National Marine Science Plan

Theme: Urban Coastal Environment

White Paper: Climate change impacts and adaptation in the urban coastal environment

Abstract Over 85% of the Australian population lives within the coastal zone. Physical impacts of climate change, such as sea-level rise and extreme inundation events, pose a considerable threat to coastal settlements and the coastal ecosystems that provision and support them. This paper considers major knowledge gaps and research needs in order to: (1) assess the risk climate change poses to coastal settlements, coastal ecosystems and the interplay between the two; (2) develop appropriate adaptation strategies for coastal settlements and ecosystems; and (3) ascertain how land-based activities and adaptation strategies will influence the adaptive capacity of coastal ecosystems.

Background

Globally, coasts and estuaries are among the most densely populated and productive environments on earth. Consequently, the threat posed to them by climate change has been attracting global research effort for at least the past 30 years (e.g. Barth and Titus 1984; Broadus et al. 1986). Initially, research was focused on assessing the impacts and risk of sea level rise. Over time, emphasis has shifted from impact and risk assessment to adaptation, and from sea level rise, to considerations of how multiple climate stressors might interact to influence the coastal environment. Research efforts have also begun to consider how stressors associated with coastal development exacerbate climate risk.

Within Australia, assessments of climate impact and risk to our coastal environments have been underpinned by a well-developed national capability in atmospheric and oceanographic research (2012 ERA ratings 3-5). Research into the adaptation of urban coastal environments to climate change has primarily occurred over the past 5-10 years, facilitated to a large extent by the National Climate Change Adaptation Facility (NCCARF), that was funded from 2008-2013 and will again receive funding from late 2014-2017. To date NCCARF has included research networks in the areas of 'Marine Biodiversity and Resources' and in 'Settlements and Infrastructure', although it is presently being restructured. In 2013, the Marine Biodiversity and Resources network included >800 members, ~55% of whom were scientific researchers and ~45% comprised of representatives from national and international government bodies, NGOs and other marine stakeholders (Holbrook and Brooker 2013a).

Additionally, the Australian Institute of Marine Science has research programs investigating interacting effects of climate change and coastal development on tropical marine ecosystems. These are supported by the National Sea Simulator, a $35 million experimental research facility that was opened in mid 2013 and allows multi-generational studies of the impacts of climate change and coastal development on tropical marine species and ecosystems. The now defunct CSIRO Climate Adaptation Flagship, established in mid 2008, was also a major hub of research on climate change adaptation of urban coastal environments.

At the state level, research has been facilitated by state government initiatives, such as the Victorian Centre Climate Change for Adaptation Research, which was funded from 2009-2013, the NSW Adaptation Hub (funded from 2013-2016) and the Western Australian Institute of Marine Science.

Federal government funding sources have included:

- **National climate change adaptation program,**: $129 million between 2007 and 2013; the Coalition Government has committed to providing $9 million to NCCARF over three years, starting from late 2014 to ensure the research programs can continue. A requirement of the renewed funding is that NCCARF deliver a tool to guide better decisions about managing risks from coastal climate change.
- **Caring for our coasts:** $25 million over five years to help coastal communities prepare and adapt to the impacts of climate change, including initiatives such as the National Coastal Risk Assessment; $100 million for a five year, Community Coast Care Program

- **Australian Research Council:** Discovery and Linkage Grants
- **CSIRO Flagships:** In the past, Climate Adaptation Flagship (Sustainable cities and coasts theme). From July 2014, Oceans and Atmospheres flagship
- **National Environmental Research Programs:** $20 million each year for research on the management and conservation of Australia's unique biodiversity and ecosystems
- **Coastal Adaptation Decision Pathways Projects**
- **The Climate Change Impacts and Adaptation Research Grants Program** is part of Stream 2 of the Regional NRM Planning for Climate Change Fund (NRM Fund), which has been developed as part of the Australian Government's Clean Energy Future plan.

State government funding sources have included (but are not limited to):
- **Victorian Centre Climate Change for Adaptation Research:** operated from 2009-2013
- **NSW Adaptation Hub:** $2.75 million over three years (2013-2016), distributed between three nodes, including a Coastal processes and a Biodiversity node

Other funding sources include contracts with local government, private companies and organizations.

