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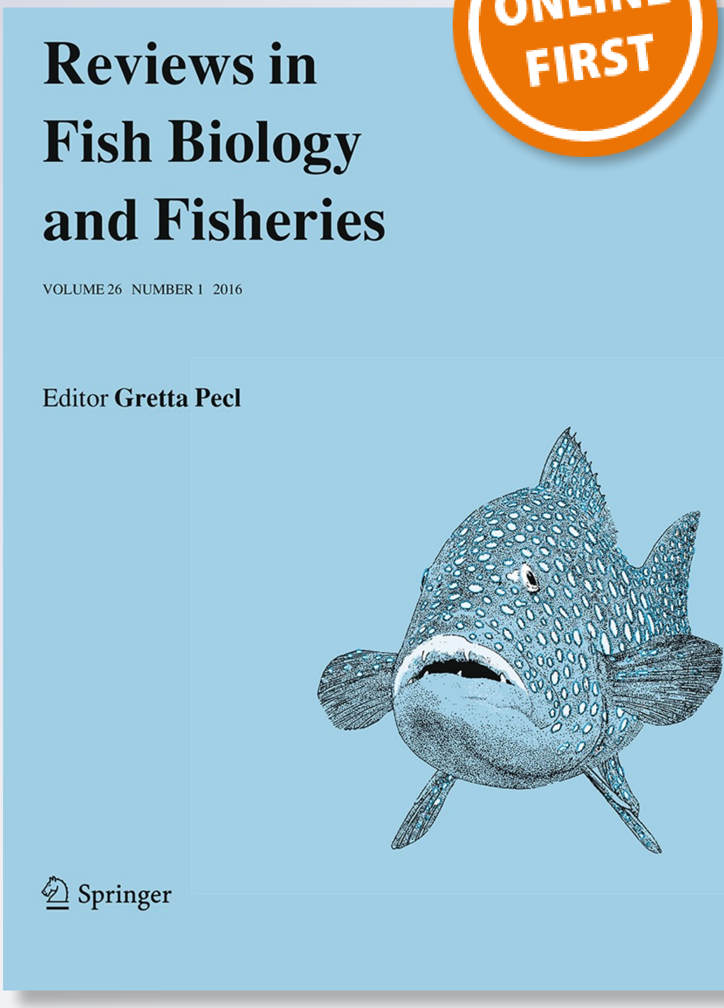

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REPORT

Planning adaptation to climate change in fast-warming marine regions with seafood-dependent coastal communities

Alistair J. Hobday · Kevern Cochrane · Nicola Downey-Breedt · James Howard · Shankar Aswani · Val Byfield · Greg Duggan · Elethu Duna · Leo X. C. Dutra · Stewart D. Frusher · Elizabeth A. Fulton · Louise Gammage · Maria A. Gasalla · Chevon Griffiths · Almeida Guissamulo · Marcus Haward · Astrid Jarre · Sarah M. Jennings · Tia Jordan · Jessica Joyner · Narayana Kumar Ramani · Swathi Lekshmi Perumal Shanmugasundaram · Willem Malherbe · Kelly Ortega Cisneros · Adina Paytan · Gretta T. Pecl · Éva E. Plagányi · Ekaterina E. Popova · Haja Razafindrainibe · Michael Roberts · Prathiba Rohit · Shyam Salim Sainulabdeen · Warwick Sauer · Sathianandan Thayyil Valappil · Paryiappanal Ulahannan Zacharia · E. Ingrid van Putten

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Abstract Many coastal communities rely on living marine resources for livelihoods and food security. These resources are commonly under stress from overfishing, pollution, coastal development and habitat degradation. Climate change is an additional stressor beginning to impact coastal systems and communities, but may also lead to opportunities for some species and the people they sustain. We describe

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the research approach for a multi-country project, focused on the southern hemisphere, designed to contribute to improving fishing community adaptation efforts by characterizing, assessing and predicting the future of coastal-marine food resources, and co-developing adaptation options through the provision and sharing of knowledge across fast-warming marine regions (i.e. marine 'hotspots'). These hotspots represent natural laboratories for observing change and concomitant human adaptive responses, and for developing adaptation options and management strategies. Focusing on adaptation options and strategies for enhancing coastal resilience at the local level will contribute to capacity building and local empowerment in order to minimise negative outcomes and take advantage of opportunities arising from climate change. However, developing comparative approaches across regions that differ in political institutions, socio-economic community demographics, resource dependency and research capacity is challenging. Here, we describe physical, biological, social and governance tools to allow hotspot comparisons, and several methods to evaluate and enhance interactions within a multi-nation research team. Strong partnerships within and between the focal regions are critical to scientific and political support for development of effective approaches to reduce future vulnerability. Comparing these hotspot regions will enhance local adaptation responses and generate outcomes applicable to other regions.

Keywords Coastal marine resources · Fisheries · Food security · Livelihoods · Vulnerability · Governance

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Climate change impacts and vulnerability of seafood dependent coastal communities

Around the world, over 3 billion people live within 100 km of the coast (UNEP http://www.unep.org/pdf/Green_Economy_Blue_Full.pdf; UN Atlas of the Oceans—www.oceansatlas.org). Many of these people live in coastal communities that range from those that are completely independent of the surrounding region to those that are fully integrated into the regional economy. Across this spectrum, the impacts of climate change will increasingly be experienced by many people, either directly, for example, by rising sea levels that inundate dwellings and other infrastructure, or indirectly by, for example, warming ocean temperatures that lead to shifts in the distribution, abundance, seasonal migrations, and reproductive patterns of commercially valuable marine species (Brander 2010). Extreme events, which are projected to become more intense under climate change (IPCC 2013), can also lead to dramatic impacts, including loss of infrastructure and housing (e.g. Wong et al. 2014). Tropical cyclones already pose a major threat at low latitudes due to their extreme winds, heavy rainfall and higher-than-normal sea-levels and can result in coastal flooding, major habitat and infrastructure damage and loss of livelihoods (Marshall et al. 2013; Mora 2014; Gasalla and Diegues 2011).

