Marine Policy
June 2016, Volume 68 Pages 229-240
https://doi.org/10.1016/j.marpol.2016.03.014
https://archimer.ifremer.fr/doc/00354/46484/

Principles for operationalizing climate change adaptation strategies to support the resilience of estuarine and coastal ecosystems: An Australian perspective

Sheaves Marcus [1, 2, *], Sporne Ilva [3, 4], Dichmont Catherine M. [5], Bustamante Rodrigo [5], Dale Pat [3, 4], Deng Roy [6], Dutra Leo X. C. [6, 7], Van Putten Ingrid [8, 9], Savina-Rolland Marie [5], Swinbourne Anne [1]

[1] James Cook Univ, Townsville, Qld 4811, Australia.
[2] James Cook Univ, TropWATER, Ctr Trop Water & Aquat Ecosyst Res, Townsville, Qld 4811, Australia.
[3] Griffith Univ, Environm Futures Res Inst, 170 Kessels Rd, Nathan, Qld 4111, Australia.
[4] Griffith Univ, Sch Environm, 170 Kessels Rd, Nathan, Qld 4111, Australia.
[5] CSIRO Oceans & Atmosphere Flagship, 41 Boggo Rd, Dutton Pk, Qld 4102, Australia.
[6] CSIRO Oceans & Atmosphere Flagship, 306 Carmody Rd, St Lucia, Qld 4067, Australia.
[7] Univ S Pacific, Sch Marine Studies, Fac Sci Technol & Environm, Laucala Bay Rd, Suva, Fiji.
[8] CSIRO Oceans & Atmosphere Flagship, GPO Box 1538, Hobart, Tas 7001, Australia.
[9] Univ Tasmania, Ctr Marine Socioecol, Hobart, Tas 7000, Australia.

* Corresponding author : Marcus Sheaves

Abstract :

Effective publicly developed adaptation strategies are crucial in managing the impacts of Climate Change. Adaptation strategy development is particularly complex in estuarine and coastal marine ecosystems because of their diverse environmental values, extensive human utilisation and the complex socio-ecological systems they support. Although many generic adaptation frameworks are available they cannot provide specific guidance for locally relevant strategy development. In contrast, situation-specific tools work well for their intended purpose but are usually unsuitable for a different situation. The gap between generic frameworks and situation-specific tools is addressed in this study by developing a set of general principles to provide guidance for the efficient and robust development of adaptation strategies. The nine principles comprise a conceptualisation of the various factors that are likely to have an effect on the success or otherwise of an adaptation strategy and they apply in any situation. An example 'adaptation checklist' that serves as a guide to practitioners in the field, will help ensure that all critical components are covered during the development of an adaptation strategy.

Highlights

► Climate change adaptation requires situation-specific strategies. ► Existing frameworks are too generic to provide case-specific guidance. ► Principles and an adaptation checklist helps guide the development of situation-specific strategies.

Keywords : Climate adaptation, Operational strategies, Estuaries, Coastal, Resilience

2 *Introduction*

One of the underlying goals of publically developed adaptation strategies must be to manage the impacts of Climate Change (CC)(e.g. sea level rise, intensification of extreme events) to maintain the resilience and integrity of ecosystems, and the social and economic well-being of populations. Achieving this goalis particularly complex in estuarine and coastal marine ecosystems (ECMEs: estuaries, coastal freshwater systems, coastal lagoons, deltas, tidal wetlands and marine waters abutting coasts) because of their diverse environmental values and extensive human utilisation, and the complex socio-ecological systems (SESs) they support [1].

Managing the ECMEfor CC impacts is environmentally, economically and socially complex. Much of the world's population is concentrated along coasts and around estuaries, and in Australia the proportion of people living in coastal areas is particularly high [2]. High population numbers and densities bring extensive agricultural, urban, industrial and port development. At the same time, ECMEs are recognised as areas of high conservation and biodiversity values [3-6], values that extend spatially and functionallyfar beyond the immediate system boundaries. ECMEs occupy pivotal locations between land and sea, and perform important roles in moderating seaward flows of nutrients [7, 8] and pollutants [9, 10], making them vital to the health and wellbeing of offshore natural assets [11]. In addition, the high productivity[7]and nursery value[12] of coastal aquatic ecosystems means they are critical to the resilience and long-term health of coastal fisheries, with many commercially and recreationally valuable species occurring in and around ECMEs, and many offshore fisheries depending on ECME nursery grounds and productivity.These vital roles mean that damage to ECMEs threatens key linkages in life-cycle and productivity chains, putting at risk the robustness, resilience and long-term sustainability of both fisheries and ecological assets of international significance.

Over the past 50 years, ECMEs have experienced increasing pressures from ever-increasing human populations, severely affecting their integrity, resilience and function [13, 14]. This historical rate of degradation is accelerating due to global CC and associated threats such as sea level rise, ocean acidification, changes in rainfall patterns and increased incidence of extreme events[15].ECMEs are among the ecosystems most vulnerable to CC[16, 17]. Their low-lying geography means they are particularly exposed to even small increments of sea level rise and to increased frequency or intensity of extreme events[18]. The juxtaposition of ECMEs with river and stream drainage networks, and the dependence of many ECMEs on specific patterns of marine/freshwater interactions [19, 20], means their nature and functioning are particularly vulnerable to changes in rainfall patterns [21, 22]. Interactions with anthropogenic landscape modifications intensify the threats to ECMEs. In fact, a substantial part of the vulnerability of ECMEs to CC is directly attributable to the pervasive impacts of human infrastructure, with structures like dams, bunds and roads preventing self-adaptation to accommodate threats such as sea-level rise [6, 23]. Without barriers in the form of human structures many ECMEs would be able to migrate landwards and so maintain their ecological functioning[18].

Anthropogenic CC is already having significant, ongoing impacts on ECMEs, their component habitats and organisms[24, 25], and the many ecosystem services they provide [26]. Even with immediate mitigation actions to reduce greenhouse gases, there will be sustained environmental changes. Therefore, it is necessary to consider appropriate adaptation strategies to minimise the inevitable detrimental impacts on ECMEs, protect their biological function, and the human populations that rely on them [27].

CC adaptation is the 'adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities'[28]. Adaptation actions aimed at reducing vulnerability of ecosystems like ECMEs to CC can take the form of changes in practices, behaviours, processes or structures in response to projected or actual changes in climate [29], and are aimed at reducing or delaying the negative consequences of CC rather than the prevention of impacts [30]. Climate Change adaptation strategies (CAS) (a set of planned adaptation actions that are developed using a formalised process) can be developed in response to observed climate impacts, or in anticipation of future CC; they can be proactive, aimed at reducing exposure to future risks, or reactive, aimed at alleviating impacts that have occurred [31, 32]. Proactive adaptation generally requires a greater initial investment but is usually more effective at reducing future risk and cost [31]. However, reactive CAS are important in dealing with risks that remain after the implementation of proactive adaptation, or due to unexpected or unavoidable impacts.

There is a relatively restricted suite of types of adaptation options available. These have been defined and discussed in many ways by various authors but can be broadly grouped into active and passive responses and distilled into ten categories (Table 1).Despite this 'simple' group of possible responses, developing effective CASin ECMEs is complicated by a variety of factors – differences in climate, tidal regimes, biological assemblages and intensity of anthropogenic interactions mean responses vary according to the local-to-regional context and the nature of natural and human-induced impacts [26]. This complexity means that for each new situation, previous adaptation strategies need to be re-assessed, re-imagined and adjusted or even re-designed – a process likely to lead to considerable work unless adaptation strategy development can be simplified and structured.

Many models and frameworks have been proposed for CC adaptation. At the most generic level are frameworks that provide general expositions of the steps needed for CAS development [e.g. 32, 33]. While these provide a description of the type of pathway, they are not intended to provide specific guidance for locally relevant CAS development [32]. Because of this, considerable energy has been expended in developing an extensive array of specific models tailored to particular situations; these are essential tools for addressing the impacts of CC, but are usually suitable for only one or a few aspects of the overall impacts [34]. They are very useful in operationalising CASs for particular situations, for instance, giving direction to the selection of appropriate tools for particular situations [34]. However, there is a substantial gapbetween the 'general' CAS frameworks [e.g. 33] and the situation-specific tools, leaving a paucity of guidance on the important aspects that need to be considered in moving from general adaptation models to an effective CAS tailored to a specific situation, an issue that we address in this research.

Because the issues involved in adaptation strategy development are complex, integrated input from a wide range of disciplines and from different perspectives is needed to fill the gap between general CAS frameworks and situation specific tools. Consequently, in a series of expert group workshops, involving a trans-disciplinary panel of environmental scientists, ecosystem ecologists, fisheries scientists, qualitative and quantitative modellers, natural resource management and governance analysts, and behavioural psychologists, we reviewed and distilled the available literature to establish key principles for developing adaptation strategies for Australia's ECME s. These principles are aimed at promoting and guiding CC adaptation plans and decisions that sustain the long-term resilience and productivity of estuaries and coastal marine natural resources in a world where uncertainty is pervasive [35]. In particular, they are aimed atpromoting the development ofinternationally applicable adaptation strategies in ways that ensureECMEs continue to provide for the SESs they support into the future, and that the resources they support are as resilient and robust as possible [36].

