Adaptive capacity: From assessment to action in coastal social-ecological systems

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Synthesis

Adaptive capacity: from assessment to action in coastal social-ecological systems

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ABSTRACT. Because of the complexity and speed of environmental, climatic, and socio-political change in coastal marine social-ecological systems, there is significant academic and applied interest in assessing and fostering the adaptive capacity of coastal communities. Adaptive capacity refers to the latent ability of a system to respond proactively and positively to stressors or opportunities. A variety of qualitative, quantitative, and participatory approaches have been developed and applied to understand and assess adaptive capacity, each with different benefits, drawbacks, insights, and implications. Drawing on case studies of coastal communities from around the globe, we describe and compare 11 approaches that are often used to study adaptive capacity of social and ecological systems in the face of social, environmental, and climatic change. We synthesize lessons from a series of case studies to present important considerations to frame research and to choose an assessment approach, key challenges to analyze adaptive capacity in linked social-ecological systems, and good practices to link results to action to foster adaptive capacity. We suggest that more attention be given to integrated social-ecological assessments and that greater effort be placed on evaluation and monitoring of adaptive capacity over time and across scales. Overall, although sustainability science holds a promise of providing solutions to real world problems, we found that too few assessments seem to lead to tangible outcomes or actions to foster adaptive capacity in social-ecological systems.

Key Words: *adaptation; adaptive capacity; climate change; coastal communities; resilience; social-ecological systems*

INTRODUCTION

Coastal communities are experiencing complex social and ecological changes at multiple scales and speeds (Steffen et al. 2011, Kareiva and Marvier 2012, Kueffer and Kaiser-Bunbury 2014, Moore 2016). The oceans are severely affected by human-induced global environmental change, with warming and acidifying waters, changing currents, and declining fish stocks that simultaneously drive related impacts on coastal ecosystems and human communities (Harley et al. 2006, Worm et al. 2006, Johnson et al. 2011). Economic globalization and markets can also drive changes in demands for certain marine species, pressure on resources, migration to coastal communities, and changes in nearshore vessel traffic (e.g., Tuler et al. 2008, Bennett et al. 2016*a*). Both biophysical and social drivers of change are presenting as risks or opportunities in coastal social-ecological systems (Adger et al. 2005*b,* Sales 2009), making it especially relevant to understand whether communities are able to adapt (Gallopín 2006, Cinner et al. 2012, Bennett et al. 2014, 2016*a*). Assessments of adaptive capacity, i.e., "the ability of systems, institutions, humans, and other organisms to adjust to potential damage, take advantage of opportunities, or to respond to the consequences" (IPCC 2014:118), can provide such an understanding (Armitage and Plummer 2010, Mcleod et al. 2016).

Along with vulnerability analysis, assessments of adaptive capacity are often used to provide the basis for planning adaptations or management actions to mitigate impacts in efforts to achieve beneficial social or ecological outcomes (McClanahan et al. 2008, Marshall et al. 2010, Hill and Engle 2013). These assessments tend to draw either from theories of ecological resilience (Holling 1973) or social resilience (Adger 2000, Folke et al. 2002, Engle 2011). In natural systems, ecological adaptive capacity is an indicator of evolutionary adaptive potential, suggesting that a species or ecosystem has the existing natural ability to persist over time and through change (Dobzhansky 1968, Smit and Wandel 2006). In contrast, the adaptive capacity of social systems refers to the ability of human actors and communities to respond to change and maintain human well-being over time (Smit and Wandel 2006). Numerous qualitative, quantitative, and participatory approaches have been developed to analyze adaptive capacity, each giving varying levels of attention to different components of the social or ecological system. As a result, each approach to assessing adaptive capacity produces different results, insights, and recommendations. However, there have been few comparative reviews of the different adaptive capacity assessment approaches that contrast their relative measures, outcomes, and applications (Gupta et al. 2010, Engle 2011, Fabinyi et al. 2014).

Given today's global challenges, an important objective of adaptive capacity assessments, indeed of all sustainability science, is to foster positive real-world action that improves the ability of a given system to adapt to change (Kates et al. 2001, Wiek et al.

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2012, Glandon 2015). However, it is generally unclear the extent to which previous efforts to measure or characterize adaptive capacity have led to on-the-ground actions to increase adaptive capacity. Furthermore, disparate assessment methodologies produce dissimilar descriptions of system properties and can lead to identification of different and even divergent interventions. By describing, clarifying, and contextualizing a diversity of assessment methods, we aim to improve the consistency and quality of adaptive capacity assessments. Here, we examine the strengths and drawbacks of 11 approaches for evaluating adaptive capacity, with a particular focus on coastal communities as linked social-ecological systems (SESs). Coastal communities are at significant risk from the cumulative effects of anthropogenic change and coastal development to climate change and they also support a large proportion of the world's human population (Hallegatte et al. 2013, Weatherdon et al. 2016*a*). As such, measuring and fostering the adaptive capacities of coastal social-ecological systems is of particular importance for researchers, planners, and policy makers (Wong et al. 2014). We identify the insights and implications of employing each approach and propose some best practices for selecting and applying different adaptive capacity techniques. We also provide a conceptual framework that links adaptive capacity assessments to management and planning actions to foster adaptive capacity across both social and ecological systems.

OVERVIEW OF APPROACHES TO ASSESS ADAPTIVE CAPACITY

The variety of ways in which adaptive capacity is defined, applied, assessed, and measured reflect a diversity of interests, areas of expertise, and theoretical rationales (Table 1). As with the application of resilience theory, understanding the adaptive capacity "of what to what" helps to frame an appropriate assessment approach as well as the corresponding actions or interventions (Fabinyi et al. 2014). Although the diversity of adaptive capacity assessment tools might be useful in different contexts, the multitude of different definitions and ways of conceiving of the problem can be unclear. This complexity and lack of conceptual clarity may increase the likelihood that an approach to assess adaptive capacity is not chosen mindfully, which is problematic given that the recommendations stemming from assessments may have real consequences for SESs.

Our aim is to provide direction to adaptive capacity assessments so as to foster and improve proactive interventions. Based on a literature review of adaptive capacity studies using key word search terms (adaptive capacity, adaptation, vulnerability, coastal communities, social-ecological systems) in Google Scholar and Web of Science for papers published between 1990 and 2015, we identified adaptive capacity assessment approaches that spanned a range of scales from local to large scale and also varied in their emphasis on social or ecological methods. We were particularly interested in research that was framed with a SESs lens. The approaches were grouped into 11 categories based on differences in methods, scale of application, and social or ecological focus: (1) large-scale social indicators, (2) large-scale ecological indicators and models, (3) integrated social-ecological indicators, (4) governance approaches, (5) multiple community surveys, (6) social experiments, (7) species-level experiments, (8) historical ethnographic approaches, (9) participatory planning approaches, (10) qualitative community-based approaches, and (11) mixed-method approaches (Table 1, Appendix 1). This list covers broad categories of adaptive capacity analyses to illustrate the range of possible approaches and may not be comprehensive. Although these approaches are described as distinct for the purposes of clarity, we acknowledge that in many cases, approaches could be taken that combine aspects of several of these tools.

We held a workshop in November 2015 with 12 academic researchers who had experience (as reflected in their publication and implementation experience) in adaptive capacity research across these categories in coastal SESs. The workshop served as an opportunity to guide discussion and provide expert opinion on the diversity of ways in which the concept of adaptive capacity is applied. The group was convened to explore the following overarching questions: What are the strengths, drawbacks, and insights of the range of approaches for analyzing adaptive capacity? How might these different approaches be applied to analyze the adaptive capacity of linked SESs? What lessons can be learned from previous efforts to bridge analyses of adaptive capacity with taking actions to build adaptive capacity? For each identified approach to assess adaptive capacity, one participant was asked to present and prepare a brief synopsis based on the following criteria:

