The case of the Water Mouse illustrates how the effects of climate change can interact with human settlements to influence a vulnerable species, and how it is important to integrate models of the effects of climate change with patterns of human settlements and behaviours.

NATIONAL FIRST PASS ASSESSMENT

SUMMARY

In 2009, the Australian Government commissioned a first pass assessment of climate change risks to Australia's coasts (Department of Climate Change 2009). This was a nation-wide broad scale assessment.

This assessment sought to:

- assess coastal vulnerability
- identify priorities for adaptation
- identify barriers to adaptation
- develop databases for information sharing
- develop tools (coastal hazard mapping) for policy responses.

The assessment process included:

- Sea-level rise of 1.1m by 2100 was used as the basis for the modelling, as an indication of risk from a 'worst case' scenario
- A 'bucket-fill' or 'bathtub' model was used to identify areas that could be inundated at a sea-level rise of 1.1m. The model inundates all land areas below that elevation
- Coastal flooding was modelled by combining sea-level rise, high water level and storm tide values
- The National Exposure Information System (NEXIS) database was used to estimate risk to buildings and infrastructure within the inundation and erosion areas, in terms of the number of buildings and the total replacement value.

This is a simple and cost-effective methodology that can be used to identify potentially vulnerable areas. However this methodology, like many first pass assessments, is likely to overestimate inundation risk as it does not include ecosystem responses or local hydrological processes.

WHAT WERE THE OUTCOMES?

The study included:

- coastal hazard mapping based on a combination of risks from erosion and inundation for use in preparing coastal adaptation strategies
- a review of coastal ecosystem responses and vulnerability
- a count and estimated replacement costs of infrastructure and buildings potentially affected by inundation and flooding
- review of infrastructure vulnerability and responses.

WHAT ARE THE IMPLICATIONS FOR THE EAST COAST CLUSTER?

Significant areas of both southern Queensland and Northern and Central New South Wales were identified as being at risk from coastal hazards.

In Queensland, the local government areas of Moreton Bay, Mackay, Gold Coast, Fraser Coast, Bundaberg and the Sunshine Coast were identified as having the highest level of risk, representing about 85% of the 35,900 to 56,900 buildings across the state at risk of inundation with a replacement value between $10.5 billion and $16 billion. In addition, about 15,000 homes are within 110 metres of 'soft' shoreline that can be eroded. Sensitive ecosystems such as mangroves and salt marshes are also at risk not only from climate change impacts, but also ecosystem squeeze.

Northern and Central New South Wales were also identified as being at significant risk. Local government areas of Lake Macquarie, Wyong, Gosford, Wollongong, Shoalhaven and Rockdale represent 50% of the 40,800 to 62,400 buildings at risk, with a replacement value between $12.4 billion and $18.7 billion. Adding to that, New South Wales has a large number of wave-dominated beaches that provide buffering against coastal hazards. Increased intensity and frequency of extreme coastal hazards as a result of climate change would increase rates of erosion on these beaches, destroying both the beach habitat and the natural buffer.

These vulnerable areas would benefit from further focused studies to identify all the risks associated with climate change in the cluster, and how best to adapt.

Figure 8. *The Gold Coast in 2009 and with estimated inundation from a sea-level rise of 1.1m (not suitable for decision-making) (Department of Climate Change 2009:88)*

EAST COAST FIRST PASS ASSESSMENT

SUMMARY

A quantitative first pass assessment was completed for the East Coast Cluster in 2014 to assess vulnerability of coastal areas to erosion and inundation. This assessment indicates potential vulnerability to sea-level rise at a broad regional scale. It is most useful to identify areas which may require more detailed assessments.

This first pass assessment included proxy information on the exposure, sensitivity and adaptive capacity of the coastal zone (including both open coasts and estuaries) to provide a vulnerability index. Coastal vulnerability was assessed using a 30m x 30m grid and 1m elevation. Indicators of exposure, sensitivity and adaptive capacity were used for each type of hazard:

- marine inundation
- marine erosion
- fluvial (stream) inundation
- fluvial erosion.

These indicators were then combined into a single index of estuarine vulnerability, on a scale from 1 to 3.