Table 1: Generic types of adaptation responses and actions (distilled fromKlein et al. 1999, Burton et al., 1993, Millar et al. 2007, Lawler 2009)

	category	explanation
Passive responses	no need for action	
	abandon	no action taken because of a lack of successful options or because of

		adverse risk-reward evaluation
	self-adaptation	no action taken with the view of allowing systems to accommodate CC through natural processes
Active responses	Prevention of loss	anticipatory actions to reduce the susceptibility of an exposed component or function to the impacts of climate
	tolerating loss	adverse impacts are accepted in the short term because they can be absorbed by the exposed unit without long term damage
	Spreading or sharing loss	actions to distribute the burden of impact over a larger region or population beyond those directly affected
	Changing use or activity	switching of activity or resource use from one that is no longer viable to another that is
	Changing location	where preservation of an activity is more important than its location and the activity is migrated to an area that is more suitable under CC
	Restoration	aims to restore a system to its original condition following damage or modification
	Rehabilitation	aims to facilitate ecosystem process recovery

3 Principles for Operational Adaptation Strategies

Developing a set of principles aimed at promoting and guiding CC adaptation needs an intrinsically different conceptualisation to the usual understanding of a CAS. Rather than a prescriptive model comprising a series of steps (e.g. Fig. 1), CAS design and development may instead be conceptualised simply as a model of the various factors that bear on the success of an adaptation strategy(Fig. 2). Such a model does not prescribe a sequence of tasks but indicates a range of factors that need to be considered – any combination might be important for a particular situation and purpose.

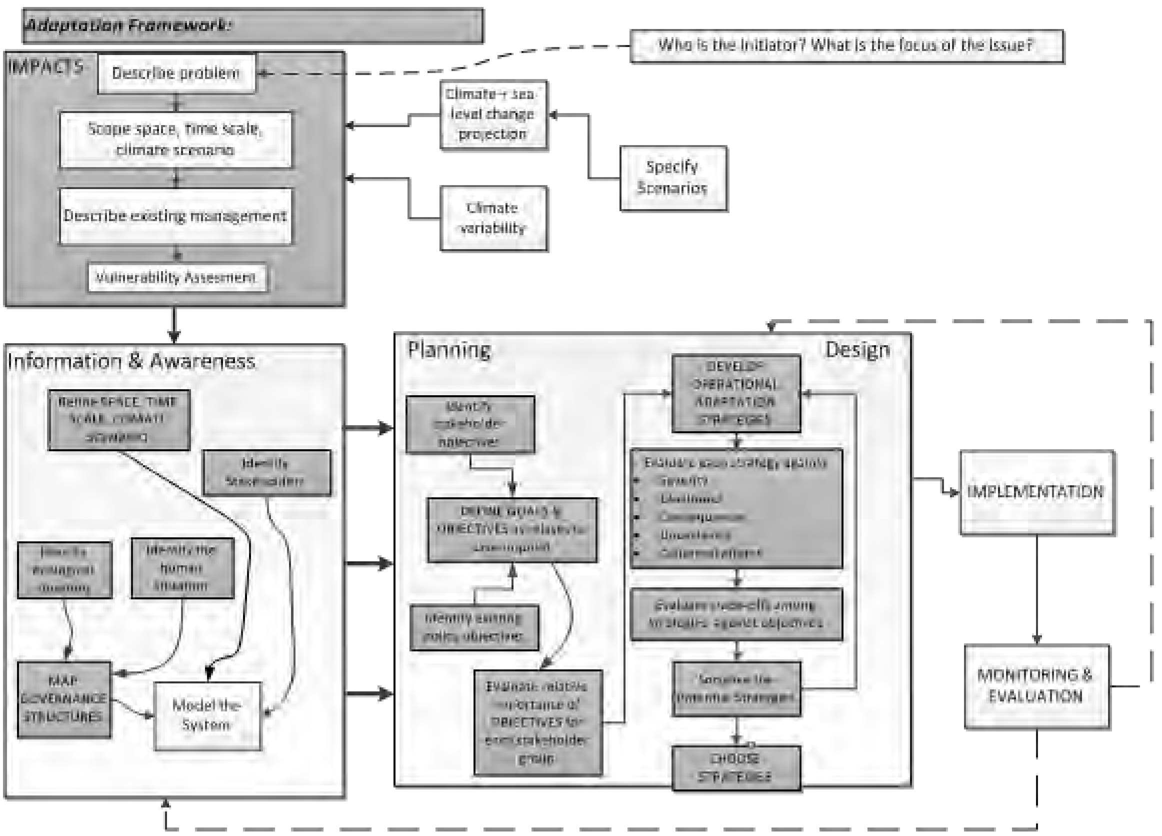

Figure 1: *Example of an adaptation framework based on the "standard" Klein et al., (1999) model framework. This is an adaptive model providing a sequence of steps specific to adaptation of estuaries and coastal ecosystems. Many models such as this have been developed to operationalise the ideas of Klein et al. (1999) for use in a specific situation.*

This type of simplified model is not constrained by a need to conform to a rigid framework and it is therefore flexible and can respond to changing circumstances, needs, regulations, and imperatives [37]. The simplified nature of this model means that, in itself, it provides no specific direction but instead provides a foundation for general principles to help direct the development of flexible adaptation strategies. Based on existing adaptation literature (see reference list) as distilled by a team of trans-disciplinary experts, such a set of principles can be grouped into two categories: (i) the Strategy Landscape, (ii) Strategy Development andImplementation (Table 2).

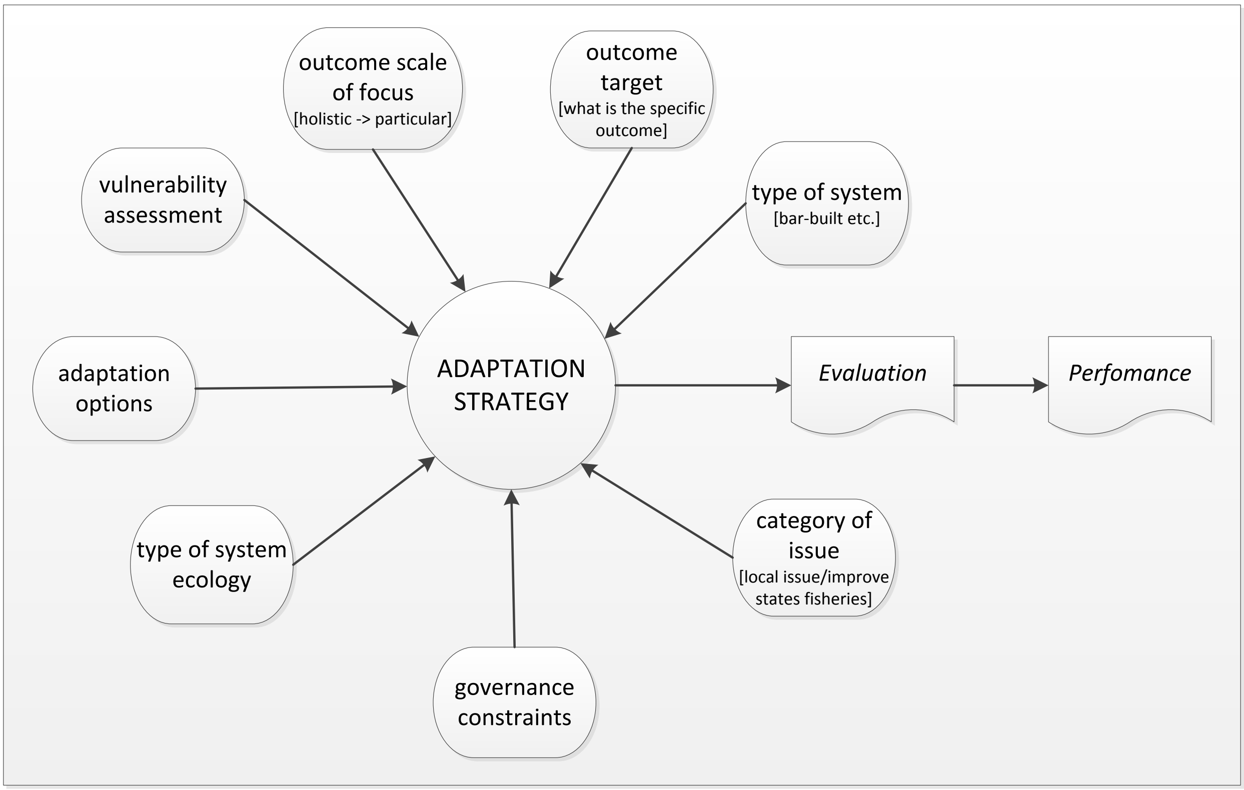

***Figure 2**: A generic model of an adaptation strategy: simply a depiction of the various factors that bear on the development of an adaptation strategy.*

