Existing spatial projections of coastal wetland response to sea-level rise in the East Coast NRM cluster

Background

Sea level is rising and the rate of sea-level rise is projected to accelerate in the 21st century. This will increase the elevation of shorelines along the open coast and within bays and estuaries.
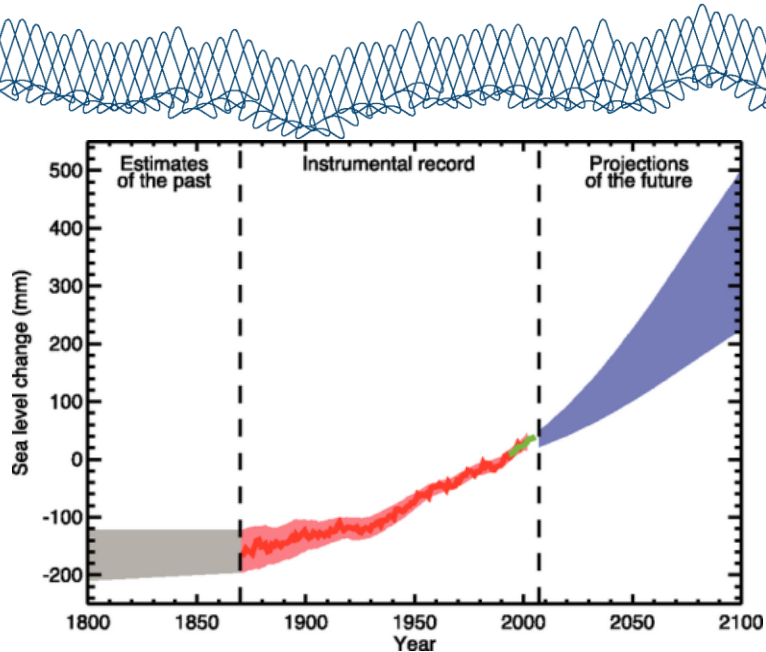

- Coastal ecosystems occur at the interface between the land and sea. They provide economically and socially important ecosystem services.

- Development in Australia has been concentrated in the coastal zone and there is continuing pressure to accommodate urban, commercial and industrial expansion.

- The increasing elevation of shorelines due to sea-level rise and encroachment of developments towards shorelines in threatens the distribution of coastal ecosystems and the services they provide.

- To adequately plan for sea-level rise and coastal developments, coastal planners and managers require information about the likely response of coastal ecosystems to sea level rise.

- Planning in the coastal zone is spatially explicit and requires spatial information about the response of coastal ecosystems to sea-level rise. Hence, spatial projections using ecosystem response models are a useful tool for coastal planners and managers in the 21st century.

- Understanding the autonomous response of coastal ecosystems to climate change is essential for increasing the accuracy of ecosystem response models and spatial projections.

Background

Coastal wetlands are concentrated around estuarine shorelines in the East Coast NRM and provide an ideal case study of ecosystem response modelling in the context of sea-level rise.

- The autonomous response of coastal wetlands to sea-level rise is variable, but is likely to include a combination of three mechanisms:

  - **Submergence** may occur when ecosystems are unable to increase elevation at rates equivalent to sea-level rise and the tolerance of in situ vegetation to inundation is exceeded.

  - **Horizontal migration** to higher elevations may occur as ecosystems attempt to maintain their intertidal position within the tidal prism.

  - **Vertical elevation gain** may occur in situ by increasing the soil volume. This may be facilitated by sedimentation, or biotic processes that increase the root and organic matter volume on soils.