Seafood-dependent coastal communities face many vulnerability issues similar to other coastal communities (e.g. coastal inundation and erosion), but also several unique aspects. Dependence on seafood can occur in a range of different ways, including for food for personal consumption, direct (e.g. sale of seafood) and indirect economic benefits (e.g. recreation and tourism), and cultural uses. Depending on alternative sources of protein and income, coastal communities may have differing reliance on the ocean for their livelihoods (Allison et al. 2009; Metcalf et al. 2013). Particularly in emerging economies, coastal communities may be highly dependent on the ocean for capture of wild seafood, provision of stock to use in coastal aquaculture, flushing of ponds, and for transport routes between communities (FAO 2014), while in other countries, tourism and commercial fishing may be the dominant economic activities (van Putten et al. 2014).

Changing species distributions have already resulted in local changes in harvested fish abundance in a range of coastal areas (Dulvy et al. 2008; Mueter and Litzow 2008; Last et al. 2011; Lloyd et al. 2012; Pinsky et al. 2013; Jung et al. 2014; Sunday et al. 2015), with subsequent movement of fishing fleets reported (Pinsky and Fogarty 2012). Many coastal communities are already experiencing climate change impacts which are expected to continue (Cochrane et al. 2009; Pörtner et al. 2014; van Putten et al. 2014). However, climate change is not impacting all ocean regions equally—with sea surface temperature (SST) warming in some 20 regions occurring at several times the average global rate of warming (Fig. 1). Identification of these marine hotspots (Hobday and Pecl 2014), and the associated biological impacts (Pecl et al. 2014a) suggests that coastal communities in these areas may be at higher risk compared to other regions. These hotspots represent laboratories for observing change and existing adaptation and developing additional adaptation options and management strategies because: (1) impacts are already being observed or will likely be observed early, and so (2) incentives to develop adaptive strategies will be strong; (3) models developed for prediction can be validated earlier; and (4) adaptation options can be developed, implemented and tested (Hobday and Pecl 2014).

Implementation of adaptation needs to be local but learning can be global

While a range of climate impacts are experienced locally, the global nature of climate change means that similar problems may occur and potentially similar

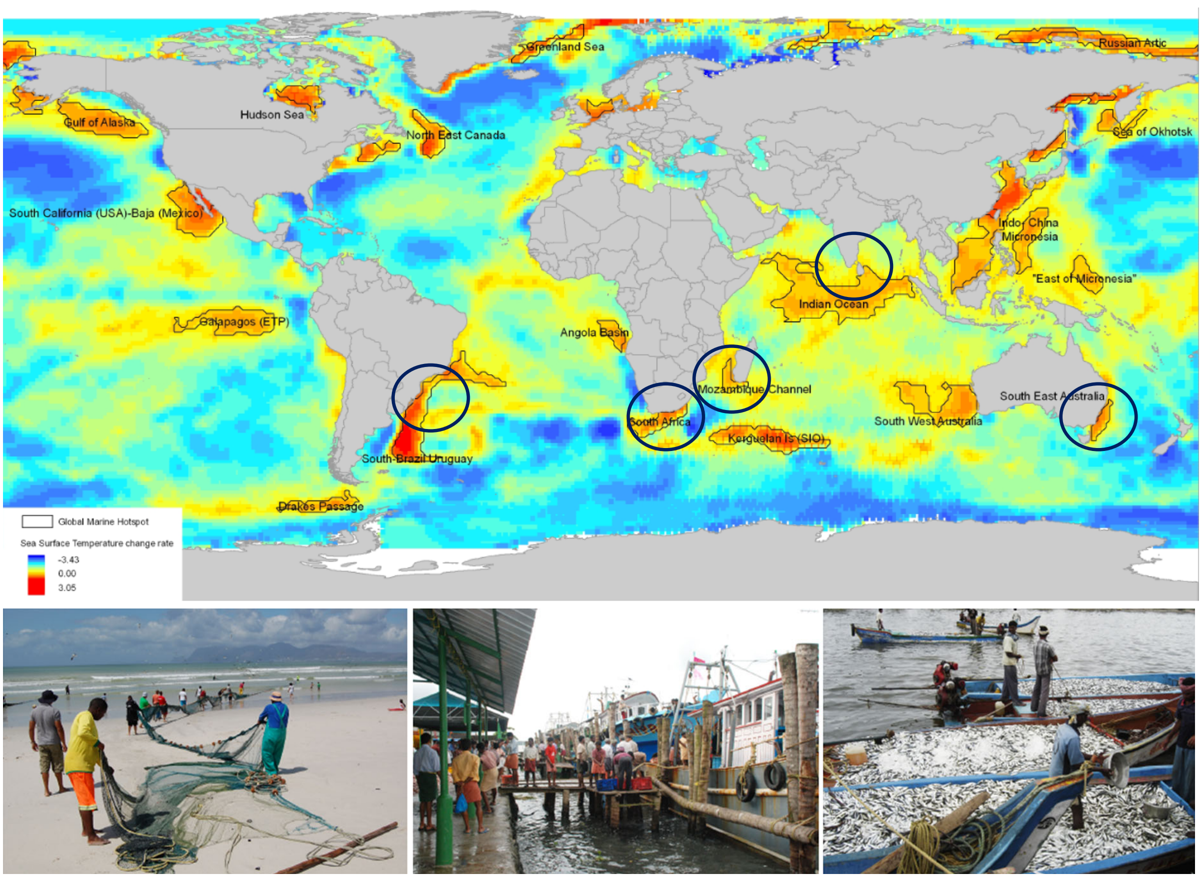

Fig. 1 Global marine hotspots—locations where surface temperatures are warming the fastest (defined as the regions where warming over the period 1950–2000 is in the fastest 10 %) are seeing changes in distribution and abundance of fished species, with impacts on the dependent seafood-dependent communities. Hotspots regions described in this paper are circled. Modified from Hobday and Pecl (2014). Pictures (L-R): K. Ortega, (ii) S. Shyam (iii) S. Shyam