Table 2: Summary of Eight Principles for Operational Adaptation Strategies

Category	Principles	Summary
Strategy Landscape	1. Successful adaptation strategies need a to be developed in a broad, holistic context	Strategies need to be developed in a SES landscape where there are many competing interests to be considered. The embedding of CC in an array of stressors and the need to consider the multiple ways in which any action can impact other facets of the SES at various temporal and spatial scales, means strategies need to be developed in a broad, holistic context.
	2. Focus on whole-of-system, long-term outcomes for socio-ecological systems	Maximum public benefit accrues from maintaining and restoring resilient ecosystems that provide healthy human living environments, support optimal biodiversity and underpin robust and productive fisheries. This is best achieved by focussing on long-term transformative outcomes at a whole-of-system scale that provide on-going benefits by enhancing resilience and reducing vulnerability into the future.
	3. Acknowledge a multi-scale vision and incorporate a multi-scale approach	The coastal space is by its nature complex; it has a large range of stakeholders with very different and, potentially, conflicting objectives. Consequently, comprehensive adaptation strategies need a vision that embraces multiple scales and leads to decisions and

		actions that embrace multi-scale understanding.
Strategy development and implementation	4. Ensure fair, representative and equitable stakeholder engagement	Comprehensive stakeholder engagement is important to achieve natural resource outcomes in the context of adaptation to CC. Engagement of all stakeholders in strategy development in a participatory approach combining top-down and bottom-up perspectives provides both a richer suite of perspectives and legitimacy through participation and consideration of stakeholder aspirations.
	5. Acknowledge diversity and complexity of governance structures and develop organisational arrangements that facilitate cross-sectoral cooperation, coordination, capacity building, knowledge generation and exchange	Australian environmental governance is a highly complex, dynamic and multi-level system with numerous governmental and non-governmental actors interacting within and across authority domains.Development of organisational arrangements that cross jurisdictional boundaries and facilitate cross-sectoral coordination is the key to effective CC adaptation.
	6. Identify enabling and constraining factors of existing institutional frameworks and align strategic responses.	Institutions as systems of rules determine the ways ECEMs are managed and governed. To achieve effective implementation CAS need to be ‘fitted into’ particular institutional context. Understanding of enabling and constraining institutional factors allows determining possible set of adaptation options and aligning adaptation responses.
	7. Employ robust and adaptable strategies that minimise harm across human and natural systems	Strategies need to be considered with respect to the life-time of their consequences. This requires the development of robust strategies that recognise the intrinsic uncertainty of our knowledge of the future and the consequent limitations on our ability to predict future events and the consequences of actions. These strategies should be robust across the range of future in the sense that they do no harm if an unexpected course of events occurs, and do not close off the possibility of future actions.
	8. Focus on achievable and realistic delivery of CAS outcomes and outcome-support tools	Fixation on one particular frameworks or particular components of frameworks is often a distraction and the strict structure of a framework can lead to unrealistic outcomes. Rather, concentrate on what is needed for the task at hand and only choose a framework if it helps achieve a specific, realistic and achievable outcome.
	9. Optimise outcomes by employing adaptive feedback cycles appropriately	Adaptation options that include adaptive management cycles should be seen as the ‘normal’ way to do business; flexible adaptive management that allows whole-of-system approach across different management levels.

3.1 Strategy Landscape

The ‘Strategy Landscape’ refers to the broad context in which CASs need to be developed if they are to provide meaningful outcomes for all stakeholders over relevant timescales. Threeprinciples form the basis of the ‘Strategy Landscape’.

3.1.1 **Principle 1:** *Successful adaptation strategies must be developed in a broad, holistic socio-environmental context*

CC is one of a suite of factors that impact ECMEs. Other stressors include port developments [38], loss of coastal connectivity [23], the hardening of foreshores [39], increasing urbanisation [40], and natural disasters [41].CCcan be best understood in the context of the Driver-Pressure-State-Impact-Response (DPSIR) framework [42]. The DPSIRframework describes the causal links between Drivers (D – natural and human-induced activities and processes that cause pressures) and the resulting social, cultural, economic and environmental Pressures (P – direct stresses on the SES), their consequences on the State (S – abiotic, biotic, social, economic, cultural conditions of the SES), the Impacts (I – effects on human and ecological systems due to changes in state) and Responses (R – actions to solve the impacts), such as management and adaptation measures resulting from the changes in the SES. In fact, many impacts (e.g. extreme events) only represent changes in the intensity and/or frequency of pressures that have been active for millennia [43]. Adaptation strategies for ECMEs need to be developed in a SES landscape where many competing interests need to be considered. For example, the construction of barriers to increase shoreline protection might adversely affect fish migration, cause erosion in areas surrounding the barrier, and impact aesthetic values, thus differentially impacting industry, livelihoods, fisheries, tourism or the environment.

The embedding of CCadaptation in the DPSIR framework and the need to consider and incorporate multiple impacts of actions on other facets of the SES leads to a problem with substantialcomplexity crossing many jurisdictional boundaries. When the need to consider short- and long-term goals and effects is included in the mix, it becomes clear that successful adaptation at anything more than the very local scale requires the development of strategies in a broad, holistic context [44]. The idea of developing adaptation strategies in a broad holistic context is an overarching principle within which the remaining eight principles are embedded.

3.1.2 **Principle 2:** *Focus on whole-of-system, long-term outcomes for socio-ecological systems*

There is ample evidence from a broad range of perspectives that maximum public benefit accrues from resilient ecosystems [45, 46] that provide healthy human living environments[47], support optimal biodiversity [48], and underpin robust and productive fisheries [49]. Robustness and resilience of ecosystem-scale resources are conferred at large scales, such as whole-of-ecosystem, whole-of-catchment or whole-of-fishery [45, 50] that include whole ecosystem complexes with connectivitybetween them.Thisis best achieved by focussing on long-term transformative outcomes that provide on-going benefits by enhancing resilience and reducing vulnerability [51].

Moving towards ecosystem resilience requires a detailed and specific knowledgebase about what constitutes a ‘healthy’ ecosystem, how to maintain it, and how to value it in ways that can be understood and appreciated by all recipients of ecosystem services [49]. In ECMEs, one key aspect of supporting resilience is to concentrate on maintaining system continuity. In the past, adaptation has usually taken the form of incremental change intended to avoid disruptions to human and ecological systems at a local scale [52]. However, these continued marginal adjustments have been ineffective at reducing long term vulnerability and preventing eventual resource degradation [53]. This lack of long term effectiveness is particularly concerning in the face of the rapid CC driven environmental change[54] that can lead to regime shifts – sudden catastrophic transitions to contrasting states [55, 56]. The alternative to incremental change is to focus on maintaining and enhancing ecosystem resilience [57]. This approach provides long-term durability and availability of natural resources because it supports continued ecosystem functioning in the face of substantial change; in essence future-proofing the system [55, 58].

Because ecological systems are intimately influenced by the social systems that rely on them (e.g. Fig. 3) ensuring resource resilience requiresa focus on SES as a whole [36]. The interconnectivity and interdependencies of SES's components will need to be accounted for in the CAS. Moreover, alternative strategies and actions will have different relative values to different sectors (public, commercial, individual) depending on timeframe over which they are considered[32]. Consequently, CAS need to incorporate a large scale, long-term view that focusses on optimising cross-sectoral benefits.This means that effective CASs will consider trade-offs that explicitly balance ecosystem outcomes and local socio-economic needs. In this setting, valuing ecosystem services in a currency that allows direct comparison of the competing values is particularly important [59]. Such valuations are rare but are nevertheless fundamental to ensuring effective management.

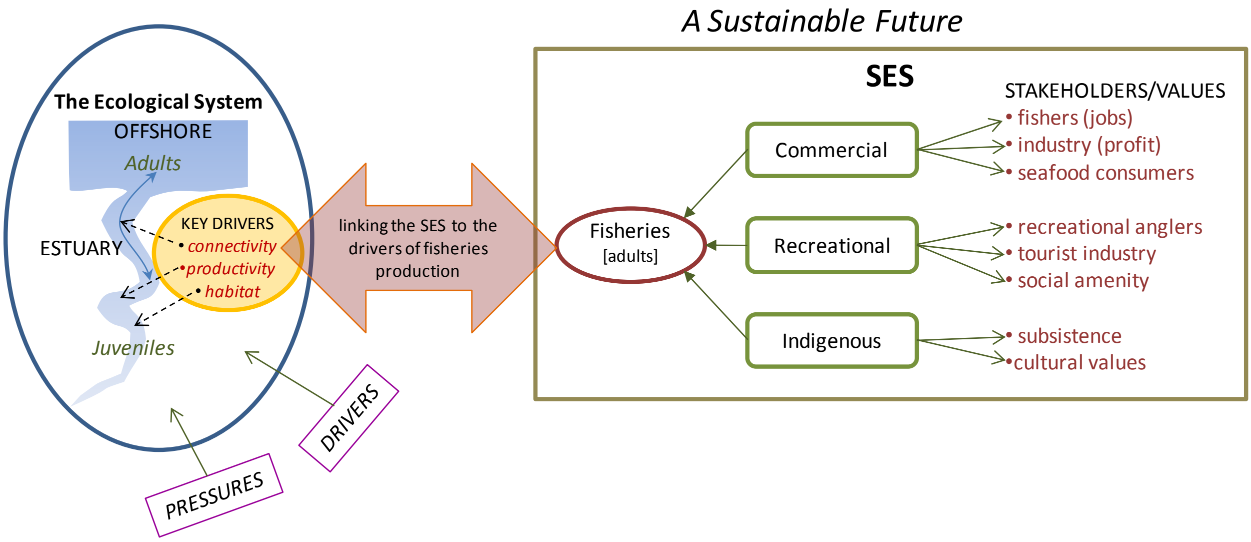

Figure 3: Example of the pathway to a sustainable future for coastal ecosystems and their Socio-Ecological systems

*3.1.3 **Principle 3:**Acknowledge a multi-scale vision and incorporate a multi-scale approach*

Due to complexity of governance systems there is often a disconnect between decision makers operating at a different scales– both temporally and spatially. For example, locals often recognise a local scale issue well before regional or national bodies. On the other hand, a long-term strategic overview of a region may be more within the domain of regional bodies than local residents. Consequently, there is the potential for disjunction between small-scale, localised management actions and large-scale catchment level management responses [60]. Moreover, due to the need for many climate adaptations to be sustained over a long time period or to manifest their effects over a long time horizon, the ecological system response to an action may be well beyond the life-cycle of a management body. Therefore comprehensive CAS need visions that embrace these multiple scales and lead to decisions and actions that encompass multi-scale understanding [61]. All proponents need to understand this multi-scale vision and recognise that incorporating it will often require different approaches by different players.