Submergence

Horizontal migration

Vertical elevation gain
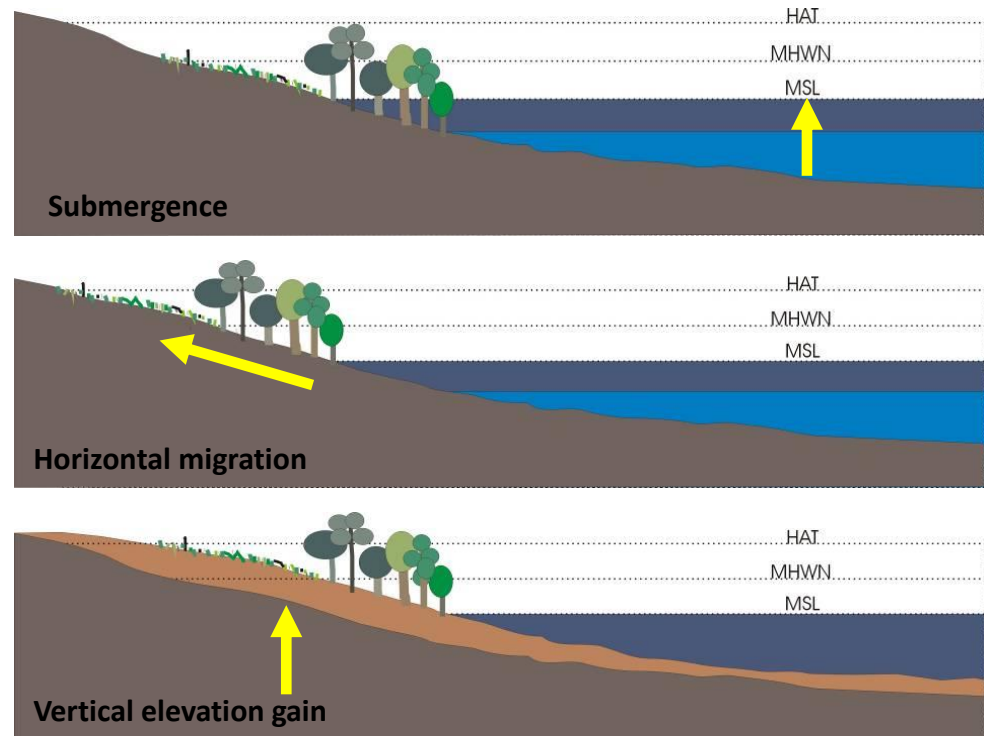
- These mechanisms should be incorporated in models and spatial projections

Coastal wetland ecosystem response modelling to sea-level rise

A range of spatial approaches are available to project coastal wetland ecosystem response to sea-level rise. Outputs will differ depending on a models capacity to project autonomous adjustment processes
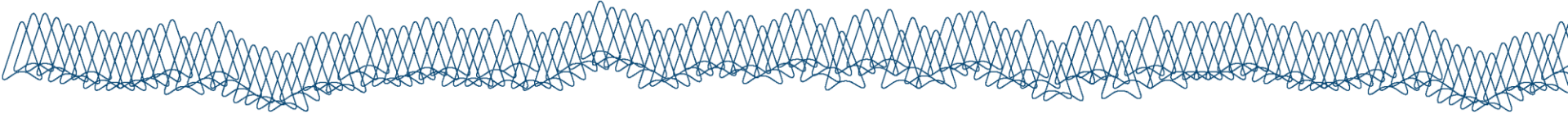
- Numerous approaches have been used in the east coast NRM cluster region. These include:
  - Elevation deficits and other indicators of adjustment
  - Bathtub models
  - Sea level affecting marshes model (SLAMM)
  - Spatially applied empirically-based elevation models

- **Aim:** To investigate coastal wetland ecosystem response modelling in the east Coast NRM to identify flaws in existing spatial projections and outcomes that are common between approaches. It is anticipated that this information will be used to guide interpretation of spatial projections and selection of models for future spatial projections of coastal wetland response to sea-level rise.

Elevation deficits and other indicators of vulnerability.

Elevation deficits are determined by comparing rates of elevation change to rates of sea-level rise. Rates of accretion may be used as a surrogate for elevation.

Elevation equilibrium occurs when Δ Elevation = Δ Sea Level; and vulnerability to submergence is low.

Elevation surplus occurs when Δ Elevation > Δ Sea Level; autonomous adjustment is high and vulnerability to submergence is low.

Elevation deficit occurs when Δ Elevation < Δ Sea Level; autonomous adjustment is low and vulnerability to submergence is high elevation. There may be a lag in the adjustment response to sea level rise.