Exposure was described by estuarine zonation – marine zones are exposed to drivers such as storm surge and sea-level rise, while alluvial zones are exposed to rainfall and run-off. Elevation and slope are also important: lower elevations are more exposed to inundation; steep slopes are more exposed to fluvial erosion but less exposed to marine erosion.

Sensitivity to erosion is a function of underlying geology: hard bedrock is less sensitive to both marine and fluvial erosion.

Adaptive capacity is related to the volume of sediment that an estuary can potentially hold (the "accommodation space"), which is dependent on a combination of the shape of the bedrock valley and the elevation of hydrological influence. When assessing adaptive capacity, elevation is used as a broad indicator of the capacity of the estuary to hold sediment. Deeper and broader valleys have more accommodation space than shallow and narrow valleys (Rogers and Woodroffe 2012).

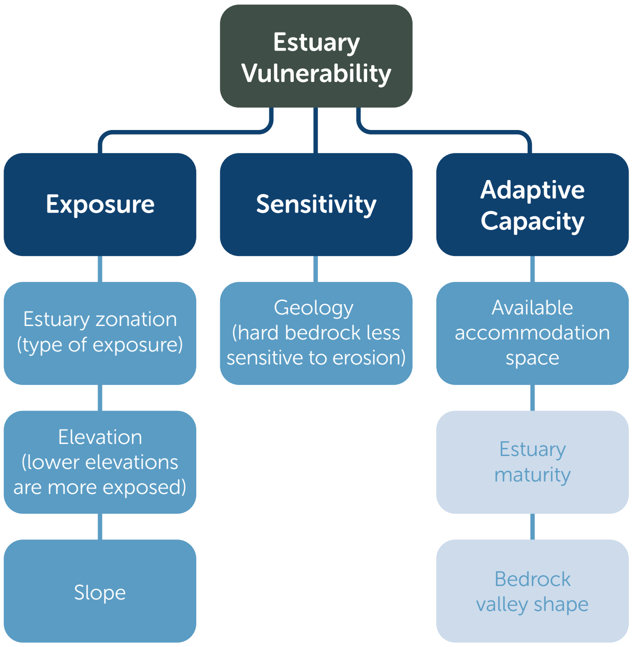


Figure 9. *A combined index of estuarine vulnerability was derived from indicators of exposure, sensitivity and adaptive capacity for marine and riverine erosion and inundation (Rogers 2014)*

Figure 10. *Combined vulnerability assessment for the Shoalhaven River, NSW (Rogers 2014)*

SECOND PASS ASSESSMENTS

THE HUNTER RIVER

A second pass assessment of the effects of sea-level rise on mangrove and saltmarsh wetlands in the Hunter River found that wetland extent may not decrease under sea-level rise as predicted by bathtub models, but could increase due to processes such as accretion and changes in sediment volume (Rogers et al. 2012; Rogers et al. 2014). The model indicated that floodgates are the primary determinant in wetland extent in 2100 under both high and low sea-level rise scenarios. Under a high sea-level rise scenario, closed floodgates would result in only 33% of wetlands remaining in 2100, whereas open floodgates would result in a 127% growth of wetland extent (Rogers et al. 2014).

This particular assessment involved the use of detailed third pass data in a second pass assessment of management options. From 2002-2010 wetland responses to sea-level rise were examined in the Hunter River, NSW, using surface elevation tables (SET), an accretion model, and a landscape elevation model.

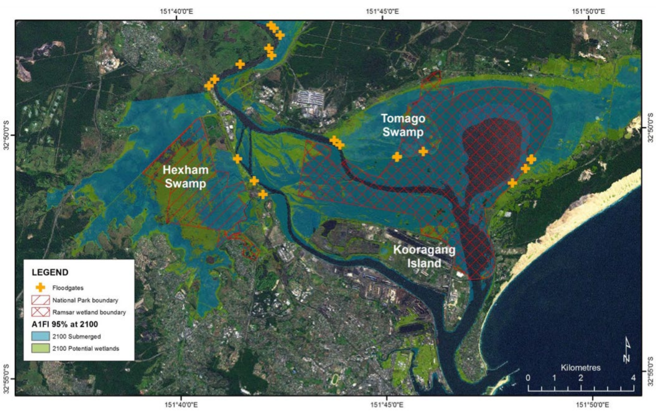


__Figure 11.__ High sea-level rise scenario in the Hunter River estuary. (Rogers and Lovelock 2015). The blue area shows the area submerged in 2100, and the green area shows potential wetlands under modelled high sea-level rise conditions. Potential wetlands in this scenario are mostly outside the existing National Park and Ramsar wetland boundaries, shown in red stripes and checks