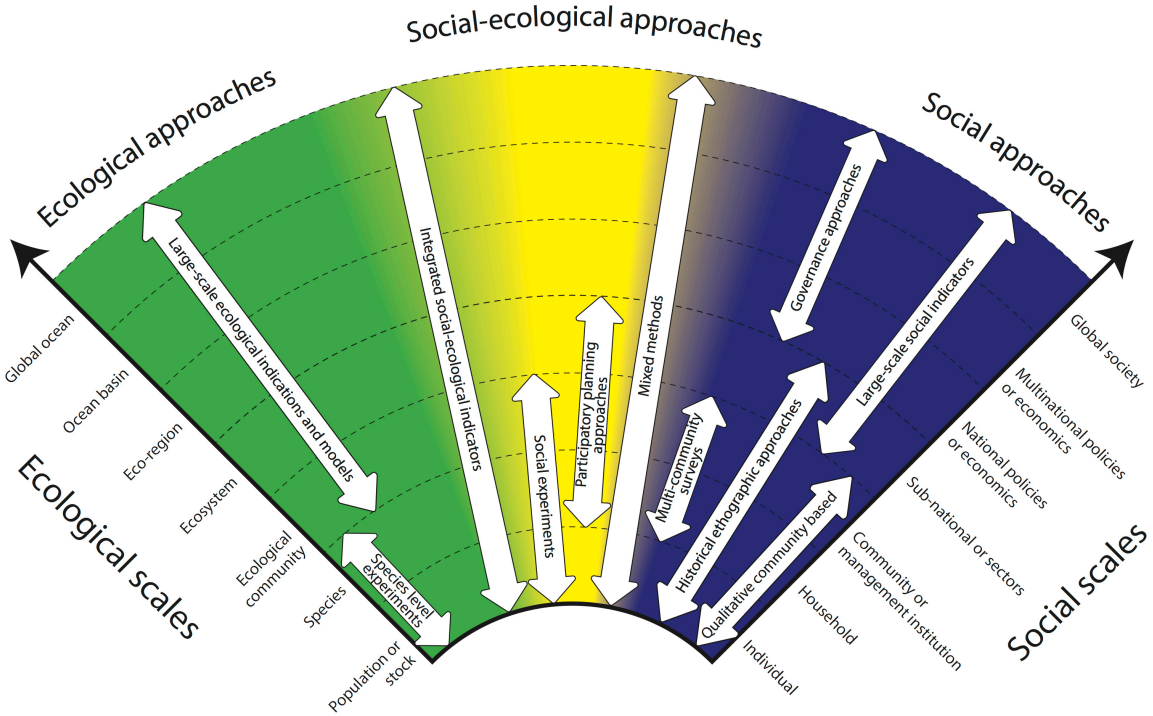
1. Describe the approach used to analyze adaptive capacity.
2. What type(s) of indicators were used?
3. At what scale was the approach applied?
4. What are the main strengths and benefits of the approach?
5. What are the main weaknesses and drawbacks of choosing this approach?
6. What insights and related practical solutions emerged from using the approach?
7. To what extent did the approach engage with and link to both the social and ecological components of the system?
8. Does the approach take a past, present, or future orientation to understand adaptive capacity?
9. How have or how can the results be integrated into decision making?
10. What are the implications for communities of using each approach (e.g., of the process, outcomes, outputs, or recommendations)?
11. What key references best reflect this approach to analyzing adaptive capacity?

Using these questions as a framework, we compared and contrasted the different approaches (see Appendix 1 for more details). To illustrate the different approaches, we drew on our own case studies and examples from the literature. Rather than simply describe each approach (summarized in Table 1), we aimed to illuminate parallels and opportunities for developing better and more integrated assessments of adaptive capacity that incorporate indicators of both social and ecological change and associated risks and that link knowledge to action. This guiding comparison of the 11 approaches was directed by five key considerations: (1) attention to social or ecological systems, (2) spatial scale, (3) temporal scale and orientation, (4) social or ecological indicators, and (5) implications and outcomes to clarify

Table 1. Summary of approaches used to measure and assess adaptive capacity of social, ecological, and social-ecological systems. Assessment approaches are listed in order of typical spatial scale of application from largest to smallest. See Appendix 1 for a detailed description of these approaches with references to example empirical studies and reviews.

Approach (social-ecological system focus)	Description	Strengths	Drawbacks	Methods and types of indicators
Large-scale social indicators	Cross-regional comparisons based on defined indicators of social adaptive capacities or vulnerabilities	Policy relevant; useful for describing relative differences across regions or communities	Generic; relative composite estimates; difficult to incorporate local knowledge and perspectives; relative measures can be difficult to apply to policies for building adaptive capacity	Relative measures of adaptive capacity across regions using additive indicators of social adaptive capacity, including risk exposure, sensitivity, social assets, wealth, learning, capital, livelihoods, and others
Large-scale ecological indicators and models	Large-scale modeling of ecological indicators to understand species and ecosystem adaptations to change	Understand large-scale patterns of adaptive responses across multiple species; useful application in detecting change for fisheries; can inform species management	Data intensive; coarse resolution because of limitations of data; uncertainty in modeled projections	Modeling based on fisheries catch data, species distributions, oceanographic data
Integrated social-ecological indicators	Uses integrated social-ecological understanding to gain a systems-based understanding of adaptive capacity	Policy relevant; examines both social and ecological drivers of change and their interdependencies	Data intensive; outcomes are relative measures; difficult to apply to local communities for management applications	Relative measures of adaptive capacity using indicators that integrate social and ecological dimensions of change in regions or communities; example framework is the I-ADApT assessment tool
Governance approaches	Literature review combined with community-based engagement is used to build understanding of governance institutions and processes	Explores the role and context of governance arrangements and decision-making processes in facilitating adaptive actions	Limited to processes, not mechanisms or contexts of change; inadequate attention to the nature of change	Interviews, governance-specific attributes, and indicators; example frameworks are Institutional Analysis and Development and Interactive Governance
Multiple community surveys	Survey or interview methods provide a comparison of adaptive capacities among multiple communities or across regions	Generates qualitative understanding of cultural, historical, and realized adaptive actions; can identify perceived barriers to adaptation	Community engagement is time consuming; interpretation and interview bias; may address responses more than mechanisms; link to specific stressors not always evident	Surveys and interviews across multiple communities using a range of social indicators
Social experiments	Behavioral economic experiments that give insight to decision-making behaviors of fishers or other stakeholders	Experimental approach is controlled and replicable; helps illuminate fisher and stakeholder decisions in response to uncertainty or risk	Community engagement is time consuming: does not reveal mechanisms of behavior unless combined with other tools (interviews or surveys)	Choice experiments, economic experiments
Species-level experiments	Experimental assessments of the adaptive potential of populations and species to a particular stressor	Experiments provide quantitative estimates of genetic variation, heritability, phenotypic plasticity to a stressor; helps to understand evolutionary potential	Focus on single (or few) specific traits; often cannot account for natural variability or interacting factors; often limited to single life-history stage; subject to sample size and logistic constraints	Lab or field based experiments to evaluate phenotypic plasticity, tolerance limits, genetic variation; common garden experiments; holding studies
Historical ethnographic approaches	Oral history, interviews, and literature are used to understand how past adaptations of communities or households may relate to present or future adaptive capacities	In-depth understanding of past types and scales of change and adaptations that occurred in response, with links made to present situation	Community engagement is time consuming, requires social networks and trust; not scalable; past changes and adaptations may not be relevant in the present	Interviews, analyses of past records, community knowledge sharing
Participatory planning approaches	Risk assessment and community planning are used to address resilience of communities or regions to change	Comprehensive utility-based understanding of viable actions and proactive planning for change	Community engagement is time consuming; requires community buy-in or knowing the gate-keepers	Combination of mixed methods: interviews, surveys, participant observation during planning events; participatory action research
Qualitative community-based approaches	Inductive methods are used to understand the adaptive capacities within a single community	In-depth, context-specific, qualitative understanding; community based; builds relationships based on understanding of self-perceived adaptive capacity	Community engagement is time consuming; requires community buy-in and acceptance; results are context specific and may not be applicable to other communities	Interviews, focus groups, participant observation
Mixed-method approaches	Combined methods are used to understand and compare diversity and flexibility of communities	Gives nuanced understanding of communities, sectors, or regions; enables comparison and identification of weaknesses and strengths, generic or common leverage points	Community engagement is time consuming; expensive; difficult to confirm the recommendations and outcomes across multiple communities	Combination of interviews, surveys, focus groups, participatory methods, policy analysis, literature reviews

Fig. 1. Comparison of 11 approaches for assessing adaptive capacity at different spatial scales and with varying attention to social and ecological systems.



the trade-offs in choosing a particular approach to assess adaptive capacity in a particular context.