Elevation capital refers to the difference between the elevation of the wetland and the elevation at which vegetation is intolerant of submergence. When capital is high, vulnerability diminishes. Surface Elevation Tables (SETs) are commonly used to monitor surface elevation change and estimate mean rates of surface elevation gain. When SETs are coupled with measures of accretion, the processes that influence elevation gain may be differentiated. Specifically, when:

- Δ Elevation = Vertical Accretion , then surface sedimentation is controlling elevation gain;
- Δ Elevation < Vertical Accretion, then below-ground processes causing subsidence or autocompaction are influencing elevation gain and increasing the vulnerability the submergence;
- Δ Elevation > Vertical Accretion, then below-ground processes causing swelling of the soil volume and uplift are influencing elevation gain and decreasing the vulnerability to submergence.
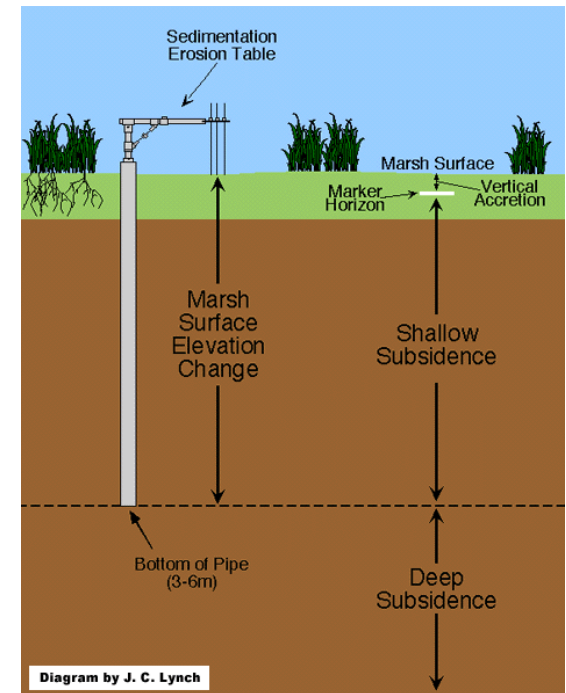

- SETs are used at Moreton Bay, Tweed River & Hunter River. Accretion has generally been found to not be a good indicator of elevation change.

- Elevation deficits have been identified throughout the study region. This is an indicator of vulnerability and should be interpreted in the context of the elevation capital.

Bathtub models

Bathtub models assume that elevation remains constant over time and the estuary fills like a bathtub as water levels increase. They only account for horizontal migration and submergence; and do not incorporate vertical elevation gain.

- Bathtub approaches are used as a first pass assessment of the area vulnerable to submergence. The most notable is the National First Pass Assessment which identified between 157 000 and 247 600 individual buildings (with estuaries excluded) at risk of inundation at year 2100 with 1.1 m sea-level rise (DCC 2009).

- Bath tub approaches have low data requirements and are easily undertaken in GIS using digital elevation models (DEMs). As such, they are commonly used in coastal zone studies where data and resources are limited. Precision is limited by the resolution of the baseline DEM used in the model.

- Bathtub approaches may be suitable when processes that alter intertidal elevations are slow or absent. This may be appropriate for rocky coasts where the lithology limits erosion and hydrodynamics limit accretion.