A dynamic elevation model was used that factored in the accretion and vertical elevation responses of mangrove and saltmarsh to rising sea levels. Two management options were modelled: leaving floodgates open and facilitating retreat of mangrove and saltmarsh into low-lying coastal lands; and closing floodgates. The potential extent of saline coastal wetland to 2100 was modelled under a low and high sea-level rise scenario for each management option.

This assessment allows an exploration of management actions (such as floodgate management) to improve and/or maintain ecosystem services. However, it should be pondered alongside considerations of a range of other factors that will also influence wetlands such as future developments and planning actions, manipulation of hydrodynamics, and the physical expression of climate change drivers on the estuary. Under a high sea-level rise scenario, most of Hunter Wetlands National Park will be lost. This has led some researchers to suggest the implementation of dynamic landuse arrangements that enable important wetlands to retreat inland as sea levels rise (Rogers et al. 2014).

SECOND PASS – A SYSTEM-FOCUSED ASSESSMENT OF EXPOSURE

Second pass assessments generally involve identifying regional variations in processes impacting an area that has been identified in a first pass assessment as potentially sensitive. This may involve identification of physical impacts and processes relating to wave, wind and storm climates, tidal regimes or vertical land movement, and provide information to assist an initial assessment of protection and adaptation options (Sharples et al. 2008).

THE MORETON BAY REGION

Both surface accretion (through sedimentation inputs) and biological accretion processes (accumulation of surface organic matter and addition of root volume on and below the soil surface) can allow coastal wetlands to adjust to rises in sea level. Within an intertidal zone, the conditions for these processes may vary. Additionally, accretion processes can decline when marsh or mangrove surface is uplifted, or sea level declines. This can result in complexity in the capacity of surface elevation to keep pace with sea-level rise across an intertidal zone.

An investigation into the variation in processes that give rise to changes in surface elevation with mangroves and salt marsh in response to rising sea level was carried out in Moreton Bay, Queensland. A wide range of intertidal wetland habitats can be found in Moreton Bay. These wetland habitats are varied across the Bay in terms of their proximity to the influence of the nearby city of Brisbane, characteristics of intertidal salt marsh, as well as other differing environmental conditions and processes. The capacity of mangroves to keep up with sea-level rise is partially dependent on sediment supply, which is influenced by circulation patterns and the delivery of sediments in river flows in parts of Moreton Bay (Lovelock et al. 2011).

On the western shore mangrove forests grow on muddy soils and are exposed to freshwater inputs from creeks and rivers. They are also exposed to sediments and nutrients that originated from flood plumes which tend to be trapped in shore due to prevailing wind direction and currents. In the eastern bay, mangroves are found in sandy sediments on the shores of high sand islands.

There is also variability in terms of inundation patterns of intertidal salt marsh between the western and eastern shores of the Bay due to differences in composition and sediment characteristics. Researchers found mangrove fringes in Moreton Bay are relatively stable with current rates of sea-level rise because of high levels of sediment inputs. Sediment inputs are likely to continue due to the high availability of sand in the eastern bay, but may be less likely in the western bay as sediment supply via rivers may be reduced as a result of drought and reduced runoff.

High rates of soil subsidence may also decrease the stability of mangroves in parts of the bay. As sea-level rise progresses, mangroves are expected to encroach on high intertidal salt marsh habitats. As a result, salt marsh habitats are more likely to have their total area reduced due to both increases in surface elevation and barriers to upslope migration such as urbanisation (Lovelock et al. 2011).

WHAT ARE THE IMPLICATIONS?