Relevance

Australia is a coastal nation. Over 85% of our human population lives within 50 km of the coast and all six state capital cities, as well as Darwin in the Northern Territory, are in the coastal zone. Australians place high recreational and aesthetic value on our coasts. Furthermore, as a consequence of the coastal distribution of our population, much of the nation’s transport, commercial, residential and defense infrastructure is located along our coastlines. Until recently, this infrastructure was planned and built under the assumption of a stable climate, of known variability.

Physical impacts of global climate change, such as coastal flooding cause by sea level rise and altered patterns of rainfall and storm surge, pose a serious risk to coastal settlements and infrastructure. The number of Australian assets that are exposed to sea level rise is great, and will increase as the Australian population grows and as assets are increasingly located in the coastal zone (DCCEE 2011). Under a sea-level rise of 1.1 m, it is predicted that more than $226 billion in commercial, industrial, road and rail, and residential assets would be exposed to inundation and erosion hazards (DCCEE 2011). There is urgent need for decisions about future development to take into consideration and adequately plan for climate change. Further, there is need to identify pathways for adapting existing settlements and infrastructure to climate change, that also enable adaptation of the amenity and services provided by the coastal ecosystems that support them.

The responsibility for climate change adaptation lies with all levels of government (Commonwealth, State, Local), businesses, households and the community.

- Governments – on behalf of the community – are responsible for managing risks to public goods and assets (including the natural environment) and creating an institutional, market and regulatory environment that supports and promotes private adaptation.
- Private parties are responsible for managing risks to private assets and incomes.

Hence, the CSIRO Climate Change Adaptation Flagship (2009) identified the following stakeholders, for which research on Climate Change Impacts and Adaptation is particularly relevant:

- Specific communities or regions which are vulnerable on the basis of their location or because of the principal industry that supports them.
- Federal, state and local governments and associated groups (e.g. local government associations, various government departments and advisory groups).
- Infrastructure management agencies (responsible for management of ports, air and land transport, water, energy, and property).

- Industry groups and particular industries, including parks management and natural resource management; construction; health; tourism; agribusiness, forestry and fisheries; insurance and finance; mining; and emergency management.
- Associations and non-government organisations, including those responsible for the built environment, the natural environment, and those involved with indigenous issues.

Many of the impacts of climate change and variability have been, or will be, experienced at the local level. As a consequence, local governments are often at the frontline of climate change adaptation. Many local governments have begun engaging in climate change adaptation activities (Gurran et al. 2011). Whereas larger local governments are able to provide resources to assist constituents prepare for climate adaptation, smaller jurisdictions are limited by resources, including the capacity of local planning staff to adequately assess development proposals in vulnerable locations. Consequently, research that can be applied at local levels is particularly important. Pathways to planning and implementing adaptation plans are, however embedded in a boarder governance framework, provided by Stated and Commonwealth Governments.

Science needs

Through 2008-2009, National Adaptation Research Plans (NARPs) were developed in the theme areas of 'Marine Biodiversity and Resources' (Mapstone et al. 2010) and 'Settlements and Infrastructure' (Thom et al. 2010), driven by NCCARF. These NARPs were revised in 2012 in the context of the evolving literature and national priorities (Cox et al. 2012; Holbrook and Johnson 2012; Holbrook et al. 2012). Many of the research needs identified and prioritised in these NARPs are relevant to the research theme of this white paper, 'Climate change impacts and adaptation in the urban coastal environment'. Although there has been significant research effort put towards some of these research priorities in the subsequent two years, many remain key research gaps (Cox et al. 2012; Holbrook and Johnson 2014; Johnson and Holbrook 2014). Hence, the list of broad science needs below draws heavily on the recommendations made by the two NARPs and their updated versions.