- On the Hunter River, Rogers et al. (2012) demonstrated that bathtub models over estimate the vulnerability of coastal wetlands to submergence. Bathtub modelling based on moderate rates of sea-level rise projected a 6% decline in the area with an elevation suitable for coastal wetlands. This contrasted modelling that incorporated horizontal and vertical elevation adjustment, which projected a 16% increase in area.
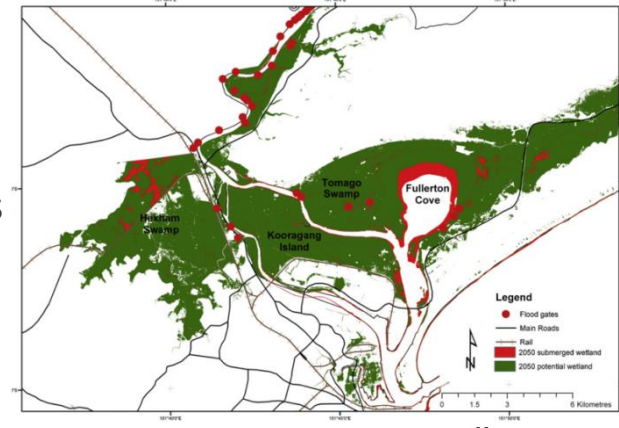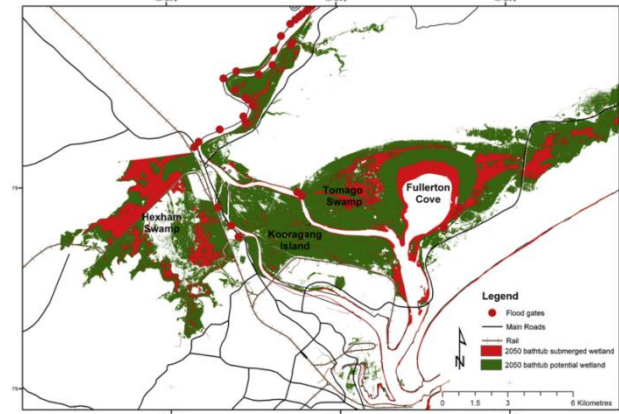
Sea Level Affecting Marshes Model (SLAMM)

SLAMM 'simulates the dominant processes involved in wetland conversions and shoreline modifications during long-term sea-level rise'. (Craft et al. 2009). There is robust discussion about the capacity of SLAMM to incorporate processes influencing elevation (Kirwan and Guntenspergen 2009).
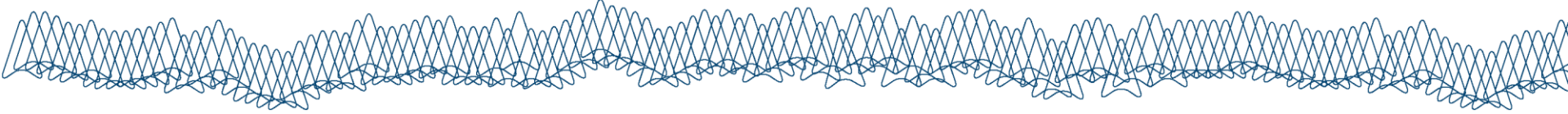
- SLAMM is freeware developed by Warren Pinnacle Consulting Inc. and requires low level spatial skills to execute (http://www.warrenpinnacle.com/prof/SLAMM/).

- SLAMM simulates the primary processes that affect the fate of wetlands as sea level rises, including inundation, erosion, overwash, salinity, and soil saturation. Model inputs consist of a DEM, tidal data, rates of wetland vertical accretion, spatial distribution of wetland vegetation and sea-level rise projections. Version 6.2 includes probabilistic approaches for simulating inundation risk.

- SLAMM has received some criticism due to the absence of mechanisms for estimating uncertainty, some of the underlying processes within the model that alter sedimentation rates and wetland elevations both spatially and temporally, and the quality of the data included in the model, particularly digital elevation models (Kirwan and Guntenspergen 2009).

- SLAMM has been used in the east coast NRM numerous times (Mills et al. 2014, Traill et al. 2011, Akumu et al. 2011, O'Mara 2012) with some success. Mills et al. (2014) integrated SLAMM with socio-economic modelling at Moreton Bay to demonstrate that coastal adaptation will require trade-offs among development and conservation goals.

# Spatially Applied Empirically-based Elevation Model

Models estuarine wetland response by establishing relationships between empirical measures of accretion and elevation, and environmental factors. The statistical relationship is applied in a spatial context to a baseline digital elevation model.

- Empirically-based elevation/accretion models have received consideration for some time; however their spatial application is relatively recent, due in part to the difficulty of projecting model parameters spatially.

- An empirically-based model was developed and applied spatially for the Hunter River (Rogers et al. 2012) using multiple sea-level rise projections and management scenarios (Rogers et al. 2013). As coastal geomorphology influences the response of landforms to coastal processes, the model is spatially explicit and cannot be directly applied to other estuaries. However the approach can be replicated elsewhere to capture the unique geomorphic response to coastal processes.