Scale (both temporal and spatial) matters and it is likely that implementation actions will need to occur on much smaller spatial and temporal scales than the strategy. At the same time, local actions that only focus on relatively small-scale local problems may have limited application when considering large-scale public resources (such as ensuring fisheries sustainability or ecosystem health). For example, while local initiatives, such as spatial and temporal closures, can be highly effective at very small-scales (hundreds to thousands of metres), their effectiveness at regional scales depends a network of similarly managed areas, and on support from sub-national or national governments in terms of monitoring and enforcement [62]. Thus, local actions conducted in isolation are suboptimal if the aim is to ensure the sustainability and resilience of ECMEs into the long term. Therefore, whereas the strategy needs to have an over-arching broad scale view linking relevant policies together, actions may need to take the form of an aggregation of several small to medium actions delivered by several agents[61]. The management systems, under which this can operate, will need to be informed by, and inform, actions at all scales.

In taking a multi-scale approach it is important to acknowledge the reality that objectives need to be relevant to specific impacts and vulnerabilities; they should produce effective outcomes for the target issue at the relevant scale. A multi-scale perspective requires that gains at the target scale should be consistent with, and value-add to, goals at larger conceptual scales of the adaptation strategy landscape, and should be operable and appropriate in the light of other coastal and CC issues [33]. The final adaptation strategy should not hamper but instead value-add to larger strategy goals otherwise it may increase the risk of a negative overall outcome.

3.2 Strategy Development and Implementation

Principles 1, 2 and 3 set the context for CAS development. Strategy development and implementation provides 'how to' guidelines that comprise a group of factors that need to be considered to ensure that adaptation strategies are developed with large-scale goals in mind, and in particular, to ensure that actions taken lead to optimal outcomes given uncertain knowledge and potentially conflicting objectives. There are sixcomprise 'Strategy Development and Implementation'.

*3.2.1 **Principle 4:** Ensure fair, representative and equitable stakeholder engagement*

Comprehensive stakeholder engagement is vital to achieve natural resource outcomes in the context of adaptation to CC [63, 64]. Indeed, empirical evidence suggests that the ability of societies to adapt is determined, in part, by the ability to act collectively [65]. Engagement of all stakeholders in strategy development in a participatory approach, combining top-down and bottom-up viewpoints, provides a richer suite of perspectives and a greater potential for objectivity and legitimacy [60, 62]. Stakeholder involvement needs to occur from the beginning to the end of the process, to ensure connections between large-scale objectives and local solutions are maintained. Keeping stakeholders engaged requires facilitation of on-going stakeholder interest and involvement through mentoring and championing, and by ensuring they are intimately involved in, and have the power to influence, decision-making.

There are several types of stakeholder engagement processes, largely defined by the tasks to be undertaken and their socio-political context, but also by the capabilities and aspirations of stakeholders [66].*Instructive involvement* is a mechanism for information exchange. *Consultative involvement* is where stakeholders have a degree of influence over the process and outcomes. *Cooperative involvement* is where primary stakeholders act as partners in the decision-making processes [66]. None of these types of involvement is more desirable than another, nor are they mutually exclusive, rather they provide a set of adaptable approaches to optimise engagement and achieve end goals whilst considering stakeholders' expectations and aspirations. It is important to combine and choose the stakeholder engagement approach that suits the particular situation and the question at hand.

A multitude of projects have developed 'frameworks' or 'road maps' to assist with or direct engagement with communities over CC issues and to help communities develop adaptation plans (e.g. [67, 68]. Many methods can be applied to interact with communities, but the reason for the interaction (e.g. to obtain information, to establish community engagement, to promote community adaptation) will generally dictate the most appropriate avenue of interaction. For example,Fernández-bilbao, Woodin [67]base their approach for community adaptation planning and engagement on three types of adaptation situations: (1) low conflict, controversy or uncertainty about the adaptation, (2) need for buy in from a number of stakeholders, or (3) high conflict, controversy and uncertainty about the need to adapt and/or the way to adapt.

An advantage of deliberative methods that involve active stakeholder participation is that the process of undertaking the adaptation assessment plays an important role in catalysing social learning and collective action [69]. This is very advantageous because the sharing of experiences in group discussions provides rich outcomes in terms of, for instance, the ability to process uncertainty information [70]. This approach is particularly useful when the problem is complex and uncertainty is high[35, 71]. Social learning takes place when groups of multiple stakeholders, with a diversity of values, get together to discuss, model, and find solutions to problems[72, 73]. Social learning frameworks have been used in a climate adaptation context mainly in case study applications; for instance, water resources, wildlife management and agriculture[72]. Social learning is increasingly gaining momentum compared to more traditional methods of information dispersal and expert-based teaching [e.g. 74, 75, 76], because of its value when uncertainty is pervasive [35].

Stakeholder participation may be difficult to achieve because it is sometimes difficult to identify interest groups in the first place. Consequently, community profiling aimed at determining the various interest or stakeholder groups, and gaining an understanding of the demographic profile of potentially affected communities is important [77]. There are many hard-to-reach groups within communities and these groups experience a range of barriers to participation including, for instance, age, mobility, language, personality types and access to opportunities [78], as well as world views, perceptions, behaviours and cognition [79]. While overcoming these barriers can be difficult, such strategies as snowball sampling, use of centralized lists and registers, population and cluster screening, media-based advertising and involvement of community groups have been applied within health disciplines for engagement of hard-to-reach populations [e.g. 80]. Using similar strategies in adaptation planning may help address the issues surrounding ongoing communication with stakeholders, however difficult they may be to reach.

*3.2.2 **Principle 5:**Acknowledge diversity and complexity of governance structures and develop organisational arrangements that facilitate cross-sectoral cooperation and coordination, capacity building, knowledge generation and exchange*

Governance systems, particularly in ECMEs, are fragmented into different tiers of government and local bodies, making a co-ordinated approach to management difficult [81]. No single agency manages ECMEs. Therefore, a common problem are spatial and functional mismatches where the resource management jurisdictions do not coincide with the boundaries of the ecological entity [82-84]. Actors must negotiate different goals in an attempt to manage simultaneously for multiple uses (e.g. fisheries, water quality, tourism, biodiversity) [82, 85]. Cooperation and coordination arrangements are arguably the key to effective multiple use management [82, 83, 86-88].

There isa variety of ways in which cross-sectoral interactions can be organised.Over time, Australian jurisdictions have experimented with a variety of organisational arrangements to enable an integrated approach to environmental problems. For example, one approach is the use of bridging organisations[89, 90]. In Australia they are known to have effectively crossed management and ecological boundaries and to have successfully facilitated the flow and exchange of information and knowledge within and across SES[88, 91]. Other arrangements include formalised management organisations, councils, committees, working groups, coordinators, taskforces and consultative bodies[92].

There is no single recipe for organisational design. However, there are several organisational issues that require consideration in development and implementation of CASs. These include: (a) ongoing engagement and communication among agencies, with other industries, their regulators and the public; (b) clear definition of roles and responsibilities; (c) leadership in promoting interests, disseminating information and forming strategic partnerships; (d) effective production and exchange of knowledge and information on ecological assets and their values; and (e) adequate human, financial and technical capacities [37].

*3.2.3 **Principle 6:** Identify enabling and constraining factors of existing institutional frameworks and align strategic responses*

Institutions are the laws, policies, regulations, norms, customs, cultural processes and other rules that shape human action [93].Institutions determine the roles and responsibilities, govern decision-making processes and interactions[94, 95].They are one of the core determinants of the abilities of governance actors to bring strategy into action. Therefore an essential part of CAS development is to identify institutional factors that contribute to or work against conservation ofECMEs. Identifying institutional context allows to understand which rules will condition CC adaptation and determine the potential scope of adaptation actions.

Institutional systems are complex and dynamic. For example, Australia's ECMEs are under the jurisdiction of seven bodies; the six States and the Northern Territory. There are seven different regulatory frameworks reflecting differing histories of political development, resource uses, and social, economic and political conditions. Furthermore, statutes, regulations, strategies and other instruments are frequently amended, revoked and reinvented [96] which brings new opportunities and challenges. As a result, it is difficult to predict how institutional arrangements will evolve to deal with CC issues over long term. This means that CAS will need to be 'fitted into' different contexts and maintain flexibility to adapt to changes in the political environment.

