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Striking the balance: Coastal development and ecosystem values

Climate Adaptation Flagship

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EXECUTIVE SUMMARY

Overview

The goal of this project was to improve understanding of how the monetary and non-monetary values of coastal ecosystems may be affected by climate change and how the decision-making processes that affect Australia's coasts will need to adapt to account for these changing values.

We show, based on analyses of four areas of decision making – problem diagnoses, values, economic evaluation, and planning – that a range of fundamental changes are required to effectively adapt our coasts to climate change. We examine how scientists, communities and decision makers might interact and converse about the challenges of adapting coastal areas to climate change in the presence of uncertainty and contested values and interests. Some of the key insights include:

1. Coastal management problems are often complex, multi-scale and non-linear, making them difficult to define and leading to multiple, legitimate and often contested solutions being proposed.
2. Existing decision-making and policy processes only consider a subset of possible futures and possible adaptation options and pathways because they do not adequately account for:
    a. the fact that future values and preferences of individuals and groups for the balance between nature and development will be different than today's.
    b. small-probability high-impact events, which if seriously and appropriately considered in economic analyses, can lead to entirely different options being assessed as preferable.
    c. slow-changing variables and path-dependent processes. Constraints on existing decision and policy spaces, and entrenched institutions and organisational arrangements (e.g., existing budgetary and short-term planning cycles) can unintentionally lock development into unwanted trajectories.
    d. diverse and changing cross-scale effects that can require problems and decision processes to be reframed.

3. No single policy, process or insight will result in effective coastal adaptation due to the nature of climate change in coastal systems. The attribution of impacts and responsibilities and therefore investment in adaptation options must be coordinated across all levels of government and private actors to ensure that important but often unintended and indirect consequences of decisions are accounted for.

4. Due to the potentially large-scale changes projected, the ways in which people think about how and why they value attributes of coasts may need to change. For example, a species conservation ethic may need to be replaced by a framework that specifies suitable goals when species will inevitably be lost.

5. People and groups have multiple and contested values and interests regarding coastal ecosystems which are unavoidably mixed with, and changed by, policy design, policy processes and knowledge about how the system functions. It is therefore important when engaging local communities about the values they wish to protect under future climate change, that their values and interests are deliberated and negotiated as part of the policy design and implementation processes.

6. We demonstrate a new approach to economic modelling that can help local governments develop and evaluate integrated strategies for adapting coastal ecosystems, public infrastructure and private dwellings to changing inundation risks. Preliminary analysis suggests:

    a. The private amenity value of waterfront property will continue to provide incentives for development in at-risk areas, and subsequent calls for public expenditure on protection.
    b. Consideration of coastal ecosystem values may affect the desirable adaptation strategy. For example, even small amenity values for beach-dune systems may mean that policies that defend adjacent houses but result in the degradation or loss of beach-dune systems are not justified on economic cost-benefit grounds.
    c. Identifying appropriate coastal policies is therefore likely to require evaluating complex trade-offs involving a range of public and private values.

7. Existing (legacy) development and associated service infrastructure such as roads and the supply of essential services may encourage further concentration of assets in

at-risk areas. Information, incentives and regulations that consider this effect on future development are therefore important focal points for adaptation.

Background

Coastal ecosystems are in decline in Australia. Historically this decline has been largely driven by development pressure. Planning decisions today may have substantial and unintended impacts on remaining coastal ecosystems. The combination of development in at-risk areas and climate change is likely to accelerate future ecosystem losses and will limit adaptation options. The problem is exemplified by ‘coastal squeeze’, the loss of natural coastal areas that are trapped between a rising ocean and fixed landward boundaries such as seawalls, which presents a significant ongoing policy challenge.

At the same time, coastal ecosystems provide a range of ecosystem services which are important to many Australians and perform a significant role in sustaining our cultural identity and material wellbeing. These services include storm-surge protection, wind breaks, flood mitigation, habitat for birds, fish breeding grounds, amenity and recreation. Iconic coastal areas also have important heritage and biodiversity values. Yet many of these values are taken for granted, are difficult or impossible to quantify, and cannot be effectively considered in existing decision-making processes and institutions. Coastal adaptation, therefore, requires that we rethink many aspects about how decisions are made.

Approach

This report focused on four aspects of decision making to assess how coastal decision-making processes might need to be adapted to a changing climate.

1. Diagnoses: We developed a framework for assessing whether our current decision-making systems allow us to adapt to climate change and to diagnose what changes in complex coastal management systems may be needed in order to adapt.
2. Values: We describe the range of ways in which concepts of value are used in decision making; develop a framework that makes explicit the complicated interdependencies between values, institutions and knowledge; explain what

this means for the way values are described and decision-making processes consider people’s values under climate change.

3. Economic evaluation: We develop a ‘proof of concept’ economic model using dynamic Bayesian networks to support decisions about adapting coastal settlements to changing risks of inundation and erosion that can account for key difficulties such as uncertainty, long time horizons, extreme events and scheduling decisions. We demonstrate how this approach can be used to evaluate the options available in a relatively simple house-dune system (compared to a complex estuary, for example) at threat of damage and inundation by sea level rise from one in 20 to 30 year storm events. The model was developed in consultation with planners, asset managers and scientists, and was based on a section of beach and houses at Surfside Beach in Batemans Bay, New South Wales. The adaptation options modelled and evaluated were: beach nourishment only to protect houses as required; construction of a seawall now; beach nourishment to protect houses until a seawall is constructed in 2040; and beach nourishment to protect houses combined with a trigger to construct a seawall if sea level rises by more than 25cm. In all of these scenarios, houses were to be maintained in good condition and replaced if lost.
4. Planning: We undertake a survey of individuals’ attitudes to a sea level rise policy and discuss how coastal planning processes may need to be altered to effectively consider the range of community values for private property and coastal ecosystems in order for policies to be more acceptable to communities.

The economic modelling approach, capability and selected results

An important component of adapting to climate change involves building the capacity to comprehensively analyse options. Discussions with local and state policy makers during this investigation indicated that economic modelling of adaption decisions will be valuable in evaluating trade-offs between natural systems and development (particularly the protection benefits of natural systems versus built structures) and developing coordinated strategies for land-use planning, environmental management and related public infrastructure provision.

To effectively evaluate coastal trade-offs and inform strategic land-use planning under climate change requires economic modelling capabilities that can account for:

- the many costs and benefits that affect residents (e.g., house inundation, property values), governments (e.g., capital works costs), and natural assets (e.g., loss of the protective and amenity values provided by a beach-dune system);
- the long time horizons (50+ years) involved;
- the ability to schedule decisions over time;
- multiple interacting and uncertain changes in coastal processes (e.g., storm patterns and sea level rise);
- unpredictable extreme events characterised by low probabilities and large damage;
- site-specific ecosystem behaviours, requiring model structure about the key processes driving system change to be based on expert opinion.

Traditional economic analysis of the costs and benefits of different policy options typically produces a single dollar figure estimate of the net benefit of a particular policy. Such approaches require that future values are adjusted to an equivalent present value – typically by discounting – and allow analysts to aggregate values and report a single net present value (NPV) under each policy option. The policy option with the largest NPV is generally preferred from a welfare maximising perspective.

When evaluating the performances of policies under an uncertain future, however, it is important that the economic evaluation is able to account for two issues which traditional economic approaches are ill-equipped to deal with: 1) unpredictable and multiple possible futures and 2) the scheduling of flexible policy options.

In dealing with the former, assumptions need to be made about what the future might be like. In this case, we may assume that the future plays out according to a single scenario. Alternatively, we may consider a range of scenarios and evaluate how well each policy option performs under all possible future scenarios. In this case, economic modellers typically assign probability weights to each scenario (based on expectations of their likelihood of occurrence) and calculate the expected (i.e., the probability-weighted average) NPV for each policy option. Reporting economic analysis of policies as an expected NPV when the future is uncertain, however, creates several problems. In reporting an average value, information is lost about how each policy intervention performs under the possible futures. This loss of information is a concern if there is a possibility that some policy interventions may perform well on average, but poorly in extreme (i.e., low-probability, high-impact) events. A difficulty with this probability-based approach is that it is difficult to estimate probabilities and our estimates of these probabilities can have a large effect on the expected NPV. This is particularly the case for rare events where it may be difficult to tell if an event has a one or two per cent chance of happening, but this difference doubles the weight given to a potentially huge consequence when calculating an expected NPV.

The second issue is that we need to consider how each policy might be implemented in uncertain futures. Decisions will still need to be made under uncertainty but may be adapted to events as they unfold. We want to understand how well a certain policy intervention can adapt to a range of future events. The NPV criterion may still provide an appropriate measure of the performance of an intervention, but rather than focus on identifying the strategy that performs best ‘on average’ or ‘on expectation’ it is often more informative to examine how well the strategy performs under a range of possible futures.

We develop a modelling approach which allows us to address these issues.

Bayesian belief network modelling

The Bayesian modelling approach makes it possible to calculate the NPV of the system under each management strategy for each possible permutation of future states of the system. Each permutation specifies the state of each variable in all time periods: that is the sea level, storm frequency, seawall status, house condition, number of houses lost, and dune condition. It is therefore possible to calculate the costs and benefits that occur in each time period under all possible combinations of these specified states. The model also calculates a probability of each of these possible combinations of states occurring.

The probability of any particular combination of states is determined by the combination of the conditional probability tables and the specification of the initial conditions of the model (e.g., the probability of a high sea level rise in 2060 conditional on the sea level in 2040 and conditional on the sea level in earlier time steps). These steps are undertaken within a Monte-Carlo simulation which involves running the model thousands of times to calculate the probabilities and associated NPVs of each management strategy for all possible combinations of the state variables over time. Combining the estimated NPVs under all possible permutations of future states, and the probability of each of these permutations occurring, we can produce a probability distribution of the NPV for each management strategy.

Key results from the economic modelling:

We demonstrate the ability of this approach to estimate the probability distributions of the NPVs of a selection of management strategies, as listed in Table 1.

Table 1. Specification of management options for model analysis

Scenario name	Management specifications
1) Nourish (“nourish”)	Beach nourishment to protect houses as required No seawall construction Maintain houses in good condition and rebuild lost houses
2) Seawall 2010 (“sw2010’)	No beach nourishment Build a seawall in 2010 Maintain houses in good condition and rebuild lost houses
3) Seawall 2040 (“sw2040”)	Beach nourishment to protect houses until a seawall is built Build a seawall in 2040 Maintain houses in good condition and rebuild lost houses
4) Seawall medium (“swmed”)	Beach nourishment to protect houses until a seawall is built Build a seawall if sea level rises by more than 25cm. Maintain houses in good condition and rebuild lost houses

The expected NPV of each of the four management strategies listed in Table 1 are plotted in Figure 1. The results in Figure 1 indicate that the seawall 2010 strategy does not perform as well as the beach nourishment option (i.e., compare scenarios ‘nourish’ and ‘sw2010’). This is because the construction of a seawall imposes costs in the form of upfront construction costs and (assumed) decreased amenity values that are not compensated for by the reduced risk of loss of houses.

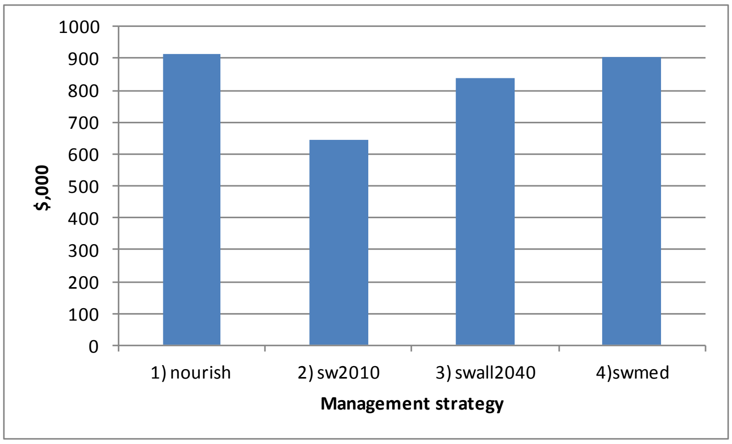

Figure 1. The expected net present value of each of the four management strategies

A comparison of the probability distributions of NPVs in Figure 2 reveals the performance of the first two management scenarios under thousands of possible combinations of sea level rise and storm surge. Of particular interest is comparing the performance of the two management regimes under unlikely but expensive events (i.e., compare the left-hand tails of the probability distributions of the two management strategies). Although the probability and magnitude of extreme events are difficult to estimate it is important that these events are accounted for in economic assessments of various options due to their potentially catastrophic consequences, no matter how small their chance of occurrence. It is clear from the relatively fat left-hand tail of the probability distribution of the NPV of the seawall option that the seawall strategy doesn’t perform as well under extreme events. This is largely because under the conditions of extreme events the seawall option not only incurs the upfront costs of seawall construction and the ongoing costs of the lost dune amenity, but also incurs the costs of house damage/loss in extreme storm events.

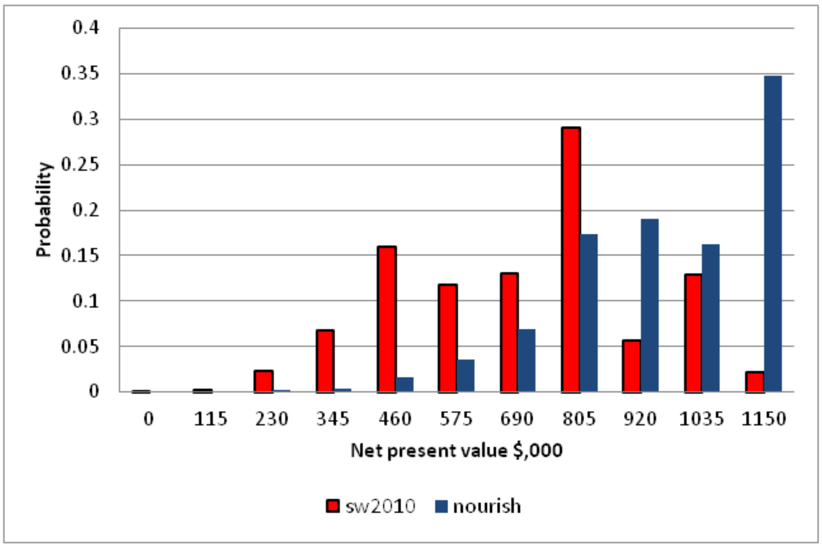

Figure 2. The probability distribution of the 50-year NPV for the management strategies of beach nourishment and building a seawall in 2010 (sw2010) for Surfside Beach in Batemans Bay, New South Wales

Finally, a comparison of the NPVs of each of the three seawall strategies (Figure 1) demonstrates the model's ability to value delaying the building decision until 2040 (scenario 'swall2040') or until sea level rise is greater than 0.25m (scenario 'swmed'). Delaying the seawall provides benefits because the capital costs are delayed, the dune system is maintained in the initial time periods, and then provides protection when the risks of loss are greater. An additional insight from Figure 1 is the value of the option to wait for future events to unfold before committing to an irreversible investment such as a seawall. Decisions such as these are likely to be important strategic considerations in adapting to climate change. However, calculation of option values typically relies on sophisticated continuous-time mathematical models that are difficult to develop and from which generalisations often cannot be drawn. A simpler approach based on conditional decision trees can provide similar analysis, and the DBN model developed here provides a way to automate this approach. This is demonstrated by specifying a management scenario where the decision to build a seawall in the future is conditional on the rise in sea level (scenario 4: 'swmed'). In this case, the wall is only built if and when the sea level increases by greater than 0.25m. The expected value of this strategy is shown in Figure 1 (scenario 'swmed'). This strategy has a similar NPV to the no seawall ('nourish') strategy. The option value of delaying the seawall's construction is therefore equal to the difference between the NPV of the 'seawall 2010' scenario and the conditional ('swmed') scenario.

Structure of the report

Chapter 1 – Structuring climate adaptation: A framework for decision- and sense-making

This chapter focuses on developing a conceptual framework to identify the different elements of coastal systems so that problems in the coastal zone can be appropriately diagnosed and solutions proposed. A key element of the framework is to identify the roles of decision makers, community groups and researchers in decision- and sense-making in coastal areas.

The framework reveals that local governments and communities must be a central part of decisions affecting the future sustainability of Australia's coastal areas. The framework also reveals that intervention from the Australian Government is not only about helping local decision makers improve their processes, but that changes are needed throughout the decision-making system (in particular, the relationships and engagement processes between government at all levels and communities).

Chapter 2 – A framework for analysing ecosystem values under climate change

Climate change poses new problems for the ways in which natural systems are managed, and requires us to rethink the role that 'values' play in guiding society's interactions with nature and how these values are used in decision-making processes. This chapter aims to establish a framework that allows for a systematic approach to reconsidering values associated with ecosystems in light of a changing climate, and how this process can and should inform adaptation decision making.

For complex problems – such as the adaptation of coastal systems to climate change – the value concepts required are more complex and do not permit the degree of separation among decision makers, researchers and the public that has become institutionalised in local planning processes. In this context, the reliance on cost-benefit analyses – which use utilitarianism as a guiding ethical principle – to select adaptation options can further expose, rather than ameliorate, the differing and/or contested values of various stakeholders.

Adapting value concepts and ensuring that values continue to play a role in social decision-making processes requires a much closer relationship between decision makers, researchers and the public.

Chapter 3 – Building local government decision-analysis capability

This chapter presents a modelling approach that can be used by local government decision makers to evaluate different coastal adaptation strategies. While earlier findings acknowledge that traditional cost-benefit analyses cannot always adequately capture different actors' concepts of 'value', discussions with key local- and state-level decision makers suggest that economic modelling of the costs and benefits of different adaptation options may be valuable in a number of circumstances.

A 'proof of concept' economic model is demonstrated for a simple house-dune system in Bateman's Bay, New South Wales, over a 50-year period (2010-60). The model is run for four management scenarios, and the results demonstrate the capability of the model to: show how management affects total costs and benefits; capture long-term and uncertain changes; model the probability distributions of total costs and benefits, and; account for multiple compounding uncertainties.

While this approach may be suitable for modelling simple house-dune-beach systems, the complex characteristics of other coastal systems (such as estuaries) may limit the validity and value of economic modelling in these circumstances. Nevertheless, there remains strong demand from policy makers for robust economic analysis of systems with intermediate complexity and at larger scales.

Chapter 4 – The community engagement process

This chapter identifies some of the potential challenges for local-scale consultation and engagement processes on adaptation options, and suggests ways in which these consultative processes could be built upon and improved.

Research suggests that adaptation policies which are socially divisive will not be accepted by the community or effective in the long term. There are also concerns that the typical community consultation process may not only be ineffective for developing appropriate adaptation decisions, but could also inhibit effective and long-term adaptation. Effective engagement of residents in policy development cannot be limited to discussions about constituents' 'values'; rather, such a process needs to include discussion and debate on policy processes and options, and science. Analysing the responses of citizens to the engagement process through three theoretical lenses – rational self-interest, a social functionalist framework, and cultural cognition of risk – several recommendations are made for improving community engagement. A key recommendation includes the need for citizens to debate different policy options, and not just be asked about the ends they would like to achieve. This places the community at the centre of the policy-making process, and promotes the sense that the selected policy has been developed through a legitimate process and will lead to outcomes that are effective and appropriate.

Chapter 5 – General Conclusions

Implementation of difficult adaptation policies has typically been stalled by either strongly focused local political opposition, or drawn out legal challenges. For this reason, adaptation policy development has tended to occur in an environment of crisis and where ecological and future values are given little consideration. These factors suggest that the standard residential land-use planning processes will not effectively consider the existing and changing nature of values for coastal ecosystems experiencing the effects of climate change.

By providing a better understanding of how the social decision-making processes work, examining the concept of 'values', trialling the use of economic models, and studying the role of the community in policy development, this report provides useful guidelines and lessons for policymakers seeking to implement adaptation policy that is effective in the long-term and accepted by the community.

1. STRUCTURING CLIMATE ADAPTATION: A FRAMEWORK FOR DECISION- AND SENSE-MAKING

1.1 Section overview

Purpose: To develop a conceptual framework to identify the different elements of coastal systems so that problems in the coastal zone can be appropriately diagnosed and solutions proposed. A critical element of the framework is to clarify the roles of policy/decision makers, community groups and research in decision- and sense-making. The framework also contextualises the research activities of this project and how they contribute to coastal adaptation, particularly to the phenomenon of coastal squeeze[1].

Why: A conceptual framework such as this (Section 1.4) is needed in the context of coastal adaptation because the traditional framework that guides and underpins system management – where decisions are made by a clearly defined central decision maker and research is fed uni-directionally into the management cycle (Figure 1.1) – is inappropriate for the management of complex coastal systems (Section 1.2).

How: The development of the framework was informed by initial scoping studies of coastal systems, discussions with local government authorities, and a review of the international literature. The framework consists of several conceptual diagrams of coastal social and ecological systems (and associated explanations) in which the key actors and governance arrangements within which policy/decision-making processes occur are emphasised. Several bodies of literature that address dimensions such as scale, time, complexity, governance, behaviour and uncertainty are used to inform the framework and to underpin the prescriptions that flow from its application.

So what: Adaptation requires coastal systems to be viewed as complex and dynamic social-ecological systems comprising multi-actor, multi-level governance arrangements (Section 1.3.1). Such a starting point reveals that:

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[1] Coastal squeeze describes the phenomenon where natural habitats (e.g., beaches, dunes, salt marshes, sea grasses and mangroves) along the coast that would normally move landward in response to erosive forces and sea level rise are not able to do so because of the presence of buildings, roads and sea defences protecting these built structures from erosion and flooding (Doody, 2004; Wescott, 2009).

- Local and state land-use planning systems are based on the fallacy that future land use is planned and controlled. This ignores evidence along Australia's coastlines of path-dependency and lock-in to inappropriate development patterns (Section 1.4.1).
- Predictability of natural and institutional responses to changes in complex systems is the exception and not the rule (Section 1.4.2).
- The unpredictability of complex systems combined with cognitive biases and conflicting worldviews – driven by ideology and group interest – results in ambiguity and equivocality and makes defining problems and solutions contentious and difficult (Section 1.4.2).
- System behaviours are affected by multiple decisions made at different spatial and temporal scales (Section 1.4.3).
- Values and preferences depend on multiple dimensions of social-ecological systems, which are evolving in unpredictable ways under climate change (Section 1.4.3).