1. *Refining coastal process models so that they are a useful tool for predicting erosion and inundation at the local scale*

Urban coastal environments are variably exposed to the impacts of climate change. Coupled models of fluvial–estuarine–oceanic phenomena are required in order to identify low-lying coastal lands at risk of inundation under extreme events. Models relating sediment transport to hydrodynamic processes are needed to assess erosion hot spots under future climate scenarios. Presently, there is inconsistency in approaches to regional hydrodynamic modeling which, in turn, gives rise to differences in the interpretation of coastal inundation and riverine flooding data. Existing hydrodynamic models need to be refined to link riverine floods with wave-induced storm surges. Better information is needed about hydro-dynamic processes and interrelationships with sediment supply over time, including thresholds and tipping points that could result in fundamental landform changes. These models will help in identifying the locations and time-points of switchover from accretion to erosion events and from normal flow to flood events.

Improved projections of future climate change for the Australian coastal zone would be aided by the development of a coastal climate model which integrates existing terrestrial, marine and sea level models and considers the interactions amongst these. In particular, improved information is required with respect to climate change impacts on winds and hydrodynamics (i.e. waves, tides and currents) around the Australian coastline (Hadwen et al. 2012).

2. Identifying when and where to apply the various social, ecosystem-based, engineering and technical approaches to adaptation of coastal settlements and infrastructure

A number of different options are available for adaptation of vulnerable Australian coastal communities to coastal flooding and erosion caused by climate change. These options include: (i) retreat (e.g., property relocation); (ii) accommodate (e.g., natural disaster management); and (iii) protect (e.g., hard and soft engineering options) (Klein et al. 2000). Which of these options to pursue will depend on the exposure of the settlement to climate change, the socio-economic capacity of the community to retreat or protect, the economic and environmental costs and benefits of the options. Whereas large settlements typically have a high capacity to adapt via protection, smaller settlements may not have the socio-economic capacity to do so.

Historically, approaches to coastal protection in Australia have involved hard engineering, such as construction of seawalls, revetments, groynes and breakwalls to mitigate sea-level rise and storm-surge or constructing dams to mitigate flooding. More recently, use of soft engineering, such as beach scraping, to reshape dune systems, and beach nourishment, has been growing in popularity. Other potential strategies involve ecosystem-based strategies such as the restoration of living shorelines, that buffer wave energy and trap sediments, and land-based restoration activities that enhance water retention and decrease runoff into river systems and estuaries. Although, on sandy beaches, soft engineering is increasingly preferred over hard engineering because it conserves public beach amenity and is viewed as ecologically more benign, it is a short-term solution, with renourishment required every 3-5 years, unless the cause of the erosion is addressed. Hence, the benefits of nourishment over hard engineering approaches may be offset by a high cost and the potential for cumulative ecological impacts from successive nourishment events (see Manning et al. 2014).

A framework is needed for evaluating when and where communities should retreat, accommodate or protect and, in the event of protection, which of the various methods to choose. This requires knowledge of: (1) how demographic pressures and socio-economics vary among Australian coastal settlement types; (2) the stakeholders affected by climate change in different coastal settlement types (e.g. fishing industry, tourism industry etc); (3) whether estuarine and coastal ecology co-varies with settlement type; (4) the socio-economic and ecological benefits of the various options in different environmental settings; and (5) the socio-economic and ecological costs of the various options in different environmental settings. Hence, this research question requires integration of science and social science.

3. Ascertaining the interacting effects of coastal development and climate change on estuarine and coastal ecosystems

In urbanized coastal environments, ecosystems are not only exposed to climatic change but also to the multiple effects of coastal development that may include habitat destruction, sedimentation, pollution, and species invasions. Although it is widely acknowledged that the condition of individuals, communities and ecosystems will influence their capacity to adapt to climatic change, relatively few studies have actually tested this or ascertained the tipping points at which state changes or negative feedbacks occur. Studies examining interacting effects of climatic stressors and coastal development have primarily focused either on the issue of coastal squeeze (i.e. where urban structures such as seawalls prevent intertidal communities from shifting landward in response to sea level rise) or else the interacting effects of nutrient enrichment, temperature and enhanced carbon dioxide on rocky reef assemblages, the latter almost exclusively in small laboratory mesocosms (e.g. Russell et al. 2009). There is need for studies considering interacting effects of coastal development and climate change on other estuarine and coastal ecosystems, at ecologically relevant scales, and levels of complexity. Determining which adverse ecological responses to climate change can be reduced by management interventions that reduce, cap or eliminate other stressors is critical to the maintenance of productive and functional estuarine and coastal ecosystems.

