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Adapting Management of Marine Environments to a Changing Climate: A Checklist to Guide Reform and Assess Progress

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ABSTRACT

Documented impacts of climate change on marine systems indicate widespread changes in many geographic regions and throughout all levels of the ocean's food webs. Oceans provide the main source of animal protein for over a billion people, and contribute significantly to food security for billions more. Clearly, if we are to continue to derive these benefits, then the rate of adaptation in our human systems needs to at least keep pace with the rate of ecological change for these benefits to continue. An Australia-wide program of research into marine biodiversity and fisheries explored the opportunities for policy and management to respond to a changing climate. The research program spanned all Australian estuarine-nearshore and marine environments—tropical, subtropical, and temperate—and focused on two key marine sectors: biodiversity conservation and fisheries (commercial, recreational, and aquaculture). Key findings from across this strategic and extensive research investment were the need to foster resilience through habitat repair and protection, improve resource allocation strategies, fine-tune fisheries management systems, and enhance whole of government approaches and policies. Building on these findings, from a climate adaptation perspective, we generated a checklist of thirteen elements encompassing all project findings to assess and steer progress towards improving marine policy and management. These elements are grouped in three broad areas: preconditioning; future proofing; and transformational changes and opportunities. Arising from these elements is a suite of priority strategies that provide guidance for marine managers, policy practitioners, and stakeholders as they prepare for a future under climate change. As the research program encompassed a wide range of habitats and ecosystems, spanned a latitudinal range of over 30°, and considered a diversity of management systems and approaches, many of these elements and strategies will be applicable in a global context.

Key words: marine biodiversity; fisheries management; marine conservation; climate change; adaptation; transformation.

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Introduction

Oceans policy and management has a broad dual remit, to foster both sustainable use and biodiversity conservation (UN 1982, Article 61). This dual remit is a global challenge, particularly given the increasing pressures on the ocean as a result of human activities and the demand for seafood from a growing population (Halpern and others 2012; Maury and others 2013; Ban and others 2014; Merrie and others 2014). Production of natural resources from the oceans already exceeds the capacities of natural systems in many areas (Miles 2009), and the functioning of major biogeochemical cycles and ecosystems has been altered by anthropogenic impacts (Doney and others 2012). Yet oceans provide irreplaceable ecosystem services including defense, oxygen production, nutrient recycling, and climate regulation (Costanza and others 2014; Polovina and others 2014) valued globally in 2011 (2007 $US) at $125–$145 trillion/year (Costanza and others 2014). Australia's surrounding oceans, representing the world's third largest exclusive economic zone (~8.1 million km^2), are no exception (SoE 2011). These oceans generate considerable economic wealth through fisheries, aquaculture, tourism, oil and natural gas, and transport, estimated as $US32.3 billion [$A42 billion] per year or about 8% of gross domestic product (AIMS 2012). Fisheries and aquaculture are important industries in Australia, both economically (gross value over $US1.92 billion [$A2.5] billion) and socially (Madin and others 2012; ABARES 2013). The annual economic values of Australian marine biomes in terms of delivery of ecosystem services have been estimated as follows: open ocean $US358.6 billion [$A464.7 billion], seagrass/algal beds $US135.2billion [$A175.1 billion], coral reefs $US41.3 billion [$A53.5 billion], shelf systems $US461.6 billion [$A597.9 billion], and tidal marsh/mangroves $US30.3 billion [$A39.1 billion] (Blackwell 2005).

As in other regions, Australia's oceans, marine biodiversity, and dependent industries (for example, fisheries and aquaculture) are already experiencing and responding to a changing and more variable climate (Lough and Hobday 2011; Poloczanska and others 2012; Hodgkinson and others 2014). The flow-on effects from climate through to ecological and economic change are occurring at a more rapid rate in marine compared to terrestrial systems (Poloczanska and others 2013). Adapting to this changing climate is essential if Australia is to maintain, build upon, and profit from the wealth of public and private goods and services provided by the marine environment (Holbrook and Johnson 2014; Hodgkinson and others 2014; Johnson and Holbrook 2014). Moreover, there are 50,000 marine species known or likely to be present in Australian waters, of which 58 are listed as threatened (Butler and others 2010). This marine biodiversity is particularly susceptible to climate change impacts in coral reef, coastal wetland, estuarine, intertidal, and rocky reef habitats (Brierley and Kinsford 2009; Russell and others 2009; Hughes 2011). The rapid rate of change in the physical environment may be beyond the capacity of some species to adapt in a timely manner; survival will be dependent on management interventions that seek to reduce non-climate stressors and increase resilience (Crowder and others 2006; Brierley and Kinsford 2009; Veron and others 2009; Stein and others 2013).

Understanding resilience problems in marine sustainable resource use and biodiversity conservation can be significantly advanced through systems perspectives—in particular social–ecological system analyses (Lebel and others 2006; Folke 2010; Lockwood and others 2012). Gallopín (2006, p. 294) defines a social–ecological system, that can be specified for any scale from local to global, to include the 'societal (human) and ecological (biophysical) subsystems in mutual interaction.' A system perspective supports a spatially and temporally integrated consideration of ecological, social, economic, and policy influences on marine system dynamics in a way that can inform response strategies (Pollnac and others 2010; Kittinger and others 2012; Schlüter and others 2012; Ban and others 2013). Systems understanding can also enhance capacity for collaboration and shared decision making (Biggs and others 2011). Collaborative network of stakeholders who pool information and work together on response strategies is an appropriate pathway for dealing with the complexities of sustainable resource use (Armitage and Plummer 2010). Building shared understanding at the science–policy interface through knowledge transfer and consensus building is particularly salient in the context of climate change (Bodin and Crona 2009; Falaleeva and others 2011; Cvitanovic and others 2015).

Many individual researchers are contributing to our growing understanding of both impacts and potential responses, but coordinated programs offer the potential for greater insights, particularly in large and diverse regions such as Australia (Carpenter and others 2012; Frusher and others 2014; Holbrook and Johnson 2014). A recent program initiated in Australia was successful in linking the resources of a number of research providers to collectively and collaboratively address challenges associated with marine climate impacts and adaptation. The Fisheries Research and Development Corporation (FRDC), one of the key Australian agencies responsible for commissioning research to assist in the management of the fisheries and aquaculture resource for ongoing sustainability, was the lead partner. Collaboration with the then Department of Climate Change and Energy Efficiency and other government investors led to the design and implementation of a $9M program of research: the Climate Change Adaptation—Marine Biodiversity and Fisheries initiative (Creighton 2014). The program design recognized that global approaches and actions to mitigate anthropogenic climate change could, at best, only slow the rate of change in the physical environment. Therefore, the investment approach for this research program was to examine how Australia, through its various policy frameworks and management mechanisms, can best adapt to a changing climate (Mapstone and others 2010). As context, there was already substantial biophysical research available both regionally and globally defining the likely extent of climate change, the mitigation imperative, and the broad implications of a changing climate (for example, Poloczanska and others 2007; Mapstone and others 2010; Frusher and others 2014). Twenty-five research projects were funded under the initiative. Reflecting the diversity, size, and complexity of Australia, projects encompassed tropical to temperate systems, considered multiple habitats (estuaries, wetlands, coastal, and oceanic systems), and included aquaculture, commercial, and recreational fisheries, and marine biodiversity governance, planning, and management. All projects were required to include an assessment of the opportunities out to 2030 for adaptation through improved policy frameworks and management mechanisms.

Here, we distil from all the project-based recommendations across this portfolio of research a suite of key elements required of policy and management to adequately adapt and respond to a changing climate. These elements, structured into three phases, are presented as a checklist to guide reform and assess progress towards a climate-ready marine future. To illustrate the application of these elements, we use Australian examples to indicate key areas of investment needed to better position Australia to respond to a changing climate, and more generally to global change. Our findings are directly relevant and transferable to other global regions, providing guidance for marine managers, policy practitioners, and stakeholders as they prepare for a future under climate change.