These characteristics of social-ecological systems require one or more of the following approaches to decision- and sense-making in order for adaptation initiatives to be effective (Section 1.4.3):

- Adoption of diagnostic approaches to understand the nature of problems and inform the changes required to overcome misfits between institutions and system dynamics.
- Disentangling the complex, cross-scale causes and effects of planning and conservation regulations rather than just changing the intent of planning decisions.
- Low-cost opportunities to learn about how alternative institutional arrangements or policy designs may work through the use of small-scale trials within 'niches' (Section 1.4.3 and see Heilmann (2008) for how this is being done in China).

- Applying resilience thinking to help understand how actions affect overall systems, when a system is likely to encounter a threshold, and how thresholds may be navigated.
- Awareness and understanding of the nature of uncertainty to inform the design and choice of analytical approaches and tools. In this regard, risk-management approaches to policy and decision making are warranted and need to be implemented within adaptive processes of engagement, learning and management.
- Values need to be reconsidered in decision-making processes, which require that iterative and adaptive processes are developed to enable citizens to learn about system behaviour and to deliberate and express values.
- A broadening of focus from the decision maker to include researchers, policy makers and citizens as key players in the adaptation process.

1.2 Introduction

Coastal systems are complex and characterised by all of the following:

1. they are coupled social and ecological systems that co-evolve and adapt to multiple drivers of change;
2. enhancing and ameliorating feedbacks between system variables exist (i.e., relationships are non-linear) making the consequences of change unpredictable;
3. system boundaries are difficult to define because each social-ecological system (SES) is also linked to or nested within other SES at different scales (i.e., an estuary is linked to upstream rivers, surrounding agricultural systems, and downstream marine systems) and therefore management and legislative jurisdictions overlap and trans-boundary effects are common and widespread;
4. uncertainty, unpredictability, and surprise as a result of a combination of bounded rationality, lack of information, and the strong linkages between agents and interdependencies of system components are the norm (McDaniel, 2007);
5. multi-actor, multi-level governance arrangements where the authority to make decisions and the power to influence outcomes is distributed to a complex

network of societal actors including expert groups, private corporations, developers, NGOs, and *ad hoc* coalitions of civilians; and

6. plurality of legitimate worldviews and values that lead to ambiguity in the interpretation of risks and the solutions that are proposed.

Consequently, the frameworks that traditionally guide and underpin system management[2] (Figure 1.1) – where decisions are made by a clearly defined central decision maker and research is fed uni-directionally into the management cycle – are inappropriate for the management of complex coastal systems.

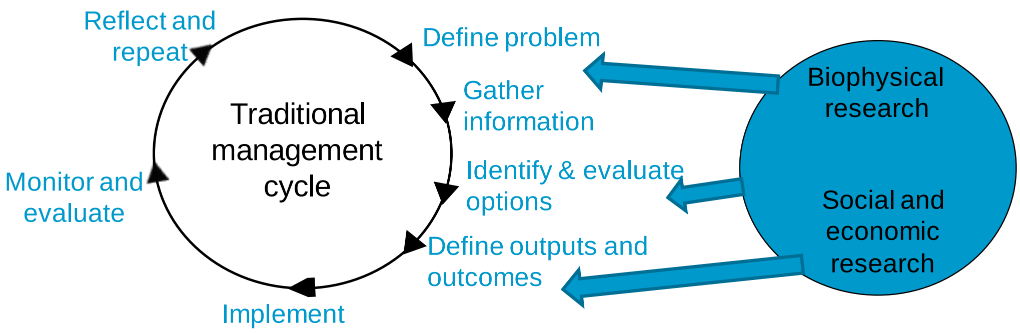

Figure 1.1. Traditional framework describing the management cycle and role of research. This model is not adequate to describe the socio-ecological system of coastal areas.

The difficulties in understanding such complex systems and in making informed and appropriate decisions are compounded when evaluating options to pre-emptively adapt to the uncertain consequences of climate change. It is therefore clear that the challenge of adapting Australia's coastal systems to climate change is a "wicked problem" (Rittel and Webber, 1973) and that a different conceptual framework is needed. A "wicked problem" is an issue or problem that emerges from a complex system where facts are uncertain, values are in dispute, stakes are often high, and decisions usually urgent (Funtowicz et al., 1999; Australian Public Service Commission, 2007).

[2] This framework largely informs and underpins the two main approaches to assessing vulnerability that have been used to date: "outcomes-based" and "context-based". O'Brien and Wolf (2010) state that "neither of these approaches can say much about what the effects of climate change mean for what people value, for example, their cultural identity and way of life, their sense of place, their visions for their future, and their human security".

1.3 Purpose of a conceptual framework

A framework provides a structured and transparent approach to identify key elements of a system (or sub-system) that enables a common understanding of the system to be reached, problems identified, and solutions proposed. We see five uses of frameworks for climate adaptation decision- and sense-making:

1. Describing decision-making processes and understanding the relationship of these processes to institutions and learning in order to facilitate:
    a. the identification of key agents and groups in multi-level governance systems; and
    b. the development of context-suitable options for decision-making processes.
2. Understanding the nature of the decision-making context and how decision-making processes cope with uncertainty.
3. Informing the roles of science, community and politics in decision- and sense-making and recognising the limitations and opportunities of research
4. Guiding the selection and development of research methods and processes that are appropriate for addressing the nature of the problem as defined in item 3; and
5. As a tool for diagnosing weaknesses in decision-making processes and identifying misfits between institutional settings and system dynamics.

We focus on the use of this framework to clarify the role of social and economic research in decision- and sense-making, to put the research activities of this project into context, and to describe how these activities contribute to climate adaptation. The use of the framework as a diagnostic tool will require further development and testing. Finally, the term ‘decision making’ is used throughout the report in a generic way and encompasses decisions about the type and design of policies (i.e., policy-making) as well as decisions about which technologies or practices to choose and how to implement them (i.e., decision-making). The term ‘decision makers’ includes all social actors with the authority to make decisions and who have the power to influence outcomes, such as expert groups, private corporations, developers, NGOs, and *ad hoc* coalitions of civilians.

1.4 The conceptual framework

The framework consists of several conceptual diagrams of coastal social and ecological systems, in which the key agents and governance arrangements (within which decision-making processes occur) are emphasised. Several different bodies of literature that address dimensions such as scale, time, complexity and uncertainty are used to inform the development of this framework and to underpin the prescriptions that flow from its application. The first two diagrams provide the conceptual basis of the elements and structure of coupled SES, including the existence of multiple decision makers acting within horizontal and vertical levels of governance. The subsequent diagrams provide graphical depictions of where, within complex SES, each of the various bodies of literature is relevant to decision- and sense-making. This is done by locating the bodies of literature on the diagrams and providing explanations of the theoretical and methodological contributions developed within each body of knowledge and their relevance to this project.

1.4.1 Australia's coasts as complex social-ecological systems

The concept of 'evolving coupled social-ecological systems' (Clark and Dickson, 2003) comprising many diverse agents interacting in non-linear ways at multiple scales, impacting and being impacted upon by their environment, provides an appropriate way to view coastal systems (Figure 1.2). When viewed in this way, Australia's coasts are clearly complex systems. To inform decision making in complex systems requires understanding the patterns of non-linear relationships[3] between agents, between agents and their environment, and between linked ecosystems over space and time. The existence of multiple, non-linear relationships between components of coupled SES means the system has emergent properties that cannot be attributed to any of the component parts, but is the result of the functioning of the system as a whole (Goldstein, 1999; Cilliers, 2008). This implies it is generally impossible to predict outcomes and unambiguously identify problems and solutions.

[3] Non-linear relationships are the result of positive and negative feedbacks, where one agent's activity can feed back on itself as well as influence other agents and components of the natural system (McDaniel, 2007)

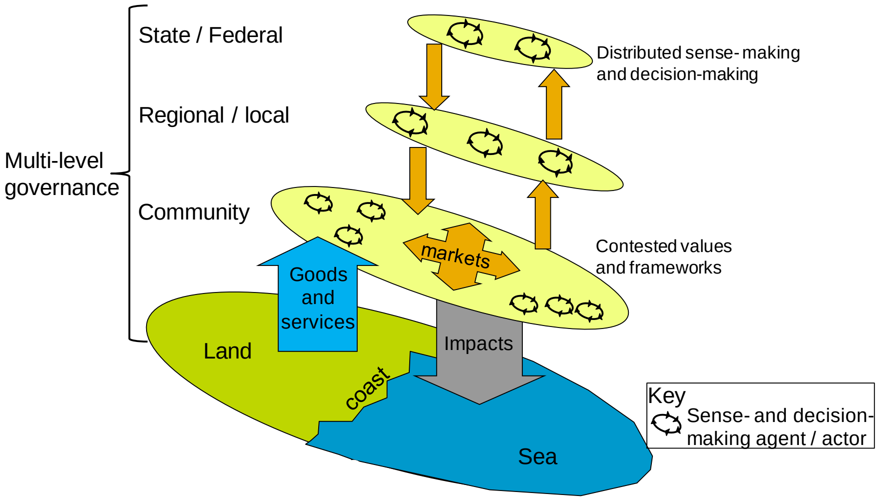

Figure 1.2. Graphical depiction of coastal regions as social-ecological systems comprising land, ocean and coastal ecosystems and multi-level, multi-agent social systems. The symbol for decision- and sense-making agents represents the traditional management cycle, based on the assumption that most agents adopt this approach.

Viewing coastal systems as complex SES is meaningful because it forces one to recognise in decision- and sense-making processes:

- the cross-scale effects and feedbacks that present some of the most significant threats to future coastal ecosystems;
- the difficulties in defining system boundaries (i.e., recognising that elements will be left out that may interact with the system in a non-linear way) and that these need to be iteratively determined with stakeholders based on objective and subjective factors;
- the importance of positive feedbacks associated with historical planning and development decisions that lead to path-dependency and lock-in to inappropriate development patterns (Abel *et al.*, 2011);
- the importance of defining the roles of actors at a range of scales and evaluating how actors and ecosystems across different scales behave and co-evolve;
- an inclusive process for identifying problems that accounts for different perspectives, values and preferences of the desirability of proposed changes; and
- that a range of different knowledge types (scientific, experiential, value-based) are needed to answer a specific question or address a particular issue.

The difficulties in accommodating and addressing these issues in decision- and sense-making are clearly apparent along Australia's coastline in the form of the widespread and continuing:

- Path-dependent residential growth patterns, which are the result of positive feedbacks, associated with legacy development decisions at a range of scales. This is because the original location and subsequent growth patterns of towns are related to the quality of the port for transportation and the feedback loops associated with demands for residential sites close to urban centres and (more recently) conservation zones. See Abel *et al*. (2011) for more details on this and other difficulties identified for the south-east Queensland coastal SES.
- Degradation of ecosystems in the face of creeping development pressures overwhelming local planning controls. A clear example of this is the over-exploitation of predator species in coastal ecosystems leading to changes in human-use patterns (e.g., from fishing village to tourist towns), as well as changing the attributes of the ecosystems valued by residents.

Complementing the characterisation of coastal areas as complex SES is 'resilience thinking' (Walker *et al.*, 2004). 'Resilience' refers to the capacity of a system to absorb disturbances and still retain the same structure and function, while maintaining options to develop (Carpenter *et al.*, 2001). The attributes of a resilient system are emergent properties that reveal the possibility for transformative and non-linear change. Resilience science is fundamentally about change processes and long-term trajectories, and provides a framework for understanding how individual actions affect overall systems, when a system is likely to encounter a threshold, and how thresholds may be navigated (Nelson, D.R., 2011). Resilience thinking allows concepts such as 'resilience', 'transformability', 'path dependency' and 'thresholds of potential concern' (i.e., irreversibility) to be used in decision- and sense-making and to guide the development of criteria to monitor natural and social systems and interventions. Resilience thinking is also useful as it provides the language and conceptual basis to assist researchers and decision makers discuss the observed behaviour of complex systems with limited information.

In the next section we clarify the meanings of key concepts – such as uncertainty, ignorance, ambiguity, complexity and equivocality – that are used throughout the report. This is followed by summaries of the key theory and methods from the literature that informs decision- and sense-making in complex SES.

1.4.2 Contextualising uncertainty, ambiguity and complexity

"Making good decisions requires a decision maker to know something about the current or future state of the world and the path to formulating an appropriate response" (Zack, 2007: 1664). In the context of SES, however, decision making is confounded by difficulties in making sense of "the current and future states of the world" (McDaniel, 2007) because of the complexity of the systems, their intrinsic variability, the lack and asymmetry of information, and the bounded rationality of the human brain. These factors result in uncertainty and unpredictability of the nature of the self-organisation, emergence, and co-evolution taking place in SES. Uncertainty and unpredictability are barriers to decision making (Moser and Ekstrom, 2010). And, depending on the level of knowledge of the decision maker and whether the conceptual framework(s) for interpreting information exists, uncertainty and unpredictability can lead to ambiguity and equivocality (Box 1).

The appropriate approaches to support decision- and sense-making in the context of complex SES depend on whether the barrier(s) to decision making is (are):

1. uncertainty caused by too little or asymmetric information;
2. uncertainty caused by the intrinsic variability of the system;
3. uncertainty caused by expert subjectivity due to cognitive biases;
4. unpredictability of the state and dynamics of the system;
5. uncertainty caused by communication patterns where word choices and message content lack reliability, relevance, and clarity;
6. the decision maker does not have a conceptual framework for interpreting the information; and/or
7. multiple interpretations of the same thing exist.

Risk describes the situation where the full range of definable and quantifiable outcomes is random, but the probability distribution governing these outcomes is known at the outset (Knight, 1921).
Uncertainty describes the situation where outcomes are likewise definable, quantifiable and random but are governed by an unknown probability function (Knight, 1921). A more severe form of uncertainty, called **fundamental uncertainty** by Perrings (2007)**, radical uncertainty** or **irreducible ignorance** by Lemons (1998), **deep uncertainty** by Lempert *et al.* (2003) and **severe uncertainty** by Ben-Haim (2006), is when not only the probability distribution is not known but the possible outcomes are also not known or are unknowable – a situation common to complex systems comprised of self-organising and adaptive structures.
Cognitive biases are largely caused by the tendency of individuals to conform their beliefs about disputed matters of fact (e.g., whether global warming is a serious threat) to values and shared morals that define their cultural identities (Kahan *et al.*, 2011). This tendency is referred to as 'cultural cognition' and descends from two theories: 1) the cultural theory of risk, which posits that individuals can be expected to form risk perceptions that reflect and reinforce one or another idealised 'way of life'; and 2) the 'psychometric paradigm', which identifies recurring cognitive and affective dynamics that cause individuals to form risk perceptions systematically different from ones we might expect if such individuals were behaving consistently with rational decision theory.
Bounded rationality is when individuals – faced with complexity, uncertainty, imperfect information and the limited capacity of the human brain – resort to heuristics and 'satisficing' behaviours (Gigerenzer and Goldstein, 1996; Kahneman, 2003).
Ambiguity represents an inability to interpret or make sense of something either because a message does not activate a knowledge frame or the interpretive knowledge does not exist (Zack, 2007; Gilboa, 2009).
Equivocality describes the situation when multiple interpretations of the same thing arise due to the existence of several competing or contradictory conceptual frameworks (Zack, 2007).
Sense-making is "a diagnostic process directed at constructing plausible interpretations of ambiguous cues that are sufficient to sustain action" (Weick, 2005: 57).
Complexity is a way of thinking about complex systems that involve large numbers of interacting elements, where interactions are nonlinear and dynamic and lead to emergent unpredictable behaviours (Cilliers, 1998; McDaniel, 2007; Snowden and Boone, 2007).
Emergence is an unplanned and uncontrollable process in which properties such as capacity emerge from the complex interactions among all actors in the system and produce characteristics not found in any of the elements of the system (Land *et al.*, 2009).

Box 1. Brief explanations of key concepts, words and terms.

Uncertainty caused by not having enough information or by the intrinsic variability of the system can be reduced by collecting and collating data and information; developing or improving the ability to predict, infer or estimate using incomplete information (e.g., computer modelling) (Zack, 2007; Ascough II *et al.*, 2008); and, creating typologies of uncertainties (Maxim and van der Sluijs, 2011), and decision problems or types under uncertainty (Stafford Smith *et al.*, 2011). In situations of unpredictability – where uncertainty cannot be reduced by merely increasing the available data, information and modelling capabilities – responses need to be flexible and robust to unanticipated events and need to be co-developed with policy, science and community within adaptive-learning and adaptive-management frameworks (Wilby and Dessai, 2010). This is discussed in Section 1.4.3.

Ambiguity and equivocality also cannot be resolved by gathering more data and information or improving modelling and computer capabilities (Dessai *et al.*, 2009). Resolving equivocality "requires cycles of interpretation, interactive discussion, and negotiation in order to converge on a single [but often provisional] interpretation" (Zack, 2007: 1667). Ambiguity is resolved by acquiring contextual or explanatory knowledge from others' or one's own learning experiences and therefore "requires cycles of interpretation, explanation and social ratification" (Weick, 1979 in Zack (2007)). McDaniel (2007) refers to these processes of reconciling ambiguity and equivocality as "sense-making", which is required not only as a response to bounded rationality, cognitive biases and conflicting worldviews but is critical to coping with both fundamental unpredictability in the dynamics of complex SES and unpredictability in the circumstances created by a lack of information.

1.4.3 Theoretical and methodological building blocks of the framework

Decision- and sense-making under uncertainty and complexity

The challenges faced by a decision maker depend on the context within which they make decisions. The context is defined by: the governance arrangements and the hierarchical level at which the decision maker sits; the complexities of the system being managed; the nature of the required changes (i.e., incremental or transformational); and the availability of resources. These factors influence the uncertainties that a decision maker will face (DECCW, 2010) such as: data uncertainty, where data or parameter inputs may be incorrect or inaccurate; conceptual uncertainty, where scientific knowledge underpinning models is incomplete or scientists disagree about basic concepts; risk, where environmental conditions are variable but their magnitudes and probabilities are known; uncertainty, where either or both the magnitude and probability of variables are not known; predictive uncertainty, where model outputs may be incorrect, inaccurate, or difficult to confirm; goal uncertainty, where there is disagreement about the best way to address the range of conflicting objectives; and decision uncertainty, where there is ambiguity about how to use analytical results in decisions and policies, largely caused by cognitive biases (see Box 1). In some situations, conceptual and predictive uncertainties may be reduced through increased research and data collection, but in complex SES these uncertainties are largely irreducible due to the intrinsic unpredictability of the system's behaviour caused by nonlinear, dynamic interactions among its many elements.

The literature proposes a mix of procedural and analytical approaches for dealing with uncertainties. For example, where uncertainties are due to system complexity and ambiguities and equivocality is present, the suggestions for decision making are more behaviourally and procedurally oriented and include: adopting 'complex-systems thinking' so predictability is seen as the exception and not the norm (McDaniel, 2007; Cilliers, 2008; Duita *et al.*, 2010); making decisions that are flexible and robust to a wide range of potential futures and that need to be implemented within adaptive management frameworks and underpinned by the precautionary principle (Lempert *et al.*, 2003; Dessai and Hulme, 2007; Hallegatte, 2009; Ranger *et al.*, 2010; WRI, 2011); and processes and principles for engaging, consulting and deliberating with stakeholders in the identification of problems and the options for adaptation (Funtowicz and Ravetz 1993; Funtowicz *et al.*, 1999; Head, 2007; Dowd *et al.*, 2008).

In situations where sufficient knowledge exists about the functioning of the system – and the system is sufficiently simple to decompose to a subset of states, agents, and dynamic interactions for the purposes of improved understanding – then a wider mix of approaches become available for consideration. These approaches range from computer-simulation modelling approaches capable of mimicking cause-effect relationships between system elements to conceptual frameworks and the use of typologies. Examples of these types of approaches are summarised in Table 1.1.

Multi-actor, multi-level governance

Governance is broadly defined as the informal and formal governmental, market, and civil-societal processes and institutions that guide and restrain the collective activities of individuals and groups (Renn *et al.*, 2011). Some authors differentiate between horizontal and vertical governance (Lyall and Tait, 2004), where the horizontal level includes relevant decision makers or organisations involved in both competitive and cooperative relations at the same hierarchical level within a political-administrative segment or "organisational field" (Scott, 2008). Vertical level governance describes the links between these segments or fields (i.e., the institutional relationships between local, regional, state and international levels). When various levels are involved the notion of multi-level governance is advanced (Renn *et al*., 2011). A multi-agent, multi-level, polycentric governance structure is depicted in Figure 1.3 based on our conceptual framework.

Examples of where governance arrangements can impede effective adaptation decision making include: situations where the effects of change cross jurisdictional boundaries and/or are unequally distributed across jurisdictions (Walker *et al*., 2009; Dovers and Hezri, 2010); powerful vested interests prevent necessary transformational change in the face of extreme or systemic threats (Anthoff and Hahn, 2010; Smith and Stirling, 2010); when there is limited transfer of resources and power to local government, even when the responsibilities have been devolved to the local level (Lane *et al*., 2004; Næss *et al*., 2005; Abel *et al*., 2011); and where misfits between institutional settings and the dynamics of systems exist (Ostrom, 2006; Folke *et al.*, 2007; Brondizio *et al.*, 2009).