- Integration with management scenarios demonstrated the failure of current approaches to conservation planning, as conservation boundaries may not adequately protect coastal ecosystems that are migrating due to sea-level rise; and the need to accommodate wetland migration, in this case by facilitating tidal exchange across the coastal floodplain through the management of an existing network of levees and floodgates.
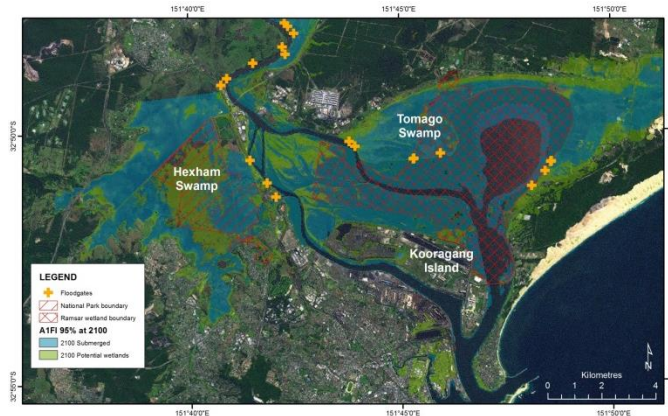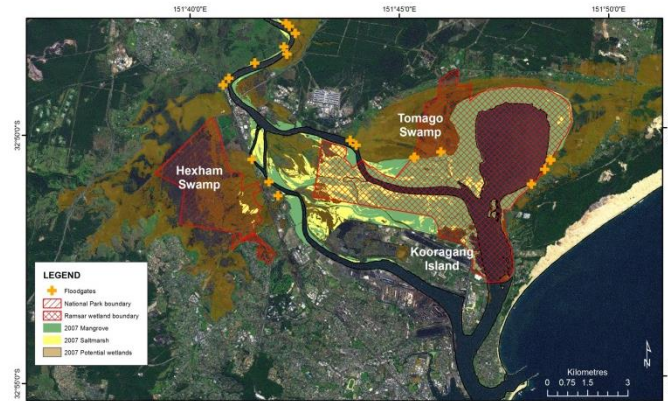
Summary

Spatial models consistently demonstrate changes in ecosystem distribution. Sea-level rise is projected to encroach on coastal ecosystems from seaward directions, and coastal developments are projected to at least limit horizontal wetland migration, but may also encroach upon coastal wetlands.
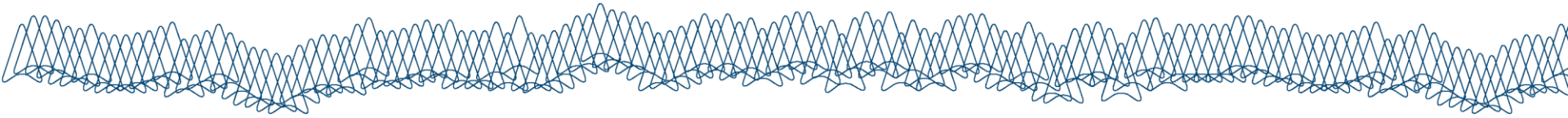
- Approaches to spatial modelling differ in the way they incorporate autonomous ecosystem responses to sea-level rise. Consequently, there has been some criticism of spatial models (e.g. Kirwan and Guntenspergen, 2009)

- Their usefulness for ecosystem planning in the 21st century has been demonstrated within the east coast NRM (e.g. Mills et al. 2014 and Rogers et al. 2013). This is only achieved when due consideration is given to the autonomous ecosystem response to sea-level rise, and spatial models are integrated with socio economic data.

- Data needs are relatively high for integrated ecosystem response and socio-economic modelling; and will limit wide-spread application of these approaches.

- The increasing availability of high resolution DEMs (i.e. LiDAR derived DEMs) will improve the precision of models.

- Spatially explicit biophysical data is currently limiting our capacity for extensive spatial modelling of ecosystem response to sea-level rise throughout the east coast NRM.

- A summary of existing spatial coastal wetland ecosystem response modelling is provided in supplementary material.

References

- Adame, M.F., Neil, D., Wright, S.F., Lovelock, C.E., 2010. Sedimentation within and among mangrove forests along a gradient of geomorphological settings. Estuarine, Coastal and Shelf Science 86, 21-30.