Phases in Establishing Adaptation Response Capability for Marine Policy and Management

Management of marine resources for conservation and sustainable harvest is more challenging than ever. A range of anthropogenic activities has triggered environmental changes that greatly exceed natural background fluctuations (Rockström and others 2009; Steffen and others 2011; Steffen and others 2015). Most pervasive is a changing climate resulting in altered physical conditions in many marine regions around the world (Doney and others 2012; Hobday and Pecl 2014). Moreover, global change will also lead to altered adaptation responses in human systems, economic opportunities, and conservation priorities, all of which will require revised policy frameworks and management approaches.

Systems thinking demonstrates that climate (and its impacts) is but one of many issues that might contribute to policy and management decisions. Indeed marine management, by virtue of being multi-objective and needing to meet diverse and sometimes competing user needs, is best served by a multi-component approach that incorporates climate as one of many issues to be accommodated. Responses to address the challenges of climate change will range from those that are minor or incremental through to those that involve more radical shifts in resource management and utilization (Stafford-Smith and others 2011; Park and others 2012; Wise and others 2014). Accordingly, our synthesis recognized three interlinked phases of the adaptation process. Historically, management of marine biodiversity and resources has not necessarily or typically taken a systems view. Thus, there is a need to ensure that policy, management, and institutional structures are better aligned so that there is a solid platform on which to develop adaptation responses (Frusher and others 2014; Wise and others 2014). We term this first necessary phase '*preconditioning*.' Once policy and management structures are aligned, '*future proofing*' of systems can include the knowledge assimilation and building of conceptual understanding required to begin operational processes and direct actions on the ground. This phase highlights the need for integrated systems thinking and approaches, based on an interdisciplinary and social–ecological systems view. Lastly, to facilitate the sustainable use and conservation of living marine resources into a vastly different future, both '*transformation and opportunity*' need to be considered. In the next section, we summarize all the project-based findings from the research program, and from these we inductively develop thirteen elements across these three phases that serve to guide and assess adaptive policy and management reforms.

Imperatives for Enhanced Marine Biodiversity and Fisheries Management: A Climate Checklist

Based on review of the portfolio of research projects, supporting literature, and the experience of the authors, we derived a climate checklist consisting of 13 ''elements'' spread across the three phases (Table 1). These elements were derived and then consolidated by considering the findings and recommendations that were made in each of the projects. The 25 projects spanned seven different areas: oceanographic environment ($n = 1$), aquaculture and fisheries ($n = 11$), marine biodiversity and fisheries (8), carbon sequestration ($n = 1$), coastal tourism and amenity ($n = 1$), community-led adaptation ($n = 1$), and knowledge ($n = 1$). Several of these projects were deliberately commissioned to fill perceived gaps in the portfolio, including specific projects on estuaries and inshore, habitat repair, carbon sequestration, and knowledge. Key elements from each of the 25 projects for enhanced marine biodiversity and fisheries management were identified by the authors during a half-day workshop and subsequently refined by the same team. Within each project, between 4 and 13 of the elements were addressed, with an average of nine elements for the fisheries and biodiversity projects. Each of the elements was addressed by an average of 16 projects, with a range between 9 and 24 projects (Elements 11 and 1, respectively) (Table 2). In the remainder of this section, we describe each of these elements, which are designed to guide and assess policy and management reform, with a particular focus on adaptation capacity for dealing with climate change. We note that elements in each phase may need to be re-assessed over time to ensure alignment to deliver the expected benefits.

Elements of a Preconditioning Phase

Our suite of elements provides an assessment of the *preconditioning* necessary to enable improved policy and management. *Policy and management need to respond to changing social–ecological conditions, so interventions must be flexible and adaptive* (*Element 1*). Inshore, coastal, and marine systems are dynamic,

Table 1. Summary of the Elements Described in the Text for Guiding and Assessing Marine Policy and Management Change, in Each of Three Phases.

Phase	Element
Preconditioning	Policy and management need to respond to changing social–ecological conditions, so interventions must be flexible and adaptive
	Action for climate adaptation must be a part of larger social and economic adaptations to changing circumstances
	Climate policy should be implemented as part of integrative, multi-objective policy and management
	In responding through management interventions to changing social–ecological system interactions, it is essential to include climate influences
Future proofing	Fostering resilient healthy ecosystems is an imperative for policy and management
	Policy and management must address spatial and temporal scales that match the values and issues of concern
	Catchment management is essential for positive marine outcomes
	In responding to threatening processes, it is essential to ensure ecosystem integrity
	In protecting key species, site- and species-specific strategies are essential
Transformation and opportunity	Changes brought about by a changing climate must be assessed for beneficial opportunities
	In responding to increased climate variability and change, a transition towards flexible total stock or population management systems is essential
	Policy and management must take advantage of the key role marine ecosystems can have in carbon sequestration
	Carbon sequestration in marine systems is best done as part of a multi-objective approach

Table 2. Project Findings and Implications for Climate Change Adaptation.

Project focus	Project number and title	Relevant finding	Preconditioning			
			Social–ecological change	Socio-economic adaptations	Multi-objective policy	Interventions address climate change
Oceanographic Environment	1. Understanding the biophysical implications of climate change in South Eastern Australia: Modeling of physical drivers and future changes	Development and improvement of the existing physical models is not a roadblock to further fishery adaptation planning	✔			✔
Aquaculture	2. Ensuring the Australian oyster industry adapts to a changing climate: a natural resource and industry spatial information portal for knowledge and informed adaptation frameworks	There is a common need to access information that is both locally relevant and nationally positioned	✔	✔	✔	✔
Fisheries and Aquaculture	3. Development and testing of a national integrated climate change adaptation assessment framework	Adaptation frameworks should foster decision strategies based on a combination of fishery performance and human social–economic performance	✔	✔	✔	✔
Fisheries and Aquaculture	4. Vulnerability of an iconic Australian finfish (Barramundi, *Lates calcarifer*) and related industries to altered climate across tropical Australia	Both wild caught and cultured Barramundi are likely to extend south in range and total population and resource planners should begin to implement various scenarios into fisheries planning models	✔	✔	✔	✔
Fisheries	5. Growth opportunities for Australian fisheries and aquaculture under climate change	Stronger connection between different sectors and segments in the supply chain confers resilience	✔			
Fisheries	6. Risk assessment of impacts of climate change for key species in South Eastern Australia	Fisheries managers need to be proactive in positioning themselves to undertake a strategic and structured approach to adaptation planning	✔	✔	✔	✔
Fisheries	7. Identifying management objectives hierarchies and weightings for four key fisheries in South Eastern Australia	It is important to articulate the objectives of fisheries management as an early step in fisheries adaptive management and of integrating climate change driven changes into this process	✔	✔	✔	✔