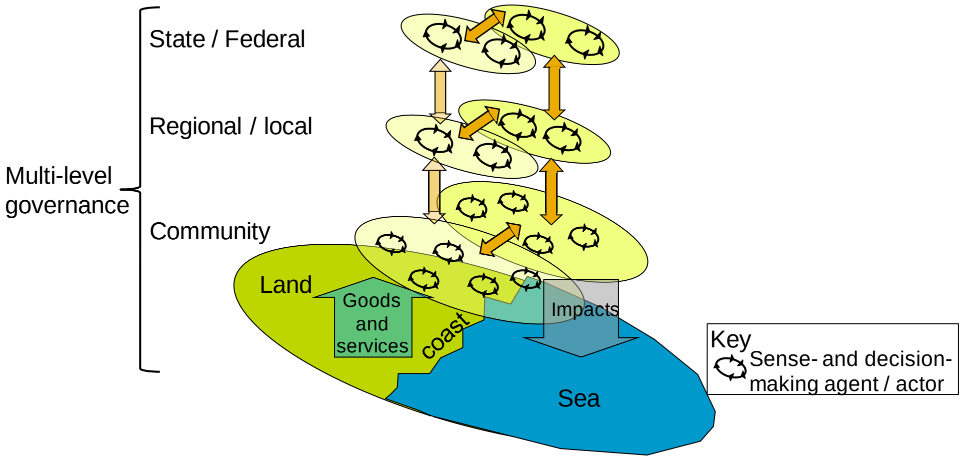

Figure 1.3. Graphical depiction of a multi-agent, multi-level and polycentric governance structure that is typical of the context within which decisions are made on the coast. In contrast to Figure 1.2, this shows the multiple jurisdictions and polycentric nature of governance regimes.

Table 1.1. Summary of approaches for dealing with risk and uncertainty in decision making

Tool	Focus	References
Cost-benefit analysis (CBA) techniques: from traditional CBA, to risk analysis using Monte Carlo, to dynamic analysis based on 'real options' techniques	CBA compares the present values of the streams of economic costs and benefits over a project. A positive net present value indicates a resource allocation that leads to socially beneficial outcomes. The analysis can account for social, economic and environmental impacts, assuming commensurability between these, and for risks and system dynamics.	(Dixit and Pindyck, 1994; Purnamasari *et al*., 2002; Hertzler, 2007; Mezey and Conrad, 2010)
Optimisation methods: "grey" linear-programming, dynamic programming, or evolutionary algorithms	Implemented within CBAs to determine an optimal solution, based on simplifying assumptions: i) efficiency, equity and sustainability issues are separable; and ii) complete substitution between environmental quality and economic growth is always allowed.	(Huang *et al*., 1992), (Wise and Cacho, 2011) (Vasquez *et al*., 2000)
Multi-criteria analyses to inform decisions on trade-offs between incommensurable items	Multi-criteria evaluation methods based on the 'incommensurability principle' are an evaluation methodology alternative to CBA. In a multi-criteria problem there is no solution optimising all criteria at the same time. Since no uniquely 'correct' policy exists the focus is on the quality of the process to reach compromise solutions.	(Funtowicz *et al.*, 1999; Janssen and van Herwijnen, 2005)
Agent-based approaches	Evaluation of social and institutional constraints to decision making.	(Berger *et al*., 2006; Janssen and Ostrom, 2006)
Bayesian network modelling	Use of beliefs and expert opinions about causal networks and subjective probabilities to assess uncertainty.	(Ticehurst *et al.*, 2008; Burgman *et al.*, 2010)
Robust control	Assesses the design of decision rules that fare well (i.e., minimise worst case loss) across alternative models and reveal implications of model uncertainty for decisions.	(Williams, 2006)
Info-gap models	Determine minimally acceptable outcomes in the face of non-statistical uncertainty associated with biophysical system measures and changing aspirations of stakeholders.	(Regan *et al.*, 2005; Ben-Haim, 2006; Burgman *et al.*, 2010)
Statistical methods for analysing spectral properties of data	Used to identify signals of threshold effects and provide early warnings of impending change.	(Biggs and Rogers, 2003; Carpenter and Brock, 2006; Biggs *et al.*, 2009)
Fuzzy-rule and fuzzy-logic models	Accommodate systems where only linguistic descriptions of variables exist and which overcome the inability of probability theory to deal with imprecision of perceptions.	(Zadeh, 2006; Ascough II *et al*., 2008)
Qualitative approaches (e.g., mind maps, signed digraphs, story-telling)	These draw out inter-relationships and convey complex ideas (which can be combined with quantitative measures of uncertainty if possible and appropriate).	(van der Sluijs *et al*., 2005; Dambacher *et al*., 2007)
Typologies	Used to reduce complexity of issues or systems by identifying and then grouping based on common characteristics.	(Ascough II *et al*., 2008; Maxim and van der Sluijs, 2011) (Dessai and van der Sluijs, 2007)

Proposals within the literature to help overcome these barriers to adaptation involve:

1. using diagnostic approaches to probe the nature of problems and inform the changes required[4] to overcome misfits between institutions and the dynamics of SES (Australian Public Service Commission, 2007; Ostrom, 2007; Young *et al.*, 2008; Bunce *et al.*, 2010). In addition to Ostrom's "diagnostic approach for going beyond panaceas" (2007), the adaptive cycle concept can also be used to understand where in the adaptive cycle the system is and reveal opportunities for change (Swanson *et al.*, 2010).

2. introducing new organisational and institutional settings to solve resource-access and resource-management problems. Any one of the following will be appropriate depending on the diagnosed problem (Figure 1.4) and the anticipated outcome: 'command-and-control' where management objectives are defined and enforced by public authorities; the creation of a market to allocate and regulate resource-use rights (see Stavins, 2003); and collective actions where the use and monitoring of the resource is done under cooperative (see Ostrom, 2005) or joint-venture (see OECD, 2008) arrangements. The institutional components that underpin these organisational approaches involve (Ménard, 2011):

    a. *legal regimes* comprising actors in parliament, courts, and police services that define the nature of the rights, the conditions of their transfer and enforcement, and therefore the shaping of how actors behave when undertaking transactions;

    b. *political regimes* comprising politicians and bureaucrats that design and implement enabling policies and regulations consistent with the laws; and

    c. *ideological regimes*, comprising a mix of dominant and subordinate ideologies, that are made up of cultural cognitive elements (i.e., "the shared conceptions that constitute the nature of social reality and the frames through which meaning is made") and normative elements (i.e., "the prescriptive,

[4] Institutional changes that may be required include: the goals to set for an institution, the rights to be conferred by the institution, the rules to be implemented, the decision-making procedures to be followed, and the key agencies and hierarchies responsible for implementation of the institution (Young *et al.*, 2008).

evaluative and obligatory dimensions") (Scott, 2008: 428) that underpin the behaviours and perceptions of actors when undertaking transactions.

3. expanding existing risk-management and decision-making processes to include ways of better characterising problems (Renn *et al.*, 2011), and allowing opportunities to reframe perspectives to reflect changing values and beliefs based on learning (e.g., Pahl-Wostl, 2009, triple-loop learning);

4. incorporating experts, stakeholders, and communities in communication and deliberation to ensure knowledge and policy development is co-produced (Lane *et al.*, 2004; Swanson *et al.*, 2010). Corfee-Morlot *et al.* (2011) highlight the importance of "boundary organisations" in facilitating local science-policy assessment;

5. promoting linkages between local, state and federal governments and across formal and traditional knowledge systems (Berkes, 2002; Næss *et al.*, 2005; Smith and Stirling, 2010); and

6. the creation of 'niches' at the local scale where innovative institutional ideas, policies, land uses, and technologies can be tested and refined into viable alternatives for scaling up (Heilmann, 2008; Rotmans and Loorbach, 2009; Geels, 2011) and fed into national policy-making, planning, and development processes.

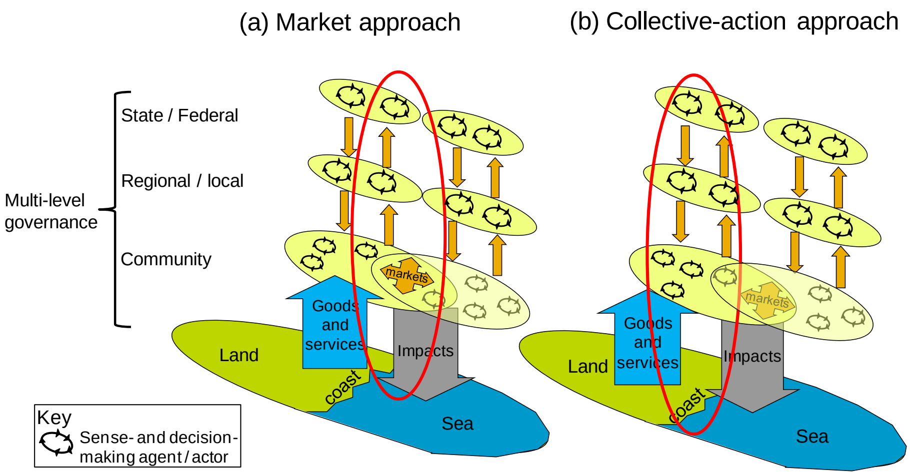

Figure 1.4. Market-based and collective-action approaches to resolving misfits between governance arrangements and the dynamics of complex coastal ecosystems

1.5 Using the conceptual framework in our research

The conceptual framework provided a structured approach to viewing and understanding coastal systems as coupled, evolving SES with multi-actor, multi-level governance arrangements. In doing so it highlighted the complexity of such systems and the fact that there are many inter-related and interconnected issues impeding effective adaptation to climate change. The various bodies of literature used to inform the development of the framework made it clear there are numerous approaches for overcoming barriers to including ecosystem values in coastal development and adaptation decisions. Critically the framework revealed:

1) that the decentralised and polycentric nature of governance arrangements mean that local governments and communities are key players in determining the future sustainability of Australia's coastline; and

2) the interventions required are not purely about helping decision makers make better decisions but that changes are needed throughout the system, particularly the relationships and engagement processes between local governments and communities.

These findings have informed the development of the project activities which have been structured to: co-develop modelling capacity with local government planners for use in evaluating tradeoffs between options for adapting to sea level rise; provide a framework for reconsidering values associated with ecosystems in the context of adapting coastal management to climate change and how these can and should inform adaptation policies and decisions, and; understand community/individual perspectives and values about climate change, their preferences for alternative adaptation options, and contribute to the development of adaptive processes for engaging with communities. These sense-making and decision-support activities are located on the conceptual framework in Figure 1.5, where it is also acknowledged that these two groups of actors are operating within the top-down frameworks provided by the state and Commonwealth governments, which directly affect the adaptation decision-making context (e.g., state governments produce regional development and infrastructure policies that have major effects at the local scale).

The benefits of approaching the project in this way were that the complexity and uncertainty of the context and needs of local government and communities were accommodated in the outputs of the project, thus ensuring their relevance, applicability and usefulness in decision- and sense-making.

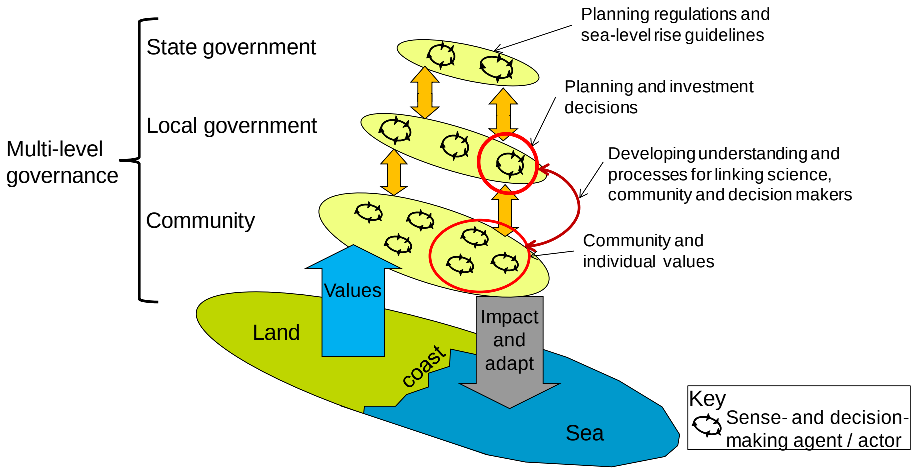

Figure 1.5. Locating the activities of the research project in the conceptual framework

2. A FRAMEWORK FOR ANALYSING ECOSYSTEM VALUES UNDER CLIMATE CHANGE

2.1 Introduction

People experience and benefit from ecosystems in many different ways. The way these benefits are conceptualised and expressed as values plays a key role in the management of natural systems. Climate change, by changing the nature of the problems and responses, requires us to rethink the roles that values play in guiding society's interactions with nature and how these values are used in decision-making processes. Our aim here is to describe a framework that permits a systematic approach to reconsidering values associated with ecosystems in the context of adapting coastal management to climate change, and how these can and should inform adaptation policies and decisions.

Why existing approaches to values constrain adaptation

The likelihood of ongoing, long-term change which can be fundamentally uncertain and unpredictable means there are several ways in which existing approaches to values may constrain adaptation of coastal SES.

- Values, in the sense of guiding principles for a good society (e.g., liberty, equality, and fraternity) are intended to be enduring, and to guide individuals and societies through uncharted territory. However, as a system changes, the ways in which people think about how and why they value attributes of a system may change or need to change. Decision-making systems that do not consider changing values may limit adaptation. For example, a species conservation ethic may need to be replaced by a framework that specifies suitable goals when species will inevitably be lost.
- The ways in which people are asked to express their values about ecosystems to inform decision-making processes may constrain adaptation. For example, if people are concerned about the impact of ecosystem changes on future generations, asking about the monetary values of specific conservation programs may require them to make judgements about future changes that are very difficult or impossible to know.

- New ways of describing the behaviour of natural systems are required when the climate is changing. For example, descriptions of ecosystems that focus on species conservation may need to be replaced by concepts that focus on how the system will respond to climate change, and how management might steer it towards desirable states. These changing concepts for describing the behaviour of systems may require a reassessment of how values are used to guide decisions.

In particular, the way values are viewed within neoclassical economics[5] approaches to decision support needs to be reconsidered if values are to effectively inform adaptation decisions.

Approach, scope and relation to the report

We develop a framework that is intended to guide analysis of when and how the use of values in decision-making processes may need to be revised under a changing climate. This analysis focuses on individual decision-making processes relevant to coastal ecosystems. Examples include:

- Markets for housing;
- Local government land-use planning and development approval processes;
- Land and environment courts; and
- Catchment and estuary management authorities and groups responsible for planning and investments.

We look at three areas where changes may be required to the way values are considered under climate change:

- The relationships among the public, researchers, experts, and decision makers in the decision-making processes.
- The roles played by economists and social scientists in informing decision processes, and engaging with the public.

[5] Neoclassical economics is used to describe approaches to economics that focus on the determination of prices, outputs, and income distributions in markets through supply and demand, often mediated through a hypothesised maximization of utility by income-constrained individuals and of profits by cost-constrained firms employing available information and factors of production, in accordance with rational choice theory (Campus, 1987).

- The formal and informal institutions that define social decision-making processes.

2.2 The roles of values in environmental decision making

A standard conceptualisation of how knowledge of the way a natural system functions and human values inform decision-making processes in natural resource management (NRM) is shown in Figure 2.1.

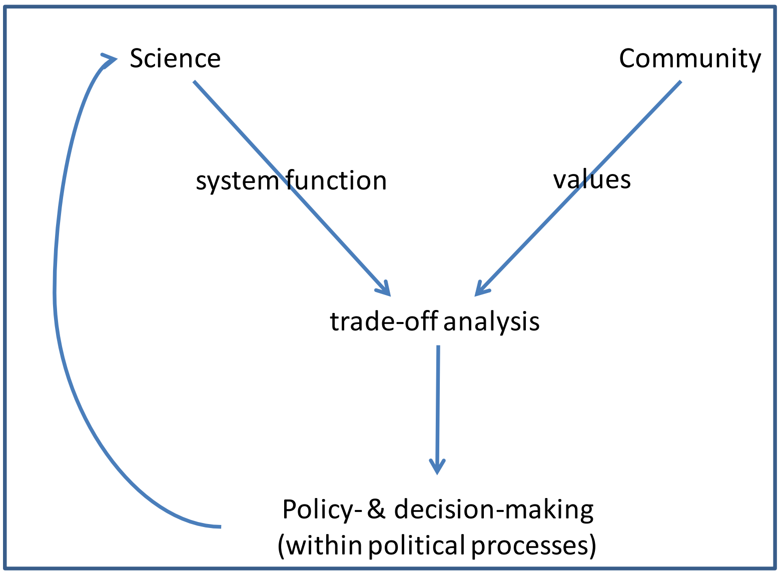

Figure 2.1. A standard model of how values are perceived and used within policy- and decision-making (see NRC, 2005; Liu *et al*., 2010; and Barbier, 2011 for applications of this)

This view of decision-making processes in NRM separates science, community, and decision making into three clearly defined groups and roles. Science is used to objectively develop understanding of the environment, describe different management options and analyse the implications of these options. Community members are asked to state their preferences about the environment and evaluate different options. Trade-off analysis is used to articulate how different values are affected by different options, and the policy- and decision-making processes decide how the different values should be considered.

We describe three roles that notions of value can play in this process, and define some terms for use in our discussion. The first function is to enable systems behaviour to be described, researched and discussed, which requires:

- ***A concept of what is valued.*** This may be a relatively simple concept, such as a definition of an object (e.g., a brick) or something more complex (e.g., a bundle of property rights associated with home ownership, or an abstract concept such as biodiversity). The ecosystem services approach to evaluation implies that there are attributes of the natural system valued by people (e.g., amenity and cultural services). However, the term 'ecosystem service' is often taken as referring to the *good or service itself* rather than the *concept* of what the thing is. For the function of values to be performed, appropriate concepts of what it is about nature that we value needs to be specified. We use the term *concept of what is valued* to allow for the full range of aspects and scales of nature (from specific objects and species to ecosystem functions) to be recognised. This becomes important when discussing more abstract concepts of what is valued such as biodiversity, landscapes or ecosystem health that, we argue, are required for describing complex SES.

A second role is to allow people to express views and preferences for possible changes in the physical world, based on how they expect these will impact on their interests, in order to inform or influence a decision-making process. An expression of values requires:

- **A method for communicating the significance of the change of the object of interest**. This may be expressed in monetary terms (e.g., people are willing to pay $30 per kg of fish), or it may be a vote, or a speech in a community forum. For the purposes of this document we refer to any conceptual framework people use to express views about why something is important as ***an expression of value***.

A third role that values play is to provide principles to help guide decision making:

- Ideological and ***ethical principles*** provide guidance for individual actions for ***social decision-making processes*** that involve multiple values held by different people and groups. ***Ethical principles*** inform and form part of the institutions (the rules and norms) that define a social decision-making process.

> Utilitarianism is an example of an ethical principle that shapes the rules governing market-based exchange.

Note that the three terms: ‘concept of what is valued’, ‘an expression of value’ and ‘ethical principles’ are collectively referred to as ***value concepts***.

When one focuses on the roles of values, the following aspects of value concepts become clear:

- A concept of what is valued relates to concerns about the physical world. The expression of value therefore requires views of how the world works to be conceptualised and communicated.
- A concept of what is valued exists in peoples’ minds, not in nature. It is necessary to recognise people and their thoughts as central to any discussion of values. How people conceptualise values and express them is therefore central to understanding how values can be considered in society’s decision making.
- Expressions of value are made in the context of social decision-making processes. The expression of value must be meaningful within the context of the ethical principles and related institutions that guide decisions. A market is an example of a social decision-making process in which expressions of value are mostly in terms of money offered to influence the decision of participants in the exchange of goods or services[6].

Taking the perspective that value concepts *play a role* in social decision-making processes suggests we can examine how well they play this role. When looking at the roles that value concepts play in social decision-making processes, we argue that the above three aspects (i.e., the physical, individual and social aspects) of value concepts are necessary and related components. In fact, it is because value concepts have these three ‘faces’ that they enable society to partition social decision-making into the three domains (science, human thought, and social decision making) as shown in Figure 2.1. A consequence of this three-sided nature of values, however, is that if concepts of value are thought to be inadequate for managing a natural system, defining useful concepts of

[6] There are examples of markets where expressions of value are in terms of goods or services such as ‘rewards for ecosystem services’ (Barry, 2011)

value will not only need to involve the public, researchers and decision makers, but will involve them in different roles and relationships than those defined in Figure 2.1.

The relationships among communities, researchers and decision makers in rethinking values

The need for decision makers (as defined in Section 1.3), scientists and communities to engage closely to manage natural systems is well established and widely practiced (e.g., Lane *et al.*, 2004; Head, 2007; Dowd *et al.*, 2008; Gorddard and Kelly, 2010; Swanson *et al.*, 2010). Similarly, the understanding that science cannot play an entirely objective, value-free role in complex social problems is not new. For example this problem, and its implications for the role of science in informing policy in highly contested and complex social-ecological contexts is discussed in the post-normal science literature (e.g., Funtowicz and Ravetz 1990, 1993; Pielke, 2007).

Here we focus on the implications of the required changes in *value concepts* for the roles and interactions among communities, scientists and decision makers to enable effective adaptation. Figure 2.2 presents a schema of the main concepts and relationships that follow.

The central circle in Figure 2.2 emphasises the close connections between the three value concepts: ethical principles, concepts of what is valued, and expressions of value. These play a primary role in guiding decision making, enabling relevant descriptions of systems behaviour to be researched, and allowing communities to express their concerns about the system, respectively. These value concepts must play these roles and must effectively work together for the system to function properly.