4. *Ascertaining how land-based climate change adaptation decisions can be developed and implemented to also support adaptation of marine resources and biodiversity*

As the transition zone between the land and sea, estuarine and coastal ecosystems are influenced by processes occurring in each of these other biomes. Consequently, climate change impacts to and adaptation of coastal settlements is likely to have a major impact on estuarine and coastal ecosystems (Holbrook and Johnson 2012). Through the rapidly growing field of green engineering (see separate white paper by Dafforn et al.) we have begun to consider how hard engineering (e.g. construction of seawalls, breakwalls, groynes, barrages etc) that is commonly practiced to protect coastal settlements from sea-level rise, erosion and storm surge, may be modified to promote the biodiversity of rocky reef communities. However, little is known about how the design of these structures influences impacts to adjacent ecosystems such as subtidal sediments, tidal flats, seagrass beds, and mangrove forests. Nor has it been specifically considered how these structures might be engineered to maximize the adaptive capacity of biodiversity to climate change. Furthermore, as green roofs and walls gain momentum as a climate change adaptation tool on the land, it is unclear how their widespread implementation might benefit the adjacent coastal environment by intercepting runoff and altering microclimate.

Additionally, little is known of how soft engineering (e.g. beach scraping to rebuild dune systems, beach nourishment, revegetation of dune systems and estuarine shorelines – sometimes with non-native species - to stabilize sediments) may modify estuarine and coastal ecosystems or in some instances allow for the migration and expansion of supra-tidal, intertidal, and shallow subtidal habitats in response to sea level rise. Although there has been some work done on ecological impacts of beach nourishment internationally (e.g. Peterson et al. 2014, Manning et al. 2014), in Australia only two published papers have addressed its ecological impacts (Jones et al. 2008; Schlacher et al. 2012).

Understanding how land-based adaptation of coastal settlements modifies quality, quantity and periodicity of river discharges, estuarine and coastal water quality, the grain size of sediments, coastal connectivity and habitat availability to estuarine and coastal organisms is a first step in ascertaining how land-based adaptation strategies may be modified to also support adaptation of coastal biodiversity.

5. *Evaluating adaptation options for estuarine and coastal ecosystems in urban environments*

Estuarine and coastal ecosystems may respond to climate change autonomously, through migration and behavioural, phenotypic and evolutionary change or through human intervention (e.g. selective breeding, assisted translocations etc). The ability of coastal ecosystems to adapt and respond to changes in environmental conditions arising from climate change pressures rests, in part, with the eco-evolutionary dynamics of keystone species (e.g. seagrasses). In urban environments, the capacity of organisms to autonomously adapt to climate change may be diminished if their prior condition is compromised by other stressors, habitat is not available for migration and range shifts, or effective population sizes are small (and hence genetic material available for selection is diminished).

There has been relatively little work examining the capacity for estuarine and coastal organisms to display cross-generational adaptation to climate change, and how this varies according to urban habitat context. Although there has been some consideration of how marine spatial planning (e.g. establishment of reserves and protected areas) may assist in climate change adaptation, other options, including assisted translocations and breeding programs have received relatively little attention.

Sea level rise may create new opportunities for habitat migration / expansion into marginal, low lying agricultural and industrial lands adjacent to estuaries. However uptake of these options will require greater certainty around: funding sources; economic models; soft engineering techniques; and success indicators.

6. *Cross cutting tools and approaches to support the application of knowledge to climate change adaptation planning*

The complexity of the coastal zone is clearly shown in the above discussion. Effective decision-making must be based on the integration of information from multiple sectors, and must account for the influence of multiple drivers and pressures. The population of Australia will continue to grow and the demand for coastal resources will increase. There is a strong need for the development of knowledge and tools which support multi-faceted policy and decision making and helps decision makers understand and deal with the complexity. This includes the needs for effective communication approaches, consideration of appropriate temporal and spatial scales, and links to stakeholders who may not traditionally have been engaged in the decision-making processes.