Table 2. continued

Project focus	Project number and title	Relevant finding	Preconditioning			
			Social–ecological change	Socio-economic adaptations	Multi-objective policy	Interventions address climate change
Fisheries	8. Identification of climate-driven species shifts and adaptation options for recreational fishers: learning general lessons from a data rich case	Long-term fisher collected data sets offer opportunities to investigate complex interactions between species-level change, environmental signals and anthropocentric impacts	✔	✔		✔
Fisheries	9. Management implications of climate change effect on fisheries in Western Australia	Monitoring of key environmental variables and habitat is essential to enable early detection of changes in abundance and therefore allow for proper assessment and management recommendations before fishing takes place	✔	✔	✔	✔
Fisheries	10. Effects of climate change on reproduction, larval development and population growth of coral trout (*Plectropomus* spp)	Recognizing the sensitivity of coral trout to increasing temperature, ocean acidification, and climate-induced habitat degradation the imperative is to understand how these affect will manifest in terms of the productivity and sustainability of wild fisheries		✔		✔
Fisheries	11. Implications of climate change on fisheries resources of northern Australia—vulnerability assessment and adaptation options	Appropriate adaptation must include detailed analysis of options; prioritization of adaptation responses; impact assessment and profitability analysis for indigenous. Recreational and commercial fishers; and detailed specification of the pathways and actions to be implemented	✔	✔	✔	✔
Fisheries	12. Implications of climate change for recreational fishers and the recreational fishing industry	Management activities that assist in ensuring resilience of fish populations will be a useful first strategy in responding to a changing climate	✔	✔	✔	✔

Table 2. continued

Project focus	Project number and title	Relevant finding	Preconditioning			
			Social–ecological change	Socio-economic adaptations	Multi-objective policy	Interventions address climate change
Fisheries	13. Preparing fisheries for climate change—assessing alternative adaptive options for four key fisheries in South Eastern Australia	The design, application, and review of management strategies will require improved understanding of biology such as recruitment dynamics and ecology; increased monitoring of key biophysical attributes and stocks to populate models; harvest strategies that deliver sustainable economic yield; and extension of model outputs into management decision making	✔	✔	✔	✔
Fisheries and Marine Biodiversity	14. Potential futures for Australia's South Eastern marine ecosystems, quantitative Atlantis projections	Integrative adaptive management across all users of the marine and coastal environments is the most effective means of maintaining sustainable, desirable, and productive marine ecosystems under all levels of global change	✔	✔	✔	✔
Fisheries and Marine Biodiversity	15. Revitalizing Australia's Estuaries	The return on investing in restoration ecology of Australia's coastal ecosystems well exceeds the benefits accrued from all prior major Australian initiatives in environmental repair	✔	✔	✔	
Fisheries and Marine Biodiversity	16. Estuarine and nearshore ecosystems—assessing alternative adaptive management strategies for the management of estuarine and coastal ecosystems	Ensuring ecosystem robustness and resilience are maintained at whole-of-resource scale is essential to ensure public good outcomes	✔	✔	✔	✔
Marine Biodiversity	17. Pre-adapting a Tasmanian coastal ecosystem to ongoing climate change through reintroduction of a locally extinct species	A comprehensive decision framework is essential to assess conservation translocation proposals	✔	✔	✔	

Table 2. continued

Project focus	Project number and title	Relevant finding	Preconditioning			
			Social–ecological change	Socio-economic adaptations	Multi-objective policy	Interventions address climate change
Marine Biodiversity	18. Human intervention options for seabirds and marine mammals under climate change	Direct interventions exist and must be tested for efficacy.	✔		✔	✔
Marine Biodiversity	19. Changing currents in marine biodiversity governance and management: responding to climate change	Common challenges are improving knowledge of the social–ecological system; stakeholder communication and information; improving capacity to deal with uncertainty and complexity; preparedness for change; lack of broad public and political support for the values of marine biodiversity; and integration and coordination gaps amongst and across government agencies.	✔	✔	✔	
Marine Biodiversity	20. Adaptive management of temperate reefs to minimize effects of climate change: Developing new effective approaches for ecological monitoring and predictive modeling	Long-term monitoring is essential for detecting and describing change and informing appropriate management responses.	✔		✔	
Marine Biodiversity	21. Adapting to the effects of climate change on Australia's deep marine reserves	Adaptation strategies involving assisted translocation and the use of artificial substrates may be required to conserve the cold water coral reefs that characterize seamounts in the Southeast Marine Reserve.	✔		✔	
Carbon sequestration	22. Comparative sequestration and mitigation opportunities across the Australian landscape and its land uses	Carbon storage and sequestration in coastal ecosystems provides an additional tool to mitigate globally; an opportunity to strengthen social– economic resilience of Australia's coastal communities and industries; avoids significant emissions from ecosystem degradation; and supports wetland conservation efforts	✔	✔	✔	

Table 2. continued

Project focus	Project number and title	Relevant finding	Preconditioning			
			Social–ecological change	Socio-economic adaptations	Multi-objective policy	Interventions address climate change
Coastal tourism and amenity	23. Beach and surf tourism and recreation in Australia: vulnerability and adaptation	Coastal managers will need to utilize a menu of adaptive management strategies to minimize the economic losses associated with climate change impacts on beaches	✔	✔	✔	
Community-led adaptation	24. A marine climate change adaptation blueprint for coastal regional communities	Key components of community response include working within a boundary organization; integrating climate change with other stressors; bringing together biophysical and human dimensions; being inclusive and encompassing the entire marine community; combining qualitative and quantitative approaches; and ensuring access to up to date information and research findings	✔	✔	✔	
Knowledge	25. Climate Change Adaptation: Building community and industry knowledge	To increase knowledge uptake requires specialized understanding and approaches	✔	✔	✔	

Project focus	Project number and title	Relevant finding	Future proofing				
			Resilient ecosystems	Scales that match values/issues	Manage catchments	Ecosystem integrity	Site-and species-specific strategies
Oceanographic Environment	1. Understanding the biophysical implications of climate change in South Eastern Australia: Modeling of physical drivers and future changes	Development and improvement of the existing physical models is not a roadblock to further fishery adaptation planning		✔			

Table 2. continued

Project focus	Project number and title	Relevant finding	Future proofing				
			Resilient ecosystems	Scales that match values/issues	Manage catchments	Ecosystem integrity	Site-and species-specific strategies
Aquaculture	2. Ensuring the Australian oyster industry adapts to a changing climate: a natural resource and industry spatial information portal for knowledge and informed adaptation frameworks	There is a common need to access information that is both locally relevant and nationally positioned	✔	✔	✔		
Fisheries and Aquaculture	3. Development and testing of a national integrated climate change adaptation assessment framework	Adaptation frameworks should foster decision strategies based on a combination of fishery performance and human social–economic performance	✔	✔		✔	
Fisheries and Aquaculture	4. Vulnerability of an iconic Australian finfish (Barramundi, *Lates calcarifer*) and related industries to altered climate across tropical Australia	Both wild caught and cultured Barramundi are likely to extend south in range and total population and resource planners should begin to implement various scenarios into fisheries planning models	✔	✔	✔	✔	
Fisheries	5. Growth opportunities for Australian fisheries and aquaculture under climate change	Stronger connection between different sectors and segments in the supply chain confers resilience				✔	✔
Fisheries	6. Risk assessment of impacts of climate change for key species in South Eastern Australia	Fisheries managers need to be proactive in positioning themselves to undertake a strategic and structured approach to adaptation planning	✔	✔	✔	✔	✔

Table 2. continued

Project focus	Project number and title	Relevant finding	Future proofing				
			Resilient ecosystems	Scales that match values/issues	Manage catchments	Ecosystem integrity	Site-and species-specific strategies
Fisheries	7. Identifying management objectives hierarchies and weightings for four key fisheries in South Eastern Australia	It is important to articulate the objectives of fisheries management as an early step in fisheries adaptive management and of integrating climate change driven changes into this process	✔	✔		✔	✔
Fisheries	8. Identification of climate-driven species shifts and adaptation options for recreational fishers: learning general lessons from a data rich case	Long-term fisher collected data sets offer opportunities to investigate complex interactions between species-level change, environmental signals and anthropocentric impacts		✔	✔	✔	
Fisheries	9. Management implications of climate change effect on fisheries in Western Australia	Monitoring of key environmental variables and habitat is essential to enable early detection of changes in abundance and therefore allow for proper assessment and management recommendations before fishing takes place	✔	✔	✔		
Fisheries	10. Effects of climate change on reproduction, larval development and population growth of coral trout (*Plectropomus* spp)	Recognizing the sensitivity of coral trout to increasing temperature, ocean acidification, and climate-induced habitat degradation the imperative is to understand how these affect will manifest in terms of the productivity and sustainability of wild fisheries	✔	✔		✔	