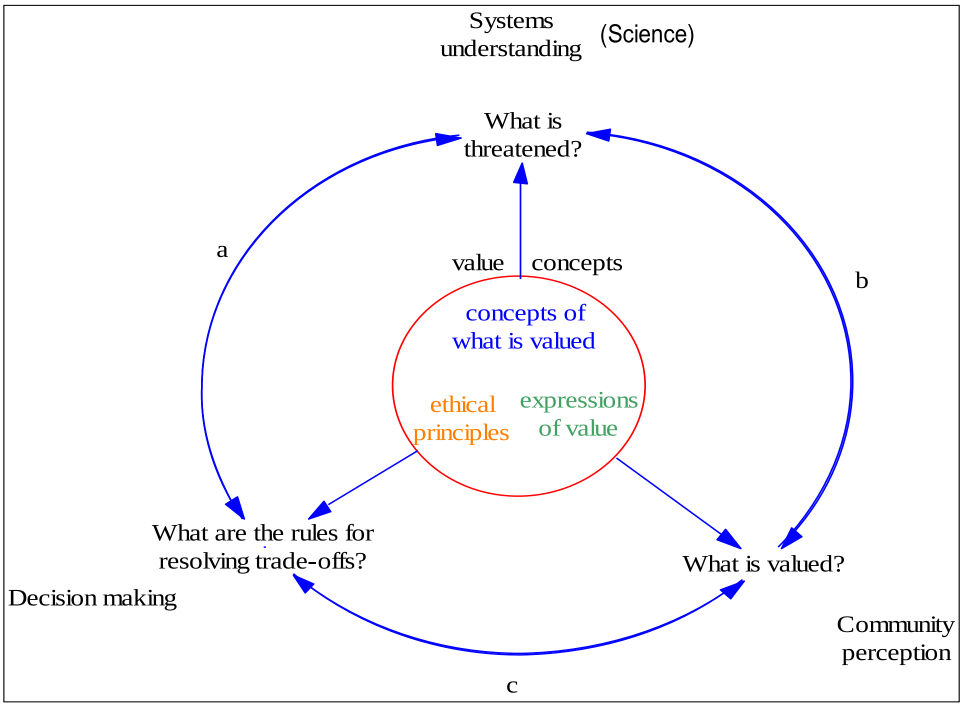

Figure 2.2. A schema of the main concepts and relationships involved in decision- and sense-making. Concepts of value play a role in linking the different groups (communities, policy makers and researchers) involved in collective decision-making processes. 'a' = links between decision making and science; 'b' = links between communities and science; 'c' = links between communities and decision making

Our suggested framework for analysis of how well values are considered in coastal adaptation is to systematically evaluate how well these physical, individual and social aspects work in isolation and together. We may therefore ask the following of each of the value concepts:

- Do the *concepts of what is valued* enable a scientifically defensible description of how the system functions?
- Do the permitted *expressions of value* enable people to describe their concerns, views and preferences about the functioning of the natural system?
- Do the *ethical principles* provide appropriate guidance for decision making?

Most of the changes required of existing decision-making processes for them to better accommodate ecosystems relate to how well these elements work together.

Values and the links between decision making and science (link a)

The issues in this context relate to whether the *concepts of what is valued* are meaningful in terms of the ethical principles used by the decision-making process, and conversely, whether the *ethical principles* enable valid and useful conceptualisations of how the biophysical system operates so that *concepts of what is valued* can be identified.

Mismatches between the *concept of what is valued* and the spatial and temporal scales of decision making – or between the *concept of what is valued* and ethical principles – may make the former meaningless within the decision-making framework (see Arild (2009) for a detailed exposition of this problem when using "appraisal methods as value articulating institutions"), or imply that the type of decisions that can be made do not permit influence over the *concept of what is valued*. For example, since the Commonwealth's Environment Protection and Biodiversity Conservation Act (1999) (EPBC Act) does not formally recognise landscape[7] aspects of nature as a concept of what is valued, landscapes are not formally considered in conservation and development planning. As a consequence, landscapes are more likely to be affected by cumulative development decisions, because each development decision is only considered in terms of its effects on certain species. Brunckhorst *et al.* (2006), Brunckhorst and Reeve (2006), and others have recognised this and, in response, are developing approaches for planning and managing the "eco-civic" balance across landscapes, and improving understanding of nested institutional design for multi-scale resource governance. Another example of the mismatch between the ethical principles of the decision process and the concept of what is valued is how public administration instruments are structured to recognise and value expert, ordered and rational knowledge over local and community knowledge (Adams, 2004).

Current institutions were designed or evolved to respond to past threats to values. Climate change introduces a new range of environmental changes that threaten values that might have been regarded previously as secure and not in need of management.

[7] Cultural landscapes are, however, provided for under the 'World Heritage Properties' and 'National Heritage Places' components of the EPBC Act (http://www.environment.gov.au/epbc/protect/index.html). In this context, cultural landscapes are defined as: aggregations of places, features, objects, archival material, memories and perceptions of social and contemporary significance.

Climate change is also likely to affect the relative importance of coastal values to stakeholders as some values increase and others decline in importance (e.g., protective values of coastal ecosystems may grow relative to their scenic values). Frequently, addressing threats to a value has negative impacts on other values. Resolving such trade-offs is one reason we have many institutions. It may be that existing institutions can readily address trade-offs involving new values (or vastly different threats), however it is more likely that resolution of such trade-offs needs to be governed or guided by higher-level institutions or purpose-specific policy processes.

The search for *concepts of what is valued* (or the quantification of inappropriately defined concepts of value) independently of the decision-making process can become pointless with increases in the complexity of the system and the number of relevant decision nodes. Specifically, standard economic analysis is based on the concept of a well-defined homogenous unit of an environmental good or service so that management alternatives and values can be defined in terms of addition or subtraction of these units. Analysis of policy options in complex systems need descriptions of policy alternatives that consider the multiple and flow-on effects of various options on the systems. A range of different *concepts of what is valued* (e.g., species, ecological communities, ecosystems, landscapes) and *expressions of value* (i.e., other than monetary values) matched to the decision-making context, scale and associated ethical principles are therefore necessary.

Values and the links between the public and science (link b)

Here we examine how well the concepts people use to express values relate to the *concepts of what is valued* used by scientists to measure and model the systems behaviour. As a simple example, people may express values for conservation of species in a fixed area and not consider that climate change may be shifting species distributions. If scientists are finding evidence of shifting species distributions, it would be reasonable to argue that there is a need for a process to reconsider the expressions of value for ecosystems using concepts other than species conservation.

People's understanding of what a healthy system should look like (i.e., the ecosystem's structure, composition and functions) will be intimately related to the way in which they think about their values for the system. As a result, the questions of ‘what is valued?’ and ‘what is threatened?’ are required to guide each other in an iterative process. Implications include:

- Standard survey-based approaches to peoples’ preferences (e.g., willingness to pay surveys) are unlikely to result in meaningful responses when the system behaviour is complex and uncertain, and non-linear change is a possibility.
- There is a legitimate role for science to interact with communities to define and develop concepts of what is valued. The concepts must create meaningful descriptions of the physical world to enable scientific analysis of options and also to reflect peoples’ concerns about the world.
- The range of scales at which the *concepts of what is valued* operate need to be matched to the scales at which people are asked to value changes. Relevant interest groups may therefore change with our understanding of the system and a varied set of interest groups at a range of scales may need to be consulted.

The match between scientific *concepts of what is valued* and peoples’ expressions of value may not converge simply through increased engagement. An emotional/cultural view of social cognition of sea level rise suggests that presenting scientific information to those predisposed to reject it can actually strengthen their adherence to an opposing opinion (Nyhan and Reifler, 2010). Linking psychology, culture, values, perceptions of the accuracy of information, and risk, Kahan *et al.* (2011) demonstrated in their experiments that the ideology of participants predicted their tendency to accept or reject evidence on a range of topics, including climatic change. In that case study, participants were classified into two main ideological groups according to their position along two axes: whether they believed society should be individualistic or communitarian; and whether they believed society should be hierarchical or egalitarian. Participants readily accepted evidence if it was compatible with their ideology, and rejected that which was not.

To establish communication about new and controversial policy that addresses risk and uncertainty, it is necessary to identify the various ideologies of the stakeholders, and link the policy to measures that are potentially compatible with those ideologies, and with narratives with which they are familiar (Kahan *et al.*, 2011). Values are formed in a social context, and individual values are influenced strongly by the values of others, so stakeholders are more likely to accept information and adaptation measures if they are presented by a person with a similar ideology – a business leader, for example, in the case of a person whose ideology is individualistic-hierarchical (Kahan *et al.*, 2011).

Since expected institutional arrangements for decision making affect the processes of science and community co-developing *concepts of what is valued* and expressions of value, this process cannot be detached from policy development. In addition, people hold values about the process of decision making (such as fairness) that often need to be addressed simultaneously with a discussion of the functioning and values of the bio-physical system.

Values and the links between the public and decision making (link c)

Here the focus is on whether the decision-making process and the *ethical principles* that guide the process enable people to effectively express their values. For example, in surveys of economic values for ecosystems, many people reject the implicit assumption that their value for an ecosystem is appropriately expressed in monetary terms. Alternatively, expressions of monetary values for a scenic view are valid and influential in the context of a property market.

A key issue is that separation of decision making from citizens often requires communication about values in a manner that is free of context of either the decision options, or the physical system. Requests by policy makers for economists to calculate the value of an ecosystem or ecosystem service stem from this need, as do requests for community consultation. If values cannot be effectively expressed under these conditions, however, the relationship between decision making and citizens may need to be reconsidered.

Conventionally, economics has regarded humans as rational beings whose decisions optimise the realisation of their values and preferences. However, people's *expressions of value* cannot be expected to be derived from a pre-existing set of stable and consistent preferences that is independent of the decision-making context or their understanding of how complex and uncertain SES function. Rather, there is evidence that the predominant responses to new evidence are initially, and often entirely, emotional and intuitive. Rationality is added subsequently to support an emotional position (Haidt, 2001). Moreover, the cultural role adopted by an individual affects their worldview (Tetlock, 2002; Alexander *et al.*, 2011). Therefore, surveys of values using stated preference methods such as contingent valuation and choice modelling (Barbier, 2011) are not useful for valuing ecosystem services (i.e., the emergent properties of dynamic complex systems; see Section 1.4.1) because they are not part of a participative process that addresses the ideological foundations of espoused values.

Valuing adaptation options requires people to consider how to prepare for changing disaster risks, as well as how they think about the value of long-term changes (O'Brien and Wolf, 2010). An inherent problem of values surveys is that people have difficulty evaluating unfamiliar or hypothetical changes as opposed to events they have experienced. They have not yet experienced the new biophysical circumstances, will not know what the new value priorities of their ideological peers will be, and the most severe impacts are not expected to be within their lifetimes. Deliberative processes where stakeholders explore potential changes and their consequences are likely to be more useful in such circumstances than surveys that only capture their current prejudices (Kenter *et al.*, 2011). Wilson and Howarth (2002) and Spash (2007, 2008) discuss the use of deliberative valuation methods that address the links between ideology, values and information.

Finally, the application of valuation techniques to estimate the economic value of an ecosystem service might best be done when the ecosystem services' values can be ascribed (i.e., the values are not intrinsic or held), measured at the margin, and expressed in terms of exchange (Abson and Termansen, 2010). This is mostly possible for provisioning services such as harvested fish, aquaculture, and timber, but it is not possible for the intrinsic, spiritual, cultural, and indirectly useful values derived from supporting and regulating services (such as disease regulation, production of atmospheric oxygen, soil formation, nutrient cycling, and ecosystem resilience).

2.3 Values and the role of economic analysis in coastal adaptation

By emphasising the various roles that values play in decision making, the values framework presented above (Figure 2.2) provides a context for discussing the appropriate role of economic cost-benefit analysis in coastal decision processes. We briefly discuss some of these issues here.

Firstly, economic cost-benefit analyses use utilitarianism as a guiding ethical principle. This may not always be the framework used to guide a decision-making process, so economic analyses may not be considered relevant to all decision makers. Even where it can be argued that it should be relevant, utilitarianism may not be the only relevant ethical principle. Acknowledging the different ethical principles in practice may permit a more considered view of how economic analysis relates to decision makers. It also opens the possibility of subjecting the decision-making criteria to evaluation of how they will perform under different circumstances.

Second, economic analysis requires *concepts of what is valued* to meet stringent logical requirements that enable them to be priced and quantified in a way that permits the prices and quantities to be added according to the conventions of accounting. Limits on the ability to sensibly apply this approach to complex interacting systems need to be acknowledged. *Concepts of what is valued* that can inform social decision-making processes but do not meet these criteria are often used, and are typically called indicators. Developing more complex concepts that are designed to reflect peoples' concerns may be equally useful inputs into decision making even if they do not support a monetary valuation.

Third, economic valuation focuses on the opportunity-cost that individuals are willing to forego as the appropriate *expression of value*. While this is extremely valuable, in situations where the opportunity costs are complex and uncertain other guiding ethical principles may be valid and other ways of expressing values may therefore be of use.

We advocate an approach to economics that is firstly positive: that is, it argues that the usefulness of economic cost-benefit analysis in supporting decisions will depend on how the economic framework matches the way values are treated within the particular decision-making processes.

The approach we recommend is also normative in that it suggests we should reconsider the role of economic analysis to inform decision making. While acknowledging the role of economics in providing estimates of the monetary value of natural capital to make it commensurate with other forms of capital and inform adaptation option tradeoffs, the nature of many of the changes under climate change will often render these estimates less useful. We therefore argue that, in contexts where changes are uncertain, multifaceted and involve significant intergenerational equity issues, a key change that is required is a shift in focus of economic analysis from evaluation of options to an analysis of institutions and their ability to effectively accommodate and account for changing and uncertain value concepts.

We are not suggesting that markets and market-based value concepts have no role to play in coastal adaptation. On the contrary, market-based policy analysis is likely to be critical in assessing aspects of decisions where opportunity costs are clear, lifetimes are relatively short and distributional issues are minor. Rather, we emphasise that markets are only one relevant context within which values can be expressed and decisions made, and that a values framework based on Welfare Economics – the basis of cost-benefit analysis and mainstream environmental economics – may not be relevant. We also emphasise that Welfare Economics should perhaps be expected to reasonably inform, but not determine, decision-making processes. This contrasts with some Ecological Economics critics of Welfare Economics (Gowdy and Erickson, 2005) that instead focus on redefining the criteria for decision-making and on replacing the neoclassical Welfare Economics framework with assessment frameworks based on multiple criteria (which is no more effective at accommodating the real difficulties of uncertain and dynamic value concepts associated with climate change adaptation).

There are many assessments and critiques of the economic frameworks that rely on market and non-market values to weigh up policy options (see for e.g., Arild, 2009; Nelson, J.A., 2011; Wegner and Pascual, 2011), and as such we are not going to focus our analysis on these. Rather, we focus briefly on two questions: If we do not use

Welfare Economics, what criteria should we use to evaluate how well institutions manage values? And, what methods are appropriate for evaluating institutions?

Criteria for evaluating institutional arrangements

In evaluating how well institutions are working, as opposed to appraising decision options, we have the luxury of not having to choose a single solution. It is useful, therefore, to consider multiple perspectives from which institutional arrangements can be judged to be good enough, rather than search for a consistent set of criteria that define the best arrangements. Possible conditions that could be used to assess the quality of the institutional system include:

Values-focused criteria such as:

- For any values that people argue should influence the management of the system, there must be a decision-making process that saliently, credibly and legitimately considers these values.
- The policy- and decision-making processes must be suited to the nature of the values it considers. That is, it must be capable of taking the values into account, and of effecting the appropriate changes.
- The people affected by the resulting decisions should generally view the decision process as legitimate, fair and wise (Wondolleck and Yaffee, 2000: 231), and agree to abide by the resulting decision.

Pragmatic criteria such as:

- The ability of a given decision-making process to effectively change the physical drivers of the values it claims to manage. Here, ‘ability’ might be measured by the persistence of decision makers and their decisions, and the power and agency of decision makers that are required to ensure changes are carried through.
- The robustness of institutions: suitability of the decision-making system for the range of plausible circumstances that it may need to cope with under climate change.

- The ability to direct resources, based on learning about and accommodating changes including changes in the relevant values.
- The ability to enable institutional adaptation rather than reinforcing current inertia.

Evaluating how well institutions allow the expression of values

Researchable economic questions that emerge from this discussion relate to determining if certain institutional arrangements are likely to achieve an outcome considered to be of value. Since multiple criteria are needed to evaluate the effectiveness of institutions at managing coastal ecosystems, multiple approaches are likely to be needed to measure and evaluate institutions. In particular, we argue that small-scale trials of novel institutional arrangements are likely to be a suitable and credible means of doing this. One reason for this is that the ways in which institutions actually work depends on the social, economic and institutional context, so the effect of changes are difficult to predict. People's expression of values will also be determined by the institutional context, and therefore will be difficult to evaluate outside of actual trials. As a simple example, the price that people are prepared to pay in an environmental market such as carbon abatement is difficult to predict, and may be inconsistent with the values expressed by people in other decision-making processes. Small-scale trials of altered institutional arrangements enable evaluation of the institutions from multiple disciplinary perspectives using a range of different criteria. Small-scale trials can also help overcome the inertia to change in institutions. The Grand Canyon's experimental management program provides a good example of this. In this case, the multiple, nested leaders recognise the uncertainties and complexities of the system, believe that resolution of environmental issues can only be discovered – not achieved – by predetermined policy, and have created space and opportunities for experimentation and learning that built trust amongst stakeholders and created new institutional platforms for adaptive management (Gunderson and Light, 2006).

2.4 Application– adapting concepts of what is valued to climate change

This section looks at what would be involved in revising the *concepts of what is valued* so that coastal ecosystems can be more effectively considered in decision-making processes. We use coastal ecosystems along the south coast of NSW as the context for this discussion. In this section, we also describe how concepts of biodiversity may need to be supported by concepts of ecosystems and landscapes to ensure that values for coastal ecosystems are effectively considered in policy and management decisions. We also discuss the institutional aspects of these concepts, illustrating some of the ways in which analysis of the biophysical system needs to consider and inform institutions.

The native ecosystems of the south coast of NSW are valued and experienced by people in a multitude of ways, including use and non-use values. Among the use values are the protective, recreational and habitat values of beaches, dunes and wetlands, and the recreational and commercial values of fisheries. Among the non-use values are the intrinsic and option values of these same assets. These values contribute to the wellbeing of residents, national and international visitors, and to businesses. Many of these values play a key role in decisions that people make about their own activities in the region and in planning and regulatory decisions that affect the actions of others.

Many of the species and ecosystems that give rise to values will be affected by climatic change, but the consequences will be strongly mediated by coastal development patterns (Ticehurst *et al.*, 2007), as these examples show:

- The protective, habitat and amenity values of beaches and dunes depend on the quantity of sand. Protective structures built in one place to protect assets can divert currents and cause erosion elsewhere (IOC, 2009). The quantity of sand is determined by the balance of erosion from storms and deposition during calms. Phases of high storm intensity have occurred in the past and increased intensity may be a feature of climate change. Sea level rise would increase the spatial influence of storms. If sea level crosses a threshold then it will probably interact with storm intensity to erode beaches and dunes faster than they deposit (Department of Climate Change, 2009).

- Mangroves are important fish and bird habitat, have scenic value and attenuate waves (Barbier *et al.*, 2008; Valiela and Fox, 2008). Mangroves trap sediments, and as long as the rate of accretion is not less than the rate of sea level rise, they can colonise land as the sea rises – provided the land is available and suitable for colonisation (Harty and Cheng, 2003; Duke, 2006). Salt marshes, also important fish and bird habitat, being on the landward side of mangroves and at slightly higher elevation, will lose area to mangroves as the sea rises if constrained by topography or infrastructure. There are likely to be thresholds below which the area of mangroves or salt-marshes remaining is insufficient to support particular species.
- Sea grasses are important fish habitat and stabilise the substrate. Increased turbidity and epiphyte loads due to cumulative nutrient enrichment are the primary causes of sea grass decline. Hard urban surfaces and drains enhance freshwater flows that can potentially cause threshold changes in erosion-sedimentation patterns, affecting the turbidity of sea water and its depth. Urban runoff carries nutrients and other pollutants in sewage. Nitrate levels in the Brisbane River, for example, are reported to have risen 22 fold, and phosphate eleven fold since 1950 (Duke *et al.*, 2003; Duke, 2006).

Understanding the range of values supported by coastal ecosystems and how they might be affected directly and indirectly by climate change is therefore important for assessing the societal impacts of climate change and designing programs and institutions to minimise the negative impacts on those values.

Biodiversity is incorporated into existing policy in various ways. The most direct articulation of biodiversity values in formal institutions involves threatened species (and ecological communities), as described in the Commonwealth's Environment Protection and Biodiversity Conservation Act (1999) and NSW's Threatened Species Conservation Act (1995). Threatened species and ecosystems are frequently identified as the headline indicators of the status of biodiversity, and their conservation is the primary basis of much biodiversity management. However, there are many aspects of biodiversity, other than threatened species, that are valued by society for cultural and material purposes (Millennium Ecosystem Assessment, 2005). Some of these other values are described and deliberately protected. For others, there are no clearly defined concepts of what is valued that are incorporated into decision-making processes. Some are protected informally or incidentally under the umbrella of the formally defined values. Where there is not a well-defined concept of what is valued it may no longer continue to be protected under some scenarios of future climate change.

In addition to the need for concepts of what is valued to include values that no longer fall under the umbrella of currently protected values, concepts of what is valued may also need to accommodate threats, assets and management options that are of concern under climate change. As well as focusing on threatened species and communities, many current planning processes are implicitly based on the assumption that species distributions and ecosystem types are more or less static. As a result they may not be well suited to the inevitable changes to biodiversity under climate change. Some values associated with coastal ecosystems will be more affected by climate change than others. Some will inevitably change to the extent that seeking to preserve them might be either very expensive or futile.

To be effective, efforts to manage coastal ecosystems need to focus on those values that are vulnerable under the combined impacts of climate change and other pressures, but that can potentially be maintained through management. For example, it is likely to be difficult to preserve the *current* nesting sites of some threatened shore birds as dunes erode, but it might be feasible for the populations to survive in new locations. Similarly, many coastal freshwater wetlands are likely to be affected by saltwater intrusion and flooding; in these cases preserving the current composition of species and ecosystem type would be very difficult. Attempts to do so could readily involve unsightly, expensive and intensive infrastructure and engineering management (levees, altering ground levels, pumping of saline groundwater, flushing with freshwater), and be marked by losses of characteristic species and degradation of the freshwater ecosystem. As an alternative, it may be feasible to manage the transition as salt-tolerant species establish, and the ecosystem transitions to salt-water wetland (e.g., saltmarsh), then to mangrove, then seagrass as tidal influences increase and sea level rises. As these transitions occur, it may be feasible for the ecosystems to continue to support primary production and nutrient cycling, and provide habitat for a diverse range of species, albeit a mixture of species that changes over time. Thus the *ecosystem health* may be preserved, possibly with the help of careful management, while it undergoes an inevitable change in *ecosystem type*. Values associated with the specific fresh water ecosystem will no longer be provided in that location; however, they may be provided elsewhere, and there will be new values associated with the new species and ecosystems. Most importantly, values associated with a healthy ecosystem will be maintained the whole time.