solutions may be appropriate in widely separated regions. In recognition of this, the Belmont Forum (http://igfagcr.org/index.php/about-us) was created in 2012 by the International Group of Funding Agencies for Global Change Research (IGFA) in order to help transform the funding research landscape in this field. The Belmont Forum is a high level group of the world's major and emerging funders of global environmental change research and international science councils. The aim of the Belmont Forum is to deliver knowledge needed for action to mitigate and adapt to detrimental environmental change and extreme hazardous events (http://www.belmontforum.org/iof). The first Belmont research funding call was to address coastal vulnerability arising from climate change (http://igfagcr.org/index.php/belmont-internal-pages/21-reports/89-2013-funded-projects). Coastal vulnerability can arise due to an increase in exposure to climate change, and is compounded by the sensitivity of coastal communities, and offset (or not) by their adaptive capacity (Allison et al. 2009). Reducing coastal vulnerability is seen as an important policy goal in many countries, and a focus on seafood-dependent coastal communities is the topic for the collaborative project illustrated in this paper, and funded under the Belmont Coastal Vulnerability Program. This collaborative project, involving six southern hemisphere countries and two partners in the northern hemisphere, seeks to understand and reduce the climate change vulnerability of seafood-dependent coastal communities in fast-warming marine regions.

The focus of the Belmont project *Global Understanding and Learning for Local Solutions* (GULLS) is on countries adjacent to five of these southern hemisphere hotspots—South Africa, south-east Australia, Mozambique Channel, southern India,[1] and south-east Brazil (Fig. 1). These regions were chosen because they all have seafood-dependent communities and provide social, economic and ecological commonalities and contrasts that should generate important insights from comparative study. They also have ecosystems that can differ substantially in structure from those of the well-studied northern hemisphere, thus detailed study is needed to determine impacts and responses to climate change. By connecting researchers from these locations we expect to rapidly learn how best to characterise and reduce coastal vulnerability. The overall GULLS objectives reflect a set of actions that are globally applicable and seek to:

i. Build regional skill-sets that can reduce coastal vulnerability by evaluating and characterizing likely impacts and communicating these aspect broadly,
ii. Create predictive systems that will inform decision makers about the expected consequences of coastal changes;
iii. Develop alternative adaptation options within coastal communities; and
iv. Define the long-term implications of selecting a particular option in terms of economic, social and environmental outcomes.

The focal southern hemisphere hotspot locations are a subset of the rapidly warming marine regions. The broader set of regions are beginning to be connected via a Global Marine Hotspots Network (www.marinehotspots.org), which was formalized in 2010 following an international workshop (Pecl et al. 2010) and has resulted in a range of studies documenting biological change in hotspots (Pecl et al. 2014a). Lessons from this southern hemisphere study will be of interest to other hotspot regions experiencing rapid marine change and can provide guidance for more slowly warming regions that will experience changes in future as global warming continues.

Reducing coastal vulnerability—the GULLS challenge

In March 2014 GULLS researchers representing focal hotspot countries met in Grahamstown, South Africa. Researchers from the United States and United Kingdom are partners in the project and also attended the workshop. This meeting focused on work that would occur within each hotspot region and on the development of common methods to allow comparison between the countries. As a culturally and disciplinary diverse group, GULLS researchers faced several initial challenges, including differing research priorities, experiences, and engagement approaches regarding seafood-dependent coastal communities. For instance, definitions of "seafood-dependent" varied between hotspot regions, ranging from

[1] India lies in the northern hemisphere, but the associated hotspot is predominately in the southern hemisphere (see Fig. 1).

communities with no other source of protein and income, to those where the seafood industry was only a small part of a coastal communities identity. Despite differences, it soon became apparent that similar bio-physical changes were being observed in each of the hotspot regions ("Rapid change is already occurring in southern hemisphere hotspot regions" section; Table 1), and that learning from each other would yield rewards. Differences in existing knowledge, reflecting differences between data rich and data poor systems, were considered to influence attention given to these issues. It was acknowledged that drawing on lessons from elsewhere can supplement local knowledge on impacts, and help to inform and facilitate management decisions. It was agreed that best-available local knowledge and information should be used in advising decision-making. Where sufficient data and information are lacking, relevant and comparable information from other areas can assist. Being able to attribute drivers to observed change is important but not always essential. Broad adaptation options can be adopted to address a decline in say, a valuable seafood species, and implementation can proceed, with ongoing adaptive review, as more information on causation is gathered.

Climate change impacts on coastal communities present a range of complex issues, beyond the capability of any single discipline (Schmidt and Moyer 2008; Porter et al. 2014) and focusing on a single aspect of the system is unlikely to lead to better outcomes, as system dynamics will overwhelm such attempts (Cochrane et al. 2011). Consequently, interdisciplinary studies are also required, linking physical, biological, social, economic and governance aspects to provide more complete appreciation of the multifaceted nature of the challenges, opportunities and adaptive capacity in the regions.