Table 2. continued

Project focus	Project number and title	Relevant finding	Future proofing				
			Resilient ecosystems	Scales that match values/issues	Manage catchments	Ecosystem integrity	Site-and species-specific strategies
Fisheries	11. Implications of climate change on fisheries resources of northern Australia—vulnerability assessment and adaptation options	Appropriate adaptation must include detailed analysis of options; prioritization of adaptation responses; impact assessment and profitability analysis for indigenous. Recreational and commercial fishers; and detailed specification of the pathways and actions to be implemented		v	✔	v	
Fisheries	12. Implications of climate change for recreational fishers and the recreational fishing industry	Management activities that assist in ensuring resilience of fish populations will be a useful first strategy in responding to a changing climate	✔	✔	✔	✔	
Fisheries	13. Preparing fisheries for climate change—assessing alternative adaptive options for four key fisheries in South Eastern Australia	The design, application, and review of management strategies will require improved understanding of biology such as recruitment dynamics and ecology; increased monitoring of key biophysical attributes and stocks to populate models; harvest strategies that deliver sustainable economic yield; and extension of model outputs into management decision making		✔		✔	✔

Table 2. continued

Project focus	Project number and title	Relevant finding	Future proofing				
			Resilient ecosystems	Scales that match values/issues	Manage catchments	Ecosystem integrity	Site-and species-specific strategies
Fisheries and Marine Biodiversity	14. Potential futures for Australia's South Eastern marine ecosystems, quantitative Atlantis projections	Integrative adaptive management across all users of the marine and coastal environments is the most effective means of maintaining sustainable, desirable, and productive marine ecosystems under all levels of global change	✔	✔	✔	✔	✔
Fisheries and Marine Biodiversity	15. Revitalizing Australia's Estuaries	The return on investing in restoration ecology of Australia's coastal ecosystems well exceeds the benefits accrued from all prior major Australian initiatives in environmental repair	✔	✔	✔	✔	
Fisheries and Marine Biodiversity	16. Estuarine and near-shore ecosystems—assessing alternative adaptive management strategies for the management of estuarine and coastal ecosystems	Ensuring ecosystem robustness and resilience are maintained at whole-of-resource scale is essential to ensure public good outcomes	✔	✔	✔	✔	✔
Marine Biodiversity	17. Pre-adapting a Tasmanian coastal ecosystem to ongoing climate change through reintroduction of a locally extinct species	A comprehensive decision framework is essential to assess conservation translocation proposals	✔	✔		✔	✔

Table 2. continued

Project focus	Project number and title	Relevant finding	Future proofing				
			Resilient ecosystems	Scales that match values/issues	Manage catchments	Ecosystem integrity	Site-and species-specific strategies
Marine Biodiversity	18. Human intervention options for seabirds and marine mammals under climate change	Direct interventions exist and must be tested for efficacy.	✔				
Marine Biodiversity	19. Changing currents in marine biodiversity governance and management: responding to climate change	Common challenges are improving knowledge of the social–ecological system; stakeholder communication and information; improving capacity to deal with uncertainty and complexity; preparedness for change; lack of broad public and political support for the values of marine biodiversity; and integration and coordination gaps amongst and across government agencies	✔	✔	✔	✔	✔
Marine Biodiversity	20. Adaptive management of temperate reefs to minimize effects of climate change: Developing new effective approaches for ecological monitoring and predictive modeling	Long-term monitoring is essential for detecting and describing change and informing appropriate management responses	✔	✔	✔	✔	✔

Table 2. continued

Project focus	Project number and title	Relevant finding	Future proofing				
			Resilient ecosystems	Scales that match values/issues	Manage catchments	Ecosystem integrity	Site-and species-specific strategies
Marine Biodiversity	21. Adapting to the effects of climate change on Australia's deep marine reserves	Adaptation strategies involving assisted translocation and the use of artificial substrates may be required to conserve the cold water coral reefs that characterize seamounts in the Southeast Marine Reserve.	✔	✔		✔	✔
Carbon sequestration	22. Comparative sequestration and mitigation opportunities across the Australian landscape and its land uses	Carbon storage and sequestration in coastal ecosystems provides an additional tool to mitigate globally; an opportunity to strengthen social– economic resilience of Australia's coastal communities and industries; avoids significant emissions from ecosystem degradation; and supports wetland conservation efforts	✔	✔	✔	✔	
Coastal tourism and amenity	23. Beach and surf tourism and recreation in Australia: vulnerability and adaptation	Coastal managers will need to utilize a menu of adaptive management strategies to minimize the economic losses associated with climate change impacts on beaches		✔			✔

Table 2. continued

Project focus	Project number and title	Relevant finding	Future proofing				
			Resilient ecosystems	Scales that match values/issues	Manage catchments	Ecosystem integrity	Site-and species-specific strategies
Community-led adaptation	24. A marine climate change adaptation blueprint for coastal regional communities	Key components of community response include working within a boundary organization; integrating climate change with other stressors; bringing together biophysical and human dimensions; being inclusive and encompassing the entire marine community; combining qualitative and quantitative approaches; and ensuring access to up to date information and research findings	✔	✔			
Knowledge	25. Climate Change Adaptation: Building community and industry knowledge	To increase knowledge uptake requires specialized understanding and approaches		✔			

Project focus	Project number and title	Relevant finding	Transformation and opportunity			
			Identify opportunities from change	Flexible total stock/ population m-ment	Carbon sequestration opportunities	Carbon part of multi-objective approach
Oceanographic Environment	1. Understanding the biophysical implications of climate change in South Eastern Australia: Modeling of physical drivers and future changes	Development and improvement of the existing physical models is not a roadblock to further fishery adaptation planning				

Table 2. continued

Project focus	Project number and title	Relevant finding	Transformation and opportunity			
			Identify opportunities from change	Flexible total stock/ population m-ment	Carbon sequestration opportunities	Carbon part of multi-objective approach
Aquaculture	2. Ensuring the Australian oyster industry adapts to a changing climate: a natural resource and industry spatial information portal for knowledge and informed adaptation frameworks	There is a common need to access information that is both locally relevant and nationally positioned			✔	✔
Fisheries and Aquaculture	3. Development and testing of a national integrated climate change adaptation assessment framework	Adaptation frameworks should foster decision strategies based on a combination of fishery performance and human social–economic performance	✔			
Fisheries and Aquaculture	4. Vulnerability of an iconic Australian finfish (Barramundi, *Lates calcarifer*) and related industries to altered climate across tropical Australia	Both wild caught and cultured Barramundi are likely to extend south in range and total population and resource planners should begin to implement various scenarios into fisheries planning models	✔	✔		
Fisheries	5. Growth opportunities for Australian fisheries and aquaculture under climate change	Stronger connection between different sectors and segments in the supply chain confers resilience	✔	✔	✔	✔
Fisheries	6. Risk assessment of impacts of climate change for key species in South Eastern Australia	Fisheries managers need to be proactive in positioning themselves to undertake a strategic and structured approach to adaptation planning	✔	✔		