2.4.1 Implications for existing institutions

In some situations, planning for and facilitating such transitions may require relatively minor updating of local planning processes and procedures. Other situations, such as a transition from one ecosystem type to another, however, may require changes in the informal or formal institutions. For example, deliberation and negotiation with local communities or influential stakeholders, or changes in state legislation or policy may be required if it is habitat for threatened species or there are strong associations with the current ecosystem. At the extreme, such transitions may have implications for obligations under international agreements (e.g., signatories are expected to manage Ramsar sites to maintain the "ecological character" of each site[8], which may not be possible, or even desirable, under climate change).

This transition can be characterised as a paradigm shift from seeking to preserve the current situation to managing ecological change to minimise losses, maintain resilience, and/or ensure options are maintained. Such a paradigm shift can be applied at the level of species and ecosystems as described in the shore bird and wetland examples above, or for whole landscapes.

Landscapes consist of a mixture of human-dominated and more natural ecosystems. As sea level rises and other climate change impacts occur there will be changes in both the human and natural parts of the landscape, including changes in agricultural practices

[8] "Ecological character is the combination of the ecosystem components, processes, benefits and services that characterise the wetland at a given point in time (Ramsar Convention 2005a, Resolution IX.1 Annex A). Changes to the ecological character of the wetland outside natural variations may signal that uses of the site or externally derived impacts on the site are unsustainable and may lead to the degradation of natural processes, and thus the ultimate breakdown of the ecological, biological and hydrological functioning of the wetland (Ramsar Convention 1996, Resolution VI.1)." (DEWHA, 2008)

and ecosystem types. Resisting these changes would be difficult, but it might be feasible to ensure that as they occur the overall balance between human and natural influences does not change undesirably.

The core of this paradigm change is recognising that some values may be lost as biodiversity and ecosystems change, others can be preserved, and new ones developed. It is therefore necessary to unpack the different types of values associated with species, ecosystems and landscapes, and assess which values are likely to be affected by climate change and which may be more feasible to protect (possibly including values considered to be “higher” or more fundamental). Values associated with coastal ecosystems are socially constructed, likely to vary with context (beach to estuary, estuary to estuary), and will evolve over time. Therefore an urgent area of research needs to involve understanding these values, how they change, and how they can best be used to inform policy and management.

2.4.2 Ecosystem concepts for informing coastal ecosystem assessments under climate change

We present a framework in Table 2.1 to help people think about how different aspects of coastal ecosystems will change, along with their associated values. This suggests properties that might be more feasible to protect, but not how much they might be valued by society.

The different dimensions of biodiversity are listed in the first column of Table 2.1. While similar to the traditional genes-species-ecosystems categorisation of biodiversity, this is intended to reflect the dimensions which people might experience and value in various ways. The dimensions in the first three rows reflect what someone might experience, respectively, when bird watching, on a stroll through the bush, and looking out from a headland, hilltop or aeroplane. These dimensions are quite different ecologically from each other, and we suggest they are readily recognised as being valued by the ‘person in the street’. As discussed above, species and their collectives (ecological communities) dominate official expressions of biodiversity value, but there are examples of values associated with the other dimensions being protected in some conservation programs. In this framework, the ecosystem dimension relates to the *quality* of nature that might be experienced, and the landscape dimension relates to the *quantity*. The ecosystem dimension represents the condition of the functioning ecological unit including key ecological processes. It is multi-scaled, including for example the condition of a patch of rainforest habitat, a wetland, and the ecosystem of an estuary with its terrestrial, freshwater and marine components linked by ecological processes. Landscapes, including ‘seascapes’ and ‘riverscapes’ refer to SES made up of multiple ecosystems and human activities; in the framework, this dimension captures the degree of human domination of nature from the scale of an individual’s local surroundings through to the continent. The fourth row in the table, biological diversity, is perhaps a more technical and hidden dimension, but it represents the all-important variation at multiple scales within the totality of genes, species and ecosystems that gives rise to and maintains the other three dimensions.

The second and third columns include various attributes (of the biodiversity dimensions) that give rise to values. The second column includes those attributes that are associated with biodiversity in largely unchanging environments. In contrast, the third column seeks to identify attributes of biodiversity associated with ‘dynamic’ biodiversity outcomes that are more likely to persist and continue to provide value, as attributes in the second column are affected by climate change.

The attributes in the second column are, coincidently, exactly the types of attributes that might be recorded in contemporary assessments of the state of biodiversity, and changes in these attributes are typically (sometimes legislatively) regarded as declines or potential losses. The paradigm shift described above involves shifting the focus of management from the second to third column; part of the technical challenge in doing this involves developing a robust set of attributes for the third column and translating them into ‘climate-change resilient’ conservation objectives. Doing this will also necessitate giving more explicit attention to the attributes of biodiversity in the second, third and fourth rows. The social and institutional challenge is then re-negotiating conservation priorities with stakeholders at local, state and national levels in the face of limited resources and the realities of change.

Dimension of biodiversity Entities valued by society, each at multiple scales	Attributes of biodiversity Current 'static' outcomes	 'Dynamic' outcomes
Individual species and genes (fundamental units of biodiversity, including ecological communities)	Abundance, distribution and co-occurrence (community) (also population genetic diversity and demographic structure)	*Existence* of a species (surviving and evolving somewhere)
Ecosystem and habitat (quality, ecosystem processes, from a terrestrial or aquatic patch to key ecological processes)	Ecosystem type (composition, structure and function; condition relative to type)	Ecosystem *health* (key ecological processes, maintaining and/or cycling water, carbon, nutrients, soil, primary productivity, species diversity)
Land/river/seascapes (quantity, social-ecological system, degree of human domination, ecosystem services, surrounds to continent)	Mixture of types of human uses and natural biodiversity	The *balance* of uses (the proportion of resources, productivity and biodiversity appropriated by humans)
Biological diversity (genetic, α, β, γ)	Change in species and ecosystems identity	Patterns of diversity

Table 2.1. A framework classifying different attributes associated with four dimensions of biodiversity. The first three dimensions might be more readily recognised and valued by society in different ways and the fourth is a more technical, hidden dimension of biodiversity. 'Static' outcomes are those that could be achieved with unchanging biodiversity. 'Dynamic' outcomes are those that could be achieved as biodiversity changes in response to climate change. Attributes associated with dynamic outcomes may be more suitable as the basis of future conservation objectives (adapted from Dunlop and Brown, 2008).

Ensuring the existence of a species is a relatively straightforward aspiration (e.g., 'minimising species loss at the continental scale'). This could involve ensuring habitat becomes available for species unable to persist in their current locations, and managing those locations so they become suitable for new species. The attributes we list in the third row for ecosystems, landscapes and biological diversity are currently much more contestable scientifically. For example, objectives for ecosystem health might be described in terms of levels of biological productivity, storage and cycling of carbon, nutrients and water, formation of soils, maintenance of species richness and trophic structures, and demographic and structural diversity. Landscape objectives might be described in terms of the balance between natural- and human-dominated land uses, or the partitioning of primary productivity. By explicitly combining potentially conflicting biodiversity and production outcomes, landscape objectives are likely to be socially as well as scientifically contestable. Objectives for biological diversity might be described in terms of the richness and spatial structuring of variation in different levels, or maintaining the ‘evolutionary character of Australian biodiversity’.

2.4.3 Implications for coastal squeeze and land-use planning

The changing concepts of ecosystems that we argue are required to inform decision-making processes of societal values are potentially readily adoptable by government and catchment management authorities. Ensuring these concepts are appropriately considered in local land-use planning, however, may be a more challenging task. The plot-by-plot decision making that is the focal point of land-use planning requires tightly defined concepts to guide decision making. The proposed concepts of coastal ecosystems, particularly related to landscapes and ecosystem health, permit articulation of the cross-scale effects that result, such as those from cumulative development pressure. They may therefore be valuable in enabling the planning process – including Strategic Environmental Assessments[9] – to better account for the effects of cumulative development. The requirements for tightly defined concepts to inform planning approvals and appeals, however, may mean they need to be further refined and adapted.

2.5 Summary: reconsidering values under climate change

A focus on values was motivated by concerns that the ways in which values are used to support and inform societal decisions about coastal ecosystems may limit adaptation. To analyse this issue, we developed a framework that focuses on the different roles that values play in enabling people’s concerns to be appropriately considered in social decision-making processes.

We define three concepts related to values (i.e., value concepts) that serve different roles: *ethical principles* or ideological frameworks help guide decision making;

[9] In Australia, Strategic Environmental Assessments (SEA) are required to assess the cumulative impacts of all proposed developments. SEA theory and practical application, however, are increasingly being reported to under-deliver in terms of cumulative effects: “Whilst SEA implementation is now well advanced, we are still not taking sufficient account of cumulative effects at the level of practice” (IAIA, 2012). Reasons proposed to explain this include: current methods are insufficiently robust to deal with the complexity of the often inter-jurisdictional nature of cumulative effects; the Cumulative Effects Assessment (CEA) procedures are not sufficiently integral to policy and planning at all levels (local to national); and the goals of development and conservation, and associated criteria for monitoring and evaluation, are inappropriately designed to account for cross-scale effects in planning and policy (see, for e.g., World Bank, 2005).

concepts of what is valued (e.g., biodiversity) allow researchers to describe, measure, and model the system; and *ways of expressing values* allow citizens to express their concerns in order to influence one or more of the several *social decision-making processes* which influence coastal ecosystems.

These three value concepts allow the task of decision making to be spread across three key sets of actors: *decision makers* (defined in Section 1.3), the *public*, and, because adaptation requires learning or sense-making as well as decision-making, *researchers*.

We suggest that an analysis of the suitability of values for adaptation should focus on determining whether the different value concepts can play their roles in the decision-making process. That is, do the ethical principles, expressions of value, and concepts of what is valued enable effective decision making?

We emphasise that these concepts are closely related and need to work together. For complex problems such as the adaptation of coastal systems we argue that the required value concepts are more complex and do not permit the degree of separation among decision makers, researchers and the public that has become standard and institutionalised in, for instance, local planning processes. Adapting value concepts and ensuring that values play their intended role in social decision-making processes requires a closer and changed relationship between these three groups. Key points include:

- Citizens cannot be expected to express values for ecological outcomes outside of the context of the rules of the decision-making process, and without a deliberation of how the system functions.
- There is a legitimate role for science to interact with communities and policy makers to define and develop concepts of what is valued.
- The *concepts of what is valued* need to be effectively matched to the *ethical principles* used to guide decision-making processes. Both the ethical principles and the concepts of what is valued may need to be reconsidered.

Implicit in this discussion was an analysis of the role of economic approaches to the evaluation of decision options. Economic analysis assumes specific ethical principles, concepts of what is valued and ways of expressing values that may match neither the existing decision-making process, nor the characteristics of the decision-making problem. This perspective can help to understand how economic analysis can effectively relate to decision-making processes that are not framed as economic problems, and therefore help specify the appropriate role for economic decision analysis in these contexts.

We then look at how different concepts of what is valued may be applied to coastal systems. Specifically we describe concepts of ecosystem health, landscapes, and diversity which may be helpful in informing various decision processes. We suggest that it may be useful to develop and trial such concepts in catchment-scale planning processes. Such concepts may also help overcome the cross-scale problems caused by the plot-by-plot nature of land-use planning in many terrestrial ecosystems.

3. BUILDING LOCAL GOVERNMENT DECISION-ANALYSIS CAPABILITY

3.1 Introduction

This component of the project focused on developing ways to assist local government decision makers to evaluate coastal adaptation strategies. We present a modelling approach developed for this purpose, and illustrate some of the key capabilities using preliminary analysis of adaptation options for Surfside Beach, NSW.

The remainder of this introduction describes how the approach to decision support evolved from discussions with key local- and state-level decision makers about decision-support needs, analysis of the nature of systems and issues, and evaluation of the available modelling methods and processes. This process identified potential value in quantitative economic modelling of the costs and benefits of adaptation options using dynamic Bayesian networks to support local government planners and asset managers.

3.1.1 Motivation for decision support

The need for policy makers to evaluate the multiple benefits and costs associated with adaptation options suggests a potential value for formal quantitative economic modelling. A meeting with local government planners and asset managers indicated that economic modelling of adaptation decisions may be valuable in:

- *Helping evaluate the complex trade-offs involved in coastal adaptation.* Coastal adaptation involves multiple costs and benefits that can be reasonably quantified and compared within an economic cost-benefit framework. Modelling has the potential to systematically compare these values, assisting decision makers to weigh up the various tradeoffs.
- *Providing formal analysis to guide and justify coastal planning and infrastructure decisions.* Current standards for evaluating the costs and benefits of coastal development decisions are often *ad hoc* in nature, and planners must rely on intuitive judgements to make decisions. Formal decision-making evaluation may be able to provide a demonstrably defensible evaluation process.

- *Enabling integration of land-use planning decisions with public infrastructure provision.* The need to adapt to a changing climate affects the way land-use planning and infrastructure provision are coordinated. Investment in long-lived infrastructure needs to consider the future servicing needs of an area. Protection or retreat of public infrastructure needs to be coordinated with strategies for adapting private infrastructure that face related threats.
- *Comparing the protection benefits of natural systems with built structures.* The protective effects of natural and enhanced dune systems are typically considered and evaluated within adaptation studies. However, if these values are to be routinely evaluated and invested in as part of standard local government infrastructure management, there is still a need for natural systems to be valued as an asset in a way that enables them to be compared with other public infrastructure assets, and in a way that considers the impacts of climate change on their value.

3.1.2 Development and selection of a decision support modelling method

Analysis of the characteristics of coastal systems identified in literature review and workshop with coastal experts and policy makers suggests that key criteria for modelling include the ability to:

- account for the full range of costs and benefits to residents (e.g., house floods, property values), governments (e.g., capital works), and natural assets (e.g., loss of a beach and dune systems);
- model long time horizons (50+ years) and consider the scheduling of decisions over time;
- explore the implications of multiple interacting and uncertain changes (e.g., changing storm patterns and sea level rise);
- consider scenarios with low probabilities but potentially large costs; and
- adapt to the site-specific nature of system behaviour and permit the model structure to be based on expert opinion about key processes driving change.

Discussions with coastal geomorphologists and a review of ecological literature suggested that Bayesian belief networks are an appropriate and widely used method for capturing an understanding of the behaviour of ecological systems in a way that can inform management (Sigurdsson *et al.*, 2001; Ticehurst *et al.*, 2007). The need to consider uncertain trends, focus on exploring potential changes in the state of the system, and to sequence management over long timeframes, suggested that a dynamic version of a Bayesian network model may be an appropriate method.

A ‘proof of concept’ model of a relatively simple house-dune system (as compared to a complex estuary) was developed to assess the potential of this approach. Examples of intended capability include:

- evaluation of the costs and benefits of ‘defend’ vs ‘retreat’ strategies including the value of dunes for storm protection;
- evaluation of strategies for timing investment decisions; and
- integration of suburban infrastructure and planning decisions. For example, could inundation threats to road infrastructure be a trigger for relocation of residential housing?

Feedback from local and state policymakers from evaluation of the proof of concept model (shown in Figure 3.1) indicated that this approach may be valuable for the uses cited in Section 3.1.1 above. They also committed to invest time in developing a trial model. Surfside beach in Batemans Bay, along the south coast of NSW, was identified as an appropriate trial site, given current policy interest and available background information.

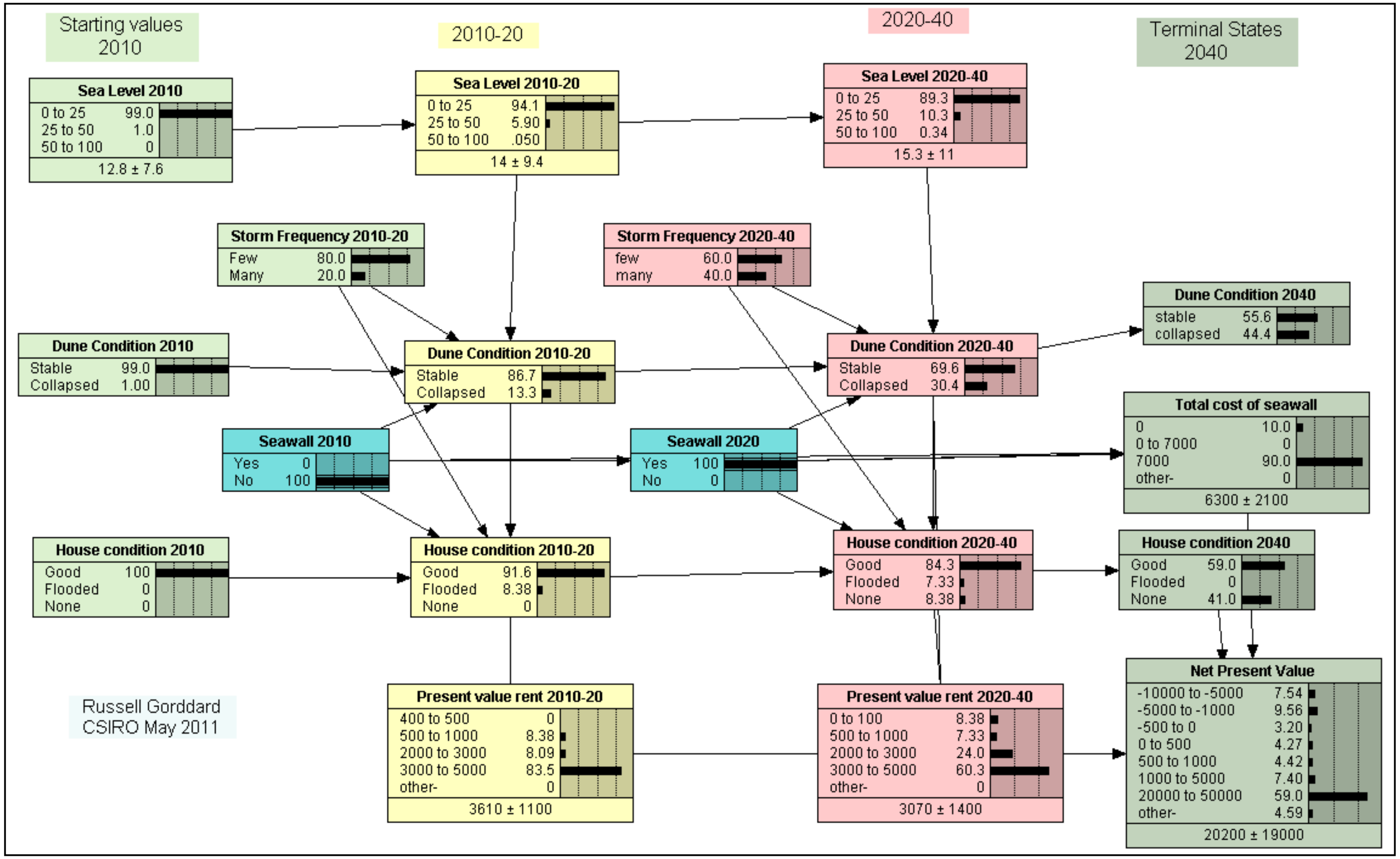

Figure 3.1. Schematic of the 'proof of concept' model for a simple house-dune system used to determine net present value, accounting for factors such as house condition, storm frequency, dune condition, seawall cost and sea level.

3.2 Context for decision analysis

The framework developed in Section 1 emphasised that a diverse range and tiers of decision makers and decision-making environments are important in adaptation responses. Our modelling analysis is focused on residential land-use approvals made by local government planners on land identified as being at risk from inundation due to sea level rise and storm surge. However, other decision-making environments (discussed below) limit and define the scope for decisions at the local government level, and influence the costs and benefits of these decisions. These include:

- *Land zoning at the local level and regional planning at the state level.* These decisions determine the supply of land for housing and therefore the opportunity costs of changes in available coastal land for housing (expressed through the housing market). In places with areas of undeveloped land it is therefore possible for zoning authorities to offset the cost of loss of residential land from inundation by changes in zoning. Such actions will alter the cost of lost land.
- *Public infrastructure provision*. The private value of housing reflects the capitalised value of local public amenities such as schools, transport access and green space. Future public infrastructure investments, responding to the growth of a regional centre, may increase growth pressure and the private value of development on a risky site. Path dependent regional growth of this nature is likely to be a key determinant of the value of residential assets at risk from natural hazards. Local planning decisions respond to local growth pressures (Abel *et al.*, 2011). The cumulative effects of local planning restrictions, however, restrict housing availability on a national scale, and are therefore changing the location of growth in an arbitrary and unplanned way (Glaeser, 2011). Evaluation of local planning decisions should therefore account for their role in future growth trajectories both locally and nationally. However, the marginal impact of local decisions and the coordinated state-level land-planning processes often make considering these externalities at the local scale impractical, and highlight the importance of considering cross-scale effects in adaptation responses.

- *Environmental management at larger scales.* A range of cross-scale changes may affect the value of environmental assets over time. The role of a dune system in providing connectivity in the landscape may change with surrounding development, as may the relative scarcity of different species. As discussed in Section 2, different ways of conceptualising the values of the dune may be needed to capture these changing cross-scale effects.
- *Insurance markets which move the risk of lost housing to people who can bear the risk at lower cost.* The effectiveness of insurance markets therefore partially determines the value of planning decisions affecting risky areas. Of particular concern is the lack of effective insurance for the loss of house values that occurs when the risk of inundation changes over time (Doherty, 2010). The inability to spread this risk increases the cost to society of this risk.
- *Individual property owners who invest in coastal real estate under conditions of changing risk and high uncertainty about future climate and social institutions.* While economic advice traditionally tells us that policy should not interfere with buying decisions in the absence of a well-defined market failure, there is growing evidence that buyers can make imperfect decisions (which they later regret when buying houses in risky areas), and that asset markets can produce distorted price signals. Careful policy design is needed to address these issues and is beyond the scope of this report. However, doing so will influence the value of different local government planning actions.