The multi-nation GULLS project team seeks to build effective and long-lasting collaborative links that persist beyond the duration of the current funding. To build this sense of partnership, team members completed a widely used survey of environmental attitudes, the New Environmental Paradigm (NEP), which can reveal world views ranging from environmentally-focused eco-centric (high scores) to human-focused anthro-centric (low scores) (Dunlap 2008; Hawcroft and Milfont 2010). Results allowed the project team insight into their cultural differences regarding perceptions of climate change vulnerability and actions to reduce it. Sample sizes for each country ranged from 1 to 12 and thus we used results to inform additional discussion rather than to describe definitive patterns. The NEP survey showed some country differences between perceptions of our ability as environmental stewards (Fig. 2). For example, Australia and South African participants were less optimistic with regard to development of solutions to environmental problems compared to Indian and United Kingdom participants (Fig. 2a). NEP scores for each category paralleled the overall patterns (Fig. 2b), and provide context for the development of culturally appropriate adaptation options.

As an initial measure of the strength of the collaborative links in the project team, meeting participants undertook a network analysis, which identified linkages as they existed at the start of the project (Fig. 3). As may be expected, this initial network shows that many of the links are between a small number of researchers. These individuals, from three countries, formed key links and connected the entire network. This network reflects how the project was initiated and developed—the key bridging connections assembled the project team. By repeating this analysis at regular intervals, we will be able to track the emergence of linkages between researchers and investigate why (for example—if these researchers have the same disciplinary background, or were co-members of working groups). The project leaders plan to use this approach to ensure that linkages for less connected individuals are strengthened and diversified, such that collaboration and project success is not overly reliant on a few individuals, and to ensure that disciplines are integrated across the research effort.

Rapid change is already occurring in southern hemisphere hotspot regions

Project participants in each hotspot region reported a wide range of observed changes in the physical environment, biological responses, and impacts on coastal communities, including fishers (Table 1). Observed changes in biological elements reflected changes reported widely around the planet. While more limited, some management and policy responses were also reported. These tended to focus on reducing the biological vulnerability (e.g. restricting fishing

Table 1 Summary of changes observed in the GULLS hotspots and examples of responses from a management and policy perspective

Hotspot	Environmental change	Biological change	Community (fishing) change	Response to change	Key references
South-east Australia	Poleward extension of the East Australia current and rapid ocean warming	Distribution changes in urchins, zooplankton, and fish. Declining recruitment and habitat quality for commercial species	Declining catches of some species, movement of vessels between areas	Management changing catch limits in response to declining recruitment	Johnson et al. (2011) Frusher et al. (2014) Robinson et al. (2015)
Southern Africa	Increase in upwelling-favorable winds significant decrease in dissolved oxygen at specific areas on the West Coast increased intensity of the Agulhas current	Distribution changes in fish (e.g. sardine and anchovy) and rock lobsters. Declining abundances of several species targeted by the line fishery sector	Declining catches of some species in traditional fishing areas, resulting in lower incomes. Movement of fishing operations	Management procedure to determine allowable catch for small pelagic fish based on abundance and recruitment. Reduction in fishing rights and access limits in some areas	Moloney et al. (2013) De Oliveira and Butterworth (2004)
Mozambique channel	Impacts on the distribution, availability and stability of the marine and coastal resources in the region, mass coral bleaching, increased intensity and frequency of cyclones and resultant increased sedimentation	Changes in the distribution of certain 'charismatic' species (whales), reef and offshore fish stocks affected by reef degradation and sedimentation, respectively	Food insecurity, increased migration to new fishing grounds, increased supplementary livelihoods, or conversion from the livelihood altogether, impacts on tour routes and packages and tourists' choice of destination	Not known	USAID (2008) CI and WWF (2008)
Brazil	Sea surface temperature has increased by 1.12 °C since 1957, increased coastal erosion and ENSO effects. Climate-driven shifts in coastal winds and wave patterns	Shifts in the distributional range of commercially important species have observed	Livelihood and infrastructure impacts as a result of coastal erosion	Not known	Gasalla and Diegues (2011) Muehe (2010) Souza et al. (2013)
India	Increase in sea surface temperature by 0.2–0.3 °C. Increased occurrence of extreme climatic events—22 cyclones during last 14 years along the Indian coast. Rise in sea level along the Indian coast. Lower pH in inshore waters	Increase in dispersal and abundance of small pelagic fishes—oil sardine and mackerel. Change in spawning season. Reduction in mean size at maturity of mackerel and threadfin breams. Reduction in fecundity of coastal prawns	Loss in fishing days due to the extreme weather conditions. Change in composition of the fish catch	New gears for exploitation of new resources have emerged. Identification of temperature-resilient species like Silver Pompano. Integration of climate resilient technologies like pokkali cum fish farming and multi-trophic farming	CMFRI (2012, 2013, 2014) Vivekanandan (2011) Shyam et al. (2014a) Shyam et al. (2014b)