Table 2. continued

Project focus	Project number and title	Relevant finding	Transformation and opportunity			
			Identify opportunities from change	Flexible total stock/ population m-ment	Carbon sequestration opportunities	Carbon part of multi-objective approach
Fisheries	7. Identifying management objectives hierarchies and weightings for four key fisheries in South Eastern Australia	It is important to articulate the objectives of fisheries management as an early step in fisheries adaptive management and of integrating climate change driven changes into this process	✔		✔	✔
Fisheries	8. Identification of climate-driven species shifts and adaptation options for recreational fishers: learning general lessons from a data rich case	Long-term fisher collected data sets offer opportunities to investigate complex interactions between species-level change, environmental signals and anthropocentric impacts	✔			
Fisheries	9. Management implications of climate change effect on fisheries in Western Australia	Monitoring of key environmental variables and habitat is essential to enable early detection of changes in abundance and therefore allow for proper assessment and management recommendations before fishing takes place	✔	✔		
Fisheries	10. Effects of climate change on reproduction, larval development and population growth of coral trout (*Plectropomus* spp)	Recognizing the sensitivity of coral trout to increasing temperature, ocean acidification, and climate-induced habitat degradation the imperative is to understand how these affect will manifest in terms of the productivity and sustainability of wild fisheries		v		

Table 2. continued

Project focus	Project number and title	Relevant finding	Transformation and opportunity			
			Identify opportunities from change	Flexible total stock/ population m-ment	Carbon sequestration opportunities	Carbon part of multi-objective approach
Fisheries	11. Implications of climate change on fisheries resources of northern Australia—vulnerability assessment and adaptation options	Appropriate adaptation must include detailed analysis of options; prioritization of adaptation responses; impact assessment and profitability analysis for indigenous. Recreational and commercial fishers; and detailed specification of the pathways and actions to be implemented	✔	✔		
Fisheries	12. Implications of climate change for recreational fishers and the recreational fishing industry	Management activities that assist in ensuring resilience of fish populations will be a useful first strategy in responding to a changing climate	✔	✔	✔	✔
Fisheries	13. Preparing fisheries for climate change—assessing alternative adaptive options for four key fisheries in South Eastern Australia	The design, application, and review of management strategies will require improved understanding of biology such as recruitment dynamics and ecology; increased monitoring of key biophysical attributes and stocks to populate models; harvest strategies that deliver sustainable economic yield; and extension of model outputs into management decision making	✔	✔		

Table 2. continued

Project focus	Project number and title	Relevant finding	Transformation and opportunity			
			Identify opportunities from change	Flexible total stock/ population m-ment	Carbon sequestration opportunities	Carbon part of multi-objective approach
Fisheries and Marine Biodiversity	14. Potential futures for Australia's South Eastern marine ecosystems, quantitative Atlantis projections	Integrative adaptive management across all users of the marine and coastal environments is the most effective means of maintaining sustainable, desirable, and productive marine ecosystems under all levels of global change	✔	✔	✔	✔
Fisheries and Marine Biodiversity	15. Revitalizing Australia's Estuaries	The return on investing in restoration ecology of Australia's coastal ecosystems well exceeds the benefits accrued from all prior major Australian initiatives in environmental repair	✔		✔	✔
Fisheries and Marine Biodiversity	16. Estuarine and near-shore ecosystems—assessing alternative adaptive management strategies for the management of estuarine and coastal ecosystems	Ensuring ecosystem robustness and resilience are maintained at whole-of-resource scale is essential to ensure public good outcomes	✔		✔	✔
Marine Biodiversity	17. Pre-adapting a Tasmanian coastal ecosystem to ongoing climate change through reintroduction of a locally extinct species	A comprehensive decision framework is essential to assess conservation translocation proposals	✔			

Table 2. continued

Project focus	Project number and title	Relevant finding	Transformation and opportunity			
			Identify opportunities from change	Flexible total stock/ population m-ment	Carbon sequestration opportunities	Carbon part of multi-objective approach
Marine Biodiversity	18. Human intervention options for seabirds and marine mammals under climate change	Direct interventions exist and must be tested for efficacy.				
Marine Biodiversity	19. Changing currents in marine biodiversity governance and management: responding to climate change	Common challenges are improving knowledge of the social–ecological system; stakeholder communication and information; improving capacity to deal with uncertainty and complexity; preparedness for change; lack of broad public and political support for the values of marine biodiversity; and integration and coordination gaps amongst and across government agencies			✔	✔
Marine Biodiversity	20. Adaptive management of temperate reefs to minimize effects of climate change: Developing new effective approaches for ecological monitoring and predictive modeling	Long-term monitoring is essential for detecting and describing change and informing appropriate management responses				✔
Marine Biodiversity	21. Adapting to the effects of climate change on Australia's deep marine reserves	Adaptation strategies involving assisted translocation and the use of artificial substrates may be required to conserve the cold water coral reefs that characterize seamounts in the Southeast Marine Reserve.				

Table 2. continued

Project focus	Project number and title	Relevant finding	Transformation and opportunity			
			Identify opportunities from change	Flexible total stock/ population m-ment	Carbon sequestration opportunities	Carbon part of multi-objective approach
Carbon sequestration	22. Comparative sequestration and mitigation opportunities across the Australian landscape and its land uses	Carbon storage and sequestration in coastal ecosystems provides an additional tool to mitigate globally; an opportunity to strengthen social– economic resilience of Australia's coastal communities and industries; avoids significant emissions from ecosystem degradation; and supports wetland conservation efforts	✔		✔	✔
Coastal tourism and amenity	23. Beach and surf tourism and recreation in Australia: vulnerability and adaptation	Coastal managers will need to utilize a menu of adaptive management strategies to minimize the economic losses associated with climate change impacts on beaches	✔			
Community-led adaptation	24. A marine climate change adaptation blueprint for coastal regional communities	Key components of community response include working within a boundary organization; integrating climate change with other stressors; bringing together biophysical and human dimensions; being inclusive and encompassing the entire marine community; combining qualitative and quantitative approaches; and ensuring access to up to date information and research findings	✔		✔	
Knowledge	25. Climate Change Adaptation: Building community and industry knowledge	To increase knowledge uptake requires specialized understanding and approaches				

The 13 elements are elaborated in Table 1. A tick (✔) indicates that the project identified the element as important. Project reports for each of these are available from www.FRDC.com.au.

yet many current management practices are spatially static (Hobday and others 2014a). Our responses to a changing and more variable climate must also become adaptive and flexible (Grafton 2010). Marine examples are rare, but an exemplar is the operational use of dynamic spatial management to regulate fisher access to regions off the east coast of Australia (Hobday and Hartmann 2006; Hobday and others 2010). Short-term management responses to extreme events, such as modified regulations, spatial closures, and redistribution of activities, can also facilitate recovery for impacted ecosystems and dependent industries (Hodgkinson and others 2014), and could be developed strategically rather than following an event (GBRMPA 2011). Both fisheries and conservation management must recognize the dynamic nature of inshore and marine resources. There is no static or set of climax communities that we must strive to protect. One favored approach is to plan adaptation interventions that seek to ensure greater resilience (Vogel and others 2007; Plagányi and others 2014). Ecosystems must have the greatest capacity possible to sustain shocks such as extreme climate events while recognizing that there will be changes such as those brought on by a changing and more variable climate that are beyond our ability to readily reduce.

Action for climate adaptation must be a part of larger social and economic adaptation to changing circumstances (Element 2). The drivers of social and governance change are broader than just climate-related issues. Indeed in project discussions with fishers and marine managers, climate change adaptation was rarely the most important influence on practice change and future planning (Pecl and others 2014a). Other issues such as changing markets, increasing input costs, availability of labor, community attitudes, and policy imperatives for nature conservation were often of more immediate concern (Fleming and others 2014; Lim-Camacho and others 2014). Climate change adaptation is therefore best undertaken as part of the overall management process for inshore, coastal, and marine social–ecological systems.

