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

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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.

1. Introduction

One of the underlying goals of publicly 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 goal is 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 ECME for CC impacts is environmentally, economically and socially complex. Much of the world's population is concentrated along coasts and around estuaries. For example in Australia the proportion of people living in coastal areas is particularly high at around 80% [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 functionally far 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

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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 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 CAS in 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 reassessed, 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 gap between 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 is addressed 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, a series of seven (face-to-face) expert group workshops were conducted, followed by phone hook-ups and email conversations. The workshops involved a trans-disciplinary panel of up to 10 researchers (with a core of 6 regular members), consisting of environmental scientists, ecosystem ecologists, fisheries scientists, qualitative and quantitative modellers, natural resource

Table 1
Generic types of adaptation responses and actions (distilled from Klein et al. [33], Burton et al. [112], Millar et al. [113], Lawler [62]).

	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