Evaluation of local government planning decisions must therefore be made under assumptions about how these various decision makers will behave over time. We demonstrate how the model analysis can help integrate planning decisions with asset management. This analysis, however, emphasises that effective solutions are likely to require a coordinated change in the above institutions.

3.3 Model description and development process

3.3.1 Model overview

We focus on modelling the costs and benefits of options for the management of Surfside Beach in Batemans Bay, NSW (Figure 3.2). Surfside beach is approximately 800 metres long and is backed by about 40 housing lots that are potentially at risk of loss from storm damage, with this risk likely to increase with rising seas and changing storm characteristics. The beach is bounded by rocky headlands at each end.

Figure 3.2. Aerial photograph of Surfside Beach, Eurobodalla Shire, NSW. The modelling focuses on the circled houses.

Eurobodalla Shire Council, the local government authority responsible for the management of the Surfside area, currently has an interim sea level rise adaptation policy for this area that focuses on retreat from existing land. The Council, however, is interested in exploring options for adapting this strategy to public infrastructure or exploring alternate management pathways such as beach nourishment, building a seawall and adaptive designs (including raising floor levels and 'retreat ready' homes). Since the beach is bounded by rocky headlands at each end, the option to build protective seawalls or other structures must be done along the entire beach or else wave energy will be transferred to neighbouring unprotected infrastructure. For this reason the beach must be effectively managed as a single unit.

Motivation for council to consider climate adaptation strategies today comes from several directions. First, the houses in the area are typically ageing and ripe for redevelopment. Substantial private investment may therefore occur in assets at increasing risk of inundation and loss. Second, applications for new development in the area may affect existing conservation values and will also be at risk of inundation from future sea level rise. Third, council asset managers are responsible for developing management strategies for long-lived public infrastructure that services the area and which needs to account for future settlement and coastal protection options. In this regard, key assets include sewerage pumping stations which may require protection or relocation, and roads which are due for upgrading and may be pre-emptively raised to accommodate future sea level rise[10].

The area therefore provides a good case study of house-dune systems at threat from climate change. The model described here focuses on a limited set of issues and options, which are selected to be relevant to decision makers and to demonstrate the generic capacity of this approach to analyse adaptation options. The model therefore focuses on three sets of assets and associated management options:

- A seawall as an example of long-lived public infrastructure.
- The housing stock.
- The condition of the dune and beach.

Building seawalls to defend a single house typically causes increased erosion in adjacent areas as wave energy is transferred along the beach. If a seawall is to offer effective protection it therefore needs to be built along the entire length of the beach. We therefore assume that management is uniform along the length of the beach. This restriction on management options plus the uniform nature of the beach cross-section permits the model to focus on a single representative block-width cross-section of the beach. Results and values are reported on a “per house” basis. The costs and benefits

[10] Another climate change threat to residential housing and of concern to council is the increased risk of flooding for an adjacent ICOLL (Intermittently Closed and Open Lakes and Lagoons). However, this primarily affects a different group of houses so is not considered within the current model.

associated with the dune and beach system are also reported for each (approximately 20 metre long) section in front of each house.

3.3.2 Model development

The model development process consisted of five steps.

- *Specify a conceptual model of the system.* With key variables describing the management controls, drivers of change, state of the system, the evaluation criteria, and the relationships among them. This process involved consulting end users and coastal experts to describe the possible behaviour of the system under climate change. The conceptual diagram of Surfside, developed in consultation with a coastal planner and asset manager for Eurobodalla Shire Council, is shown in Figure 3.3. Arrows that return to the same variable indicate that the current state of this variable influences its state in the next time period.
- *Specify the specific states that each variable can occupy.* A characteristic of the approach is that it emphasises the possible alternative states of the system variables, rather than focusing on quantifying the value of different variables. This is desirable as it permits exploration of long-lived, irreversible infrastructural investments, changes in system function, and the use of expert judgement about possible transformations that might occur under climate change. In our example, transformation focuses on loss of the beach-dune system. For variables describing the state of built infrastructure, the selection of possible states is relatively straightforward. Housing stock is specified as being either good, old or absent. Management options are specified in a similar way. Housing management options are either to maintain, replace if damaged, or abandon. Continuous variables such as sea level are categorised in different bands that are likely to have different implications for the system behaviour. In this case, sea level is classified as either low (0-25cm Australian Height Datum (AHD)), medium (25-50cm AHD) or high (>50cm AHD).
- *Specifying the relationship among variables.* The possible influence of one set of variables on the state of any given variable is specified in terms of a conditional probability table. Figure 3.4 shows the conditional probability tables used to

model sea level change emphasising how beliefs about present sea levels influence beliefs about future sea levels. The conditional probability table specifies the model user's assessment of the chance that the dependent variable will be in a specified state, given the state of factors that influence it. In our example the chance that the sea level will be within a specified band during the time period 2010 to 2020 is assumed to depend on sea level at the start of this time period.

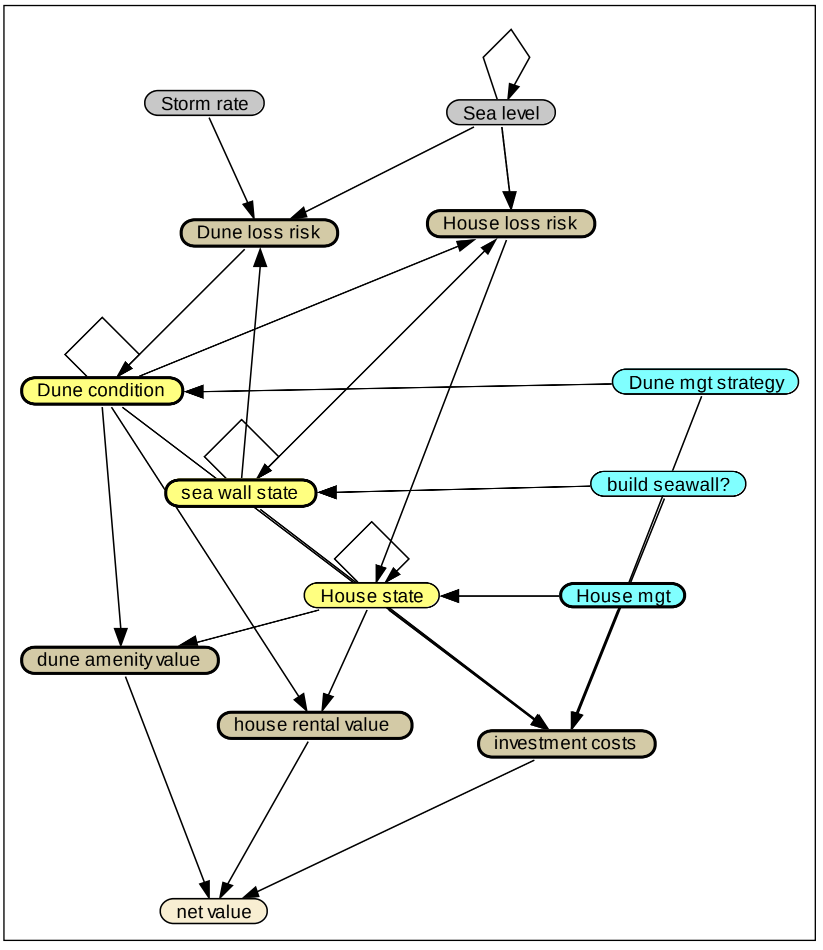

Figure 3.3. Conceptual systems diagram of the Surfside house-dune system, including factors such as dune loss risk, dune condition, house state and rental value, dune amenity value, storm rate and sea level.

- *Specify the time steps and dynamic links in the system*. We model a 50 year period from 2010 to 2060 in three time steps: from 2010 to 2020, from 2020 to 2040, and from 2040 to 2060. Decisions can be made at the beginning of each time step. Therefore, the starting state of the system is defined in 2010. Decision variables which hold for the period 2010-20 are then defined. The state of a variable is described in two ways. One set of calculations quantifies and tracks the probability of transition to alternative possible states from the beginning to the end of a time period. A second set of calculations tracks the properties of the system *within* time steps, such as the chance of house loss and subsequent rebuild. Figure 3.4 provides an illustration of how the Netica software uses conditional probability tables to specify the relationship among variables, and to present the resulting posterior probability distribution. This example shows that sea level during each time period is modelled as having a subjective probability of occurring in one of three states (high, medium or low). In contrast with scenario modelling where a single state must be specified, this approach permits a range of future states to be considered. The probability of a medium or high sea level and storms are assumed to increase with each time step. Figure 3.3 shows how this trend in the likelihood of a higher sea level is implemented.

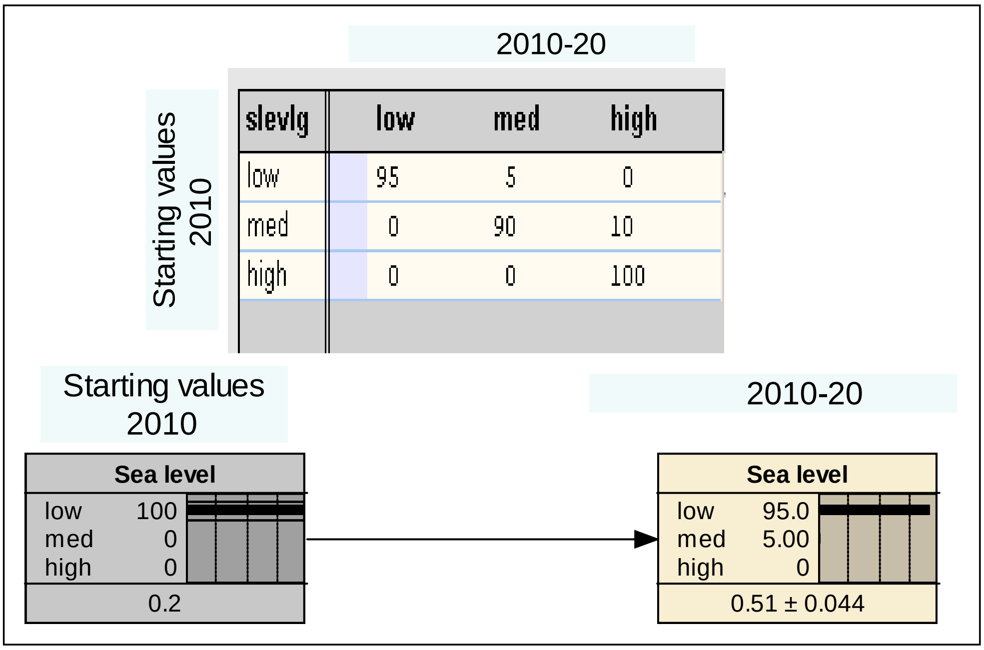

Figure 3.4. An example of conditional probability tables and the relations to the structure of the 'proof of concept' model.

- *Specify the costs and benefits associated with different states of the system.* The default values used for the price parameters are reported in Table 3.1. The cost of nourishing beaches and building a seawall are indicative values based on expert opinion and council engineering studies. House replacement prices are approximations based on local sales data. The annual benefit to households from occupying the house is assumed to be equivalent to the potential rental return and specified as 5% of the total property value. We account for the amenity value from dunes that accrue to those living near the area (termed public amenity value) separately from the benefits received by those living in adjacent houses (called house amenity value). The house amenity value will influence the value of rebuilding. The values used for both amenity values are indicative values based on previous studies. The presence of a dune system is assumed to increase the rent value by 40%, or $12,000 per year (an estimate based on inspection of online holiday house rental prices). The public amenity value of the beach can only be estimated with error. Values of roughly $18-$45 per visit are reported in the literature (Raybould and Lazarow, 2009). We assume a value of $400,000 per year for the beach, or $10,000 for each house-width section of beach per year, implying 25-60 visitors per day on average. Future work will include sensitivity analysis of results to these parameters.

The discount rate is a critical parameter in economic evaluations whenever costs and benefits occur at different points in time, and especially when they occur over a long time period. Harrison (2010) proposes that 8% be used as the base rate when evaluating public investments and that testing should be done over a range of 3-10%. Sukhdev (2008) reports that most studies of environmental policy areas such as biodiversity and ecosystem services – where the costs of inaction now accrue in the far distant future – used a social discount rate of 3-5%, and that none was below 3%. In this study we use a base rate of 5% for the first time step and a rate of 3% for the remaining time steps. This approach is motivated by concerns about intergenerational equity and is aligned with the current international trend to use differential declining rates. The UK Treasury, for example, uses a 3.5% discount rate for the first 30 years, a 3% rate for the next 40 years, which then progressively declines to 1% for +300 years when evaluating public policies and projects (HM Treasury, 2003; Hepburn, 2007). A final justification for using a declining utility discount rate (i.e., hyperbolic discounting[11]) comes from commonly observed human behaviours such as inadequate saving and diminishing impatience (Laibson, 1997).

Parameter	**Units**	**Default values**
Beach nourishment costs	$'000 per time per house	30
House rental value	$'000 per year per house	30
House building replacement cost	$'000	300
Old house rental value	Rental value of an old house as % of rental value of a new house	50
Seawall cost	$'000 per house(20m of beach)	50
Real discount rate	% per year	5 and 3
Public amenity value of beach	$ per year per house (20m of beach)	10,000
Value of beach to house rent	% increase in house rental value	40

Table 3.1 Parameter values for economic variables used to parameterise the base-case runs of the model

3.3.3 Model development status and disclaimer

The current model of Surfside Beach has been developed to a state sufficient to demonstrate its capability. The model structure was developed with, but not revised by, local policymakers. Most parameter values were based on judgement, but require checking by experts. Review and systematic error checking of the model is also required. The model results should therefore not be considered suitable for making policy judgements, but rather they are intended to demonstrate the capability of the modelling approach.

3.4 Model capability

We illustrate the capability of the model using the results from four preliminary model runs. The name and management assumptions of these runs are specified in Table 3.2. For simplicity, in all management scenarios we assume that houses are maintained in good condition and replaced if lost.

Scenario name	**Management specifications**

[11] Hyperbolic discounting refers to the application of time-declining discount rates to trade-offs between present and future consumption to try to provide an explanation for commonly observed 'anomalies' in human behaviours such as procrastination, addiction, and inadequate saving (Hepburn *et al.*, 2010).

1) Nourish	Beach nourishment to protect houses as required No seawall construction Maintain houses in good condition and rebuild lost houses
2) Seawall 2010	No beach nourishment Build a seawall in 2010 Maintain houses in good condition and rebuild lost houses
3) Seawall 2040	Beach nourishment to protect houses until a seawall is built Build a seawall in 2040 Maintain houses in good condition and rebuild lost houses
4) Seawall Medium	Beach nourishment to protect houses until a seawall is built Build a seawall if sea level rises by more than 25cm. Maintain houses in good condition and rebuild lost houses

Table 3.2. Specification of management options for model analysis

We compare the result of these runs to demonstrate the capability of the modelling approach to:

- Compare the costs and benefits of different adaptation strategies while capturing: long-term and uncertain changes (e.g., sea level rise); unlikely but expensive events (i.e., using a probability distribution of total costs and benefits); and multiple compounding uncertainties. To do this we compared the benefits of building a seawall in 2010 with the option of relying on dunes for coastal defences. In these runs we assumed people continue to build and maintain houses when they expect this to be profitable. (i.e., comparing scenarios 1 and 2)
- Account for the timing of investment decisions. To do this we analysed the relative benefits of building a seawall in 2010 with building in 2040 (i.e., compare scenarios 2 and 3)
- Account for the value in future flexibility in investment decisions. To do this we analyse a strategy where the decision to build a seawall in the future depends on the sea level (i.e., comparing scenarios 2 and 4)
- Account for multiple values of ecosystems. We analyse the value of alternative management strategies when dunes provide protection values to houses, as well as amenity value that increases the rental returns to houses at risk.

3.4.1 Comparing the costs and benefits of adaptation strategies

Here we compare scenarios 1 and 2. In scenario 1 the houses rely on the existing beach and dune system for protection from storm damage. Beach nourishment is used to maintain protection in front of houses. In scenario 2 a seawall is built in 2010. In both scenarios, houses are assumed to be maintained in good condition and replaced if they are lost to storm damage. Figure 3.5 shows the effects of our assumptions about climate change (i.e., expected sea level and storm frequency) on the trajectory of these variables and the effects of these on dune condition and the chance of house loss per year.

Note that the probabilities of storm events and sea level rise are intended to be indicative rather than reflecting current scientific opinion. That is, the model permits us to explore the implications of assuming a small probability of a sea level rise greater than 0.5 metres within 40 years. Also note that in these graphs, results that are averaged over the (10 or 20 year) time steps are shown as occurring in the middle of each time step (i.e., 2015, 2030 and 2050). The starting and ending values of variables for each period are shown as occurring in 2010, 2020, 2040 or 2060.

The model results shows dune condition being maintained under the nourishment strategy, but being gradually lost if a seawall is built. The probability of houses being lost to storm damage increases with rising sea levels and increasing storm frequency. This rise, however, is greater under the nourishment strategy than the 2010 seawall strategy.

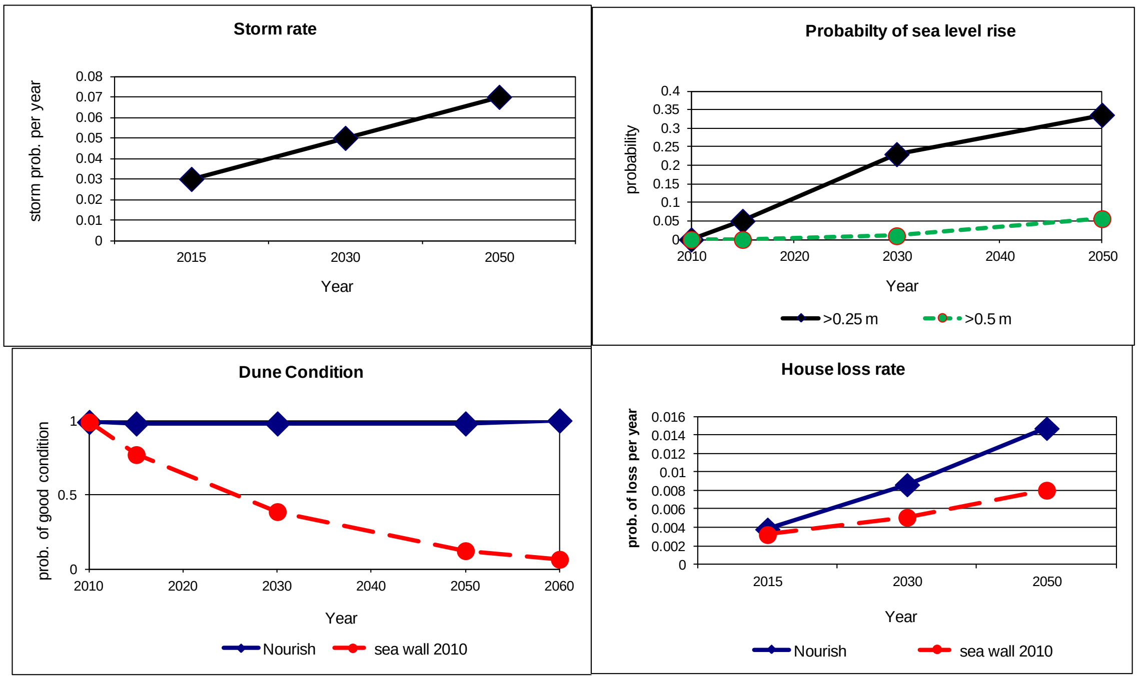

Figure 3.5. Summary of the model results comparing the management strategies of either building a seawall in 2010 or beach nourishment.

Economic analysis of the costs and benefits of different policy options typically report a single dollar figure estimate of the net benefit of applying a particular policy. In order to compare costs and benefits in different time periods, future values are adjusted to an equivalent present value (typically by discounting), allowing analysts to aggregate values and report a single estimate of the net present value (NPV) under each policy option. In our example, the expected NPV of each house-width section of beach is $913,000 under the nourishment strategy and $644,000 under the seawall strategy (Figure 3.6, first two bars).

Generally the option with the largest NPV is the preferred option from a welfare maximising perspective. However, in situations where the performance of policies under an uncertain future is being assessed, the evaluation must account for two issues.

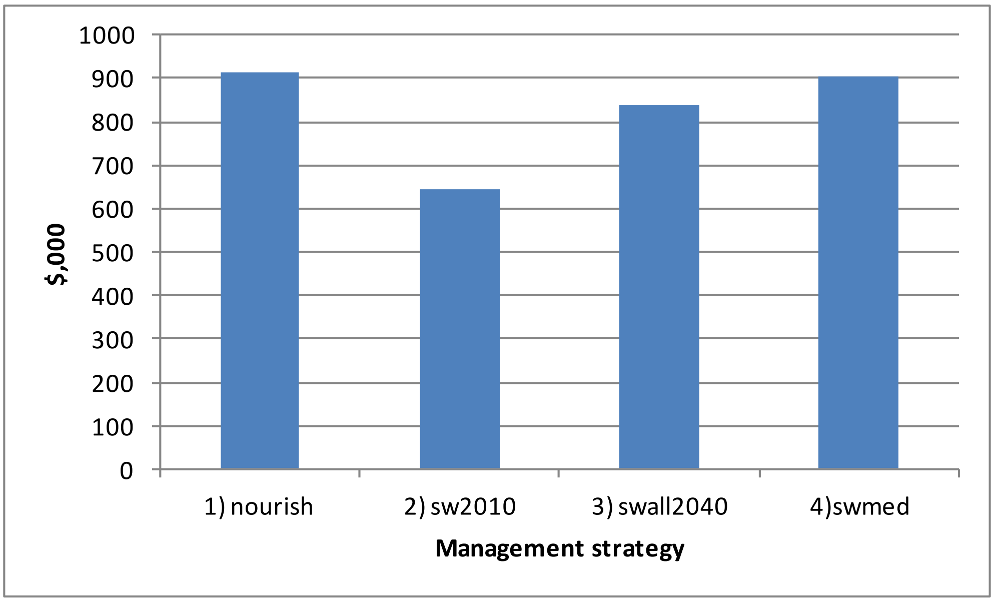

Figure 3.6. The expected net present value of each of the four management strategies

First, assumptions must be made about what the future will be like. We may assume that the future plays out according to a single scenario. Alternatively we may consider a range of possible future scenarios, and evaluate how well each policy option performs in each scenario. In this case, economic modellers typically assign probability weights to each scenario (based on expectations of their likelihood of occurrence) in order to calculate the expected (i.e., the probability-weighted average) NPV for each policy option. Reporting economic analysis of policies as an expected NPV results in loss of information about how policies perform under each future. This loss of information is a concern if there is a possibility that some policy interventions may perform well on average, but poorly in low-probability, high-impact events. In particular, probabilities for rare events are hard to estimate, but can have a large impact on the expected value. For example, it may be difficult to tell if an event has a 0.01 or 0.02 chance of happening, but this difference would double the weight given to the potentially huge consequences of an extreme event when calculating an expected NPV.