Cross cutting research includes the need for information to help integrate mitigation and adaptation approaches and ensure the most cost effective outcomes are achieved that do not result in unforeseen consequences.

7. Taking stock

Research output is being generated at a rapid rate across the world. A formal approach by which outputs are integrated and consolidated to help understand the breadth of knowledge available in relation to key questions would help direct research effort, but also help the uptake of research by end users. Funding for this sort of work is difficult to obtain and should be a strong consideration.

Perspective

It is now well established that our climate is changing as a result of human activities that have increased greenhouse gas emissions. Although efforts to reduce greenhouse gas emissions remain a high priority, further climatic changes are expected across all emissions reductions scenarios. Hence, it is important that we plan and prepare for the unavoidable impacts of climate change, both on coastal settlements, as well as the coastal ecosystems that provision these and provide important regulatory and recreational services. Because many of the effects of climate change will be experienced at the local scale, adaptation options must take into consideration spatial variation in exposure to climate change, the vulnerability of human settlements and the coastal ecosystems that support them, the adaptive capacity of settlements and ecosystems, and the regulatory frameworks in which adaptation will occur. Hence, although there is considerable global research-effort into climate change impacts to and adaptation of urban coastal environments, this cannot necessarily be applied to Australian coastal environments which differ in climate change exposure, ecosystem structure, human pressures and regulatory framework. Hence, research focused at the local scale is urgently needed in Australia.

Exposure of Australian urban coastal environments to climate change

To improve models of how estuarine and coastal shorelines will respond to climate change, and to better understand how multiple interrelated variables give rise to extreme inundation events, better data are needed. Although the Australian Integrated Marine Observing System has made major inroads into addressing the deficiency of data for Australia's oceans, its coverage of coastal and estuarine environments is limited. Monitoring programs are needed that provide measurements of coastline position, nearshore waves, sea levels and coastal currents. These measurements need to be accompanied by data on land elevation, coastal bathymetry and fresh water run-off from the terrestrial environment. A Coastline Observatory, spanning at least 15 or more representative coastal shoreline sites, has been proposed so as to provide baseline data on Australia's coastal and estuarine environments, and to provide data against which to test the predictions of newly emerging coastal models (Woodroffe 2012).
Timeframe: establish within 5 years.

Impacts of climate change on urbanized coastal ecosystems

While advances are being made in this field in Europe and North America, the focus has tended to be at the broader, coastal ocean scale which does not adequately consider the more localized but nonetheless significant impacts that may occur at the urbanized estuary scale. Furthermore, very little is known about the Australia context which fundamentally differs from the northern hemisphere systems due to differences in climate, trophic status, history of urbanization and geomorphology. Scientific priorities for addressing this issue in Australia can be divided into key areas: monitoring / baseline data collection; addressing knowledge gaps through targeted research; building functional ecosystem response models that allow scenario testing of multiple stressors and prediction of likely impacts on ecosystem function.

Monitoring – There is need to establish a network of sentinel sites at which biological and physico-chemical changes are monitored over long time periods to elucidate trends and provide a baseline for assessing climate change impacts. The sites should be selected such that they include tropical, subtropical and temperate ecosystems, in estuaries and the coastal ocean, and should span urban contexts ranging from capital cities, regional centers and smaller urban settlements.

Timeframe: establish within 5 years.

Targeted research – The response of many species of conservation priority to climate change has not been determined. In particular, little is known about the adaptive capacity of key ecosystems in urbanized sub-tropical and temperate coastal environments (Holbrook et al. 2012). Targeted research is needed to establish impacts of multiple stressors on keystone species, and on their adaptive capacity to climate change.
Timeframe: next 5 years

Building functional response models - Better functional models linking catchment pressures to ecosystem response are needed to understand and predict the implications of potential interactions between increased coastal development and climate change. These models need to be suitable for application to different systems (e.g. riverine estuaries, ICOLLs, lakes) and need to consider primary producers (seagrass and macroalgae), invertebrates and fish.
Timeframe: Models developed over next 5 years, and refined over next 10 years.