Assessing the factors influencing subsidence in Moreton Bay is integral to understanding the fate of mangroves in the western bay with sea-level rise. Both natural and human barriers to upslope migration of salt marsh habitats are likely to decrease the total area of salt marsh, with consequences for biodiversity in these habitats (Lovelock et al. 2011).

This modelling and analysis indicate that mangrove fringes may be relatively stable in Moreton Bay, with the western bay forests more vulnerable to subsidence from sea-level rise. Modelling such as this can assist decision-making relating to landuse planning and planning of coastal infrastructure that allow sufficient sediment supply and manage potential processes of soil subsidence.

THIRD PASS ASSESSMENT IN THE TWEED RIVER

THIRD PASS – A DETAILED ASSESSMENT AT A LOCAL SCALE

Third pass assessments are conducted on a site-specific scale, and require information on sediment and vegetation accretion, subsidence and erosion, as well as specific coastal processes and responses like longshore drift, storm surges and intrusion of seawater into groundwater tables. As this data is time-intensive and resource-intensive to collect, third pass assessments are usually limited to small spatial scales (e.g. a single estuary) and are targeted to priority or vulnerable areas. Third pass assessments are often used to provide data for (parameterised) second pass assessments.

COASTAL WETLAND RESPONSES TO SEA-LEVEL CHANGES

Coastal wetlands exist in a relatively narrow strip between the ocean and the land, and their distribution and extent are affected by their tolerances for inundation, soil and water salinity and other factors. Sea-level rise has the potential to affect coastal wetlands through change in water level, inundation patterns and salinity. Coastal wetlands can respond to increases in sea level by accretion processes that increase their surface elevation.

The lag between rises in sea level and increases in wetland surface elevation is known as an elevation deficit, and indicates the adaptive capacity of the wetland.

Sea-level rise and rainfall have both been proposed as causes for recent changes in the distribution of coastal wetlands in Australia. Changes in surface elevation can be measured and correlated with rainfall, water level and other variables.

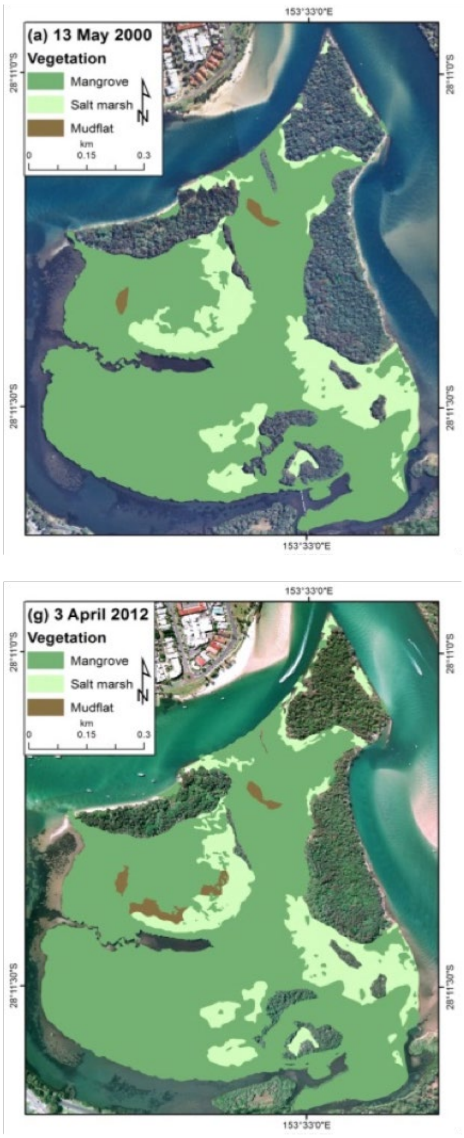


Figure 12. *Mangrove expansion and saltmarsh decline in the Tweed River between 2000 and 2012 (Rogers and Lovelock 2015)*

UKEREBAGH ISLAND STUDY

The effects of sea-level rise on mangrove, saltmarsh and mudflat ecosystems were studied on Ukerebagh Island in the Tweed River by mapping vegetation distribution and measuring surface elevation trends (Rogers et al. 2014). Mangroves had been expanding and saltmarsh declining at the site. Observed changes over the study period were:

- water level increase: 4.24mm/yr (+/- 0.16)
- mangrove surface elevation increase: 1.4mm/yr (+/- 0.03)
- saltmarsh surface elevation increase: 0.17mm/yr (+/-0.09).