- Akumu, C., Pathirana, S., Baban, S., Bucher, D., 2011. Examining the potential impacts of sea level rise on coastal wetlands in north-eastern NSW, Australia. Journal of Coastal Conservation 15, 15-22.

- Craft, C., Clough, J., Ehman, J., Joye, S., Park, R., Pennings, S., Guo, H., Machmuller, M., 2009. Forecasting the effects of accelerated sea-level rise on tidal marsh ecosystem services. Frontiers in Ecology and the Environment 7, 73-78.

- DCC, 2009. Climate Change Risks to Australia's Coast: A first pass national assessment. Department of Climate Change, Canberra, Australia.

- IPCC, 2007. Summary for Policymakers, in: Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M., Miller, H.L. (Eds.), Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

- Kirwan, M.L., Guntenspergen, G.R., 2009. Accelerated sea-level rise - a response to Craft *et al.* Frontiers in Ecology and the Environment 7, 126-127.

- Lovelock, C., Bennion, V., Grinham, A., 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, 745-757.

- Mills et al. (in press) reconciling development and conservation under coastal squeeze from rising sea-level. Nature Climate Change (in press)

- O'Mara, J. 2012. Sea level rise and landscape change in intertidal wetlands. Bachelor of Science Honours Thesis, university of Queensland

- Rogers, K., Saintilan, N., Copeland, C., 2012. Modelling wetland surface elevation and its application to forecasting the effects of sea-level rise on estuarine wetlands. Ecological Modelling 244, 148-157.

- Rogers, K., Saintilan, N., Copeland, C., 2013. Managed Retreat of Saline Coastal Wetlands: Challenges and Opportunities Identified from the Hunter River Estuary, Australia. Estuaries and Coasts, 1-12.

- Rogers, K., Saintilan, N., Howe, A.J., Rodríguez, J.F., 2013. Sedimentation, elevation and marsh evolution in a southeastern Australian estuary during changing climatic conditions. Estuarine, Coastal and Shelf Science.

- Rogers, K., Saintilan, N., Woodroffe, C.D., 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, 46-56.

- Traill, L.W., Perhans, K., Lovelock, C.E., Prohaska, A., McFallan, S., Rhodes, J.R., Wilson, K.A., 2011. Managing for change: wetland transitions under sea-level rise and outcomes for threatened species. Diversity and Distributions 17, 1225-1233.

Contacts
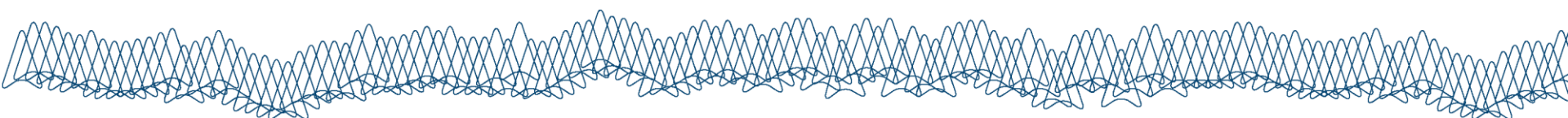
Dr Kerrylee Rogers
The University of Wollongong
GeoQuest Research Centre
Kerrylee@uow.edu.au

(02) 4239 2512
www.smah.uow.edu.au/
geoquest/index.html

Dr Morena Mills
The University of Queensland
Global Change Institute
morena.mills@uq.edu.au

(07) 3443 3113
www.gci.uq.edu.au

Professor Cath Lovelock
The University of Queensland
Global Change Institute
c.lovelock@uq.edu.au