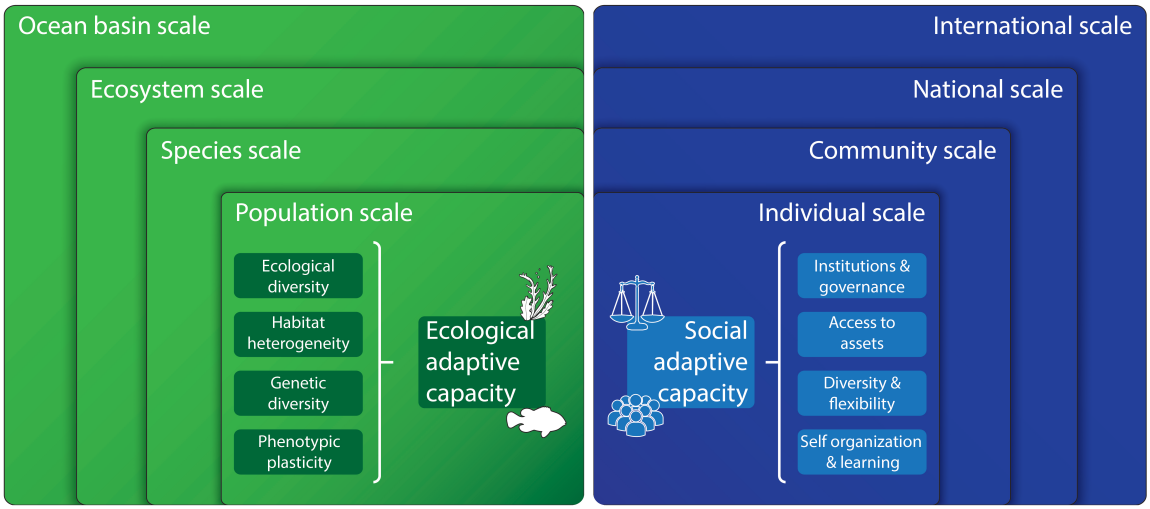
Attention to social or ecological adaptive capacity

Adaptive capacity assessments have tended to focus on either ecological or social adaptive capacity, with emerging approaches increasingly bridging social and ecological methods (Fig. 1). Ecological adaptive capacity can be assessed at a range of scales using field or laboratory experiments (species-level experiments; e.g., Crozier and Zabel 2006, Eliason et al. 2011, Whitney et al. 2013) or large-scale analyses and models of thermal tolerance, species traits, fisheries catches, biomass, ocean conditions, or market-based data on fisheries landings over time (large-scale ecological indicator approaches; Sunday et al. 2011, Cheung et al. 2015). Both small- and large-scale ecological assessments offer valuable information about adaptive capacities to disturbances such as climate change and increase the understanding of ecosystem responses to changes such as increasing temperatures. However, in isolation, the response or management applications of these empirical and model-based studies remain theoretical and without context to the appropriate or feasible policy changes and other responses that result in meaningful action. Social adaptive capacity assessments tend to focus on aspects of governance at different scales (e.g., local rules or actions, or federal macro policies) or on agency (of communities), norms and beliefs, the ability to predict and have foresight related to environmental conditions and change, occupational mobility and diversity, social capital and leadership, and the political and economic contexts for adaptive capacity (Armitage 2005, Folke et al. 2005). Reflecting the diversity of social-system components and the different social scales at which they can be applied, a broader range of approaches to assess social adaptive capacity have emerged (Fig. 1). Integrated social-ecological approaches consider a set of bridging adaptive capacity concepts that apply to both social and ecological systems or that incorporate the feedbacks and interactions between ecological and social systems by incorporating metrics of both. For example, when flexibility is assessed in both social and natural systems, it is possible to describe how social groups (e.g., fishers) respond to changes in natural conditions (e.g., fisheries abundance) as well as to changes in governance or other social structures (Blythe et al. 2014, Aguilera et al. 2015, Finkbeiner 2015).

Spatial scale

Adaptive capacity can be assessed at different interacting spatial scales using a range of scale-appropriate measures in either ecological or social systems (Adger et al. 2005*a,* Hill and Engle 2013; Fig. 1). Large-scale approaches based on large-scale ecological (Aguilera et al. 2015) or social indicators (e.g., Allison et al. 2009, Himes-Cornell and Kasperski 2015), ecological modeling-based studies (Cheung et al. 2015, Gattuso et al. 2015), and governance analyses (Dietz et al. 2003, Armitage and Plummer 2010, Gupta et al. 2010) provide rapid comparative results for policy decisions and, in some cases, may be operationalized more quickly than in-depth assessments at smaller scales. However, a limitation of large-scale studies is that they do not incorporate local, traditional, or cultural knowledge, address household or individual capacities, and, because of their large scale and coarse approach, often do not allow for local validation of results or vetting of recommendations. In contrast, community-based participatory methods can provide nuanced understanding of the dynamic nature of a group or community

Fig. 2. Example measures of adaptive capacity in ecological or social systems across spatial scales. Measures are examples only and are not meant to be prescriptive or specific to a given scale as shown here.



and its historical, present, and potential adaptive responses, as well as include the views and preferences of community and stakeholders (e.g., Henly-Shepard et al. 2015). Participatory methods may also integrate well with qualitative methods such as interviews and quantitative methods such as surveys in developing a deeper and more holistic understanding of household- to community-level adaptive capacities and strategies (Bennett et al. 2014, 2016*a,b*). However, action-research, community-based methods, and mixed-method approaches may require significant time commitments (e.g., years; decades for historical approaches) that exceed research program and funding time lines. Each approach to assessment has different strengths and weaknesses of which the researcher needs to be mindful.

Temporal scale and orientation

The measurement of adaptive capacity is generally for a given time period and based on available data and the selected indicators. Assessments of adaptive capacity can focus on short-term time scales (measuring coping or acclimation potential) or over longer time scales (enabling social adaptation or evolutionary adaptation). In ecological systems, short-term adaptive strategies usually refer to acclimation to a new (or temporary) environmental state; acclimation may draw on phenotypic plasticity, habitat diversity, or short-term behavioral responses (Stillman 2003). If an environmental stressor or shift continues, long-term adaptive strategies depend on evolutionary responses at the species level or migration strategies (leaving the area for better suited habitats; Jensen et al. 2008, Chown et al. 2010, Ekstrom et al. 2015). Social communities may cope with change in the short term through social networks, informal arrangements, alternative income generating activities, or financial remittances from overseas family members (Adger 2003, Adger et al. 2007).

The temporal orientation of adaptive capacity assessments can also focus on learning from the past, examining the present, or predicting future response capacity. Rarely are assessments of adaptive capacity conducted over multiple time periods (although see Cinner et al. 2015), with the majority of assessment methods focusing on the recent past or present (Engle 2011). An exception to this is historical ethnographic methods, which focus specifically on how human communities have adapted to changing environmental conditions in the past, with insight for present or future adaptive capacities (Berkes and Jolly 2001, Turner and Clifton 2009, Blythe et al. 2014). Conversely, ecological modeling techniques (Cheung et al. 2009, 2010, Weatherdon et al. 2016*b*) or analyses of governance and institutions (Brooks et al. 2005) can apply scenario planning to assess future adaptive capacities (Peterson et al. 2003, Tompkins et al. 2008, Tschakert and Dietrich 2010, Oteros-Rozas et al. 2015, Bennett et al. 2016*b*). Future predictions of adaptive capacity are especially relevant for urban planning and disaster planning in coastal settings, where assessments can indicate important vulnerabilities for policy or management action (Adger et al. 2005*b,* Malakar 2013, Henly-Shepard et al. 2015). Planning approaches to adaptive capacity include "participatory futures approaches" for community-based climate change adaptation, which engage and empower community members to be active collaborators in developing community scenarios that facilitate coevolutionary adaptation to climate change, rather than passive adaptation (Gidley et al. 2009).

Indicators: social, ecological, or integrated

We broadly categorize indicators that are commonly used for measuring the adaptive capacity of both social and ecological systems (Table 2, Fig. 2) in an effort to provide useful insights to guide policy and management improvements across scales (Armitage and Plummer 2010). Indicators can be quantitative measures of adaptability summarized as indices (Yohe and Tol 2002) or can comprise qualitative perceptions of individuals or communities about their capacity to adapt (Armitage and Plummer 2010, Hinkel 2011, Bennett 2016). Ecological indicators of adaptive capacity (Fig. 2) are based on diversity and flexibility across a range of traits (e.g., life history or behavioral) and organizational levels (e.g., genetic, species, populations) as well as access to and interactions with suitable habitats (Aitken et al. 2008, Mawdsley et al. 2009, Hutchings 2011, O'Connor et al. 2012, Benscoter et al. 2013). Social indicators of adaptive capacity (Fig.

Table 2. Examples of generic social and ecological measures used in assessments of adaptive capacity. Many of these measures are operationalized as indicators in assessments.