In a similar context, most projects found that *climate policy should be implemented as part of integrative, multi-objective policy and management* (Element 3). Marine policy approaches generally include concepts such as ecosystem-based management, managing complexity, integrated monitoring and assessment systems for sustainable economic yield, fostering regional economies, and ensuring food security (Grafton 2010; Bell and others 2011). Recognition of the effects of a changing climate must be integrated into this complex policy agenda. In the Whitsundays region of the Great Barrier Reef, for example, while current governance arrangements have good adaptive capacity in many respects, the critical areas for improvement are (i) engagement of local government, catchment management authorities, and local advisory bodies in integrated coastal and marine planning and management, and (ii) improved integration and coordination between relevant agencies, and between government levels, especially integration of conservation and fisheries management (Davidson and others 2013).

In responding through management interventions to changing social–ecological interactions, it is essential to include climate influences (Element 4). Australian fisheries management, for example, already seeks to take account of multi-species and species–habitat biophysical interactions (Hobday and others 2011) and the consequences for wider social–ecological systems in terms of commercial opportunities and outcomes. Climate is part of what influences these interactions so any changing climate and its impact on interactions will also need to be recognized (Hobday and others 2008; Plagányi and others 2013). Commercially targeted annual prawn stocks such as School Prawn, *Metapenaeus macleayi*, Banana Prawn (*Fenneropenaeus merguiensis*), and Tiger Prawns (*Penaeus esculentus* and *Penaeus semisulcatus*) all respond and interact to rainfall and runoff in the proceeding 8–10 months of juvenile phases before the stock enters the fishery, and such leading indicators can be used to plan fishing management and strategies (Plagányi and others 2013).

Elements of a Future Proofing Phase

Within the phase of 'future proofing,' and intersecting with the preconditioning phase, is recognition of the issues of resilience, scale, and relevance, as described in the next four elements. If we are to minimize any negative impacts of change, then *fostering resilient healthy ecosystems is an imperative for policy and management* (Element 5). If we repair and then protect and sustainably use inshore and marine resources, then productive healthy ecosystems will be more resilient to perturbations such as extreme events (Miles 2009). Extreme events include marine heatwaves, cyclones, terrestrial droughts (and therefore lack of freshwater runoff to foster productivity in our estuarine and nearshore zones), and terrestrial floods (and often major fish kills from deoxygenation, massive increases in sediment load and sudden changes to water chemistry such as acidic effluent from drained wetlands that accompanies floods). Repairing for increased resilience is a key priority for future proofing investment. Globally, the most valuable marine habitat and biodiversity resources are coastal resources, especially estuaries, floodplain wetlands, and nearshore habitats (for example, Diaz 2002; Vaquer-Sunyer and Duarte 2008; Creighton 2013a, b; Creighton and others 2015). These inshore and nearshore resources are also most at threat from extreme climate events (Dichmont and others 2014). Increased focus on investment in repair will enhance resilience and optimize the multiple public benefits derived from these inshore and coastal resources. The Australian Government recently recognized these potential benefits in allocating funding for repair research as part of Australia's Marine Biodiversity Hub in the *National Environmental Science Programme* (http://www.environment.gov.au/science/nesp).

Healthy, resilient systems also require relevant management approaches, as represented by the next two elements in this phase—*policy and management must address spatial and temporal scales that match the values and issues of concern* (Element 6); and building further on the requirement for resilient healthy ecosystems, *catchment management is essential for positive marine outcomes* (Element 7). To illustrate, current fisheries management are usually sub-divided into smaller jurisdictional regions rather than operating at the geographic scale of the stocks we seek to manage (Link and others 2011). In Australia, this larger scale management might be facilitated through recognition of three broad regions that approximate the ranges of much of our living marine resources—southeast, tropical, and western (Hobday and others 2008). Climate is one of the drivers towards this more holistic approach to cross-jurisdiction marine management. Catchment management also represents a holistic approach, as marine, estuarine, and riverine ecosystems are connected with flows of material and biota. The health of these systems is adversely impacted by effluent from catchment uses (Creighton 2013a, b). Climate change and the increasing likelihood of extreme flood events with ability to dump higher loads of effluent in receiving waters make it even more imperative to reduce catchment effluent—sediments, nutrients, and poisons, all of which adversely impact on the productivity, health and resilience of riverine, and estuarine and marine ecosystems.

Lastly in this phase are elements related to protective management such as setting aside areas for marine parks and species-specific conservation—*in responding to threatening processes, it is essential to ensure ecosystem integrity* (Element 8); and recognition that specific approaches will be required at the species level—*site- and species-specific strategies are essential* (Element 9). Conservation management of marine systems should focus on ecosystem integrity including stocks, flows, fluxes, and ecosystem interactions and must seek to minimize any threatening processes that impact on ecosystem integrity. Providing marine park protective management for a suite of representative ecosystems, bioregion by bioregion, without simultaneously seeking to minimize the impact of all threatening processes including climate impacts, will prove to be insufficient for biodiversity conservation. A changing climate will change the impact of many threatening processes. A changing climate also demonstrates the potential inadequacies of static management responses such as hard and fast marine park zonings and boundaries. For individual species, a changing climate will impact on key species of high conservation value such as seabirds and marine mammals (Chambers and others 2014; Hobday and others 2014b) and iconic habitats (Thresher and others 2015). Site- and species-specific management to minimize the impacts of a changing climate is essential if we are to conserve these populations, and their roosting or resting, breeding, and feeding habitats. A focus for these direct interventions will be iconic species and habitats, which also play an important role in communicating the threats of climate change to the general public (Ochoa-Ochoa and others 2013).

Elements of a Transformation and Opportunity Phase

The expected impacts on some marine social–ecological systems from external drivers such as climate change are expected to cause fundamental shifts in system identity. For example, Tasmanian saltmarsh communities are already undergoing community transitions associated with climate change and relative sea level rise (Prahalad and others 2012). In terms of marine biodiversity conservation, leadership shown by the Great Barrier Reef Marine Park Authority played a critical role in transformation of Great Barrier Reef governance to an ecosystem-based management regime (Olsson and others 2008). However, in any changing system, there will be winners and losers—interventions will not be possible for all impacted species and ecosystems. There will be opportunities and so *changes brought about by a changing climate must also be assessed for beneficial opportunities* (Element 10). Some commercially valuable species will be advantaged by a changing climate. For example, Pecl and others (2014b) and Robinson and others (2015) suggest a southward range extension of Eastern Rock Lobster (*Sagmariasus verreauxi*) range, while the productive fishery region for the Southern Rock Lobster (*Jasus edwardsii*) may contract southward. Some marine production systems will be benefited by climate change. For example, Jerry and others (2014) project a southward extension of suitable environments for Barramundi (*Lates calcarifer*) aquaculture, whereas for other species, production systems may be challenged (for example, suitable inshore aquaculture areas for Atlantic Salmon (*Salmo salar*) may decline (Battaglene and others 2008; Spillman and Hobday 2014). A positive facilitative approach to industry development is essential and will be better informed through value chain analysis and the identification of key opportunities (Lim-Camacho and others 2014; Plagányi and others 2014).

To build on the opportunities for shifts in productivity, there will need to be changes to foster better management of any particular fishery stock or species population—*in responding to increased climate variability and change, a transition towards flexible total stock or population management systems is essential* (Element 11). In particular, a changing and more variable climate will lead to changing and more variable fish stocks. Populations will change in abundance, composition (age classes, and so on), and location. Incorporating climate impacts in fisheries management requires management processes, opportunities, and controls to incorporate temporal and spatial variations in the target stock or the ecosystems that sustain that stock. Early detection of stock changes is essential as spawning stocks can become depleted if there is a downturn in recruitment that is undetected and fishing pressure is maintained. The Western Rock Lobster (*Panulirus cygnus*) fishery has avoided any large reduction in spawning stock because of the early intervention on the decline in recruitment (Caputi and others 2014).