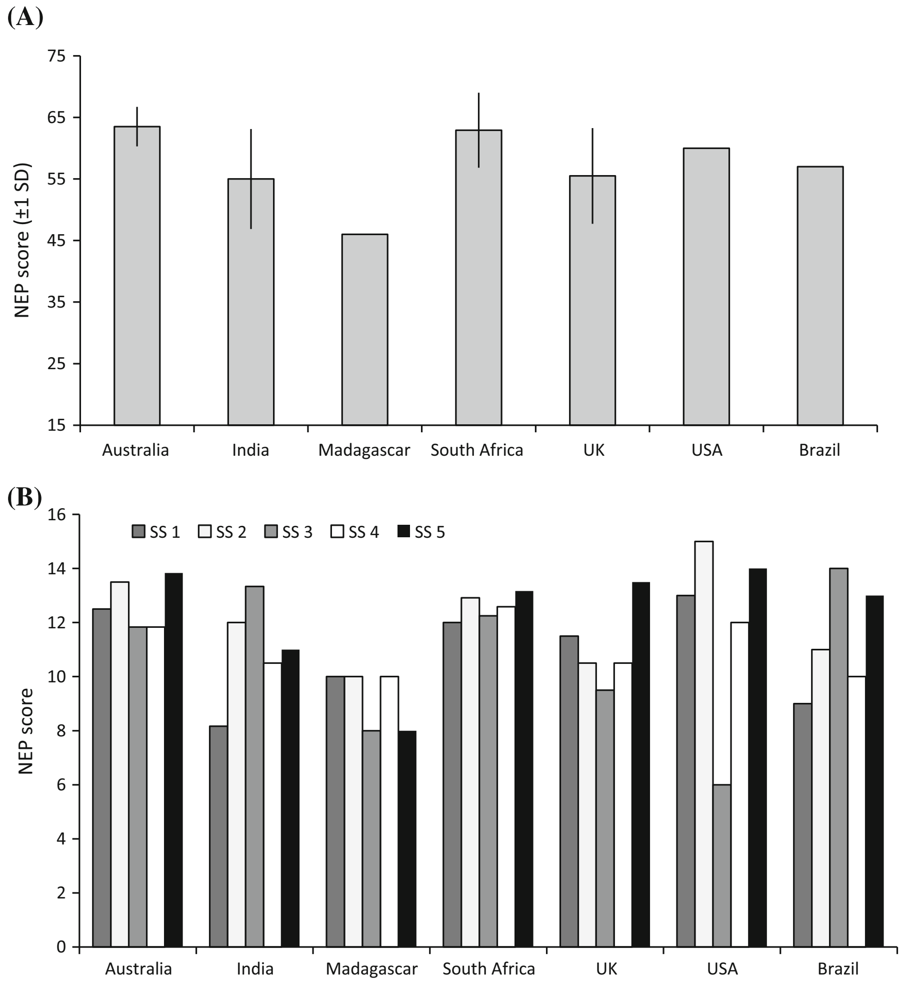

Fig. 2 **a** Average new environmental paradigm (NEP) scores for 30 workshop participants from each participating country. *Higher scores* indicate an eco-centric view of nature, rather than an anthro-centric view. **b** *Average scores* for NEP elements for participants (SS 1–5), with *higher scores* indicating agreement with sets of questions linked to the following propositions; SS1 limits to growth exist; SS2 nature has inherent value even without humans; SS3 the balance of nature is fragile; SS4 rejection of exemptionalism (humans do not need to conform to rules of nature); and SS5: the possibility of an ecocrisis. Additional explanation of these elements is provided in Dunlap (2008)

activity) rather than on reducing the vulnerability of the dependent socio-economic system.

Despite widespread evidence of changes from a range of taxa, data availability on biological change varies between hotspots, with the research-intensive countries having longer time series and more published studies. Socio-economic data were also variable, with most high quality data on seafood-dependence coming from the emerging economies, perhaps reflecting the intensity of local scale study of coastal communities. Ecosystem models and end-to-end models have been developed for most hotspot regions (e.g. South Africa: Shin et al. 2004; Travers et al. 2010; Smith et al. 2014, Australia: Fulton 2011; Mozambique Channel (Madagascar): Wendland et al. 2010; India: Vivekanandan 2011; Brazil: Gasalla and Rossi-Wongtschowski 2004; Gasalla et al. 2007; Gasalla et al. 2010), and can be used for attributing or projecting change. Oceanographic models for some hotspot regions also exist and have been used to project larval dispersal (IBM-ROMS in South Africa: Roberts and Mullon 2010; and Brazil: Martins et al. 2014). The project team also has access to state-of-art ocean projections via the UK partners. These projections are made using a high resolution global ocean model with biogeochemistry, run under RCP8.5 scenario (the highest IPCC AR5 CO_2 emission scenario) to year 2099 (Popova et al. 2016). Horizontal model resolution (1/4°) is higher than that available in the CMIP5 archive and which allows for more regional detail of the ocean and ecosystem dynamics on a spatial scale relevant to the marine hotspots. Thus, future projections of SST, stratification, nutrient supply, primary production, ocean acidification and

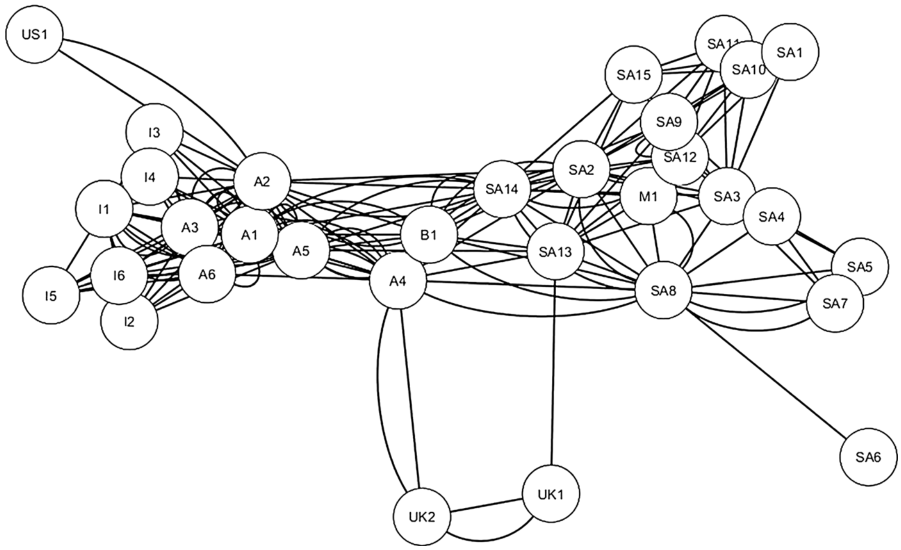

Fig. 3 Network analysis for the participating scientists at the time of project initiation. (*I* India, *A* Australia, *SA* South Africa, *UK* UK, *M* Madagascar, *B* Brazil, *US* United States). Individuals are coded by *number* and *country code*

deoxygenation can be generated for each of the hotspots. We will determine if these hotspots, identified on the basis of historical observations, remain the fastest warming areas in the future via a global comparison, and if the rapid change in SST is also an indicator of rapid changes in the other climatic stressors.