In this location, the sequence of changes in wetlands appears to be:

- sea levels rise, as a result of both long-term drivers and short-term variability in rainfall
- the surface elevation of mangroves and saltmarshes increases, but at a slower rate in saltmarshes
- saltmarsh vegetation is lost and some areas convert to unvegetated mudflat
- mangroves expand into some areas of unvegetated mudflats.

WHAT ARE THE IMPLICATIONS?

Coastal wetlands are threatened by sea-level rise on the ocean side and urban development on the land side, resulting in coastal squeeze. Increasing the delivery of sediment to wetlands, the sequestration of sediment within wetlands or increasing the volume of soil through greater productivity and organic matter, may help wetlands to respond to sea-level rise and remain in place. Conditions of low rainfall and El Niño conditions may limit wetland resilience by limiting increases in surface elevation.

The lag between rises in sea level and increases in wetland surface elevation is an indicator of wetland adaptive capacity. A high elevation deficit may be a trigger for management intervention, particularly for saltmarsh, which is more vulnerable to sea-level rise than mangroves.

OTHER CASE STUDIES AND RESOURCES

OTHER CASE STUDIES

The Hunter and Central Coast Regional Environmental Management Strategy (HCCREMS) program developed a Climate Change Adaptation Plan based on integration and prioritisation of risks identified through local government climate change risk assessments (HCCREMS 2010). Specific policies and actions that could reduce vulnerability were identified. Some of the actions recommended included increasing information and modelling of climate change impacts, improving knowledge building amongst the community, increasing community involvement in adaptation processes, and building capacity within planners on approaches for managing the land use planning and legal implications of climate change impacts.

http://www.hccrems.com.au/RESOURCES/Library/ClimateChange/HCCREMS_Coastal_Councils_Adaptation_Report.aspx

The city of Rockingham in Western Australia used a coastal vulnerability assessment when developing a Climate Change Response Strategy, including assessing of sea-level rise impacts and implications for adaptation. It is a long-term strategy that includes two main responses:

- organisational, including increasing knowledge of climate change within the council, developing a business continuity plan, and minimising costs of planning and adapting for climate change
- community-based, including building climate change knowledge within the community, ensuring reliable services during extreme weather events, and addressing issues of health and safety as a result of climate change.

http://rockingham.wa.gov.au/getmedia/9527a050-aeae-4e28-b18c-357c73bbacd5/1-nov_final-cor-climate-change-response-strategy.aspx

The Sydney Coastal Councils undertook a project to map and respond to coastal inundation as a result of climate-induced sea-level rise. They used detailed LiDAR data to identify areas at risk, inform planning and management strategies and improve consistency of responses to managing and adapting to climate change.

http://www.sydneycoastalcouncils.com.au/Project/Mapping_and_Responding_to_Coastal_Inundation

The Sydney Institute of Marine Sciences and the Australian Climate Change Adaptation Research Network for Settlements and Infrastructure conducted various research projects into coastal processes and responses to improve the efficiency and effectiveness of adaptation management policies and strategies in NSW.

http://climatechange.environment.nsw.gov.au/Adapting-to-climate-change/Adaptation-Research-Hub/Coastal-Node

Geoscience Australia conducted a nationwide assessment in 2012 of the vulnerability of coastal groundwater aquifers to sea-water intrusion to identify areas at risk (Ivkovic et al. 2012). Of the 27 case study areas for which a detailed analysis was possible, 47% were highly vulnerable, 34% moderately vulnerable and 17% had a low vulnerability to sea water intrusion. A further 20 sites were identified as highly vulnerable as sea water intrusion has already been documented.

http://www.ga.gov.au/about/what-we-do/projects/water/a-national-scale-vulnerability-assessment-of-seawater-intrusion

The Coastal Sediment Compartment project aimed to improve coastal vulnerability assessments to sea-level rise by improving shoreline erosion risk assessments (Mariani et al. 2013). Beach erosion was estimated for case study areas in NSW for a range of storm events and sequences of single or multiple storms. Clustering of storms is important when predicting beach erosion, as well as rip currents and sediment loss.