The importance of both the time dimension and the need to focus on underlying causal mechanisms is demonstrated by the failure of an early fisheries management intervention that involved closure of the Shark Bay Southern Saucer Scallop (*Amusium balloti*) fishery. This closure did not address the cause of the problem which was beyond the influence of any fisheries management intervention—the severity of the recruitment downturn was due to mortality of adults that followed an extreme runoff event and high sediment loads to Shark Bay (Pearce and others 2011). In this case, sustainable catchment management that recognized the value of the downstream fishery resource would have ensured adequate groundcover of the catchment land, thereby reducing the likelihood of a significant rain event being accompanied by extensive soil erosion. Clearly a systems approach to management that was built on an understanding of flows, fluxes, connectivity, interaction, cause, and implications would have benefited this fishery.

The last two elements deal with the opportunities for marine systems and our uses of marine systems, to contribute to the overall climate change mitigation agenda. Although adaptation remains the primary focus for the regional fishery and management sector, a number of Australian marine projects recognize that *policy and management must take advantage of the key role marine ecosystems can have in carbon sequestration* (Element 12). Coastal, nearshore marine, and estuarine ecosystems, by virtue of being the most productive of the world's ecosystems, are also the highest per hectare sequesters of carbon. Lawrence and others (2012) detail that Australia's coastal wetland ecosystems sequester and bury carbon at rates of up to 66 times higher and store five times more carbon in their substrates than those of our terrestrial ecosystems, including forests, on a per hectare basis. Taking up less than 1% of landmass, the average national annual carbon burial of coastal ecosystems may account for 39% of that for all ecosystems—183.2 Tg (million tonnes) CO_2 eq y^{-1} of a total of 466.2 Tg CO_2 eq y^{-1} (Lawrence and others 2012). Yet, Australia is estimated to be losing its coastal wetland ecosystems at an annual rate of 0.01–1.99% for mangroves, 1.17% for saltmarsh, and 0.05% for seagrass (Lawrence and others 2012). There is also potential for substantial gains in carbon sequestration by the reinstatement of tidal flows and habitat repair of degraded coastal wetland ecosystems, especially Australia's floodplain wetland resources that are currently wastelands, drained and/or levied off from tidal flows but not supporting any viable land uses. The next step from a policy perspective for Australia and indeed internationally is for coastal ecosystems to be incorporated into National Carbon Accounts. Flow-on benefits are likely to be higher levels of protection for remaining nearshore marine and estuarine ecosystems and where possible their reinstatement through repair works.

Lastly, and similar to earlier elements in terms of the need for actions on adaptation to be multi-objective and multi-faceted, *carbon sequestration in marine systems is best done as part of a multi-objective approach* (Element 13). Investments in climate change mitigation could most usefully focus on those opportunities that also provide multiple benefits to the global community and local economy. From a marine perspective, repairing coastal ecosystems of seagrasses, mangroves, salt marshes, and floodplain wetlands globally not only provides the highest per hectare carbon sequestering opportunity but also delivers outcomes for local to regional food security, employment, and biodiversity.

Key Priorities for Marine Policy Development and Management

To illustrate how best to apply these thirteen elements incorporating climate change concerns into marine policy and management, we detail below suggested priorities for Australian activities within the three broad classes of preconditioning, future proofing, and transformational change. Where possible, these are linked to similar activities internationally.

From a preconditioning perspective, we need to know more about our marine systems, devise and implement strategies based on an understanding of total populations, and formulate more flexible policy to achieve conservation and fisheries sustainability goals.

Preconditioning: Stock Assessment

Pecl and others (2014a) detail the need for enhanced stock assessment methods and for the findings to be rapidly incorporated in management. Smarter and real-time stock assessment and population predictions will foster a more profitable and sustainable fishing sector. Improved stock assessment should also rapidly identify when there are major shifts in our populations or systems, foster ''double loop learning'' so that we learn from experiences, and revise our understanding (Lockwood and others 2012; Hodgkinson and others 2014). Such risk management approaches are now also being considered in other countries, including the USA and Canada (for example, Gaichas and others 2014).

Preconditioning: Total Populations

For many of the short-lived fisheries target species such as prawns (Poloczanska and others 2007) and squid (Pecl and Jackson 2008), annual populations vary markedly and will do so more as climate change impacts. This is a direct consequence of increasingly variable climate, rainfall, runoff, and sea surface temperatures. Influence on population dynamics will also extend to the estuary and nearshore dependent species such as in Australia, Barramundi, Sea Mullet (*Mugil cephalus*), and Mulloway (*Argyrosomus japonicus*). Changing eddy and sea surface temperature dynamics will affect international target species such as Southern Bluefin Tuna (*Thunnus maccoyii*) (Hartog and others 2011). Improved population prediction, linked to climate and all other key variables, will ensure effort can then be better matched to productivity. The follow-on will be increased profitability and sustainability by better matching annual and varying sustainable economic yields to the stock available (for example, Wayte 2013).

Several projects including #9 Caputi and others (2014), # 11 Welch and others (2014), #12 Creighton and others (2013), and #13 Pecl and others (2014a) stressed the need for underpinning policy development so that biodiversity conservation and fisheries management are based on total populations, rather than jurisdictional legacy (Link and others 2011). Marine and inshore fisheries target species such as Snapper (*Pagrus auratus*), Spanner Crab (*Ranina ranina*), and Eastern and Southern Rock Lobsters are already documented as changing range (Last and others 2011; Robinson and others 2015). Likewise seabirds and marine mammals are not constrained to particular jurisdictions. With increasingly variable populations, moving to whole-of-stock/population monitoring and management, whatever the jurisdiction, is one of the next major steps in both fisheries management and species conservation.

Preconditioning: More Flexible Management Arrangements

Related to variations in populations is the need to encourage more flexible conservation and fisheries management. Compare this to current conditions where some fisheries and most biodiversity management are strongly focused on input controls (for example, allowable number of fishing dories, or rigid take- or no-take zones within parks, roosting and breeding refuges, and other spatial entitlements and zones). Where input controls are used, their design and implementation need to incorporate flexibility to respond to climate variability and change. A stronger focus on responding to and taking account of more variable populations, stocks, flows and fluxes will be essential if we are to ensure the sustainability of inshore and marine resources. In the case where fisheries management uses output controls, such as quota, management responses may include changing reference points and fishing harvest strategies in response to changing environmental conditions (for example, Wayte 2013), whereas for conservation, output control equivalents might include implementing conservation interventions in critical years to maintain population sizes when species are particularly vulnerable (Hobday and others 2014b).

Similarly, in project #19, Davidson and others (2013) and Haward and others (2013) evaluated existing marine governance and noted that rigid boundaries for marine parks or for fisheries entitlements have limited relevance when stocks are fluctuating and changing distribution. Pecl and others (2014a) (project #13) benchmarked several Australian fisheries against a set of governance attributes covering accountability, planning, transparency, incentives, adaptability, and knowledge. Flexible approaches accept that social–ecological systems are managed with incomplete knowledge so that management authorities need flexibility to adjust strategies, including management zones and marine use boundaries, based on the results of monitoring (Lockwood and others 2012).

Future Proofing: Seeking Multiple Outcomes

Gaining additional investment in marine policy and management is always challenging. We suggest the best approach to future proofing is to focus on strategies with multiple beneficiaries. These include multi-objective multi-sector strategies such as investment to repairing nearshore and estuarine habitat to reinvigorate inshore productivity and foster resilience to extreme events; single sector strategies with multiple benefits such as fishing by-catch reduction and pest management on islands; and single objective multi-benefit strategies such as improved weather and climate forecasting. Coordination across sectoral and jurisdictional boundaries is also required to plan and manage coastal development so that impacts on marine environments are taken into account. In Australia, for example, marine issues are often not considered in statutory planning and development approval processes at the local government level. There are also institutional disjunctions between conservation and fisheries planning and management processes. Governance reform is needed to address such integration and coordination gaps across government levels and agencies.