Characteristics of social adaptive capacity		Characteristics of ecological adaptive capacity	
Category	Indicator	Category	Indicator
Diversity and flexibility		Diversity and flexibility	
	Livelihood and income diversity		Species diversity
	Economic opportunities		Genetic diversity
	Level of dependence on natural resources		Functional redundancy across species
	Occupational mobility		Response diversity across species
	Place attachment		Species' life history traits (e.g., metabolic rates, size, reproductive strategies such as generation time, fecundity)
	Migration patterns		Broad habitat range and tolerance
	Willingness to change		
Access to assets		Habitats and interactions	
	Household material assets (e.g., boats, gear)		Habitat availability
	Community infrastructure		Habitat heterogeneity
	Levels of education		Habitat connectivity (opportunity)
	Financial status and access to sources of credit		Rate and magnitude of habitat disturbance
	Access to markets		Habitat diversity
	Bridging social capital and institutional supports		Phenology
	Natural capital		
	Equity, rights, and access to resources		
	Cultural memory, traditions, and assets		
Learning and knowledge		Capacity to adapt within species	
	Resource monitoring and feedback mechanisms		Behavioral change (e.g., prey switching) and learning
	Knowledge of disturbance (e.g., climate change)		Phenotypic plasticity
	Perceptions of risk		Tolerance limits
	Spaces and platforms for learning		Rapid genetic adaptation of traits through behavior change and acclimation
	Diversity of knowledge and information sources		Reproductive rate and capacity for dissemination
	Ability to anticipate change		Dispersal capacity
	Recognition of causality and human agency		Migration capacity
	Intergenerational learning capacity		
Governance and institutions		Self-organizing systems	
	Levels of trust, social capital, and networks		Community structure and dynamics
	Gender and race relations		
	Levels of participation and quality of decision-making processes		
	Planning capacity		
	Presence of local environmental institutions and strength of social norms		
	Quality of governance and leadership in environmental policies and agencies		
	Accountability of managers and governance bodies		
	Active risk management and adaptive governance processes		

2) can be grouped into four broad categories: access to assets, diversity and flexibility, learning and knowledge, and governance and institutions (Adger 2003, Brooks et al. 2005, Allison et al. 2009, Hinkel 2011, Bennett et al. 2014). Some indicators of social and ecological adaptive capacity complement each other (e.g., diversity, flexibility, modularity, access to assets or habitats), whereas others do not have an ecological equivalent (e.g., social capital, innovation, institutional structures, governance strategies; Walker and Salt 2006, Nemec et al. 2013; Table 2). An important distinction between social and natural systems is that humans have agency and foresight, theoretically leading to learning and proactive decision-making power, whereas natural systems and species assemblages generally do not have agency or foresight (Walker et al. 2002, except in some indigenous world views; Kimmerer 2013, Turner 2014).

Implications and applications of adaptive capacity approaches

If applied to the same case study, each of the 11 approaches highlighted here would reveal varied insights and produce very different recommendations for policy or management. For example, an assessment of the ecological adaptive capacity of a commercially valuable fish species might suggest that managers restrict harvesting or target particular stocks with higher adaptive capacity (e.g., Pacific salmon; Whitney et al. 2013). In contrast, assessments of social adaptive capacity of the same fishing community might recommend gear restrictions, livelihood diversification programs, or basic service provision support to assist the human community dependent on that fishery. Thus, choosing any one approach inevitably involves the prioritization of different actions and potential trade-offs such as different scales of analysis and insights, levels of attention to social and ecological systems, temporal orientation, as well as methods and indicators (Table 1). The approach chosen will also be driven by the objectives and skills of the researcher or research team. Overall, one consistent weakness across all methods included here is the lack of direct connection between assessments and actions taken to augment adaptive capacity. To select the most relevant and effective approach, it is important to be mindful of the many

choices to be made prior to assessment as well as the good practices for evaluating and building adaptive capacity.

SYNTHESIS OF LESSONS LEARNED

Drawing on our review, we present: (1) a set of considerations for framing the problem and choosing an appropriate assessment approach, (2) key challenges that require attention when analyzing adaptive capacity in SESs, and (3) good practices for linking results to action to foster adaptive capacity (Table 3).

Framing adaptive capacity research: choosing an assessment approach

Adaptive capacity assessments are commonly limited by a lack of clarity on the assumptions and contextual outcomes of a particular method or a lack of attention to the applicability of an assessment tool to the context, scale, or stressor under consideration (Adger and Vincent 2005, Engle 2011). These barriers limit the accuracy of the relative estimates of adaptive capacity and the applicability of results when seeking to identify policy solutions and thus diminish the potential for implementing proactive measures for fostering adaptive capacity within and among systems. Some approaches can contribute to more than one of these goals. Being clear and transparent about the purpose and mindful of methods will strengthen the analysis. To address these challenges, we highlight seven key questions to ask when selecting an assessment approach (Table 3), which include: the adaptive capacity of what, to what, of whom, and for whom; the scale and orientation of adaptive capacity; the types of indicators and methods that are available and relevant; and the purpose of the analysis. By highlighting these framing questions, as well as key challenges and good practices, the intention is that adaptive capacity assessments can become more transparent and intentional, and the results more applicable.

The adaptive capacity of a SES is inherently normative and scale dependent: The assessed adaptive capacity of an ecosystem or social community could be interpreted differently from the eyes of a policy analyst, facilitator, or stakeholder because each of these people has a different perception of the system and stressor (s) in question (Adger 2003, Cote and Nightingale 2012, Bennett 2016). The spatial scale of assessment is selected by the analyst and influences the results and recommendations of the assessment. Temporal scale also matters. Indicators of adaptive capacity reveal effects and responses over both slow and fast temporal scales. Building adaptive capacity of either social or ecological components of a system will also affect certain groups more than others. If the effect or change continues, coastal communities will need to develop long-term adaptive strategies that may be more dependent on governance, planning, infrastructure, adaptive management, sense of place, or even emigration (retreat) from factors such as rising sea levels (Tol et al. 2006, Adger et al. 2007, Berman et al. 2012, Joakim et al. 2015).

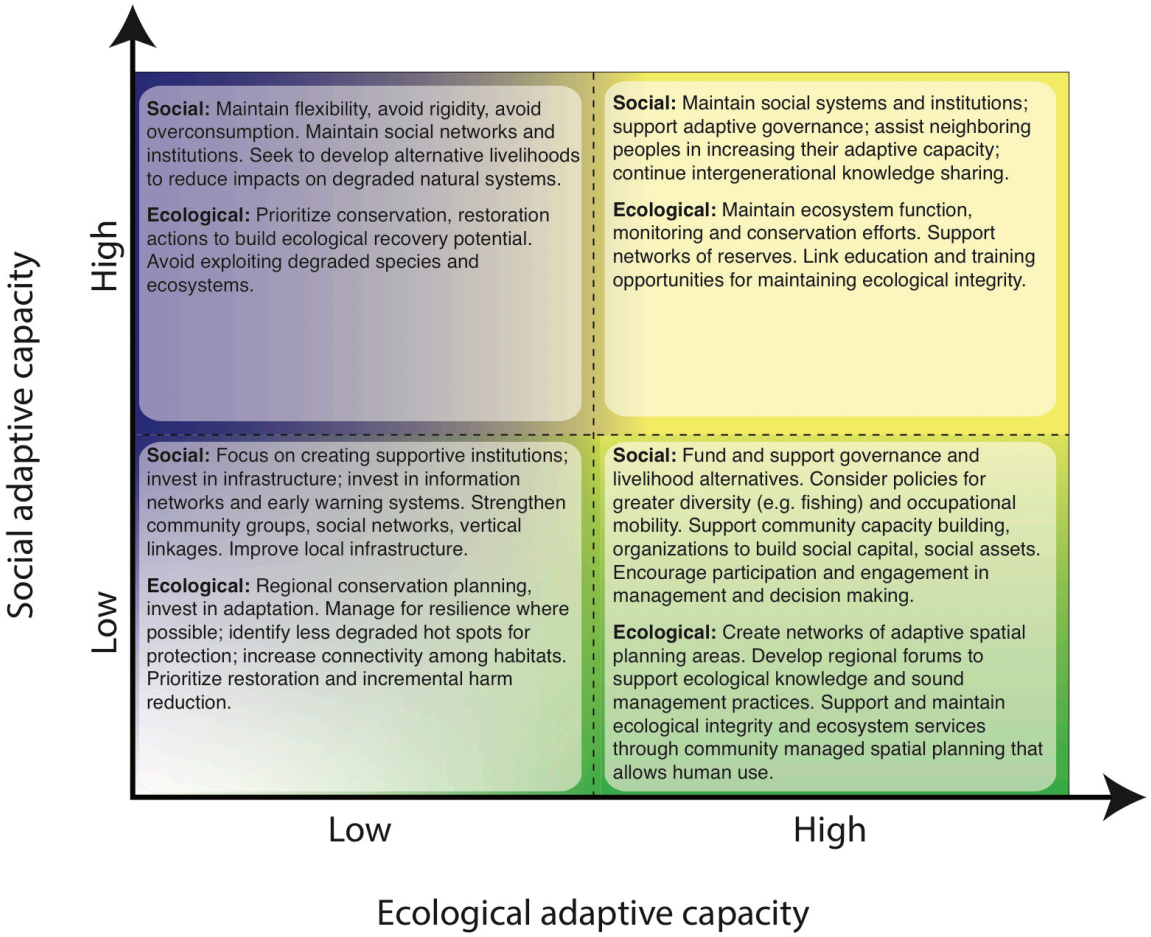
Evaluating adaptive capacity: influential factors and key challenges