Approaches for understanding and reducing vulnerability

Workshop participants agreed on a range of common approaches across the hotspot regions, which would allow comparison and elucidation of general approaches to reducing vulnerability. Moreover, the strategic work plan developed may also serve as a guide for development and implementation of similar projects seeking to synthesise outcomes from across geographically, politically and culturally disparate communities.

In addition to documenting evidence of changes in coastal waters, hotspot researchers will undertake biological vulnerability assessments, which would be informed by physical change observed and expected in each region and a sensitivity analysis of key species (Pecl et al. 2014b). These estimates of 'climate exposure' and 'biological sensitivity' can be integrated into a measure of ecological vulnerability (Fig. 4), and when combined with measures of economic and social importance of key species, can define a measure of potential exposure of the community to changes in the availability or abundance of critical resources. This will be incorporated with estimates of adaptive capacity and resource dependence at various scales (e.g. community and individual levels) to provide an assessment of vulnerability of the socio-ecological system (Marshall et al. 2013; Fig. 4). Human resource dependency will be assessed at the local (household) level using surveys based on two existing theoretical frameworks: the vulnerability model (e.g. IPCC 2007; FAO 2013; Marshall et al. 2013), and livelihood analysis (Allison and Horemans 2006). We have broadened the basic framework to include important measures of personal, occupational, and institutional flexibility (e.g. Marshall et al. 2007; McClanahan et al. 2008; Daw et al. 2009; Cinner et al. 2012; Bennett et al. 2014) to allow derivation of a measure of socio-ecological vulnerability (SEV) (Metcalf et al. 2015). We will collect the required data in each of the participating countries using a culturally appropriate version of a common survey developed collaboratively, and which allows flexible delivery through online, mail-out, and one-to-one interview survey options, all of which have been used by the project members in other situations. In

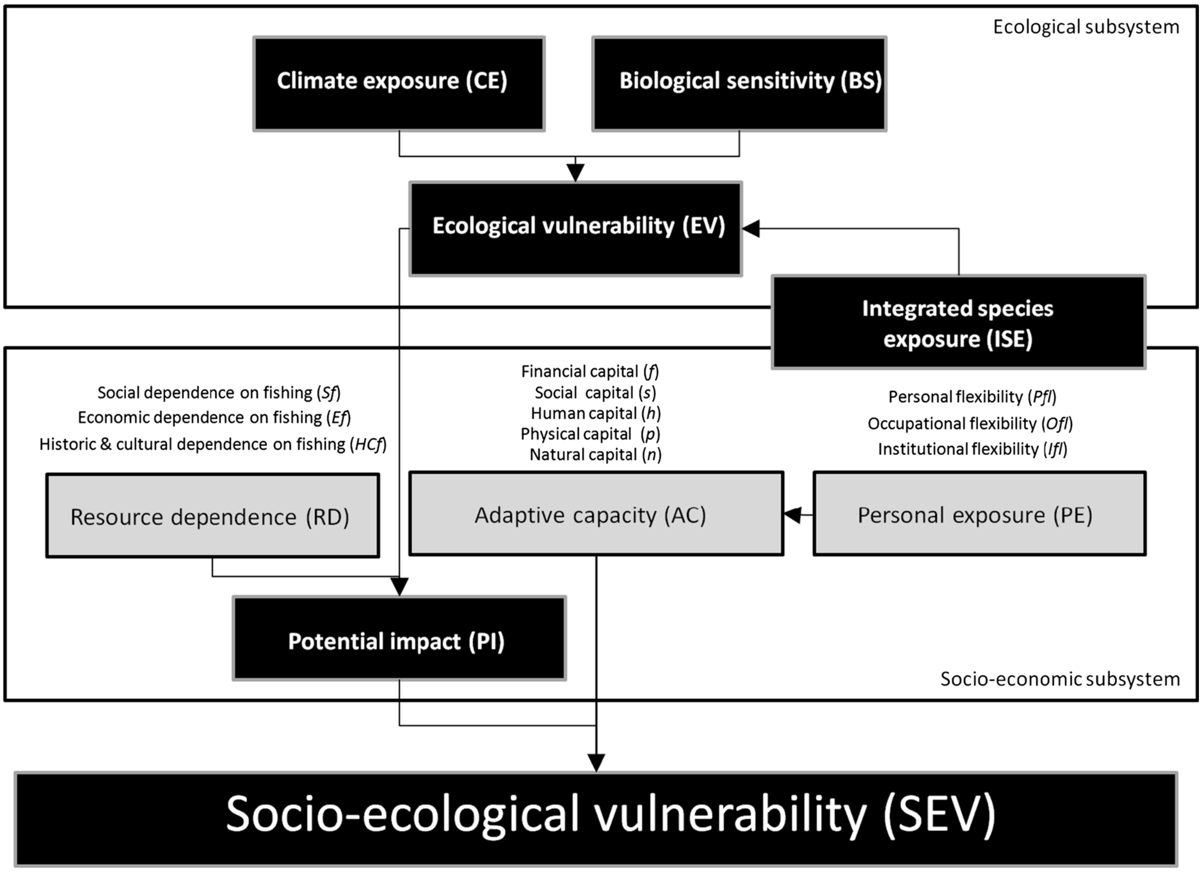

Fig. 4 A model of socio-ecological vulnerability as characterised by linked ecological- and socio-economic subsystems. The potential impact (PI) of the ecological vulnerability and household, community, or sectoral resource dependence, combined with adaptive capacity and personal exposure defines socio-ecological vulnerability at these different scales. Modified from Marshall et al. (2013) and Metcalf et al. (2015)

combination with physical and biological projections, relative SEV measure can be used to inform potential adaptation options (Fig. 4).