Establishing institutional factors that are critical for developing and implementing CAS can be a challenging task. Opportunities and constraints for CC adaptation can be created by different sets of rules such as property rights, planning and environmental protection legislation, taxation and budgeting systems, land and environmental resource markets, rules prescribing authority domains and policy making processes.Nonetheless, analysis[97]reveals that there are several common dimensions that are central to the pursuit of long-term protection of ECMEs: (1) strategic goals and supporting framework; (2) mandate boundaries; (3) cross-jurisdictional integration; (4) distribution of financial resources; and (5) incentive systems (Table3). Depending on the governance level and scales of CASs these may need to be considered as external barriers or addressed in action plans.

Table 3: Details of common institutionaldimensions that are central to the pursuit of long-term protection of ecological assets of Australian coastal fisheries

Dimension	Description
Strategic goals and supporting framework	A lack of shared long-term vision, goals and strategic framework developed for ecologically relevant scales can become a significant impediment for adaptation planning and targeted investment. Governance responses to various pressures affecting Australia's coastal habitats are still developed in ad hoc fashion and implemented at a relatively local level [107].
Mandate boundaries	Protection of fisheries ecosystem assets does not fall neatly within conventional sectoral boundaries. Many regulators responsible for fisheries management are deficient in authority to achieve stated habitat protection outcomes (e.g. have no control over the impacts on riparian or coastal vegetation, development on private land). Limited mandates may also affect strategic planning with responsible authorities focusing on those actions within the scope of their mandate.
Cross-jurisdictional integration	Australian coastal zone is a contested space. Long-term protection of fisheries assets remains dependent upon the level of incorporation of protective measures into legislative frameworks providing for activities affecting these assets indirectly. If these frameworks lack sufficient power to prevent adverse effects, the loss of habitats will continue.
Financial resources and revenue sources	Each jurisdiction has a different mix of government and non-government management bodies which are or can be potentially involved in the protection and maintenance of fish habitat assets. However, CAS need to be sensitive to the capacities and funding sources of these bodies. For example, Australian local governments do not control allocation of fisheries resources and often do not have the revenue necessary to adequately deal with issues, which could potentially impact fisheries.
Incentive systems	Planning and implementation of adaptation responses (e.g. increase in protected areas, rehabilitation of degraded habitats) requires consideration of broader economic context and established incentive systems. Such plans and actions involve important economic asset (e.g. land) that may affect multiple stakeholders, so an extension of the scope of applied incentive-based instruments may be required to align priorities and involve private land-holders in the management and maintenance of assets.

3.2.4 ***Principle 7:*** *Employ robust and adaptable strategies that minimise harm across human and natural systems*

There has been considerable theoretical [35, 98] and practical [99] development of the concept of *Robust Decision Making* (RDM). RDM is based on the idea that, where outcomes are uncertain, it is best to use robustness rather than optimality as a decision criterion, to characterise uncertainty with multiple representations of the future, and to select strategies that perform acceptably across the range of plausible outcomes [100]. RDM uses an iterative framework that provides a way forward when substantial uncertainty limits predictability of outcomes and so prevents the determination of optimal outcomes.

RDM contrasts with traditional decision making based on *Optimum Expected Utility* (OEU) that assumes that the likelihood of a particular outcome can be described by a single probability distribution, leading to a predictable link between action and effect [100]. CAS should always be placed in the context of the *Precautionary Approach* (PA), where decision makers should strive to prevent harm when uncertainty is pervasive [98]. An RDM approach challenges decision makers to explore a wide range of plausible outcomes, so can help reduce problems of overconfidence in outcomes that hamper traditional decision-analytic methods in situations where uncertainty is substantial [101]. There are a variety of robust strategy goals (Table 4) and several tools that assist in this process of developing a robust action under uncertainty (e.g. Management Strategy Evaluation [102]).

Table 4: Some common robust strategy goals, their attributes and examples

Goal	Attributes	Example
No-regrets	Actions that will produce no known detrimental impacts on the target situation regardless of uncertainty of outcomes and that have no known adverse collateral impacts	Replanting mangroves to replace forest lost after a cyclone Improve the habitat value of a seawall
Minimising collateral damage	Choices that minimise detrimental impacts to other sectors of actions that address imperative needs	Make choices that have the lowest impact on surrounding values (e.g. agriculture) where immediate action is required (e.g. due to legislation) to prevent severe degradation of protected areas
Reversibility	Actions that minimise future damage and costs of retrofitting if initial outcomes are inappropriate	Constructing a culvert under a road to reconnect an isolated area of coastal wetland
Bet hedging	Solutions that incorporate 'safety' features; important where desirable actions may have undesirable outcomes under some circumstances	Reconnect wetlands with culverts but include flood gates to allow exclusion of excessive tidal water to maintain hypersaline conditions
Safety margin	Build in extra capacity to facilitate future change that extends the effectiveness time-frame of actions; increases longevity of beneficial outcomes; usually an addition to other strategies	Assume sea-level rise will be faster than predicted and increase minimum elevation criteria for resettlement when moving dwellings landward away from foreshores
Increasing time horizon for additional action	Actions that allow time for other options to be developed and implemented	Move houses back from foreshores to facilitate habitat migration allowing time for development of alternative responses to habitat loss
Maximising complimentary benefits	Actions that result in the maximum network of advantages across all affected sectors	Legislation aimed to provide benefit across impacted sectors
Balancing risk and reward	Choose less attractive action with more assured benefit where value of the attractive action with greater potential value is uncertain	Restock fish if value of removing a barrier is uncertain in the long term (e.g. because of uncertainty about future river flow patterns)
Soft options	Approaches that do not involve remedial actions; these are reversible solutions that keep options open	Detailed monitoring to give early warning of the need for specific action if it is ever required, coupled with pre-planning of potential responses

The inherent uncertainty of responses of aquatic ecosystems [103] suggests that a *Robust Strategy* (RS) will usually be most appropriate. Given that ECMEs are not only ecologically complex, developing a RS in ECMEs can be described as a 'wicked problem ' [104, 105], because interactions within and among the social, economic, and ecological systems are highly complex, nonlinear, and—to a large degree—unknown. Wicked problems have no technical solution and are never solved once and for all [104]. They require governing interactions that are participatory, communicative, and adaptive [105]. RSs are therefore based on the idea of minimising the potential of unacceptable outcomes rather than necessarily obtaining an 'optimal' but risky solution. Ideally, a RS is insensitive to uncertainty in relation to specific outcomes [106] and the system [102]. A RS might involve trading-off optimal performance for reduced sensitivity to violations of assumptions, adopting a strategy that performs well across a wide range of alternative responses, or selecting an approach that keeps options open, such as a no-regrets strategy [98]. RSs should be adaptive in the sense that they should be designed to shape and maximise the options available to future decision makers [100] and allow iterative learning to better understand the system over time [71]. RSs are usually set in the context of the adaptive management approach of act, monitor and learn [57, 71] under uncertainty [102].

Action criteria based on understanding the nature and extent of uncertainty provide the basis for identifying achievable outcomes and sensible approaches to measuring their success. However, it is critical that all parties involved in the process have a full appreciation of uncertainty and its implications [35]. Communicating this effectively, and ensuring that this understanding is explicit in all levels of decision-making, is a major challenge, but is critical to success. It is necessary to ensure that uncertainty is fully included in decision-making and thus enable end-users (e.g. politicians, the public sector) to understand the value of outcomes free from unrealistic expectations.

*3.2.5**Principle 8:** Focus on achievable and realistic delivery of CAS andan application of support tools*

Many CAS analysts concentrate on developing 'frameworks' (models that scope out a series of steps to lead the proponent through adaptation strategy development). Many frameworks are available and several may be applicable to any specific case. However, the diversity in structure and conditions of ECMEs, the diversity of challenges faced, combined with pervasive uncertainty, have implications for the tools that support strategy development. No single framework will be applicable across all, or even most, ECME situations; if they are general enough to have broad utility they will be too non-specific to be operationally useful. Similarly, if they are tightly constrained they will usually be too restrictive and inflexible for general applicability.

Regardless of which framework works best for a specific system, or whether the choice is to proceed free from the constraints of any framework, it is worth developing an Adaptation Checklist to help ensure all critical aspects are covered during the process of developing an effective adaptation strategy (e.g. Table 5). An Adaptation Checklist should be treated as a guide rather than a prescription; some components may not be necessary in a particular situation, others may be missing, and the order of steps may well change from case to case.