Following the framing of an adaptive capacity assessment approach, there are several key considerations or challenges of which researchers and practitioners should be cognizant during their evaluation. Different groups or individuals can be politically marginalized or more vulnerable, leading to differential adaptive capacities (Tschakert 2007, Bunce et al. 2010). The perspectives and worldviews of researchers, stakeholders, governance agents, and change agents will doubtlessly affect the assessment and any actions to build adaptive capacity. Tools such as the SESs framework may help to understand the diversity of perspectives within a SES and the interactions therein (Basurto et al. 2013, McGinnis and Ostrom 2014). Depending on the timeline of assessment, certain tools may offer deep understanding yet be too expensive or time consuming (e.g., qualitative community engagement), whereas other tools may offer comparability across systems (e.g., large-scale index-based approaches). Ongoing evaluations of adaptive capacity are important to understand how response capacity changes over time. Adaptive capacity assessments are frequently a single project for a particular system and stressor, resulting in estimates that are quickly outdated and likely fail to connect with postassessment action (although this is rarely evaluated). Monitoring how adaptive capacity may change as the system reacts to change may allow a deeper understanding of feedbacks, trade-offs, and potential improvements to techniques for assessing and building adaptive capacity (see Cinner et al. 2015). We stress that postassessment evaluation should be a component of many adaptive capacity studies rather than single nonrepeated assessments. Although integrating across social and ecological components of a system can be beneficial, it is not always applicable in adaptive capacity studies. The IMBER-ADApT tool is a valuable example of an integrated social-ecological adaptive capacity assessment framework (Bundy et al. 2015). In choosing an integrated SESs perspective, it is more likely that multiple key characteristics of adaptive capacity as well as important trade-offs and feedbacks will be incorporated, leading to more robust analyses.

Fostering adaptive capacity: linking assessment to action

Based on our research, experience, and review of the literature, assessments and studies of adaptive capacity are rarely effectively linked to policy change or actions that promote adaptive capacity, despite clear directives or calls to do just that. For example, only one of the assessment approaches we examined linked to action based on that assessment (participatory planning; Appendix 1). The importance of participation and knowledge cocreation for enhancing adaptive capacity has long been emphasized (Folke et al. 2002). Participatory vulnerability assessments can help identify adaptation strategies that are most feasible and practical in communities with a focus on current risks, allowing for integration with resource management, disaster preparedness, and sustainable development initiatives (Smit and Wandel 2006). At the community level, linking assessments with actions may mean supporting forums for sharing knowledge within and across generations (social learning; Berkes and Jolly 2001, Pelling and High 2005). At the coastal community scale, this can mean supporting cross-generational knowledge-sharing platforms such as elder-youth groups, integrating harvesting trips among community members, or recording historical social norms that are relevant for the local ecological system (Senos et al. 2006, Turner 2014). At larger scales, linking assessment to evaluation and response offers researchers and managers the opportunity to learn from past mistakes and generate opportunities for fostering adaptive capacity (Perry et al. 2010). This might entail financial support mechanisms, government-led investments in jobs or other economic incentives, or educational platforms for community or regional leaders (Brooks et al. 2005, Bronen and Chapin 2013).

Fig. 3. A conceptual framework to link adaptive capacity assessment to adaptive capacity building in social-ecological systems. The adaptive capacity of the linked social-ecological system is first identified by assessing the level of ecological and social adaptive capacity (i.e., by conducting multiple or integrated assessments). With knowledge of the current state of the system, actions can be taken to build further adaptive capacity (e.g., improve ecological adaptive capacity) to move the system to a more desirable state. If considerations of trade-offs are not included, the system's adaptive capacity could shift in focus without gains in total adaptive capacity (e.g., ecological adaptive capacity increases at the cost of decreasing social adaptive capacity). The model is based on similar schematics by McClanahan et al. (2008) and Ban et al. (2013); actions build on those suggested by Salafsky et al. (2008) and Cinner et al. (2012).



Building adaptive capacity through social learning can support the success of other related adaptive management opportunities, both within a project and across international processes (e.g., adaptive spatial planning; Mills et al. 2015).

Overall, it is increasingly important to shift from a reactive to a proactive framework for adaptive planning. For managers and policy makers, identifying the barriers to adaptation through evidence-based indices is valuable, especially across systems and at regional scales. For coastal communities and managers, considering the linked nature of SESs could lead to sustainable policies that support both social adaptive capacity factors as well as the adaptive capacity of the ecosystem. Considering the adaptive capacity of both social and ecological systems together can help to avoid social-ecological traps (Carpenter and Brock 2008, Cinner 2011). Although there are commonalities across assessment tools and conceptual models of what makes up high adaptive capacity for both social and ecological systems (e.g., diversity, redundancy, capital), indicators cannot truly be integrated for practical applied analyses (Nemec et al. 2013). It is, however, useful to consider social and ecological indicators of adaptive capacity as additive metrics that cumulatively characterize an integrated SES as having high or low adaptive capacity to a specific impact.

We propose a conceptual framework with which to prioritize potential actions based on integrated social-ecological adaptive capacity assessments (Fig. 3), building on themes proposed by McClanahan et al. (2008). In four quadrants, we illustrate example systems in which ecological and social adaptive capacity ranges from high to low, and we identify example actions that could foster adaptive capacity in either the social or ecological

Table 3. Key considerations for operationalizing adaptive capacity research and practice.

Stage of research or application	Considerations	Explanation and examples
Framing the research: key questions and considerations when choosing an adaptive capacity assessment approach	Adaptive capacity of what?	Systems: social, ecological, or both
	Adaptive capacity to what?	Ecological: population(s), species, communities, ecosystem(s)
	Adaptive capacity of whom and for whom?	Social: individuals, households, communities, nations, governance systems, organizations, policies, politics, infrastructure, economic industries, sectors
	At what scale?	Single exposures: e.g., climate change or governance change
	At what orientation?	Multiple exposures: e.g., climatic, environmental, governance, economic, and social combined
	What types of indicators and methods?	Rate of change: rapid onset acute (discrete) shocks, continuous (chronic) exposures, or both
	What is the purpose of the analysis?	Impact: stressors, opportunities, or both
Evaluating adaptive capacity: general factors and challenges to take into account when engaging in integrated adaptive capacity assessment in coastal social-ecological systems	Equity and access	Groups and individuals have differing levels of vulnerability and adaptive capacity; pay attention to: social differentiation, marginalization, politics and power dynamics, inclusion of diverse voices and perspectives
	Diverse worldviews, knowledge, and perspectives	Different worldviews: e.g., western ecological science, social science theories, local knowledge; be cognizant of the biases and assumptions therein
	Cumulative effects of multiple exposures	Ecological: e.g., increasing storm severity, ocean acidification, biodiversity loss; Social: e.g., coastal development, population growth, economic crisis; changes can present as stressors or opportunities in systems and can be additive, mitigative, or multiplicative
	Change and complexity	Change is constant and systems are dynamic; links among system components and feedbacks cause complex and unpredictable changes in exposure and adaptive capacity
	Social-ecological interactions	Consider both social and ecological components of linked systems; consider adaptive and coping responses of both ecological and social communities and systems within an integrated assessment framework; prioritize actions that are holistic, benefiting both human well-being and ecological integrity
	Scalar interactions	Scales of adaptive capacity are not independent; evaluate interactions between components of adaptive capacity at higher and lower scales
	Trade-offs in responses	Feedbacks between adaptive responses: e.g., amplifying or diminishing effects on coastal resources resulting from behavioral changes; identify and analyze trade-offs in ecological management or social planning; incorporate decision-making tools and planning techniques that account for trade-offs into adaptive capacity analyses
	Be proactive, not reactive	Anticipate known and unknown disturbances and identify opportunities for increasing adaptive capacity in advance; reflect on potential unintended consequences of actions to build adaptive capacity; expand planning for specific stressors (e.g., sea level rise) to include possible effects from unexpected shocks (e.g., earthquakes, tsunamis)
	Limits and barriers to adaptive capacity	Stressors may overwhelm the adaptive capacity of social-ecological systems; certain factors, be they ecological, technical, social, cultural, or political, can also undermine abilities of systems to adapt; recognition of limits and barriers is an essential part of assessing adaptive capacity and identifying actions
Fostering adaptive capacity: good practices for bridging adaptive capacity assessments with action outcomes	Learn by doing and adapt	Encourage and integrate cycles of action with observation, reflection, learning, and revision (i.e., adaptive management)
	Collaboration and coproduction of knowledge	Build teams that include: researchers, practitioners, policy makers, community leaders, and implicated stakeholder groups; seek coidentification of problem; collaborative processes of knowledge gathering and integration and the coproduction of tools to manage the problem
	Shared learning	Promote knowledge sharing and social learning within and among communities and across generations; create opportunities and knowledge sharing platforms and or meetings to facilitate knowledge exchange (e.g., community exchanges)
	Promote networks and social capital	Strong networks and social capital across families, communities, and nations can strengthen adaptive capacity and enable the uptake and implementation of recommendations; risks and impacts are lessened when there are others from outside who can help
	Build capacity across scales	Work with local communities or leaders in the implementation of recommendations to strengthen local capacity to assess and respond to stressors and change; ensure that actions are being taken at higher scales to support local capacity-building efforts
	Communicate results	Results of adaptive capacity assessments analysis need to be communicated to those implicated (e.g., communities, resource users, etc.) and key decision makers, including managers and policy makers; information needs to be presented in various formats