(07) 3365 2304
www.gci.uq.edu.au

Thank you

From the East Coast Cluster

Supplementary material

Mode	Study Site	SLR Scenario and Other Parameters	Outcomes	Source
Indicator	Moreton Bay Mangrove Saltmarsh	Elevation – rod surface elevation table (RSET) Vertical accretion – marker horizon (MH) SLR – 2.358 mm y^{-1} (2000-2011)	Sandy areas, eastern bay Mangrove surface elevation gain 5.9mm y^{-1}, accretion 8.5 mm y^{-1}, subsidence 2.1 mm y^{-1}, elevation surplus 2 mm y^{-1} saltmarsh surface elevation gain 1.9mm y^{-1}, accretion 2.86 mm y^{-1}, subsidence 0.3 mm y^{-1}, elevation deficit ~0.4 mm y^{-1} Muddy, western bay Mangrove surface elevation gain 1.4mm y^{-1}, accretion 8.5 mm y^{-1}, subsidence, 7.9 mm y^{-1} elevation deficit ~1 mm y^{-1} saltmarsh surface elevation gain 0.3mm y^{-1}, accretion 0.99 mm y^{-1}, subsidence 1.3 mm y^{-1}, elevation deficit ~2 mm y^{-1}	Lovelock et al., 2011
	Moreton Bay Seaward fringed mangrove Landward scrub mangrove Saltmarsh/cyanobacterial	Tide dependent	Sediment deposition rate higher in tidal mangroves whereas in riverine mangroves sediment deposition was generally more uniformly distributed throughout the wetland High sedimentation rates indicated by – high TSS concentrations, long inundation period, and slow ebb current and high depth of inundation Higher concentrations of glomalin deposition was found in fringe zone of tidal mangroves and in the scrub zone of riverine mangroves	Adame et al., 2010
	Hunter River Mangrove, saltmarsh, encroachment zone (mangrove and saltmarsh)	Elevation – surface elevation tables Accretion – marker horizons Long-term SLR at Newcastle Harbour – 1.1 mm y^{-1} (1966-2010)	Mangrove accretion 2.85 mm y^{-1}, elevation change 2.23 mm y^{-1}, elevation surplus 1.1 mm y^{-1} Encroachment accretion 2.81 mm y^{-1}, elevation change 0.66 mm y^{-1}, elevation deficit -0.4 mm y^{-1} Saltmarsh accretion 1.72 mm y^{-1}, elevation change 1.39 mm y^{-1}, elevation surplus 0.3 mm y^{-1}	Rogers et al. 2013
	Tweed River Mangrove, saltmarsh	Water level rise 4.24 mm y^{-1} (Letitia 2A gauge 1987-2013)	Mangrove elevation change 1.40 mm y^{-1}, Elevation deficit ~2.8 mm y^{-1} Saltmarsh elevation change 0.17 mm y^{-1}, Elevation deficit ~4 mm y^{-1}	Rogers et al. 2014

Mode	Study Site	SLR Scenario and Other Parameters	Outcomes	Source
Bathtub	Hunter River Mangroves Saltmarsh	LiDAR based DEM SLR 3.65 mm y^{-1} to 2050	Mangrove and saltmarsh decline in area by 6%	Rogers et al. 2012
	Australian coastline Inundation of coastal zone to 145 m inland. Excluded most estuaries, though some embayments were included	Potential SLR of 1.1 m + modelled high water level + 1-in-100 year storm tide values (if available)	At 2100, up to $63 billion (replacement value) of existing residential buildings are potential at risk of inundation, equating to a lower and upper estimate of 157 000 and 247 600 individual buildings at risk of inundation.	DCC 2009