http://www.environment.gov.au/climate-change/adaptation/australias-coasts/coastal-compartments

TOOLS AND RESOURCES

Western Australian Government, Department of Planning (2014). *Coastal Vulnerability: Coastal Vulnerability Assessment Western Australia Projects List*

http://www.planning.wa.gov.au/674.asp

Local Government Association of Queensland (2014). *Coastal Hazard Adaptation Communication Guidelines.*

http://lgaq.asn.au/coastal-hazard-adaptation

The National Elevation Data Framework Portal by GeoScience Australia includes elevation and LidDAR data for government and other users.

http://nedf.ga.gov.au/geoportal/catalog/main/home.page

The OzCoasts website run by GeoScience Australia provides information on climate change risks to the coastal zone.

http://www.ozcoasts.gov.au/climate/index.jsp

The National Climate Change Adaptation Research Facility (NCCARF) is designing a coastal climate risk management tool, CoastAdapt, which seeks to provide practical guidance on how to manage risks associated with climate change and sea-level rise. *CoastAdapt* is designed to be relevant for local governments, natural resource managers and coastal infrastructure operators.

https://www.nccarf.edu.au/content/coastal-tool-overview

Australian Government, Department of Climate Change (2009). *Climate Change Risks to Australia's Coast: A First Pass National Assessment.*

https://www.environment.gov.au/system/files/resources/fa553e97-2ead-47bb-ac80-c12adffea944/files/cc-risks-full-report.pdf

REFERENCES

Department of Climate Change (2009). Climate Change Risks to Australia's Coast: A First Pass National Assessment, Department of Climate Change and Energy Efficiency Canberra, Australia.

Dowdy, A. et al. (2015). East Coast Cluster Summary, Climate Change in Australia Projections for Australia's Natural Resource Management Regions. Cluster Brochures. M. e. a. Ekström. Australia, CSIRO and Bureau of Meteorology.

Folke, C., Hahn, T., Olsson, P. and Norberg, J. (2005). Adaptive governance of social-ecological systems, Annual Review of Environment and Resources, 30, pp441 HCCREMS (2010). Coastal Councils Climate Change Adaptation Plan, Hunter and Central Coast Regional Environmental Management Strategy, Hunter Coastal Councils.

Ivkovic, K. M., S. K. Marshall, L. K. Morgan, A. D. Werner, H. Carey, S. Cook, B. Sundaram, R. Norman, L. Wallace, L. Caruana, P. Dixon-Jain and D. Simon (2012). National-scale vulnerability assessment of seawater intrusion: summary report. Canberra, Waterlines report, National Water Commission.

Lovelock, C., Bennion, V., Grinham, A. and Cahoon, D. (2011). The Role of Surface and Subsurface Processes in Keeping Pace with Sea-Level Rise in Intertidal Wetlands of Moreton Bay, Queensland, Australia, Ecosystems, 14, pp745-757.

Mariani, A., F. Flocard, J. T. Carley, C. Drummond, N. Guerry, A. D. Gordon, R. J. Cox and I. L. Turner (2013). East Coast Study Project – National Geomorphic Framework for the Management and Prediction of Coastal Erosion, Water Research Laboratory, University of New South Wales School of Civil and Environmental Engineering.

Marshall, N. A., C. J. Stokes, N. P. Webb, P. A. Marshall and A. J. Lankester (2014). Social vulnerability to climate change in primary producers: A typology approach. Agriculture, Ecosystems and Environment, 186, pp86-93.

Nicholls, R., Wong, P., Burkett, V., Codignotto, J., Hay, J., McLean, R., Ragoonaden, S., Woodroffe, C. (2007). Coastal systems and low-lying areas, in: Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J., Hanson, C.E. (Eds.), Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, pp 315-356.