realm to move the system toward a state where both capacities are increased. If an assessment indicates that social or ecological adaptive capacity is low, we suggest potential actions that are designed to build capacity. If an assessment indicates that adaptive capacity is already high, we suggest actions that are intended to support existing capacity against future shocks or disturbances. The suggested actions are meant to be illustrative, not prescriptive, and the appropriate actions taken will depend on the social and ecological contexts. The actions are also not meant to be exclusive, and in some cases, multiple actions across scales will be possible or necessary.

LIMITATIONS IN BRIDGING ASSESSMENTS TO ACTION

Suggesting a set of potential actions to build adaptive capacity (Fig. 3) demands some important caveats. First, important trade-offs exist between and across scales and across social and ecological systems (Walker et al. 2009). For example, building social adaptive capacity might involve diversifying or intensifying fisheries, for example, which could have the effect of decreasing biodiversity, abundance, and ecological adaptive capacities in that system (Coulthard 2012). Similarly, national-level policy changes to decrease fossil fuel production according to international

agreements may negatively affect local economies, for example, by limiting fishing activity, at least in the short term (Biggs et al. 2012). Likewise, there may be temporal trade-offs whereby actions to build short-term adaptive capacity might imply a trade-off for future outcomes if those actions create barriers for future options. It is important to foster adaptive capacity that allows a SES to cope with change while not losing adaptive options for the future (Folke et al. 2002, Armitage and Plummer 2010). Moreover, we recognize the existence of taboo trade-offs or choices between morally incommensurable values such as trade-offs between the conservation of a particular species and human health (Daw et al. 2015).

Second, we recognize that building adaptive capacity requires situated research that is sensitive to particular contexts. The development of a universal framework for adaptive capacity is neither realistic nor desirable. For example, advocacy for institutional criteria (such as flexibility, diversity, legitimacy) can lead to highly differentiated and unpredictable effects on the ground. Rather, principles for assessing and building adaptive capacity must be drawn out of the specifics of each case where unique social-ecological processes and social relations of power are observable (Cote and Nightingale 2012). However, reluctance to simplify complex phenomena into useable metrics can result in their gradual omission from research and practice. That which cannot be measured can disappear from public debates and political consciousness. Conversely, indictors or metrics allow the definition of what is important, the measurement of change, and direct research and investment (Hicks et al. 2016). Therefore, this framework is intended as a starting point for developing more targeted and context-specific actions that build adaptive capacity in coastal SESs.

CONCLUSIONS AND FUTURE DIRECTIONS

The extent and speed of global change has catalyzed broad interest in understanding and supporting the capacity of SESs to respond to, cope with, and adapt to change. Adaptive capacity assessments that focus on climate change have been applied in many contexts, including forestry (Pramova et al. 2012), agriculture (Marshall et al. 2013, Wang et al. 2013), fisheries (Kalikoski et al. 2010, Cinner 2011, Cinner et al. 2013, Aguilera et al. 2015), conservation (McClanahan et al. 2008, Mcleod et al. 2016), and disasters (Adger et al. 2005*b,* Cutter et al. 2008, Taylor 2011, Henly-Shepard et al. 2015). Several important points emerge from this literature and the broader literature and case studies on adaptive capacity. First, both the local and broader contexts of change matter. Adaptive capacity may vary depending on the changes occurring, the linkages between local contexts and global processes, the ways that linkages manifest as effects on systems and individuals, local perceptions of desirable and undesirable system states and outcomes, and the characteristics of the system that determine the suite of available responses. In other words, it is crucial to define the adaptive capacity "of what," "to what," and "for whom" (Carpenter et al. 2001, Adger and Vincent 2005, Lebel et al. 2006, Adger et al. 2012).

Second, spatial and temporal scales of social and ecological change matter. SESs produce a suite of interacting ecosystem services at multiple scales, which support interdependent social systems. These complex systems are affected by cross-scale interactions whereby large-scale decisions affect small-scale systems, and small-scale adaptive characteristics add up to region-wide norms (Klein et al. 2014). Changes, effects, and responses are all critical factors for assessing adaptive capacity and occur and interact at multiple scales. Thus, the scale of assessment ("of what") is dependent on the scale of the given stressor ("to what;" Adger 2003, Adger and Vincent 2005, Folke et al. 2005, Biggs et al. 2012). Adaptive capacity in SESs can therefore be measured across scales such as household or population, cross-community or ecosystem, national, or regional levels. In an era of rapid transformative change, it is important that both social and ecological indicators be both robust and transparent and applicable to the scale of assessment to have meaningful policy applications (Adger and Vincent 2005).

Third, increasing interest in the concept of adaptive capacity has led to the development of numerous definitions as well as conceptual and analytical frameworks with associated measures and indicators. Many of these definitions and frameworks have primarily addressed either social or ecological adaptive capacity without integrating them. There is a need for integrated ways of thinking about adaptive capacity, with the caveat that not all SESs have tightly connected feedbacks. The direct feedback mechanism between changes in social or ecological systems may be missing or delayed in some contexts (buffered by social structures or other scales of resource availability, governance, or institutions beyond the scope of study). Furthermore, adaptive capacity should be assessed both in terms of the ability to react and change in response to opportunities (positive change) as well as stressors or challenges (negative change). There is no absolute measure of adaptive capacity, only adaptive capacity relative to the specific context, scale of disturbance, and scale of analysis.

Moving forward, some important gaps in adaptive capacity application are evident. There is much to learn about which measures and indicators of social and ecological adaptive capacity are the most powerful predictors of adaptive responses. Unfortunately, there are few instances in which assessments of adaptive capacity are followed up with monitoring or postassessment evaluation of change in that system through time. Future efforts should be made to follow up on single assessments of adaptive capacity to observe and describe whether assessments were accurate and which factors in particular enabled effective responses to both slow and rapid change. In addition, more attention is needed to develop integrated social-ecological assessments. In policy-relevant time scales, fostering adaptive capacity is most applicable to social systems, although it is possible to evaluate historical change in ecological adaptive capacity over longer time scales. Thus, it is imperative that management be focused on preventing the erosion of ecological adaptive capacity (e.g., through overfishing) and building social adaptive capacity through positive proactive action (futures thinking; Tschakert and Dietrich 2010). A learning opportunity for building consistency in adaptive capacity assessment could come from the fields of environmental impact assessment, management effectiveness evaluation, and social impact studies, where metrics for monitoring, evaluation, and reporting have a more developed history. Finally, there are limited published examples of assessments that demonstrate the linking of results from assessments to building of adaptive capacity. If adaptive capacity is to be a useful concept for fostering real world change, it is imperative that researchers and decision makers work across

disciplines to develop clear, consistent methods that can support action-oriented outcomes that resonate with communities.

Responses to this article can be read online at:
http://www.ecologyandsociety.org/issues/responses.php/9325

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Appendix #1 Comparison of 11 Approaches for Analyzing Adaptive Capacity: Strengths, weaknesses, insights, implications and applications. Key references are included of case study examples and reviews for each method, where available.