Mode	Study Site	SLR Scenario and Other Parameters	Outcomes	Source
SLAMM	Moreton Bay Wetland Mangroves	B1-median estimate of 0.29m A1F1-max. estimate of 0.64m Maximal limit-1.8m	Overall - decline in wetland Mangrove decline under both expected B1 and maximal 1.8m SLR Minimal SLR showed transitions from sedge, saltmarsh and seagrass to mangroves A1F1 scenario shows mangroves will migrate inland	Traill et al., 2011
	Moreton Bay Wetlands	66% probability of occurrence from 0.44-1.23m Implementation of two adaptation strategies influence these impacts 1. Defend – where areas subject to flooding are defended by building leeves 2. Retreat – where areas subject to flooding are purchased to permit inland	- Coastal urban area within 10km from the coast and <20m in elevation will expand by 65km² (62%) - Urban areas occupy 14% of the 193km² of coastal land which has >5% chance of inundation - Existing and future urban areas of ~ 21km² (13%) will experience 20% inundation, areas 18km² (12%) will experience 50% inundation, and areas of 10m² (6%) will experience 95% inundation 1. Defend approach – if the Government chooses to build defence mechanisms as a solution to inundation then the extent of all coastal ecosystems decreases from a loss of 0.01km² of sedgelands to loss of 71km² of mangrove 2. Retreat approach – coastal ecosystems will expand by ~19km² (17%) by 2100 ❖ Upper intertidal mangrove will increase by 24-74km² (73-225%) ❖ Sedgelands-Casuarina will increase by 3-8km² (77-203%) ❖ Decline in sedgeland by 68-97% and seagrass loss of 25-29%	Mills et al., 2014
	Tweed Heads to Evans Head Mangrove & saltmarsh Inland fresh marsh Inland open water	Sea level historic trend-1.18mm/yr Marsh erosion rate-2.0 horz.m/yr Swamp erosion rate-1.0 horz.m/yr Tidal flat erosion-0.5 horz.m/yr Mean accretion rate-1.4 1.2 mm/yr Beach sedimentation rate-0.8 mm/yr Frequency of overwash-25 years Sea level rise 1.0 m by 2100	Mangrove and saltmarsh Increase 36.58 km² to ~101.64 km² (~178%) Transitional marshes increased from 0 km² to ~ 250.51 km² Estuarine open waters increase from ~35.89 km² to ~161.34 km² (+350%) Non-tidal swamps decrease from 149.26 km² to 124.72 km² (-16.4%) Inland fresh marsh decrease from 225.67 km² to 168.04 km² (-25.5%) Tidal flats decrease from 80.79 km² to 0.77 km² (-99%)	Akumu et al. 2010
	Moreton Bay Mangrove lower, mangrove upper, claypan/samphire, Sporobolus grassland	B1 scenario 0.567 m at 2100 A1FI scenario 0.671 m at 2100 1.79 m at 2100 Historic sea level rise 2.358 mm y⁻¹ Mean tide level -0.01 m Salt boundary 1.26 m Overwash frequency 1 in 25 years Surface elevation see Lovelock et al. 2011	Projected general trend of mangrove expansion and claypan/samphire decline across all scenarios Year 2000 areas for mangrove lower 10.58 km², mangrove upper 45.73 km², Claypan/Samphire 5.25 km², Sporobolus grassland 22.88 km² B1 scenario projected areas for mangrove lower 10.16 km², mangrove upper 73.52 km², Claypan/Samphire 5.18 km², Sporobolus grassland 22.44 km² A1FI scenario projected areas for mangrove lower 9.42 km², mangrove upper 79.11 km², Claypan/Samphire 4.65 km², Sporobolus grassland 22.49 km² 1.79 m scenario projected areas for mangrove lower 1.08 km², mangrove upper 86.09 km², Claypan/Samphire 0.16 km², Sporobolus grassland 23.48 km²	O'Mara 2012

Mode	Study Site	SLR Scenario and Other Parameters	Outcomes	Source
Empirical	Hunter River Mangroves Saltmarsh	Elevation – SET Accretion –MH LiDAR based DEM SLR of 3.65mm y^{-1} to 2050	Support up to 8069ha of estuarine wetland 848ha landward extension Mangrove and saltmarsh increase in area by 16% Shoreline extension of 279ha	Rogers et al. 2012
	Hunter River Saline coastal wetland	Low sea level rise projection based on B1 5% minima with maximum rise of 0.185 m at 2100 High sea level rise projection based on A1FI 95% maxima with rise of 0.819 m at 2100	Under low sea-level rise scenario - 20% increase in area by 2100 with all floodgates open. Ramsar area increase of 566ha, Hunter Wetland National Park of 1,108ha. Also the increase in elevation of the wetland surface by 2100 equates to a soil volume of 1.67×10^7 m^3 equivalent to 602,035 tonnes of carbon buried. Under high sea-level scenario - 56% decrease in potential saline coastal wetland area by 2100 with all floodgates open. - The model indicated a decrease of 1,393ha from present extent within the Ramsar area and a decrease of 992 ha in the national park.	Rogers et al. 2013