Table 5: Example of a checklist for developing an effective adaptation strategy

A: Conduct comprehensive forecasting	Effective decision-making depends on the accuracy of predictions of the full spectrum of effects of climate changes. These need to include forecast of the evolution of ecosystems and social, technological, and economic systems as well as the behaviour of the climate system itself [106].
B: Conduct ecosystem triage	Ecosystem triage relates to the process of prioritizing which ecosystems or ecosystem components are the most profitable targets for the expenditure of scarce resources [58]. It relies on the complex interplay of a number of factors (e.g. exposure, sensitivity, adaptive capacity, risk, value). Approaches and criteria will depend on the exact focus of adaptation and the specific situation, needs and resources.
C: Specify an adaptation focus	Two components of the adaptation focus are important: (i) where the focus is directed along the continuum from transformative to targeted change; (ii) whether the focus is impact- or vulnerability-driven. Transformative change includes building resilience, reducing vulnerability etc., and is aimed at long-term, sustainable outcomes. Focussing on impacts will often match with targeted solutions, while focussing on vulnerability will usually match with transformative change [51, 58].
D: Define specific objectives	Defining objectives requires a number of components: identification of assets that require adaptation action; explicit definition; relevance to specific impacts and vulnerabilities; identification of spatial limits of the area; identification of end-users and their objectives.
E: Identify end-users comprehensively	Comprehensive identification of end-users and stakeholders is important because the success of adaptation strategies often relies on the extent of stakeholder engagement [63, 64].
F: Identify appropriate climate change scenarios	This involves defining the exposure to be planned for. The scenario needs to be defined taking into account the key climate change threats which will help define the logic of the assumed time horizon.
G: Assemble all relevant information	This includes collection of information on: available GIS, risk assessments, user groups, local views on needs, capacity (people, money, infrastructure), governance situation and constraints.
H: Assess the quality of available information and identify key gaps	The quality of information available is a critical determinant of the rigour and quality of the adaptation strategy development. If possible, any major gaps identified should trigger the collection of additional information and the operation of an adaptive loop.
I: Assess and communicate uncertainties	A clear understanding of the level of uncertainty will help to determine the limits on predictability of the action-outcome link, and (usually) emphasise the extent to which robust strategies are necessary.
J: Evaluate	Evaluation of constraints of all types determines the range of adaptation actions that

constraints	are possible and consequently the eventual adaptation strategy. Constraints come in many forms (e.g. geography, local climate, local tides, socio-economic, local political imperatives etc.).
K: Assess the range of actions possible given the situation	This step involves the development of a prospectus of the range of actions available in the context of large scale constraints, local situational constraints, the nature of the threats, and the assets requiring adaptation action.
L: Chose the scopeof actions	Develop action plan in the light of available information, constraints, levels of uncertainty and possible actions. This involves consideration of the outcomes of different actions, employing decisions-support tools, considering available recommendations and advice, and prioritisation of actions.
M: Evaluate adaptation outcomes and monitor success	Many aspects need to be included in evaluation, which may include: relation of outcomes to needs and aspirations of end-users; cost-benefit analysis of adaptation solutions; assessment of scales of outcomes (e.g. conceptual, spatial, areal, temporal); context/implications: outcomes for non-target end-users, interest groups or systems (e.g. collateral damage or complimentary benefits, feasibility).
N: Reassess uncertainties	Judgement of the functional magnitude of the accumulated uncertainties will determine if it is suitable to employ the adaptation strategy or if it is necessary to continue on in an adaptive loop to enable collection of the information needed to reduce uncertainty to an acceptable level.
O: Collect additional information as necessary	Collect any additional information or develop any additional understanding as identified during the assessment of information quality or during the strategy development and evaluation process.

*3.2.6**Principle 9:** Optimise outcomes by employing adaptive feedback cycles appropriately*

Inflexible strategies are rarely effective, so it is vital to employ adaptive feedback cycles in CAS design, and to employ them appropriately. The adaptive managementloop involves iterative decision making, evaluating the outcomes fromthe previous decisions and adjusting subsequent actions on the basis of this evaluation. An adaptive process should be adopted because,in most cases, complex relationships betweencause and effect lead to'wicked problems' where optimal solutions are impossible[104, 105]. In such cases, adaptive loops allow movement towards a defined set of goals even if the specific course is initially unclear or changes in circumstances mean the initial solution becomes untenable.

Principle 9 focuses specifically on the last 3 components of the Adaptation Checklist (Table 5). The uncertainty of outcomes means that robust strategies should be the favoured actions in the adaptive framework because they provide for re-evaluation and adaptive responses. The adaptive management loop may indicate the benefit (or not) of an action at totally different time and spatial scales than was originally intended. It also affords the important benefit of making it possible to take advantage of opportunities as they arise.

3.3 Conclusion

Ecological systems are intimately influenced by the social and economic systems that rely on them. This is particularly true of ECMEs, with their broad diversity of structure, the wide range of climatic and geomorphic conditions that influence them, and the diverse interactions they have with humans. Consequently, to be effective in supporting the long-term productivity and resilience of ECMEs, CCadaptation strategies (CAS) need to be broadly and holistically focussed on sustaining whole SESs. A holistic focus is particularly crucial because, not only are there many competing interests to be considered, but CC is only one of a suite of factors that impact ECMEs. CAS also need to have whole-of-system visions that focus on long-term transformative outcomes aimed at maintaining and restoring ecosystem resilience because it provides healthy human living environments, supports optimal biodiversity and underpins robust and productive fisheries. Maintaining and enhancing ecosystem resilience provides long-term durability and availability of resources and future-proofs SESs by supporting ecosystem functioning in the face of change.

Adaptation strategy development is a very uncertain ‘science’. It involves making decisions now on (uncertain) actions to respond to (uncertain) predicted outcomes of (uncertain) predicted change. This uncertainty is pervasive, complex, multifaceted and interactive [35, 100], and is perhaps the one ‘constant’ in the whole adaptation strategy development process.Adding to the uncertainty of adaptation strategy development, ECMEs are themselves characterised by substantial and pervasive variability, incomplete knowledge bases, and complex interdependencies. These characteristics mean that problems in these systems are resistant to resolution because of tortuous relationships between cause and effect and as such they are ‘wicked problems’ [104]. The uncertainty of outcomes means a ’do-nothing’response often appears to be a pragmatic option. However, in most cases, the nature and value of the coastal resources, and their intense use by humans, means ‘do-nothing’ responses cannot provide viable long-term solutions. Such complex problems require robust solutions that give the greatest security of long-term positive outcomes in the face of uncertainty in the nature of the systems and their processes, the trajectory of change and outcomes of remedial actions[35, 100]. Consequently, it is vital to focus on outcomes that are realistic and achievable; robust solutions that are not tightly constrained by the expectation of specific outcomes but produce acceptable outcomes across a spectrum of possible response trajectories.This uncertainty and complexity extends to governance systems and the need to harmonise policy and actions, to have consistent governance and to focus on long-term outcomes further complicating pathways to successful outcomes. This is particularly important because systems outcomes may occur well beyond the life of the current management regime.

Pervasive uncertainty also means that there is continual need for more and better knowledge to support adaptation actions but,perhaps more importantly, that all involved need to be clear that there will never be 'enough' knowledge to provide certainty of outcomes[98, 103]. As a result, successful adaptation to CC requires extensive, intimate and flexible common sense engagement by the whole community. It is critical that all stakeholders are well informed, have a full appreciation of uncertainty and its implications, and wherever possiblebecome deeply engaged with adaptation planning and actions.Consequently, those charged with facilitating change (managers in the broad sense) need to focus on engagement and education. In particular, it is critical that all players understand the levels of uncertainty involved and the consequences of that pervasive uncertainty. Prescriptions will not solve the diverse problems presented by CC – flexibility and open minded approaches to achieving big picture goals to support the public good are needed.

The principles developed here provide guidance for developing robust and effective situation-specific adaptation solutions. The principles provide specific guidance not available from generic adaption frameworks. At the same time, rather than imposing a rigid structure they comprise a series of steps based on conceptualisation of the various factors that bear on the success of an adaptation strategy. Consequently, the guidance they provide can be easily and flexibly adapted to a new situation while ensuring that important issues are not overlooked.

4 Acknowledgements

This research was funded by a joint grant from Australia's Fisheries Research and Development Corporation and Department of CC and Energy Efficiency (Project No 2011/040), and supported by James Cook University, Griffith University and CSIRO Climate Adaptation Flagship. We thank Alistair Hobday for advice throughout the project, and Martha Brians and Nina McLean for support during meetings.