Future Proofing: Fostering Resilience

Creighton (2013a, b) argues that one of the priority immediate actions to buffer the systems to a changing and more variable climate must be to reinvigorate inshore productivity by repairing habitat. As an example, consider the fate of shellfish reefs and the oyster culture industry in eastern Australia. Shellfish reefs are now considered to be ''functionally extinct'' (Beck and others 2011). Sydney Rock Oyster cultivation in NSW is now about 40% the 1970s production at least in part due to deleterious catchment runoff, especially derived principally from the drainage and floodgating of major wetland resources. Redesigning catchment landscapes and repairing key components of fisheries and biodiversity productivity with the flow-on multiple public and private benefits they all provide is essential if we are to equip our inshore resources with resilience to more frequent extreme events.

Approaches that target a single species can also be effective by delivering multiple benefits to the ecosystem or to related industries. For example, to improve population persistence of threatened seabirds under climate change, pest eradication on breeding islands (for example, rats) may allow other species to thrive and also offset population losses incurred as a result of other activities (for example, fisheries by-catch) (Wilcox and Donlan 2007). Single species intervention in response to climate change risk can also have wider effects when the focal species is a keystone species or major habitat architect (for example, long-spined sea urchin (*Centrostephanus rodgersii*)). In single species or habitat interventions, attention to any additional benefits on other species can also help to prioritize efforts (Hobday and others 2014b).

Future Proofing: Providing the Institutional Framework

Davidson and others (2013), in exploring marine governance (project #19), compared and contrasted three case study areas and the effectiveness of the institutional frameworks currently in place. Institutional frameworks for multi-objective marine resilience are key to improved marine management. Much governance is single objective in focus and there are strong institutional dysfunctions between agencies. There is also no coherent funding model to cover the massive costs of marine management and monitoring across all sectors of marine use. A multi-source strategy is required, with consideration given to a mix of government, private sector, and philanthropic sources managed as endowments through mechanisms such as independent trusts (Lockwood and Quintela 2006; Lockwood and others 2012). There are opportunities to learn from successful examples of cross-jurisdictional collaboration. In the Georgia Basin-Puget Sound trans-boundary region spanning British Columbia, Canada, and Washington State, USA, successful cross-border cooperation and management has been driven by research collaborations (Fraser and others 2006). Findings from such examples can be adjusted to inform the redesign of governance arrangements in other institutional, social, and economic settings. Most importantly, without understanding the social and economic drivers in marine social–ecological systems, it is difficult to deliver on 'triple bottom line' environmental, social, and economic outcomes. Regional marine and landscape planning and management, with a strong focus on the multiple benefits streams of food security, sustainability, conservation, and increased productivity, are likely to be welcomed by the Australian community.

Future Proofing: Enhancing Weather and Climate Services

Although climate scale forecasting to the end of the century has dominated much of the thinking around impacts and responses (Hobday and Lough 2011; Stock and others 2011), shorter time scales are also relevant (Hobday and others in press). Improved marine weather and climate forecasting together with specific enhancements such as ocean current and ocean eddy forecasting can support a host of marine user decisions. These include ship movements, defense, fisheries, and oil and natural gas extraction. The increasing variability and changes in ocean conditions, the increased dynamics of near-shore eddies and currents, and changes to marine biodiversity on short-term time scales make accurate forecasting even more important for all marine users. With ocean conditions influencing much of the terrestrial weather patterns, flow-on benefits to land weather services would also be substantial. Seasonal forecasting has been implemented in several Australian conservation (Spillman and Alves 2009), fisheries (Hobday and others 2011), and aquaculture (Spillman and Hobday 2014) sectors, and represents a useful stepping stone to longer decision making, by familiarizing decision-makers with the use of forecasts on a time scale that allows the consequence of a decision to be observed (Hobday and others, in press).

Transformational Change: Marine Participation in a Carbon Economy

The carbon mitigation and energy sectors provide opportunities for transformational change. Marine policy and management can contribute globally to smarter energy use and to climate change mitigation. Fuel is a major input cost for wild fisheries (Pelletier and others 2014), marine park management, and marine research. In New Zealand, specific initiatives include incentives for installing fuel flow meters, training in smarter boat use, systems for sea 'mooring' on the fishery, more fuel efficient gear such as otter boards and nets and designs that further reduce by-catch (New Zealand Seafood Industry Council 2010). Initiatives focused on more efficient marine practices could yield multiple dividends in increased profitability (through lower labor costs and time on the fishery), reduced carbon footprint (through reduced fuel use which also has a profitability dividend), and reduced adverse impacts on such as the amount of by-catch and damage to habitat.

Integrated carbon sequestration and energy transfer systems on large scale require further research and development but may provide substantial benefits in addition to the previously mentioned proposals to repair estuarine habitat for both carbon sequestration, biodiversity, and fisheries benefits. A good example is macro-algae production linked to aquaculture or other industrial sources of nutrients and carbon dioxide for a new marine biomass platform in Australia in both onshore (FAO 2009) and offshore systems (Troell and others 2009). Such production can even counteract localized effects of ocean acidification (Jiang and others 2012).

Finally, from a mitigation perspective, policy and strategies to implement ''blue carbon'' (for example, Nelleman and others 2009; Siikamäki and others 2013) can complement the adaptation focus. Investment for carbon mitigation would also have flow-on benefits for adaptation capacity through fostering resilience and system capacity to adapt to non-climate-related drivers such as coastal development. Adaptation and mitigation are complimentary and must be part of a systemic approach to managing for a changing climate.

Conclusion

Climate change is leading to a range of changes in marine systems, influencing the distribution and abundance of exploited species and conservation-related species and habitats. Adaptation represents a regional-scale response to climate change where actions will have direct benefit. However, to respond to the threats and opportunities posed by climate change, policy and management must change to facilitate the development of adaptation options at a range of scales. If the alignment of policy and management is not compatible with responses, then *preconditioning* changes must first occur. Our checklist presents the elements that poorly prepared governance systems must first address, before the *future proofing* activities can be widely initiated. These activities are generally implemented by single agencies guided by the higher order policies. Some can be initiated immediately, while others will require greater *transformation*. Transformational opportunities where the benefits of action result in even greater feedback and reinforcement of the benefits are particularly important, and will require sustained effort to achieve.

If this identification of policy and management elements as provided in our checklist is useful, we expect that success would be visible by refinement of higher level policy documents, such as national action plans. Such improved plans would be (i) informed by a social–ecological systems perspective in which climate change is understood in the context of other biophysical and social–economic drivers; (ii) promote socio–economic adaptation, and (iii) provide a framework for cross-sectoral and multi-agency coordination and collaboration. At the future proofing stage, examples where fisheries and conservation agencies implemented test cases for particular species or systems that could be easily addressed would begin to emerge. Progress would have been made in addressing how developments in catchments and coastal regions impact on marine environments. Ongoing monitoring would assess the extent to which reducing the impact of such non-climate drivers is securing the resilience of marine systems. Transformation change will require greater coordination between disparate research fields, and resolution of issues that appear to be opposed in different sectors. Success will be indicated by leadership that secures the political and community support, governance pathways, management approaches, and investments that improve preparedness for change and take advantage of emerging opportunities while minimizing loss of important values. Such policy and practice changes would implement flexible management systems and take advantage of the carbon sequestration role of marine ecosystems. Adaptation to climate change will not be easy in all cases, and so attempts to begin with the easier elements, learn from mistakes, and to share these lessons will be critical.

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