Second, we need to consider how the policy is implemented in an uncertain future. One implementation option might be to anticipate and adaptively manage uncertainties about future events. Decisions may be made to insure against possible losses, or be delayed until key uncertainties are resolved. Decisions may also reduce or increase our options for addressing problems in the future, affecting the costs of future extreme events. We therefore need to consider futures where decisions still need to be made under uncertainty, but can be adapted to events as they unfold. We may also want to understand how well a certain policy intervention can adapt to a range of future events. The NPV criterion may still provide an appropriate appraisal of an intervention, but rather than focus on identifying the strategy that performs best ‘on average’ or ‘on expectation’ it is often more informative (and essential) to examine how well the strategy performs under a range of possible futures.

Using the Bayesian model it is possible to calculate the NPV of the system under a specified management strategy for each possible permutation of future states. Each permutation specifies the state of each variable in all time periods; that is, the sea level, storm frequency, seawall status, house condition, number of houses lost, and dune conditions. We can therefore calculate the costs and benefits that occur in each time period under each possible combination of the specified states. The model also calculates a probability of each of these possible combinations of states occurring. The probability of any particular combination of states is determined by the combination of the conditional probability tables (i.e., the probability of a high sea level rise in 2060 conditional on the sea level in 2040 and the sea level in earlier time steps) and the specification of the initial conditions of the model. Combining the information on the NPV under each possible permutation of future states – and the probability of each of these permutations occurring – we can produce a probability distribution of the NPV for each management strategy under the different management strategies.

Figure 3.7 shows the probability distribution of the NPV of all future benefits under the two management strategies. Variation in the modelled NPVs is driven by the beliefs of the distributions about possible future states of the system (particularly future sea levels and storm frequency), and uncertainty about relationships such as the impact of storms on the loss of the beach-dune system.

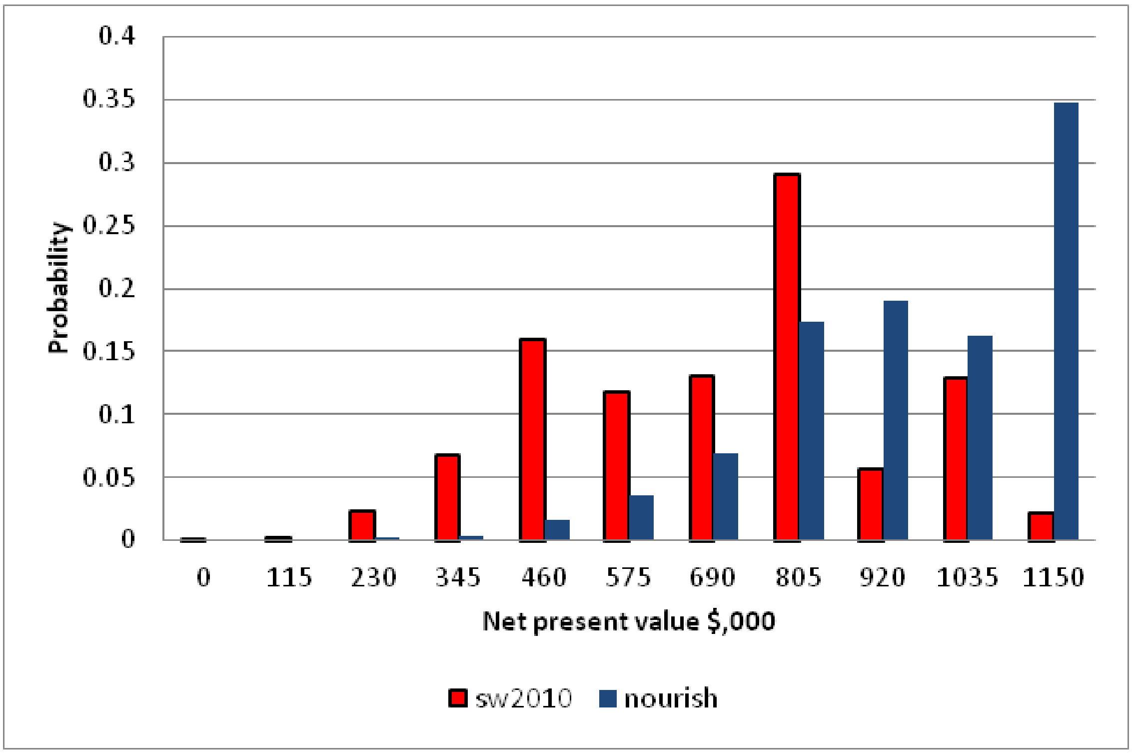

Figure 3.7. The probability distribution of the 50-year net present value for the management strategies of beach nourishment and building a seawall in 2010 (sw2010) for Surfside Beach in Batemans Bay, New South Wales

We caution that the probability of extreme events is difficult to estimate. Therefore, estimates of the exact probability of rare events should be treated with scepticism. However, this modelling approach allows us to address concerns about extreme losses by exploring the differences in the net benefits that occur in extreme scenarios under different management actions. Figure 3.7 reports the distribution of NPVs that occurs under the two management options considered. The size of losses in the left-hand tail of the distribution of NPVs allows us to compare the relative chance of large losses under extreme events, or alternatively the size of the losses associated with extreme events. Note that while the risk of lost houses is lower under the seawall 2010 strategy than under the nourishment strategy, the seawall strategy actually produces a greater chance of outcomes with low NPVs (e.g., with NPVs <$ 460k). This result partially reflects scenarios where dune amenity is lost due to seawall construction and houses are lost to storm events. The modelling approach also allows us to identify what scenarios (combination of events) produced low NPVs. As an example, an infrequent and low ($115,000) NPV occurs under the sw-2010 strategy in situations where high sea levels and storms are frequent, dunes are lost early, and houses are lost (and replaced) multiple times.

These results demonstrate the capability of the model to:

- *Model how management affects total costs and benefits.* We report expected NPVs for a number of management strategies, ranging from beach nourishment to building a seawall today, in 2020 or 2040 (Figure 3.6). The results indicate that seawall construction imposes upfront construction costs and (assumed) decreased amenity values that are not compensated for by the reduced risk of loss of houses.
- *Model the probability distributions of total costs and benefits*. This allows for the evaluation of management under unlikely but expensive events (Figure 3.7).
- *Capture long term and uncertain changes (e.g., sea level rise)*. The model considers three different possible sea levels in each time step, including a small but increasing chance of greater than 0.5m sea level rise as shown in Figure 3.5.
- *Account for multiple compounding uncertainties.* Each model run tracks multiple uncertain processes, including a range of possible sea level heights, and a range of possible storm frequencies. The ability to consider interacting uncertainties is demonstrated by the calculation of the risk or rate of loss of houses, which is a function of the sea level, and the frequency of storm events. In model development, completing the conditional probability table for the risk of housing loss requires that we consider how extreme levels of both events affect the risk of housing loss. While only the expected rate of loss is reported above, the

distribution of NPVs shows small chances of significant losses driven by the interaction of these extreme events.

3.4.2 Value of the timing of seawall construction

Figure 3.6 reports the net present value of different seawall management strategies. It therefore demonstrates the ability of the model to value delaying the building decision until 2040, or until the sea level rise is greater than 0.25m.

Delaying the construction of a seawall provides clear benefits because the capital costs are delayed and the dune system is maintained intact in the initial time periods. The seawall is eventually built to provide protection in the later time periods when the risks of inundation are greater.

3.4.3 The value of future flexibility in investment decisions

An ‘option value’ is the value of waiting for future events to unfold before committing to an irreversible investment. These are likely to be important strategic considerations in adaptation decisions. However, calculation of option values typically relies on sophisticated continuous-time models that are difficult to generalise. Simple conditional decision trees can provide similar analysis (Hertzler, 2007). The dynamic Bayesian network provides a way to automate this approach. We demonstrate this by specifying a model run where the decision to build a seawall in the future is conditional on the rise in sea level. The wall is only built if and when sea level increases by greater than 0.25m. The expected value of this strategy is shown in Figure 3.6 (scenario 4: swmed). This strategy has a similar expected present value to the nourish strategy. The option value of waiting is equal to the difference between the NOV of the ‘sw2010’ scenario and the conditional strategy (swmed).

3.4.4 Accounting for multiple values of ecosystems

One motivation for modelling is that it can account for the multiple kinds of benefits that ecosystems can provide. Here we have demonstrated the ability to analyse the amenity value of dune systems in conjunction with the protective values. Given the difficulty of estimating non-market values for ecosystems, we typically need to explore how a range of plausible values influences the benefits from different adaptation options. Here, we simply demonstrate the capability to conduct a sensitivity analysis by exploring the effect of the assumed value for the public amenity value of the beach.

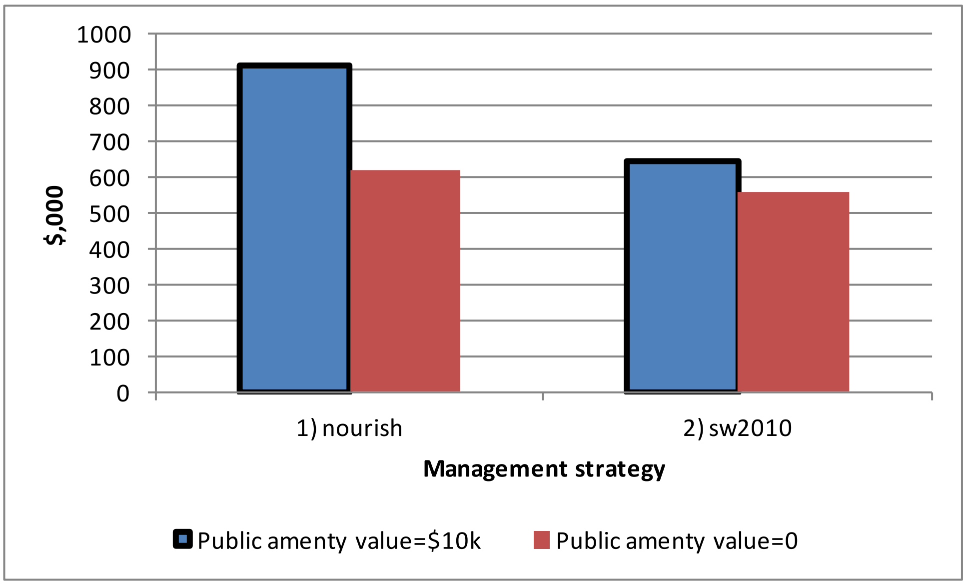

Figure 3.8. The effect of public amenity value on the expected net present value under management strategies 1) beach nourishment only ('nourish') and 2) build a seawall in 2010 ('sw2010').

Figure 3.8 compares the expected NPV of two management strategies (scenarios 'sw2010' and 'nourish', Table 3.2) when, a) the public amenity value of each house-length section of the beach is assumed to be $10,000 per year (i.e., the default value) and, b) when each house-length section of the beach is assumed to be zero per year. In this example, the public amenity value of the beach system increases the relative benefit of the nourishment strategy compared with the seawall. However, even without considering the public amenity values, the NPV of the option to build a seawall does not exceed that of beach nourishment.

3.5 Conclusions to Section 3

Evaluation of a 'proof of concept' economic model using dynamic Bayesian networks with relevant stakeholders indicates there is demand from local and state government policymakers for modelling that can evaluate adaptation options for coastal residential development. Modelling of adaptation decisions may be valuable in: helping evaluate the complex trade-offs involved in coastal adaptation; comparing the protection benefits of natural systems with built structures; enabling integration of land-use planning decisions with public infrastructure provision, and; providing formal analysis to guide and justify coastal planning and infrastructure decisions.

Preliminary results from a model of Surfside Beach in Batemans Bay demonstrate the ability of this modelling approach to: evaluate the costs and benefits of different strategies including retreat, adapt and defend; estimate the financial costs and benefits of protection provided by natural ecosystems, and allowing comparisons with built protection; evaluate the benefits of strategically scheduling investments over decades, and of maintaining flexibility for future decisions (i.e., option values), and; evaluate the benefits of coordinating planning and infrastructure investment strategies.

Preliminary lessons for coastal management include:

- Discount rates of 5% or greater imply that owners of coastal property have financial incentives to invest in development that is at risk of damage and loss due to inundation associated with 1-in-20 to 30 year storms.
- The transfer of private amenity value that would occur with the loss of waterfront properties to houses in the next row represents an externality from the perspective of the waterfront owner. Attempts to capture this private benefit by waterfront property owners will make them more inclined to build, and less likely to retreat, than would be socially optimal.
- If the value of beaches to the general public for recreational and non-use values are directly threatened by the construction of seawalls, and these values are considered, this will reduce the net benefit of seawalls.
- Where storms that threaten properties are likely to occur roughly every 1-in-20 to 30 years, discounting the future value of protection from seawalls is likely to significantly reduce their value. As a result, consideration of the amenity value of dunes can plausibly outweigh the protective value of seawalls.
- In situations where a seawall is justified on economic grounds, delaying the construction of a seawall for a specified period or delaying the construction until a specified trigger point is reached are likely to be valuable options, especially when this results in increased amenity values from dune systems.

An economic modelling approach based on dynamic Bayesian networks can be incorporated into some key characteristics of the coastal adaptation problem. These include: uncertain, long-term trends and consequences; irreversible investment decisions; multiple and interacting uncertainties, and; uncertain and location-specific system behaviour. The approach is therefore suitable for modelling house-dune-beach systems. There is demand from policy makers for analysis of more complex coastal systems such as estuaries and ICOLLS. Some important characteristics of these more complex coastal systems – such as unclear ecological goals and complex cross-scale drivers of change and adaptive-management responses – may limit the validity and value of economic modelling for these systems. In this context, consideration may need to be given to adopting a sequenced approach whereby a set of modelling case studies is developed in collaboration with local and state policymakers to establish the value of modelling for larger scale and more complex adaptation problems.

4. THE COMMUNITY ENGAGEMENT PROCESS

4.1 Introduction

A significant barrier to addressing coastal squeeze is the difficulty for government at any level to specify a process that participants trust will effectively and legitimately lead to wise and fair decisions. An important part of this issue is defining the process and purpose for engaging the public. For example, Hayward (2008: 59) cautions that difficult decisions concerning climate adaptation strategies cannot be made fairly, justly or effectively within small, time- and group-bound forums that typify community engagement on environmental issues. Hayward (2008) also suggests that "local voices must be heard in decision making, but local councils cannot be left to wrestle with difficult temporal, spatial and procedural justice questions unaided".

Our purpose here is therefore to identify some of the issues for adapting local-scale social consultation and engagement processes to deal with climate change. Focusing on the house-dune systems we argue that while there is much to learn about what an appropriate process might be, the required model for engagement is likely to be very different from the standard community consultation model embedded in current local government planning systems.

The institutional complexity of coastal land-use, particularly the contested need to reconsider residential private building approval conditions, means that consultation and engagement processes designed for other environmental issues (such as those used for catchment planning) cannot be directly applied. Local governments may therefore need assistance in developing novel processes. Much can be learned in this regard from the literature on community engagement for other environmental problems, and from extensive and intensive consultation and negotiation processes such as the Regional Forest Agreements in Australia. New consultation and engagement methods may be useful; for example, deliberative fora may be appropriate in helping to define a problem. The wicked nature of coastal adaptation, however, means it is difficult to underpin a community engagement process with a clear decision process. New ways of sequencing engagement activities are therefore also likely to be important. There is also a possibility that councils will become locked-in to current consultation practices, partly because the controversy that surrounds this issue makes it difficult to risk trialling new approaches. Although it is acknowledged in some cases, the controversy of this issue, combined with the ineffectiveness of existing approaches, may also drive councils to trial novel approaches to engagement.

A final motivation for focusing on the process of consultation is the concern that the usual process may be not only ineffective, but could also inhibit long-term adaptation. There is evidence that risk mitigation policies that are perceived to be socially divisive will not be accepted over the long term (Tompkins *et al*., 2008). A rush to implement local policy solutions may exacerbate deep community divisions and undermine long-term community resilience. Governments and councils therefore require a framework to understand the concerns of various constituents and to engage in dialogue with the community to ensure sea level rise policies do not exacerbate social, economic, legal and political conflicts.

The aims of public engagement can include developing a greater understanding of community concerns, matching policy to community needs, and providing the community with a greater sense of ownership over the design and implementation of new sea level rise policies. Beatley (2009) claims that active community “buy in” and involvement in the development of land-use plans that support community resilience is required for effective long-term implementation. Gurran *et al*. (2008) contribute overarching principles for “leading” practice with communities. Some principles on climate change mitigation and adaptation planning emerging and being reported in the literature include:

- using ecologically sustainable development principles (e.g., environmental integrity, social equity and participation, economic viability and the precautionary principle);
- supporting ecosystem-based mitigation and adaptation;
- identifying and justifying evidence-based planning responses to climate change;
- developing intergovernmental agreements involving federal, state and local governments clearly stating the commitments and responsibilities of planning for climate change;

- initiating research on understanding and responding to social vulnerability to climate change impacts, particularly in coastal areas where physical exposure, socio-economic disadvantage and population instability coincide; and
- making fundamental changes to current planning controls to enable new adaptive responses.

There is, however, still a need to define the nature and purpose of an engagement process. We base our analysis on exploratory consultations with the community at Long Beach in Eurobodalla Shire in south-eastern NSW. This case study was chosen in consultation with Eurobodalla Shire planners and was considered suitable as Long Beach is exposed to storm surges and the risk of sea level rise. It is also subject to an interim sea level rise adaptation policy implemented by Eurobodalla Shire in August 2010[12]. The Long Beach community includes households with varying degrees of exposure to the inundation risk. As a result, households also vary in the degree to which they are affected by, and aware of, the interim sea level rise policy. This allows us to examine how people with different degrees of exposure to inundation risk interpret, understand and respond to policies to manage and adapt to this risk.

We describe community responses under the headings of environmental values, responses to policy options, and concerns and expectations about community engagement processes. We discuss three theoretical frameworks that provide useful perspectives on the key issues identified including:

- the problem of addressing risks that are either infrequently experienced or expected to change in the long term;
- the contested legitimacy of decision-making processes; and
- the persistent challenges to the legitimacy of underpinning scientific knowledge, and the multiple ways in which the problem can be framed.

Our central conclusion is that for complex uncertain problems such as this, people’s thinking will mix issues related to policy development, implementation, knowledge about system functions, and values. As a result, we argue that effective engagement in a

[12] Available online: http://www.esc.nsw.gov.au/site/Publications/Strategies/PolicyReg/LivePolicyDocs%5C2326.pdf

policy development process cannot be limited to discussions about values, but needs to also include discussion and debate on policy processes, policy options, and science.

4.2 Method

Long Beach is a small, beachside settlement, on the northern side of Batemans Bay. The settlement has a relatively large population of recently arrived retirees (+65 years) with moderate household incomes. Real estate developments cater for a growing and ageing population. Many coastal areas such as Long Beach are exposed to risks of sea level rise while exhibiting higher than average levels of social disadvantage (e.g., ageing) and have a reduced capacity to adapt to climate risks (Gurran *et al*., 2008).

Our research activities consisted of informal discussions with local government officials, one-on-one semi-structured interviews by phone or in person, and a group discussion with residents living along the foreshore of Long Beach. Interviews and group discussions were held in May 2011. More details of the interviews and group discussion are provided below. We consider these activities as both research and as a trial of the initial phases of a science-based community consultation process.

This work builds on findings from an Australia-wide online survey undertaken by CSIRO which focused on understanding community views of coastal policies that considered planned retreat (Alexander *et al.*, 2011; Ryan *et al.*, 2011). We also discuss results from a community survey undertaken by Eurobodalla Shire Council (the Eurobodalla 2030 Community Strategic Plan[13]), which aimed to identify people's values, visions and aspirations for the community. The report outlines actions to promote positive lifestyles and future opportunities for all residents over the next 20 years based on contributions from over 2,000 participants and a reference group. Details of the community vision, issues and activities are articulated according to four focus areas: liveable communities, sustainable communities, productive communities and collaborative communities, which "are the heart of all the issues the community has raised and the things we need to do to achieve the future our community deserves".

[13] http://www.eurobodalla2030.com.au/find-out-more/draft-eurobodalla-2030-community-strategic-plan

One-on-one interviews

Semi-structured interviews were conducted with those identified to be at risk of inundation from sea level rise and nearby residents that would be affected by beach erosion.

The semi-structured format was chosen because it provided sufficient consistency across interviews for points of comparison, while still being open-ended to elicit in-depth responses, and flexible enough to be tailored to the participants' perspectives. Interviews were recorded and later transcribed. They were all conducted by the same researcher to ensure consistency and reliability across interviews.

The individuals and communities were identified and selected in consultation with local government officials. Over 70 invitations for interview were posted to residents with a description of the details of the study, outlining ethical considerations. Eighteen residents were interviewed in their homes or by telephone for about an hour each throughout May 2011. Half the interviewees resided adjacent to the foreshore, while others were located in elevated positions, ranging from one street back from the beach to further up and removed from the beach. Several other residents were also invited to participate based on their involvement in local volunteer organisations. The most common demographic were retirees formerly residing in capital cities (Canberra and Sydney); however, younger individuals with school-age children were also interviewed.