Adaptation options will be developed through participatory processes with seafood-dependent communities in each hotspot. Current coping strategies among communities will be discussed with stakeholder groups, to understand which strategies are working and could become more widely applied adaptation options. Additional adaptation options will be generated from the participants themselves through group and participatory methods (e.g. Leith et al. 2014; Hobday et al. 2015). Once adaptation options have been defined and evaluated with system models (see below) community-based decision-making will be conducted to determine the timeline over which each option will be applicable and at which scales these options are possible. The additional resources necessary to implement these adaptation options will be documented and prioritised.

System models will be used to generate biological projections and to test the efficacy of adaptation options under future climate scenarios in each region. Existing models, such as Ecopath with Ecosim (EwE) and Atlantis (Fulton 2011), will be used to explore options. In addition, a relatively simple generic modelling platform with a user-friendly interface (Plaganyi et al. 2012) is being developed to enable comparisons of similar systems or subset of species in each region, and to generate a common set of performance indicators (biological, social, economic). One advantage of having more than one model for each region is the ability to cross-validate the outputs of the different modelling approaches, thereby

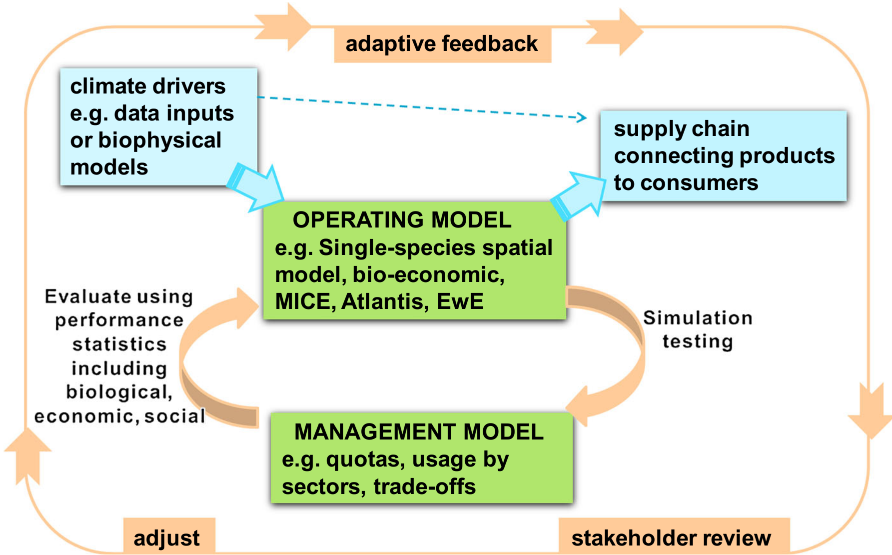

Fig. 5 Links between system components that are captured in an MSE approach, in turn implemented as part of an adaptive process to accommodate stakeholder inputs and updates in scientific understanding. MICE are Models of Intermediate Complexity for Ecosystem assessments (*Source* Plagányi 2016)

highlighting where further data or refinement of assumptions are critical and where some confidence can be inferred based on convergent model projections. High resolution oceanographic model projections will be used as drivers for both the simple and ecosystem scale models. A description of the biophysical components of each system would be insufficient on its own as a tool for assessing the efficacy of adaptation options, and linking of the models developed with social, economic and other available models or drivers will need to be undertaken where they are not already incorporated (as done in e.g. Atlantis-type models). This coupled approach is important for the counterfactual use of models—whereby the models can be a means of exploring options, suggesting and testing management and adaptation options (e.g. south-east Australia; Fulton and Gorton 2014).

Simulation models are increasingly being used to evaluate alternative management approaches and to identify potential trade-offs. Furthermore, it is increasingly recognized that Management Strategy Evaluation (MSE) is an ideal tool because of its ability to account for uncertainty as well as to make the trade-offs between diverse societal objectives explicit (Cochrane et al. 1998; Smith et al. 1999; de Moor et al. 2011; Plagányi et al. 2013). As part of MSE simulation-testing frameworks, operating models (OMs) are used to represent “true” underlying resource dynamics, and may be either single- or multi-species (e.g. Atlantis, EwE), with various complexity added such as climate drivers, bio-economic considerations and linked supply chains (Fig. 5) (Plagányi 2016). MSE will be used to test the performance of alternative adaptation options, and identify and evaluate tradeoffs in performance across a range of management objectives (Fig. 5).

Communication of these vulnerability assessments, adaptation options and potential outcomes will be delivered in each country to decision-makers and local communities. The stakeholder interviews and surveys in each region will be used to target communication, education and engagement responses. The choice of communication tools will vary amongst hotspots to accommodate specific government organisations, social, cultural and economic structures, level of education, access to technologies and environmental and climate change awareness. Communication at the global and national scales will be through international reports, policy briefs and presentations in workshops and meetings. At the local scale, more direct approaches will target the local population and governance structure at each hotspot. Our goal is to establish and maintain open communication channels with all stakeholders and to inform and involve the local population to increase local awareness of potential change and the need for action to implement sustainable adaptation measures. A second communication element is focused on formal educational programs. This will include professional development to local school-teachers and to tertiary level students and academics through workshops that will provide them with knowledge to adapt and use ocean science school-based educational materials relevant to the region. Workshops will be based on the *Communicating Ocean Sciences* and *Communicating Climate Change* courses developed by the Lawrence Hall of Science in California. Workshops for teachers and academics will provide opportunities for scientists to introduce ocean science content from kindergarten through high-school classrooms as well as in informal science education institutions, like museums, community centres, afternoon programs or summer camps. We will provide ocean science content and lesson plans including the supplies needed for teaching, and inquiry-based learner-centered science teaching approaches.