OzCoasts. (2010). Sea-level rise maps – Frequently asked questions Retrieved 23/06/2015, from **http://www.ozcoasts.gov.au/climate/sd_fqa.jsp**

Rogers, K., and Lovelock, C. Coastal Vulnerability to sea-level rise, **https://terranova.org.au/repository/east-coast-nrm-collection/coastal-vulnerability-to-sea-level-rise/coastal-modelling.pdf/view**

Rogers, K. and C. Lovelock (2015). Indicator based modelling of the response of mangrove and saltmarsh to cliamte change and climatic variability on the Tweed River, The University of Wollongong and the University of Queensland.

Rogers, K., N. Saintilan and C. Copeland (2012). Modelling wetland surface elevation dynamics and its application to forecasting the effects of sea-level rise on estuarine wetlands. Ecological Modelling, 244, pp148-157.

Rogers, K. and Woodroffe, C.D. (2012). Incorporating estuaries as a source or sink of sediment within assessments of coastline risk and adaptation to climate change, 21st NSW Coastal Conference. NSW Coastal Society, Kiama.

Rogers, K., N. Saintilan and C. Copeland (2014). Managed Retreat of Saline Coastal Wetlands: Challenges and Opportunities Identified from the Hunter River Estuary, Australia. Estuaries and Coasts, 37, pp67-78.

Rogers, K., N. Saintilan and C. D. Woodroffe (2014). Surface elevation change and vegetation distribution dynamics in a subtropical coastal wetland: Implications for coastal wetland response to climate change. Estuarine, Coastal and Shelf Science, 149, pp46-56.

Rogers, K., C. Woodroffe and C. Lovelock (2014). First order assessment of the risk of estuaries to climate change in the East Coast NRM cluster, Report produced for the NRM Planning for Climate Change Adaptation Project, University of Woolongong and Global Change Institute, The University of Queensland.

Serrao-Neumann, S., Crick, F., Harman, B., Sano, M., Sahin, O., Staden, R., Schuch, G., Baum, S. and Low Choy, D. (2014). Improving cross-sectoral climate change adaptation for coastal settlements: insights from South East Queensland, Australia. Regional Environmental Change, 14, pp489-500.

Serrao-Neumann, S., Davidson, J.L., Baldwin, C.L., Dedekorkut-Howes, A., Ellison, J.C., Holbrook, N.J., Howes, M., Jacobson, C. and Morgan, E.A. (2016). Marine governance to avoid tipping points: Can we adapt the adaptability envelope? Marine Policy, 65, pp56-67.

Sharples, C., C. Attwater and J. Carley (2008). Three Pass Assessment Approach To Coastal Risk Management. IPWEA National Conference on Climate Change Response, Coffs Harbour, Australia.

USGS. (2010). Surface Elevation Table Concepts and Theory. Retrieved 22/06/2015, from **http://www.pwrc.usgs.gov/set/theory.html**

Steffen, Will, et al. Australia's biodiversity and climate change. CSIRO Publishing, 2009.

Van Dyck, S. (1995). False water-rat. In van Dyck, S. and Strahan, R. (Eds.) The Mammals of Australia. The Australian Museum/ Reed New Holland: Sydney.

Woinarski, JCZ. et al. (2000). Further records of the False Water rat Xeromys myoides from coastal Northern Territory, Australian Mammalogy, 21.2, pp245-247.

Wong, P.P., Losada, I.J., Gattuso, J.-P., Hinkel, J., Khattabi, A., McInnes, K.L., Saito, Y., Sallenger, A. (2014). Coastal systems and low-lying areas in: Field, C.B., Barros, V.R., Dokken, D.J., Mach, K.J., Mastrandrea, M.D., Bilir, T.E., Chatterjee, M., Ebi, K.L., Estrada, Y.O., Genova, R.C., Girma, B., Kissel, E.S., Levy, A.N., MacCracken, S., Mastrandrea, P.R., White, L.L. (Eds.), Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp 361-409.

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NRM CLUSTER

CLIMATE CHANGE IN AUSTRALIA

IMPACTS & ADAPTATION INFORMATION FOR AUSTRALIA'S NRM REGIONS

Cox, M., Serrao-Neumann, S., Marshall, N. and Low Choy, D. 2015. *Coastal Vulnerability.*
Climate Change Adaptation for Natural Resource Management in East Coast Australia Project, Griffith University.
https://www.terranova.org.au/repository/east-coast-nrm-collection/planning-packages