Approach	Description	Details	Strengths, Weaknesses	Insights, Implications, Application	Key References
Large scale social indicators	Studies of relative adaptive capacity (or inversely related indicators of vulnerability), based on existing socio-economic or social data across the system.	Key Methods: Relative community assessments of risk exposure (e.g. to climate change), system sensitivity (i.e. resource dependence), and adaptive capacity of the social system (wealth, governance, assets, learning, etc.). System focus: Social Scale of Analysis: Communities to state to cross-national Temporal Focus: Present	Strengths: Can provide rapid outcomes for decision makers, and be useful for communicating differences in vulnerability and adaptive capacity among different regions, populations and communities. Relatively easy to conduct - relies on simple surveys at community level (e.g. from focus groups and RRA type research) or on secondary data. Weakness: Indices are often generic, theoretical, and composite: Difficult to evaluate. Doesn't allow for evaluations of the effectiveness of responses; difficult to incorporate traditional or cultural knowledge. Relative measures only; difficult to apply to policy for building adaptive capacity in a particular place.	Insights: Allows a broad understanding of potential relative response to stress or opportunities, generally related to how the combination of hazard exposure, dependency (sensitivity) and adaptive capacity led to differential vulnerability. Implications & Applications: Local management is not very responsive at this scale. Useful for policy and governance insights across communities or regions.	(Himes-Cornell et al. 2016) (Himes-Cornell and Kasperski 2015) (Barange et al. 2014) (Hughes et al. 2012) (Allison et al. 2009) (Brooks et al. 2005) (Yohe and Tol 2002)

Large scale ecological indicators and models	Modeling of past and present ecological changes and future adaptation potential of species and fisheries along with projected environmental changes	Key Methods: Mean responses to changes in environmental conditions: species distribution shifts, species' adaptive capacity index, rate of evolutionary changes. Attention to: Ecological Scale of Analysis: Species, biological communities, and fisheries (e.g. Large Marine Ecosystem scale) Temporal Focus: Past, present and future.	Strengths: Reveal large-scale pattern of adaptive responses and capacity to adapt to ecological change from both the perspective of species, and the fishery response to that change. Weakness: Low resolution because of limitation of data or model, need downscaling to be directly usable for regional and local scale studies; confidence is limited by the state of knowledge on species' and fisheries' adaptive responses.	Insights: Understand how species are responding to changing conditions through distributional changes, and how some fisheries are adapting to that through changes in species composition of catches. Implications & Applications: The rate of evolutionary adaptation may not be fast enough under the current rate of warming, particularly for species that have a low adaptive capacity (e.g., low genetic variability, slow turn-over rate). This tool is policy relevant for larger regional/national governance, and can be applied to identify species/fisheries most vulnerable to climate change.	(Cheung et al. 2013) (Cheung et al. 2012) (Gattuso et al. 2015) (Cheung et al. 2015) (Sumaila et al. 2011) (Lam et al. 2014)

Integrated social-ecological indicators	Studies of the adaptive capacity of social-ecological systems based on existing socio-economic and ecological data within or across systems	Key Methods: Assesses the adaptive capacity of social-ecological systems based on ecological and social data (e.g. time series of catches, biomass, ocean conditions, market price, participation). Uses existing data, key informant interviews. E.g. IMBER ADApT (Assessment of Responses based on Description, Appraisal and Typology): Vulnerability, Governability, Response and Appraisal. Attention to: Social-ecological Scale of Analysis: At all scales: Individual to multi-communities to state to cross-national Temporal Focus: Past to present, with lessons for future integration of existing studies.	Strengths: Combines multiple properties and characteristics of the system into a smaller number of variables with similar or greater descriptive power (similar to indicators of human health). E.g. The I-ADApT framework combines both quantitative and qualitative responses to enable more explanation of motivation, etc. The questionnaire format allows people involved in the event to express their opinions. Responses can be timely (e.g. as an event is happening) and does not necessarily rely on subsequent written/published reports. Weakness: Data intensive. Often considers relative measures: difficult to apply to local management. No evaluations of effectiveness of responses. Can be at an overly coarse scale with less application to local communities.	Insights: Understanding of trade offs in fisheries adaptation: In times of rapid change (i.e. climate change), allowing for adaptability by fishers will be critical for the survival of their livelihoods. The I-ADApT framework provides insights which include both natural and social system attributes and responses, as well as how they were integrated. Practical solutions pertain to how scientists, managers, and communities involved in the event responded, at both short and longer time and spatial scales, across cases. Implications & Applications: Need more rapid and effective responses to marine social-ecological crises/events - relevant at a larger policy/governance level for management. IMBER-ADApT can be applied across cases based on a core set of indicators. This method has been applied to case studies (e.g., Monterey Bay, California), and is currently in development.	(Aguilera et al. 2015) (Bundy et al. 2015) (Perry et al. 2011) (Barange et al. 2010) (Miller et al. 2010) (Cinner et al. 2013) (Cinner et al. 2012)
Governance approaches	Approach to understand the role of institutions (rights, rules, norms) and governance dimensions of vulnerability and AC. Assessments not typically framed *a priori* by	Key Methods: Assessment of governance often through conventional social science techniques (semi-structured interviews, focus groups, etc.);	Strengths: Opportunity to consider the role of existing institutions and governance arrangements in facilitating capacity of communities to adapt to change (i.e., as a dimensions of	Insights: Understand the role of networks and multilevel governance important attribute of adaptive capacity Institutions as pathways for	(Dietz et al. 2003) (Gupta et al. 2010) (Pahl-Wostl

	suites of indicators, but rather insights on institutional and governance dimensions of vulnerability and AC developed inductively from case experiences. Where the focus has been more directly oriented towards institutions/governance, some established attributes and indicators are available.	sometimes indicators used Attention to: Linked social-ecological systems and role of institutions and governance processes in mediating human interaction with the environment Scale of Analysis: Local (community-based institutions and governance arrangements) to macro (national, supra-national arrangements) Temporal Focus: Past, Present; Possible to use for future scenario planning.	vulnerable and adaptive capacity); the importance of assessing the capacity of actors to modify institutions in response to change; and that governance is multi-faceted and requires assessments of daily practices of governance, issues of institutional design and its implications, and values and principles that frame governance Weakness: Limited attention to relations of power; emphasis is on governance as context, rather than an analytical lens with which to consider principles and values, institutional design, social practices (e.g. learning). Inadequate attention to the nature of change (i.e. incremental change versus thresholds of change or regime shifts).	knowledge co-production and social learning needed for adaptive capacity Understanding of community-based institutions (customary practices, norms) as sources of adaptive capacity, renewal. Implications & Applications: Enhanced understanding of the social and institutional (formal, non-formal) capacity of actors at multiple levels to make decisions about adaptation, and the linkages/feedbacks among decision making levels about adaptive capacity. Opportunity to apply governance and institutional assessments at multiple levels; contribute to bottom-up and top-down assessments of vulnerability and adaptive capacity.	2009) (Brown et al. 2010) (Smit and Wandel 2006) (Armitage and Plummer 2010)
Multiple community surveys	Studies between several communities where adaptive capacity is measured through assets and actions taken to respond to change. Indicators based on the 5 capitals (human, financial, physical, social, natural) and adaptive strategies.	Key Methods: Household surveys, semi-structured interviews, focus groups Attention to: Interactions between social and ecological stressors, livelihoods Scale of Analysis: Household to community Temporal Focus: Recent past (1 year) to present	Strengths: Allows for inclusion of cultural, historical, or traditional adaptive techniques. Leads to an understanding of potential barriers to adaptation (e.g., economic, cultural). Personal descriptions of adaptations show that strategies vary by socio-economic status (e.g. diversification vs. intensification for poor to wealthy fishers), with differentially impacts on the ecological system	Insights: Insights into how social dynamics constrain or facilitate adaption and what the social/ecological consequences might be (e.g., intensification can increase pressure on resource), which provides better information for intervention depending on the goal of the intervention (e.g., interventions trying to reduce pressure on the resource by diversifying wealthy fishers' livelihoods may not work in this context).	(Blythe 2014) (Blythe et al. 2015) (Blythe et al. 2014) (Cinner et al. 2011)

			(e.g., diminishing vs. amplifying feedbacks). Weakness: Lower explanatory power and intervention actions as specific strategies are highly context specific	Implications & Applications: A more nuanced understanding of livelihood diversification as an adaptation strategy and of material wealth as for a potential barrier for adaptation. Methods can inform interventions to foster adaptive capacity or reduce vulnerability in communities or across sectors	
Social experiments	Social: Field economic experiments where individuals make hypothetical decisions (for economic rewards) based on real-world daily decisions and behaviors relevant to their livelihoods and context.	Key Methods: Economic experiments: Individual choice behavior (Catch decisions). Attention to: Social Scale of Analysis: Local (individual and community) Temporal Focus: Fishers are using past experiences to make catch decisions in the present (which is what we are measuring), and are also reflecting on how these lessons are applicable for the future.	Strengths: Allows researcher to understand fisher decisions in response to different sources of uncertainty in a controlled and replicable way. May also have pedagogical value in providing a platform for reflection in an interactive environment about daily decisions and behavior. Weakness: Unless used with other approaches (i.e. interviews, surveys) does not answer questions about *why* some fishers respond and behave differently or have different levels of adaptive capacity.	Insights: Fishers (within this context) have agency to confront change and uncertainty by adjusting their fishing behaviors to counteract declines in fishery resources. It is a useful way to look at the social-ecological feedbacks of multiple drivers. Implications & Applications: Using this method provides an interactive space for reflection which could induce favorable (increased communication) or unfavorable (exacerbation of power asymmetries) changes in the community itself. No known applications of the results to action.	(Camilo Cardenas and Carpenter 2005) (Castillo et al. 2011) (Gelcich et al. 2013). (Finkbeiner 2015)
Species level experiments	Lab or field based studies in which the responses of populations within a single species are assessed with respect to a particular stressor (e.g. temperature, water chemistry). The objective is to assess adaptive capacity	Key Methods: Ecological experiments assess genotypic or phenotypic variation in observable traits (or loci) within species or populations exposed to different environmental conditions (e.g. temperature,	Strengths: Conceptually simple experimental design (e.g. factorial breeding designs); Provides quantitative estimates of genetic variation, heritability or phenotypic plasticity for species and/or populations of species; Can provide evolutionary potential	Insights: Provides species-specific quantitative assessment of evolutionary potential; quantitative estimates obtained can be combined with demographic information in model simulations to predict future species persistence and	(Bernhardt and Leslie 2011). (Jensen et al. 2008) (Reed et al.