Policy mapping to identify organisations and individuals that might be agents of change in each hotspot will also be undertaken. Policy mapping identifies instruments (laws, regulations and policies), constitutional rules (formal rules at a societal scale), decision rules (those made by and affecting an identified group) and informal rules. These rules are formed by and operate at different scales—the state, community, and individual. The instruments and rules can be key governance attributes, providing a means of assessment of governance structures. We are adapting and implementing a governance analysis framework to be applied in the GULLS countries. The framework combines an existing policy mapping approach from Bainbridge et al. (2011) along with the organizational drivers identified by Dutra et al. (2015) that support climate adaptation. The combined methods will help identify and assess how such drivers are performing in different parts of the world, which will help target investments in governance to support adaptation.

Workshop participants recognised the long timescales that may be needed to effect change in some communities, and thus the need for feedback via on-ground interactions and monitoring. An understanding of these time scales would help to establish timeframes for action—and for how long and in what order adaptation actions might be implemented. In many regions, studies of local problems, and suggestion of potential solutions has not led to enduring change. The reasons for limited progress are complex and can include conflict between short-term economic and social needs and the goal of long-term sustainability, insufficient scientific information, weaknesses in the local institutions and others (Cochrane 2008; Aswani et al. 2012; Dutra et al. 2011; Dutra et al. 2014).

Many research projects are able to identify problems and suggest solutions but it is not in their remit to solve issues or take things further, except to conduct further research. GULLS is aiming to move beyond that and its aim, in each hotspot, is to form long-lasting links with bridging organisations to take the research from the identification of problems to an applied problem solving stage. These bridging organisations may be local or national government or relevant NGOs working in the area. Some of the links are already in place but will be reinforced and new links established during the course of the project as required, as often there is a disconnect between academic institutions and government departments tackling similar issues. Many of the bridging organisations are already working in or near to GULLS field sites and have similar aims and objectives to the GULLS project, *i.e.* reducing vulnerability of communities and finding adaptation options to climate change impacts. However, they often lack the research skills and breadth of data that a research group such as GULLS has access to, which is why such partnerships could be beneficial to both groups. In most of the hotspot countries, governments are the major and sometimes only large agencies with the capacity for large-scale applied action on the ground. Without links to government, attempts to change the status quo are likely to be futile. With regard to the experts involved in the project, regular meetings and two-way exchange of information and approaches will lead to on-going collaboration between the hotspot countries and as well as enduring engagement beyond the life of the project.

Challenges

While the workshop focus was on climate change vulnerability, participants recognized that a range of threatening processes influence seafood-dependent coastal communities. These include biological, management, institutional, macro-economic and political issues at a wide range of scales (Creighton et al. 2015). For example, the health and abundance of marine resources are impacted by a range of factors, including high exploitation rates, pollution and coastal development. At the same time, fisheries-dependent communities are impacted by a range of drivers and constraints, of which declining resource abundance and availability is typically only one, often a secondary problem (Cochrane 2008; Jentoft and Chuenpagdee 2009). In some hotspot regions, increasing human population growth, limited alternative sources of livelihood and demand for seafood is putting resources under stress, and increasing the vulnerability of communities that harvest seafood. Collapse of marine resource populations elsewhere has led to dramatic weakening of coastal communities, for example the Newfoundland cod (Walters and Maguire 1996) and some South American benthic shellfisheries—e.g. the Chilean fishery for loco *Concholepas concholepas* (Castilla and Defeo 2001; González et al. 2006). Recovering seafood stocks to healthy levels is considered a priority in most regions, as reaffirmed in the declaration from the United Nations Conference on Sustainable Development in Rio de Janeiro in 2012, also known as Rio + 20 (UNCSD 2012). However, the policy development and implementation challenges are substantial. The GULLS participants recognized the magnitude of the challenges and agreed it would be impossible to address the full range with the limited human and financial resources available. The approach is to target those issues and problems that fall within the expertise of the group but to ensure that a wide view is taken in interpretation of results, formulation of potential solutions, and communication of outcomes. The policy mapping described earlier will be an important tool in achieving this integrated outreach.

Current weaknesses in marine fishery and coastal management that will be considered by this project include limited integration of natural and social sciences, poor translation of scientific understanding into adaptive, multiple-use management mechanisms, and partial and fragmented policy development. Meeting participants agreed that to reduce vulnerability of coastal communities, support and change was needed at all scales, from local (e.g. household) to provincial (e.g. fishery management implementation) to national (e.g. coherent national policy) and global. This common understanding guided the development of the research and outreach approaches described earlier.

Finally, workshop participants realised the challenges in developing enduring approaches. To meet these challenges, on-ground research and action at local scales was considered a priority, with targeted interaction and communication with stakeholders to consult, discuss and deliver research findings and adaptation options. It is anticipated that integration of natural, social and economic studies, together with stakeholder participation, will identify a range of alternative options for management and policy reform. These alternatives will be provided to managers and decision-makers in coastal communities, national governments and society at large as briefing materials tailored to specific audiences. By recognizing and mapping the existing strong partnerships within and between the regions in this project, it may be possible to achieve strong scientific and political support for the development of effective science-based governance approaches. In partnership with end users and in-country stakeholders, this project will co-develop a comprehensive set of options to reduce coastal vulnerability and position vulnerable coastal communities for an improved future. As far as possible, these options will be developed via participatory and community-based methods that can build adaptation pathways that are supported by those most affected and are robust to future change (Wise et al. 2014).

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