5 References

[1] Redman CL, Grove JM, Kuby LH. Integrating social science into the long-term ecological research (LTER) network: social dimensions of ecological change and ecological dimensions of social change. Ecosystems. 2004;7:161-71.
[2] SOEC. State of the Environment 2011 Committee, Australia state of the environment (2011), Independent report to the Australian Government Minister for Sustainability, Environment, Water, Population and Communities, Canberra. 2011.
[3] Costanza R, d'Arge R, Groot Rd, Farber S, Grasso M, Hannon B, et al. The value of the world's ecosystem services and natural capital. 1998.
[4] Wu L, Lu J, Tong C, Liu C. Valuation of wetland ecosystem services in the Yangtze River estuary. Resources and Environment in the Yangtze Valley. 2002;12:411-6.
[5] Kathiresan K, Bingham BL. Biology of mangroves and mangrove ecosystems. Advances in marine biology. 2001;40:81-251.
[6] Creighton C, Boon P, Brookes J, Sheaves M. Repairing Australia's estuaries for improved fisheries production– what benefits, at what cost? Marine and Freshwater Research. 2015.
[7] Ford P, Tillman P, Robson B, Webster IT. Organic carbon deliveries and their flow related dynamics in the Fitzroy estuary. Marine Pollution Bulletin. 2005;51:119-27.
[8] Webster IT, Ford PW, Tillman P. Estimating nutrient budgets in tropical estuaries subject to episodic flows. Marine Pollution Bulletin. 2005;51:165-73.
[9] Brodie JE, McKergow LA, Prosser IP, Furnas M, Hughes AO, Hunter H. Sources of sediment and nutrient exports to the Great Barrier Reef World Heritage Area. 2003.
[10] Haynes D, Brodie J, Waterhouse J, Bainbridge Z, Bass D, Hart B. Assessment of the water quality and ecosystem health of the Great Barrier Reef (Australia): conceptual models. Environmental Management. 2007;40:993-1003.
[11] Bianchi TS, Allison MA. Large-river delta-front estuaries as natural "recorders" of global environmental change. Proceedings of the National Academy of Sciences. 2009;106:8085-92.
[12] Sheaves M, Baker R, Nagelkerken I, Connolly RM. True Value of Estuarine and Coastal Nurseries for Fish: Incorporating Complexity and Dynamics. Estuaries and Coasts. 2015;38:401-14.
[13] Meybeck M, Vörösmarty C. Fluvial filtering of land-to-ocean fluxes: from natural Holocene variations to Anthropocene. Comptes Rendus Geoscience. 2005;337:107-23.
[14] Syvitski JP, Vörösmarty CJ, Kettner AJ, Green P. Impact of humans on the flux of terrestrial sediment to the global coastal ocean. Science. 2005;308:376-80.
[15] Lotze HK, Lenihan HS, Bourque BJ, Bradbury RH, Cooke RG, Kay MC, et al. Depletion, degradation, and recovery potential of estuaries and coastal seas. Science. 2006;312:1806-9.
[16] Field CB. Managing the risks of extreme events and disasters to advance climate change adaptation: special report of the intergovernmental panel on climate change: Cambridge University Press; 2012.
[17] Seneviratne SI, Nicholls N, Easterling D, Goodess CM, Kanae S, Kossin J, et al. Changes in climate extremes and their impacts on the natural physical environment. Managing the risks of extreme events and disasters to advance climate change adaptation. 2012:109-230.
[18] Nicholls RJ, Wong PP, Burkett V, Codignotto J, Hay J, McLean R, et al. Coastal systems and low-lying areas. 2007.
[19] Sheaves M, Johnston R, Connolly RM. Temporal dynamics of fish assemblages of natural and artificial tropical estuaries. Marine Ecology-Progress Series. 2010;410:143-56.
[20] Abrantes K, Sheaves M. Importance of freshwater flow in terrestrial-aquatic energetic conectivity in intermittently connected estuaries of tropical Australia. Marine Biology. 2010;157:2071-86.
[21] Sheaves M, Johnston R, Molony B, Shepard G. The effect of impoundments on the structure and function of fish fauna in a highly regulated dry tropics estuary. Estuaries and Coasts. 2007;30:507-17.

[22] Hamilton SK, Gehrke PC. Australia's tropical river systems: current scientific understanding and critical knowledge gaps for sustainable management. Marine and Freshwater Research. 2005;56:243-52.
[23] Sheaves M, Brookes J, Coles R, Freckelton M, Groves P, Johnston R, et al. Repair and revitalisation of Australia's tropical estuaries and coastal wetlands: opportunities and constraints for the reinstatement of lost function and productivity. Marine Policy. 2014;47:23-36.
[24] Sheaves M. Is the timing of spawning in sparid fishes a response to sea temperature regimes? Coral Reefs. 2006;25:655-69.
[25] Munday PL, Dixson DL, McCormick MI, Meekan M, Ferrari MC, Chivers DP. Replenishment of fish populations is threatened by ocean acidification. Proceedings of the National Academy of Sciences. 2010;107:12930-4.
[26] Gillanders B, Elsdon T, Halliday I, Jenkins G, Robins J, Valesini F. Potential effects of climate change on Australian estuaries and fish utilising estuaries: a review. Marine and Freshwater Research. 2011:1115-31.
[27] Koehn JD, Hobday AJ, Pratchett MS, Gillanders BM. Climate change and Australian marine and freshwater environments, fishes and fisheries: synthesis and options for adaptation. Marine and Freshwater Research. 2011;62:1148-64.
[28] McCarthy JJ. Climate change 2001: impacts, adaptation, and vulnerability: contribution of Working Group II to the third assessment report of the Intergovernmental Panel on Climate Change: Cambridge University Press; 2001.
[29] Watson RT, Zinyowera MC, Moss RH. Climate Change 1995 impacts, adaptations and mitigation of climate change: Scientific-technical analysis: Cambridge University Press; 1996.
[30] Smit B, Pilifosova O. Adaptation to climate change in the context of sustainable development and equity. Sustainable Development. 2003;8:9.
[31] Burton I, Diringer E, Smith J. Adaptation to Climate Change: international policy options: Pew Center on Global Climate Change Arlington, VA; 2006.
[32] Carter TR, Parry ML, Harasawa H, Nishioka S. IPCC Technical Guidelines for Assessing Climate Change Impacts and Adaptations. University College, London, United Kingdom, and Centre for Global Environmental Research, Tsukuba, Japan; 1994. p. 59.
[33] Klein R, Nicholls R, Mimura N. Coastal adaptation to climate change: can the IPCC technical guidelines be applied? Mitigation and Adaptation Strategies for Global Change. 1999;4.
[34] Sheaves M, Dichmont C, Bustamante R, Dale P, Sporne I, Deng R, et al. Climate Change Adaptation Strategies to Support Australia's Estuarine and Coastal Marine Ecosystems. Canberra Australia: Fisheries Research and Development Corporation; 2014.
[35] Harris GP, Heathwaite A. Why is achieving good ecological outcomes in rivers so difficult? Freshwater Biology. 2012;57:91-107.
[36] Folke C, Carpenter SR, Walker B, Scheffer M, Chapin T, Rockström J. Resilience thinking: integrating resilience, adaptability and transformability. Ecology and Society. 2010;15:20.
[37] Dutra LX, Bustamante RH, Sporne I, van Putten EI, Dichmont CM, Ligtermoet E, et al. Organisational drivers that strengthen adaptive capacity in the coastal zone of Australia. Ocean and Coastal Management. 2015.
[38] Grech A, Bos M, Brodie J, Coles R, Dale A, Gilbert R, et al. Guiding principles for the improved governance of port and shipping impacts in the Great Barrier Reef. Marine pollution bulletin. 2013;75:8-20.
[39] Waltham NJ, Sheaves M. Expanding coastal urban and industrial seascape in the Great Barrier Reef World Heritage Area: Critical need for coordinated planning and policy. Marine Policy. 2015;57:78-84.
[40] Lee SY, Dunn RJK, Young RA, Connolly RM, Dale PER, Dehayr R, et al. Impact of urbanization on coastal wetland structure and function. Austral Ecology. 2006;31:149-63.

[41] Loneragan N, Kangas M, Haywood M, Kenyon R, Caputi N, Sporer E. Impact of cyclones and aquatic macrophytes on recruitment and landings of tiger prawns Penaeus esculentus in Exmouth Gulf, Western Australia. Estuarine, Coastal and Shelf Science. 2013;127:46-58.
[42] OECD. OECD Environmental Indicators: Development, Measurement and Use. Reference Paper), OECD Environmental Performance and Information Division, http://www.oecd org/env. 2003.
[43] Proske U, Haberle SG. Island ecosystem and biodiversity dynamics in northeastern Australia during the Holocene: Unravelling short-term impacts and long-term drivers. The Holocene. 2012:0959683612441840.
[44] Hughes TP, Huang H, Young MAL. The Wicked Problem of China's Disappearing Coral Reefs. Conservation Biology. 2013;27:261-9.
[45] Christensen NL, Bartuska AM, Brown JH, Carpenter S, D'Antonio C, Francis R, et al. The report of the Ecological Society of America committee on the scientific basis for ecosystem management. Ecological Applications. 1996;6:665-91.
[46] Pikitch E, Santora E, Babcock A, Bakun A, Bonfil R, Conover D, et al. Ecosystem-based fishery management. Science. 2004;305:346-7.
[47] Corvalan C, Hales S, McMichael A. Ecosystems and human well-being: A report of the Millennium Ecosystem Assessment: Island Press Washington, DC; 2005.
[48] Folke C, Carpenter S, Walker B, Scheffer M, Elmqvist T, Gunderson L, et al. Regime shifts, resilience, and biodiversity in ecosystem management. Annual Review of Ecology, Evolution, and Systematics. 2004:557-81.
[49] Dickey-Collas M, Engelhard GH, Rindorf A, Raab K, Smout S, Aarts G, et al. Ecosystem-based management objectives for the North Sea: riding the forage fish rollercoaster. ICES Journal of Marine Science. 2014;71:128-42.
[50] Richards C, Johnson LB, Host GE. Landscape-scale influences on stream habitats and biota. Canadian Journal of Fisheries and Aquatic Sciences. 1996;53:295-311.
[51] Lim B, Spanger-Siegfried E, Burton I, Malone E, Huq S. Adaptation policy frameworks for climate change: developing strategies, policies, and measures: Cambridge University Press Cambridge; 2004.
[52] Kates RW, Travis WR, Wilbanks TJ. Transformational adaptation when incremental adaptations to climate change are insufficient. Proceedings of the National Academy of Sciences. 2012;109:7156-61.
[53] Rickards L, Howden S. Transformational adaptation: agriculture and climate change. Crop and Pasture Science. 2012;63:240-50.
[54] Stafford Smith M, Horrocks L, Harvey A, Hamilton C. Rethinking adaptation for a 4 C world. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences. 2011;369:196-216.
[55] Scheffer M, Carpenter S, Foley JA, Folke C, Walker B. Catastrophic shifts in ecosystems. Nature. 2001;413:591-6.
[56] Anderson PJ, Piatt JF. Community reorganization in the Gulf of Alaska following ocean climate regime shift. Marine Ecology Progress Series. 1999;189:117-23.
[57] Holling C. Engineering resilience versus ecological resilience. Foundations of Ecological Resilience. 1996:51-66.
[58] Lawler J. Climate change adaptation strategies for resource managment and conservation planning. Annals of the New York Academy of Sciences. 2009;1162:79-98.
[59] Costanza R, Wilson MA, Troy A, Voinov A, Liu S, D'Agostino J. The value of New Jersey's ecosystem services and natural capital. 2006.
[60] O'Loughlin E, Nambiar ES. Plantations, farm forestry and water. Water and Salinity Issues in Agroforestry. 2001.
[61] Raven R, Schot J, Berkhout F. Environmental Innovation and Societal Transitions. 2012.