Adaptation of coastal settlements to climate change
The longer-term consequences of the various adaptation strategies of coastal settlements to climate change are not well understood. Models are needed that forecast socio-economic impacts of climate change under the various adaptation scenarios. These need to not only consider the direct socio-economic costs of protection, retreat and accommodation but also the indirect costs resulting from impacts of the adaptation strategy on the coastal ecosystems that provision coastal settlements and provide key regulating services. The development of such models requires integration of coastal response models, ecosystem response models and knowledge of the adaptive capacity of populations.
Timeframe: Given that decisions regarding adaptation are presently being made, these models and decision-making frameworks are urgently required. Hence, they need to be developed over the next 5 years and refined as the process models they integrate improve.

Adaptation of coastal ecosystems to climate change

Relative few studies have considered the capacity of key species to adapt to climate change over multiple generations, and under various scenarios of anthropogenic stress. The recent opening of the SeaSim facility in Townsville will provide important infrastructure for addressing these questions for key tropical species. However, research effort is also required for sub-tropical and temperate species.

There is an urgent need to gain a better understanding of ecological genetics in estuarine and coastal environments in order to plan for and mitigate for the effects of climate change. Recent advances in DNA sequencing have greatly reduced the cost of analysis, but the application of genetic techniques in estuaries remains infrequent.

As land-based strategies of adapting coastal settlements to climate change are implemented, monitoring programs are needed that examine ensuing change to coastal ecosystems at impacted and reference sites. These need to be coupled with targeted manipulative experiments elucidating the mechanisms by which change occurs, as well as development of models that can be applied under a variety of scenarios.

Although there has been some recent research effort into how marine protected areas might be used to assist in climate change adaptation of coastal settlements, Holbrook et al. 2012 continue to identify this as a high-priority research need.

Timeframe: next 5 years

Realisation

There is a major challenge for setting and delivering a data collection and research agenda to suit the coastal fringe. All levels of government, most industries and businesses and most of the community are affected and require information. It is imperative that information is delivered in an integrated way without a specific agenda related to an individual sector or there may be negative consequences.

There is an ongoing need for development of capacity of coastal researchers to operate in multidisciplinary, applied space, and for stakeholders to be able to use information properly and effectively. Skills for applied researchers include the ability to run applied research projects and to engage with stakeholders to deliver them. This includes skill development in communication and engagement.

The need for continual improvement in key data sets to support climate change impact and adaptation is essential, and to support long-term monitoring and evaluation of success. This includes ways of collecting data sets cost effectively, and delivering these at multiple spatial and spatial scales.

Funding is required along a number of lines. Attracting long-term funding for multidisciplinary, applied research that delivers to the needs of stakeholders is difficult to achieve through the Australian Research Council. When projects are funded, there is no overarching attempts or processes to integrate results and to communicate them effectively, which reduces discoverability, accessibility and uptake by users. Progressing this form of research needs a dedicated funding Program.

Outcomes from this form of Program can help to integrate results from research funded through other programs such as the ARC Discovery and ARC Linkage streams. Programs such as this enable more streamlined and effective engagement with users and specialized targeted communication. While funding for applied research is important, the need for high quality "blue-sky" research is also important, and is helpful in identifying solutions in the longer-term.

Without a long-term applied research program that is cross cutting across all sectors, it is unlikely that the needs of coastal stakeholders will be realized. In the short-term existing research and data sets can be integrated and used to support decision makers. In the longer term however, additional research needs will become apparent and new data sets and tools will need to be developed. Short-termism will not enable strategic outcomes to be achieved which has a negative effect on potential for building partnerships with research users.

Consideration should be given to reward researchers for completing and publishing applied research. This will support the development and maintenance of capacity and longer-term interactions between users.

There is need for state-of-the-art research facilities to support temperate ecosystems research. The recent opening of the SeaSim facility at Townsville will help to facilitate research investigating multi-generational responses of tropical organisms to climate change, and how this is modified by other anthropogenic stressors, associated with urban settlements. However, it will likely exacerbate the growing gulf in our knowledge of tropical and temperate ecosystem responses to climate change. Similar facilities are needed to support temperate zone research.

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