	(genotypic variation and/or phenotypic plasticity) to variation in environmental conditions.	different CO2 concentrations). E.g. Breeding designs, "common garden" experiments, molecular or genomics approaches, meta-analyses. Attention to: Ecological Scale of Analysis: Multiple populations/stocks (regional) Temporal Focus: Assess genetic adaptation or plasticity in traits to help explain current species distributions or predict future adaptive and evolutionary species responses.	based on a single generation. Weakness: Logistical constraints on the number of species and/or populations that can be included in a single study; Controlled lab experiment does not account for natural variability in aquatic systems. Does not account for multiple interacting stressors (e.g. increased temperature and higher CO_2) or trait correlations; Experiments that target specific life-history stage or single generation do not capture multigenerational evolutionary potential. .	community dynamics; gain insight into what species and/or populations have more/less potential for future adaptation. Implications & Applications: Susceptibility to changing environmental conditions varies between species and between populations of the same species: implications for species management (e.g. managing to maintain stock diversity or standing genetic variation, fisheries targeting, and species conservation priorities and approaches). Can apply to selection of populations/stocks/species for aquaculture, hatchery breeding programs), changes to fisheries objectives.	2011) (Crozier et al. 2008) (Hutchings 2011) (Whitney et al. 2013) (Munday et al. 2013) (Sunday et al. 2011) (Muñoz et al. 2014)
Historical ethnographic approaches	Analysis of past adaptive responses within a community or among several communities; at a household or community level. Indicators are based on historical knowledge, traditional engagement with ecological community, traditional ecological knowledge (TEK) holders	Key Methods: Understanding traditional knowledge systems and past adaptations; identifying times of change or stress in historical/archaeological record, oral histories, and personal experiences and analyzing responses to change Attention to: Social-ecological (integration) Scale of Analysis: Local to regional Temporal Focus: Past, recent	Strengths: Understanding of past types and scale of change, and what cultural/social/ ecological adaptations occurred in response; people can relate to changes experienced by ancestral peoples; can inspire adaptive capacity in contemporary circumstances Weakness: Past changes and adaptations many not be relevant to modern circumstances; Takes time to gain community trust and acceptance; Not necessarily applicable at large scales.	Insights: Knowledge transmission and sharing through stories and ceremonies contributes greatly to adaptive capacity of people and communities. Strong social structures really help communities adapt, along with access to resources. Knowing how ancestors have responded to and overcome changes and difficulties can inspire people to face and adapt to change in their own lives Implications & Applications: Communities where strong ties	(Alcorn et al. 2002) (Atleo 2011) (Berkes 2012) (Berkes et al. 2000) (Berkes et al. 2003) (Ford and Martinez 2000) (Menzies

		and distant		between generations are apparent also benefit from adapting to change; access to traditional knowledge is important. Community leaders and others who are trained from a very young age provide knowledge bank to draw from. The use of stories, ceremony, art, to convey experiences of past adaptation can inspire and inform adaptation to changes today, and inform ecological restoration.	2006) (Senos et al. 2006) (Turner 2014)
Participatory planning approaches	Urban and regional planning for resilience related to changing hydrological systems and risk assessments	Key Methods: Mixed methods: interviews, a regional survey and participant observation at key regional planning events over 3 years [and] participatory action research. Planning approaches to adaptive capacity have ranged from 'participatory futures approaches' to community-based climate change adaptation (by engaging and empowering community members to be active collaborators in re-visioning and developing scenarios about their communities that facilitates co-evolutionary adaptation to climate change rather than passive adaptation. Attention to: Socio-ecological system	Strengths: Comprehensive, multiple streams of evidence, easy to triangulate evidence types. Participatory action research can foster new knowledge, learning, and action to support positive social/environmental change through reconfiguring the standard processes of knowledge production. An informal collaborative can be seen as a safe shadow space for learning more inclusive and less political that other regional forums where thinking out loud, revealing uncertainties, collectively troubleshooting and learning from neighbouring municipalities may not be doable or would be considered as inappropriate (less inclusive). Weakness: Very time consuming	Insights: Participatory vulnerability assessments can help identify adaptation strategies that are most feasible and practical in communities with a focus on risks that are already problematic; while climate stresses are reviewed along environmental and social stresses, allowing for integration and co-benefits with resource management, disaster preparedness and sustainable development initiatives. Implications & Applications: Allows for in-depth *understanding* and building of *adaptive capacity* which can serve as an effective link from assessment to action. This methodology allows to identify and address specific hazards and risks while building a	(Pelling et al. 2008) (Folke et al. 2002) (Gidley et al. 2009) (Smit and Wandel 2006) (Ballard and Belsky 2010) (Tschakert and Dietrich 2010)

		Scale of Analysis: Community (municipal), sub-regional, and regional Temporal Focus: Past (historical adaptations), present, and future		generalized capacity to address change. Study findings may inform local and metropolitan scale actions by partner organizations.	
Qualitative interview approaches	Inductive qualitative assessment within a community using local knowledge engagement. Indicators include various assets, organizations, and other supports that interviewees mentioned help or have helped them adapt to changes and their impacts.	Key Methods: Interviews and focus groups; unstructured and semi-structured interview format Attention to: Social and ecological components Scale of Analysis: Household to community Temporal Focus: Past and present impacts of change and drivers of adaptive capacity	Strengths: Gives an in-depth understanding of a community with household or individual responses to change. Builds a relationship with that community. Based on self-perception of adaptive capacity from the perspective of the community members themselves. Weakness: Very time intensive; requires community buy-in, often pre-existing relationships or understanding of the community are critical. Need to build trust to collect information.	Insights: Gain a greater range of the elements of adaptive capacity. Appreciate the nuance of limitations and opportunities at an individual or household level. Insights included: 1) types and trajectories of significant processes of change being experienced by community members, 2) the array of responses being taken to change and 3) the mechanisms that either inhibit or strengthen ability to adapt or cope with changes, including nuanced data around access to supports. Implications & Applications: Provides data for planners, decision makers, and communities on what types of policies, programs, and other supports might lead to improved adaptive capacity for groups at the local level. An increased understanding of barriers or limitations to accessing exiting supports is key to increasing successful responses across community groups.	(Bennett et al. 2015) (Knapp et al. 2014) (McCubbin et al. 2015) (Ruiz-Mallén et al. 2015)
Mixed-methods	A combination of social indicators, including	Key Methods: Mix of qualitative, quantitative and	Strengths: Nuanced understanding of the factors that lead to adaptive	Insights: Numerous insights about how to increase adaptive	(Cinner et al.

approaches	interviews, surveys, focus groups, document reviews, and Photovoice processes in order to understand flexibility and diversity, the ability to self-organize, social knowledge and learning, and access to assets.	participatory approaches. Attention to: Primarily social, as well as ability to proactively respond to ecological change. Scale of Analysis: Household, Individual community to multiple community. Temporal Focus: Present	capacity. Leads to abundant data. Differentiation of the factors that led to adaptive capacity to different changes – e.g., climate change, fisheries declines, and livelihood opportunities. Results are comprehensive, showing whether communities are able to adapt, cope or react. Produces lots of recommendations. Weakness: Very time consuming and expensive. Difficult to confirm the recommendations/outcomes with stakeholders.	capacity to different changes that are occurring. Insights into some generic actions to build adaptive capacity e.g., improving relations, gender considerations, education. Research can provide insights into which factors helped communities to adapt, cope or react to changes that are occurring. Implications & Applications: Suggests actions that communities might take for policies or programs that might be implemented at higher levels to increase community adaptive capacity. No clear path to application of the results.	2009) (McClanahan et al. 2009) (Bennett et al. 2015) (Bennett and Dearden 2013) (Cinner et al. 2015) (Marshall et al. 2010) (Marshall et al. 2013)

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