[62] Aswani S, Ruddle K. Design of Realistic Hybrid Marine Resource Management Programs in Oceania 1. Pacific Science. 2013;67:461-76.
[63] Adger WN, Brown K, Tompkins EL. Why do resource managers make links to stakeholders at other scales. Norwich: Tyndall Centre for Climate Change Research (Working Paper 65). 2004.
[64] Sheppard SR, Shaw A, Flanders D, Burch S, Wiek A, Carmichael J, et al. Future visioning of local climate change: a framework for community engagement and planning with scenarios and visualisation. Futures. 2011;43:400-12.
[65] Adger WN. Social and ecological resilience: are they related? Progress in human geography. 2000;24:347-64.
[66] Sarkar SK, Deb K. Regulation in infrastructure services: progress and the way forward: Tata Energy Research Institute; 2001.
[67] Fernández-bilbao A, Woodin S, Richardson J, Zsamboky M, Bose M, Orr P, et al. Understanding the processes for community adaptation planning on the coast. Technical Report FD2624. Londres: Defra; 2009.
[68] Booth P. Stage 1 report: case studies of climate change adaptation tools and application processes used by local government practitioners. Australian Climate Change Adaptation Research Network for Settlements and Infrastructure, School of Civil and Environmental Engineering, University of New South Wales, Sydney. 2012.
[69] Eakin HC, Patt A. Are adaptation studies effective, and what can enhance their practical impact? Wiley Interdisciplinary Reviews: Climate Change. 2011;2:141-53.
[70] Albert C, Zimmermann T, Knieling J, von Haaren C. Social learning can benefit decision-making in landscape planning: Gartow case study on climate change adaptation, Elbe valley biosphere reserve. Landscape and Urban Planning. 2012;105:347-60.
[71] Walters CJ, Holling CS. Large-scale management experiments and learning by doing. Ecology. 1990;71:2060-8.
[72] Martin J, Rogers M, Winter C. Climate Change in Regional Australia. 2009.
[73] Ison R. Systems Practice: How to Act in a Climate Change World: How to Act in a Climate Change World: Springer Science & Business Media; 2010.
[74] Blackmore C, Ison R, Jiggins J. Social learning: an alternative policy instrument for managing in the context of Europe's water. Environmental Science & Policy. 2007;10:493-8.
[75] Muro M, Jeffrey P. A critical review of the theory and application of social learning in participatory natural resource management processes. Journal of environmental planning and management. 2008;51:325-44.
[76] Pahl-Wostl C. A conceptual framework for analysing adaptive capacity and multi-level learning processes in resource governance regimes. Global Environmental Change. 2009;19:354-65.
[77] Few R, Brown K, Tompkins EL. Public participation and climate change adaptation: avoiding the illusion of inclusion. Climate Policy. 2007;7:46-59.
[78] Tompkins EL, Few R, Brown K. Scenario-based stakeholder engagement: incorporating stakeholders preferences into coastal planning for climate change. Journal of environmental management. 2008;88:1580-92.
[79] Boschetti F, Richert C, Walker I, Price J, Dutra L. Assessing attitudes and cognitive styles of stakeholders in environmental projects involving computer modelling. Ecological Modelling. 2012;247:98-111.
[80] Thompson S, Phillips D. Reaching and engaging hard-to-reach populations with a high proportion of nonassociative members. Qualitative Health Research. 2007;17:1292-303.
[81] Dale PER, Dale MB, Dowe DL, Knight JM, Lemckert CJ, Choy DCL, et al. A conceptual model for integrating physical geography research and coastal wetland management, with an Australian example. Progress in Physical Geography. 2010;34:605-24.
[82] Fidelman PIJ, Leitch AM, Nelson DR. Unpacking multilevel adaptation to climate change in the Great Barrier Reef, Australia. Global Environ Chang. 2013;23:800-12.

[83] Clarke B, Stocker L, Coffey B, Leith P, Harvey N, Baldwin C, et al. Enhancing the knowledge–governance interface: Coasts, climate and collaboration. Ocean Coast Manage. 2013;86:88-99.
[84] Folke C, Pritchard L, Berkes F, Colding J, Svedin U. The problem of fit between ecosystems and institutions: Ten years later. Ecol Soc. 2007;12.
[85] Fidelman P, Evans L, Fabinyi M, Foale S, Cinner J, Rosen F. Governing large-scale marine commons: Contextual challenges in the Coral Triangle. Marine Policy. 2012;36:42-53.
[86] van Vugt M. Averting the Tragedy of the Commons: Using Social Psychological Science to Protect the Environment. Current Directions in Psychological Science. 2009;18:169-73.
[87] Vollan B, Ostrom E. Cooperation and the Commons. Science. 2010;330:923-4.
[88] Shaw J, Danese C, Stocker L. Spanning the boundary between climate science and coastal communities: Opportunities and challenges. Ocean Coast Manage. 2013;86:80-7.
[89] Cash D, Clark WC, Alcock F, Dickson NM, Eckley N, Jäger J. Salience, credibility, legitimacy and boundaries: Linking research, assessment and decision making. 2002.
[90] Berkes F. Evolution of co-management: role of knowledge generation, bridging organizations and social learning. Journal of environmental management. 2009;90:1692-702.
[91] Myers S, Thomsen D, Tarte D, Dutra L, Ellis N, Thebaud O, et al. Adaptive learning and coastal management in South-east Queensland, Australia. Sustainable coastal management and climate adaptation. 2012:157-76.
[92] Ross A, Dovers S. Making the harder yards: environmental policy integration in Australia. Australian Journal of Public Administration. 2008;67:245-60.
[93] Young OR. The institutional dimensions of environmental change: fit, interplay, and scale: MIT press; 2002.
[94] Scott WR. Institutions and organizations: Ideas, interests, and identities: Sage Publications; 2013.
[95] Ostrom E. Understanding institutional diversity: Princeton University Press Princeton, New Jersey; 1995.
[96] Urwin K, Jordan A. Does public policy support or undermine climate change adaptation? Exploring policy interplay across different scales of governance. Global environmental change. 2008;18:180-91.
[97] Sheaves M, Dichmont C, Bustamante R, Dale P, Sporne I, Deng R, et al. Climate Change Adaptation Strategies to Support Australia's Estuarine and Coastal Marine Ecosystems. 2014.
[98] Lempert RJ, Collins MT. Managing the Risk of Uncertain Threshold Responses: Comparison of Robust, Optimum, and Precautionary Approaches. Risk Analysis. 2007;27:1009-26.
[99] Harris G. Seeking sustainability within complex regional NRM systems. . In: Ostendorf B, Baldock P, Bruce D, Burdett M, Corcoran P, editors. Proceedings of the Surveying & Spatial Sciences Institute Biennial International Conference. Adelaide: Surveying & Spatial Sciences Institute; 2009. p. 1001-14.
[100] Lempert RJ, Popper SW, Bankes SC. Robust Decision Making: Coping with Uncertainty. The Futurist. 2010;44:47-8.
[101] Lempert RJ, Groves DG, Popper SW, Bankes SC. A general, analytic method for generating robust strategies and narrative scenarios. Management Science. 2006;52:514-28.
[102] Sainsbury KJ, Punt AE, Smith AD. Design of operational management strategies for achieving fishery ecosystem objectives. ICES Journal of Marine Science: Journal du Conseil. 2000;57:731-41.
[103] Harris G, Heathwaite AL. Inadmissible evidence: knowledge and prediction in land and riverscapes. Journal of Hydrology. 2005;304:3-19.
[104] Jentoft S, Chuenpagdee R. Fisheries and coastal governance as a wicked problem. Marine Policy. 2009;33:553-60.
[105] Rittel HW, Webber MM. Dilemmas in a general theory of planning. Policy sciences. 1973;4:155-69.

[106] Lempert RJ, Schlesinger ME. Robust strategies for abating climate change. Climatic Change. 2000;45:387-401.
[107] Bradley M, van Putten I, Sheaves M. The pace and progress of adaptation: Marine climate change preparedness in Australia' s coastal communities. Marine Policy. 2015;53:13-20.