Interviews were focused on descriptions of residents' attitudes towards the implementation of the sea level rise policy. To provide some background information, participants were initially asked to briefly describe what was important about living in the beachside town. Discussions were conducted about the social and equity issues relating to the sea level rise policy (e.g., fairness, procedural justice, economic implications, social cohesion, succession planning, and lifecycle stage). Other discussions focused on actions that might diminish the value of private properties and shared recreational and council assets (e.g., beaches, roads, drainage, sewerage systems, lagoons, nature and marine reserves, biodiversity, dune structure, and vegetation, etc).

Group discussions

A group-meeting with residents along the foreshore provided insights into community attitudes where the implications of the sea level rise policy were more immediate and of greater consequence. Members of the focus group were self-selecting local residents and they agreed to attend a three-hour workshop on a Saturday afternoon in May 2011 at a public venue. Each resident owned a property in the designated high-risk area targeted by the sea level rise adaptation policy. Twelve residents, mostly married retirees (five women and seven men), attended the focus group meeting. At the meeting, biophysical elements of coastal inundation and erosion were discussed, along with personal attitudes and issues of concern. Discussions then focused on the interim sea level rise adaptation policy.

4.3 Findings

Residents of Long Beach responded to questions on the general appeal of living there and on adaptation options that could be considered to threats of coastal erosion and inundation. They were forthcoming with their views on various environmental issues, local council policies, and community amenity concerns. Discussions about possible inundation events were focused on beaches, dunes, beach-front properties, storm surges, extreme rain events, and a series of swamps and lagoons that might be affected by rising sea levels. Residents differed in the time they spent in the locale, though all felt the beachside and natural environment was important to them.

4.3.1 Consensus on the value of the environment

The natural environment of the area is consciously and explicitly valued by most of the residents interviewed. Many people state that they choose to live in the location because of the environment. The Eurobodalla 2030 Community Strategic Plan for instance, indicates that the environment is valued by many residents. Residents cited the pleasure of the vista, walking pets on the beach, the water movement, the bush environment, aesthetics, fauna, geological and natural attributes as key reasons for living at Long Beach. An indication of the importance of the environment and its value to residents is that most interviewed residents are members of the local LandCare group, Coastal Watch and other community associations, even though these were not deliberately targeted. While our sample is biased by self-selection, this finding is consistent with Gurran *et al*. (2008) claim that community wellbeing in coastal communities is linked to appreciation of a unique lifestyle and ability to enjoy the natural environment.

4.3.2 Divergent views on the value of specific environmental management options

While the sentiment that the natural environment is important was agreed on, views on specific issues differed greatly among groups and depended on the context and the specific change in question. There were several attitudinal divides based on location of dwelling, attitudes to sea level rise, type of residence (permanent home, investment or holiday rental), economic impacts, and the time they spent in the area. For example, when questioned about what should be done about coastal erosion, some regarded the beach as part of a natural process stating "the beach will protect itself provided humans don't get in the way and don't do other things around the place." Some claimed that the problems may have been caused by humans but that the solution should come from natural actions. In contrast, some beachfront residents suggested that revetments (man-made off-shore reefs and other protective structures) may be acceptable or even desirable modifications to the local environment. Some residents were actively engaged in environmental activities in the community such as planting vegetation and dune restoration, and expressed firmly held ideas about the importance of maintaining dunes as a barrier against inundation. The community was polarised as to the benefits of these environmental activities and various levels of importance were attached to each.

Residents set back from the shoreline consistently expressed strong values towards the environment. They expressed environmental concerns that were of a more general nature and were less emotive than those living along the foreshore about the interim sea level rise policy.

Such disagreements about specific issues suggest that the general statements about the value of the environment are not specific enough to guide management. Therefore community surveys, such as those underpinning the Eurobodalla 2030 Community Strategic Plan, have limited capacity to inform policymakers about community values in order to guide decision making. As emphasised in Section 2, discussions of values need to be integrated with discussions on the functioning of the biophysical system and the decision-making framework.

4.3.3 Views on sea level rise adaptation policy

While general adaptation options were discussed, participants in interviews and the group discussion predominantly focused on Eurobodalla Council’s interim sea level rise policy.

Economic impacts on households

All interviewees were concerned that changes in land values due to the sea level rise policy might benefit some and harm others. The residents in the investigation area felt that their land values had eroded due to the council sea level rise policy, but acknowledged that land values had also been affected by other economic factors such as the global financial crisis, increased housing supply, historically high expectations of land value, lack of facilitates for ageing populations in the area, and the increasing number of older residents selling their properties and moving into retirement villages.

While only certain properties were immediately affected by the policy, property owners close to the foreshore felt they would bear the considerable costs of: meeting policy requirements for coastal engineering advice; unfair risk allocation; property devaluation; restricted building activities, and; reduced ability to sell due to uncertainty about future policy. The economic consequences of falling land values were of utmost concern for all residents. Residents felt the interim nature of the sea level rise policy created uncertainty and a negative outlook for future land values (their primary asset). Other concerns related to reduced ability to sell due to uncertainty, which prevented older retirees moving to retirement homes; and restriction on rebuilding if a house was lost from other hazards such as fire.

The degree of threat to an individual’s house was important in determining their view on the validity of trading-off beaches for houses, should the need arise. For residents living further up the escarpment, there was less interest in the details of the policy as they were not directly impacted by it. They were concerned about retaining access to the beach and that remedial works did not erode the beach. Residents living outside the designated investigation area were more likely to support a planned retreat option. “If the sea level rises then it’s up to the individuals to make their accommodation, so if that is retreat that is retreat; if buildings get lost to sea level rise, so be it. It’s happened before”. Some residents expressed attitudes of ‘buyer beware’ towards owners of dwellings that might be at serious risk of inundation and storm damage in the future, but others indicated that the council approved the residential zoning of these areas and may be responsible for compensating affected ratepayers.

Anger and fairness

Property owners affected by the policy considered it “excessively punitive” where residents “were not to blame for sea level rise, but a few were bearing the cost of sea level rise”. Residents most affected by the policy were disgruntled and felt discriminated against by what they perceived to be an unfair, unjust and unscientific process of policy development and implementation. The issue of compensation related to inundation was a central concern raised during discussions of the policy process and outcomes. Council policy states that “Council will not accept any costs or responsibility for the construction, maintenance or renewal of private property protection works” and “Council will not meet the costs for implementing any retreat plans for private developments within high risk sites”. Many residents expressed hostile views of these conditions, and were very concerned that the policy did not adequately address the possibility of compensation for reduced land values and possible inundation from sea level rise.

Issues concerning fairness, procedural justice and intergenerational justice were pervasive and echoed by all who attended the group meeting particularly in regard to personal asset protection.

4.3.4 Community views on science

There was still much angst about the uncertainty and complexity surrounding climate change issues, information and policies. Participants claimed that climate change science generally continued to be in dispute, with some participants sceptical and others expressing confidence in the science and the need to plan for future events. Some residents were more informed about certain scientific details than others. There was general confusion about who to trust in regards to information about climate change. A consistent finding between the foreshore residents and those whose houses were behind and up the slope of the peninsula was general mistrust in climate change information and the perception of bias and vested interests of those communicating it (see Section 4.4.2).

The implications of climate change for the foreshore were disputed, as was the science used to determine the vulnerability of the area and prioritise it for adaptation actions. Affected residents suggested that, prior to the interim sea level rise policy being adopted, further studies should have been conducted involving other public and private organisations, local knowledge, community consultation, and other councils.

Residents not convinced about the risk of sea level rise questioned the need for a policy response. This was particularly the case for those directly affected by the policy, who felt it should be withdrawn. Participants less affected by the policy were not as concerned and felt that planning for future storm and inundation events should be undertaken by the council.

Timing and legitimacy of the interim policy

Residents questioned the timing and speed of policy development. The consequence appeared to be property devaluation as far as the residents were concerned. It was questioned why this area was among the first to implement the policy in Australia. Responses such as: “Individual solutions need to be ascertained through an engineering report and determination of the costs; we need rules and guidelines, not a debate about solutions”, indicate that concerns about the legitimacy of the science are linked to concerns about the legitimacy of the decision-making process.

These findings are consistent with the literature. Whitmarsh and O’Neill (2011) find that the public tend to be poorly equipped to deal with scientific uncertainty, confused by expert disagreement, tend to lack a personal connection with ‘global’ issues that are long term and complex, and often deny the reality of their reluctance to change their behaviour. The way the general public perceives risk is different and more complex than the way technical experts view the same risk (Chapman *et al.*, 2011). When criticism and misunderstanding exist between scientists, policymakers and the public, the result is a loss of the public's faith in the ability of science to solve its problems and in political leaders to act in the public's interest (Garvin, 2001). This tension often means that public confidence can be seriously weakened if the authority is perceived to be incompetent, biased and/or compromised, or appears to arrive at decisions without considering the public interest (Baggett *et al*., 2006).

4.3.5 Legitimacy of policy processes from the community perspective

Some residents felt the council hadn't engaged the local community effectively, and that there needed to be an engagement process with more opportunities for discussions with affected residents. Those most affected by the sea level rise policy in Long Beach were vocal about their discontent, wanted the policy immediately withdrawn, and were critical of many aspects of the process, particularly the timing and consultation process. Community members expressed a strong desire for their opinions to be "heard" prior to its design and implementation. They also suggested that surveys undertaken for this research might be an avenue for resolving some of their more immediate concerns, and hoped it might present an opportunity to delay the policy until all concerns had been dealt with.

The council's recent consultation and economic visioning exercise regarding development in the region to 2030 was mentioned by some interviewees. In these cases, the consultation process undertaken by council was regarded as a good opportunity for individuals to voice their opinions, regardless of the usefulness of the report. It was also acknowledged that the consultation process in that case was fairer than usual, but they still had concerns that environmental issues didn't feature as prominently as economic issues.

Residents were consistent in stating that the problem needed a concerted state-wide approach and required state and federal intervention to support local governments. Residents also felt that more open communication with council over contentious issues was required, particularly as ratepayers were the source of council funds. There was a tendency, however, to express discontent at the local council implementing the policy. The integrity of the local council was challenged in light of several past issues and concerns about various levels of "self-interest" in the policy outcomes. As the local council was the focus of their frustration, it was argued that intervention from an outside body such as other governments or an independent organisation would legitimise the process of developing policy and engaging the community. While this suggestion was often proffered, there was little confidence or trust in the ability of government bodies to adequately, wisely and justly deal with the complexities and sensitivities involved in deliberating over contested values and attitudes, negotiating conflicting interests, and building common understanding and acceptance of the array of economic, social and environmental issues.

Need for a partnership approach

Residents argued that addressing sea level rise policy concerns could be done as a collective, rather than on an individual basis, as neighbouring residents would be similarly affected by the policy. Similarly, the view that council should see the local residents as partners rather than clients was consistently expressed by beachfront residents. This was justified on the basis that the threat of sea level rise was common to both public and private assets. In this respect, participants expected that infrastructure and public land would be protected: “If protection was allowed as a collective effort, the cost should be shouldered by the individual, but council should manage Crown land. Why wait for sewers, roads, and reserves to be washed away?”

The role of science in informing this process was also discussed. As one participant stated, “The community doesn’t have the expertise to decide on the best options, we need better consultation processes, and we need to approach this sustainably, we need an outcome of the greatest good for all involved”. Legitimate science was seen as key to the beginnings of a legitimate, deliberative and just process. They felt that further collaborative efforts could be achieved by using scientific information to inform development of an appropriate policy for protection. Links between experts and the community are likely to be important in ensuring this legitimacy. Public confidence can be seriously diminished if authorities are perceived as incompetent or biased. In general, establishing and maintaining stronger links and improved communication between research scientists and policy and program managers will reduce the science-policy gap, and facilitate better public policy decisions.

Timing of policy

The timing of the policy was seen by some as inappropriate and implementation should be informed by an event-based “trigger point” of inundation or storm surge damage. In the beach-front group discussion, event-based triggers for policies were considered as a possible way forward. This is potentially important as it may overcome the need for predictive science to inform policy. Importantly if people are prepared to discuss policy responses about contested but plausible future events, as seems to be the case, this may circumvent debate about the need to consider risks in given areas and diminish the use of calls for better science as a way to delay policy implementation. The interim policy does in fact use event-based triggers. It also, however, makes mention of temporal issues that are important for planning purposes such as the need to distinguish between expected life-spans of residential and commercial buildings and the different nature of the risk between 2050 and 2100. The mention of event-based triggers in the same context as temporally sensitive planning issues seems to be confusing to some individuals and clearly needs further explanation and discussion.

4.4 Theories informing community engagement and policy processes

In this section, we briefly discuss the application of three theoretical perspectives that have been used to understand the range of responses people have to new risks.

4.4.1 Rational self interest

Rational self interest is a theory that explains how people are expected to respond to uncertain and unknown threats. Many individuals’ responses in this case study are consistent with this theory. People whose property is threatened by an inundation policy tend to be more engaged with the issues and the policy development process and argue strongly against implementation. In addition, the impact of incentives on how people argue that the world works have been noted at least since the 1930s when Upton Sinclair stated, “It is difficult to get a man to understand something, when his salary depends upon his not understanding it.” That is, people interpret the workings of the world, and attempt to influence it, in ways that are consistent with their self-interest.

While self interest and vested interest are important aspects of the problem, they do not describe all social behaviour. A critical conclusion based on this view is that for contested property issues, intervention by a higher authority is required to avoid a "tragedy of the commons". Elinor Ostrom (e.g., Ostrom, 2006, 2007) pioneered research demonstrating that people are capable of negotiating cooperative solutions in a range of complex natural resource management problems. On the basis of this, it would be reasonable to argue that a well-designed community consultation process has the potential to produce effective policy responses to address the risk of inundation.

Other theoretical perspectives, such as the social functionalist framework (Section 4.4.2) and cultural cognition theory (Section 4.4.3), provide useful insights for designing policy processes that can further contradict or nuance the conclusions based on self-interest.

4.4.2 Social functionalist frameworks

In many circumstances, community engagement in the development of adaptation policies and strategies will involve a mix of people who reject, are unsure about, or are concerned about the risks posed by sea level rise. Hence, it is likely that a broad range of topics will be raised, such as interest in learning more about the science and policy issues, sceptical critiques of the science, concerns about the effects of policy on housing values and on the general wellbeing of the community, options to mitigate and adapt to risks, and concerns about being treated unfairly through the enactment of new policy. It is also likely that issues of morality and the values of the community will be hotly debated.

While it may not be possible to avoid conflict over complex issues involving long-term risks, it may be possible to understand more about the many concerns that can arise during an engagement process. Community engagement processes can then be designed to accommodate a range of worldviews.

A social functionalist framework is an example of how environmental planners and managers might better understand individuals' responses to proposed policies such as managed retreat and might pre-emptively reveal some of the conflicts that may arise (Alexander *et al*. 2011). Social functionalist frameworks suggest that people intuitively act as scientists, economists, prosecutors and theologians when considering complex issues. People may use one or more of these decision-making frameworks when assessing a policy, and support a policy approach that suits their frameworks for viewing the world.

Government policy frameworks that are based largely on science and economic concerns may not be compatible with the intuitive prosecutor and theological perspectives maintained by some people. Angry responses are from people using intuitive prosecutor and intuitive theological frameworks, and are not necessarily indicative of irrational or ill-informed opinion. Rather, anger espoused in response to policy implementation can be a functional and effective means to achieving individuals' goals such as the abandonment of the proposed retreat policy or achieving group cohesion when threatened by circumstances seen as a moral threat.

The perspective provided by a social functionalist framework indicates that communities will require economic and scientific information and consideration of issues of fairness and equity, transparency of process and recognition of social normative behaviour when climate-adaptation policies are being formulated and introduced. Communities will also require some time to absorb the changes and normalise their responses to changing circumstances.

4.4.3 Cultural cognition of risk

Policies designed to manage long-term risks tend to be controversial (Few *et al.*, 2007). Cultural cognition theory offers explanations for why the public can persistently disagree about the legitimacy of acting to manage risks, particularly those that are rarely experienced by individuals (Kahan *et al.*, 2011). A key hypothesis is that people's views of certain risks tend to be compatible with people's core values and beliefs. As disagreements over policy changes tend to come from polarised communities, behavioural explanations need to be based on communities or culture, rather than solely individuals. Signs of this polarisation in the Long Beach community over the scientific predictions of inundation risk and the appropriate response are evident in the above discussion. Insights into the nature of this division, and processes for ensuring it is not destructive to policy development, are clearly important. How to design policy processes to cope with this divergence in risk assessments is an ongoing research question.

Aspects of this work are discussed in Section 2.2. However it is likely that an important role for higher levels of government is to ensure the conditions exist such that polarisation does not prevent effective policy development. This is likely to involve limiting the ability of groups to stall or derail local processes, especially where a group may benefit from the status quo. Kahan (2011) suggests that market-based mechanisms that ensure people must bear some of the consequences of risk are likely to be effective strategies in overcoming these problems.

4.5 Recommendations about engagement processes

The case study illustrates the difficulty of separating the process of designing a policy mechanism to cope with changing inundation risks from the process of community engagement. People’s assessments of a policy’s capability to manage complex systems cannot be predicted based on understanding of a predetermined set of values. That is, communities need to discuss and debate different policy options, not just asked about the ends they would like to achieve. Key links include the need to discuss and debate the science in the context of a particular policy question, and the need for people to feel that the selected policy has been developed through a process that is legitimate and fair, and will lead to outcomes that are legitimate and fair.

Current local land-use planning approaches that embed this separation between community consultation, science and policy development are unlikely to result in effective and accepted policy. Such an approach is likely to continue to produce significant anger and financial uncertainty, and provide strong incentives for those affected to inhibit policy development via political, legal and social actions. In other words, the lack of legitimate, community-based policy development processes is a key barrier to adaptation.

The implication is not simply that more and better consultation is required, but that developing effective and accepted policies requires that communities are engaged more directly in the policy design and implementation processes. It is probably not possible to provide a comprehensive set of principles for how this community engagement might best be done for coastal inundation policies. Ostrom (e.g., 2005) provides the relevant theoretical background; but the problem differs from other common pool resource problems in that inundation policy formulation will need to deal directly with the highly evolved, complex and almost sacrosanct property and planning institutions, as described in Section 1. The formulation of new policies in such highly contested and uncertain contexts, where the responses of individuals and communities are likely to be unknown and unpredictable, requires an approach where innovative local institutions can be developed, trialled, and evolved in collaboration with policymakers, communities and science. Such approaches have been successfully adopted internationally and reported in the literature (Geels and Schot, 2007; Maréchal, 2007; Heilmann, 2008; Rotmans and Loorbach, 2009; Smith and Stirling, 2010). While engagement processes of this type are time consuming and costly, investment in such processes in strategically selected areas should be viewed as small-scale trials aimed at developing alternative models for both policies and policy processes that can then be more easily adapted to other areas and mainstreamed.

Other implications for consultation processes drawn from this case study include:

- State and federal government participation and engagement are vital for the legitimacy of a policy change process. The inherent uncertainty about the required role of these higher levels of government and the difficulty of defining an overarching process need to be addressed as part of a local process. A boundary organisation may be vital in facilitating this process (Corfee-Morlot *et al.*, 2011). Such organisations can legitimately argue for a particular approach in a local forum without speaking on behalf of government, and have a mandate to engage various aspects of government as required. A bottom-up process also requires rethinking the way in which state and federal governments ensure the interests of the broader Australian community are considered, particularly in relation to local claims on state and federal public finances, interests of future generations and the environment. A shift in the role of state and federal governments from attempting to define rules that constrain local policy processes, to developing processes for articulating how state and federal governments might respond to proposed local policy may be needed (especially where trials of new approaches are required).

- Ensure communities avoid becoming polarised over issues that arise from climate change and climate-change adaptation policies. Although the causes of polarisation of community views on long-term risks are not fully understood, building social capital may avoid and resolve many of the possible conflicts that arise in such complex, contested and uncertain environments. This may involve establishing and maintaining stronger links and improved communication between research scientists, policymakers and communities, and developing capabilities to undertake effective processes of deliberation and negotiation.

5. GENERAL CONCLUSIONS

This project focused on how coastal ecosystems can be better considered in the process of adapting coastal development to climate change. Internationally, experience suggests that desirable adaptation policies in this domain have been relatively easy to design but difficult to implement (e.g., Hayward, 2008). Typically, implementation of difficult adaptation policies is stalled by either strongly focused local political opposition or drawn out legal challenges. In this process, adaptation tends to occur in crisis situations where ecological values are given low and short-term priority. This pressure on coastal ecosystems is in addition to a history of decline in the face of creeping development pressure that gradually overwhelms local planning controls in many areas (Section 1.2.1). These factors suggest that we should be concerned that standard residential land-use planning processes will not effectively consider existing or changing values for coastal ecosystems. This difficulty with effective adaptation policy implementation may be interpreted as a need for stronger regulations and incentives. We argue, however, that the community resorting to political and legal challenge should be seen as them using societal safety valves to signal discontent with the land-use planning system.

This project begins four lines of research that we see as required to enable effective adaptation of the coastal land-use system:

- Developing appropriate frameworks that provide a broad view of how the social decision-making system functions. We identified local land-use planning and the closely linked residential housing markets as important focal points for adaptation.
- Examining the ways values are used in decision-making processes and how these may need to be reconsidered if people's values for a changing coastal landscape are to be effectively considered.
- Trialling the use of decision-support models to build the capacity of key decision makers to evaluate options and help develop the links between science and policy.
- Examining the role of community in policy processes. In this regard, we have argued that there is a need for consultation processes to debate policy options,

rather than discuss values, and that these processes need to be built on close three-way links among scientists, policymakers and communities (Section 2).

The executive summary describes our general conclusions from the work. Based on this analysis, a key challenge for future work is to develop pathways to allow appropriate institutions to evolve. This can be done using small-scale trials of policy development processes that involve strong links among communities, local decision makers, and experts of various kinds. State and federal government have a range of roles to play in such trials. A key challenge is to learn how these links across the scales of governance can be effectively managed to enable local-level evolution of effective coastal institutions.

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