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Assessing climate change vulnerability in fisheries and aquaculture

Available methodologies and their relevance for the sector

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An earlier version served as a background document for the global Expert Workshop on Assessing Climate Change Vulnerability in Fisheries and Aquaculture: Available Methodologies and their Relevance for the Sector, which was convened by the FAO Fisheries and Aquaculture Department Climate Change Working Group and the Global Partnership on Climate, Fisheries and Aquaculture (PaCFA) in Windhoek, Namibia, from 8 to 10 April 2013, and hosted by the Benguela Current Commission. It benefited from the constructive comments received from PaCFA members, and in particular those of Prof James Muir, to whose memory this publication is dedicated. Outcomes of the discussions and feedback provided by participants at the Windhoek Expert Workshop have been incorporated in the present publication.

Abstract

From relatively limited and narrow uses two decades ago, the concept of vulnerability has emerged as a key dimension of the development debate. Be it in relation to climate change, disasters, globalization and economic development, and social–ecological system changes more generally, vulnerability is a complex and multifaceted concept that has attracted the attention of scholars and development practitioners from all disciplines. The many interpretations of vulnerability and its many scales (e.g. individual, community, ecosystem, countries, continents) and fields of application have led to a wide array of propositions regarding ways and means by which vulnerability could be studied, characterized, understood, and acted upon. This multiplication of approaches and methodologies of assessment has enabled new insights into the causes and consequences of vulnerability, but has also caused some confusion among practitioners and led to the voicing of a need for clarification and guidance on how best to approach the study of vulnerability. This publication provides an overview of vulnerability assessment concepts and methodologies. It sheds light on the different vulnerability assessment methodologies that have been developed, and on how these are conditioned by the disciplinary traditions from which they have emerged. It also analyses how these methodologies have been applied in the context of fisheries and aquaculture, with illustrative examples of their application. A series of practical steps to assess vulnerability in the fisheries and aquaculture sector is proposed in order to support climate change specialists working with communities dependent on fisheries and aquaculture, as well as fisheries and aquaculture practitioners wishing to incorporate adaptation planning into the sector's management and development.

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Abbreviations and acronyms

ABM	agent-based model
ARCC	Adaptation and Resilience to Climate Change
AR4	IPCC Fourth Assessment Report
CAM	Climate Change Vulnerability Assessment and Adaptation Methodology
CC	climate change
CSI	climate sensitivity index
CVI	coastal vulnerability index
EAF/EAA	ecosystem approach to fisheries/aquaculture
EEZ	exclusive economic zone
GDP	gross domestic product
GIS	geographic information system
HadCM3	Hadley Centre for Climate Prediction and Research model
IPCC	Intergovernmental Panel on Climate Change
KnETs	knowledge elicitation tools
LMB	Lower Mekong Basin
LVI	livelihood vulnerability index
MCDA	multi–criteria decision analysis
PaCFA	Global Partnership on Climate, Fisheries and Aquaculture
PET	potential evapotranspiration
PICTs	Pacific Island countries and territories
PRA/RRA	Participatory rural appraisal / rapid rural appraisal
PROVIA	Programme of Research on Climate Change Vulnerability, Impacts and Adaptation
PVI	physical process vulnerability index
P–GIS	participatory geographic information system
SAWS	South African Weather Service
SEVI	Socio-economic Vulnerability Index
SIDS	small island developing States
SL	sustainable livelihoods (framework)
SVI	social vulnerability index
UNFCCC	United Nations Framework Convention on Climate Change
USAID	United States Agency for International Development
VA	vulnerability assessment
VSD	vulnerability scoping diagram

1. Introduction

From relatively limited and narrow uses two decades ago, the concept of vulnerability has emerged as a key dimension of the development debate, often discussed and analysed along with its counterpart: resilience (Miller *et al.*, 2010). Be it in relation to climate change, disasters, globalization and economic development, and social–ecological system changes more generally, vulnerability is a complex and multifaceted concept that has attracted the attention of scholars and development practitioners from all disciplines. The many interpretations of vulnerability and its many scales (e.g. individual, community, ecosystem, countries, continents) and fields of application have led to a wide array of propositions regarding ways and means by which vulnerability could be studied, characterized, understood, and acted upon. This multiplication of approaches and methodologies of assessment has enabled new insights into the causes and consequences of vulnerability, but has also caused some confusion among practitioners and led to the voicing of a need for clarification and guidance on how to best approach the study of vulnerability. This document provides an overview of vulnerability assessment concepts and methodologies, focusing on issues relevant to the fisheries and aquaculture sector to support climate change specialists working with communities dependent on fisheries and aquaculture, as well as fisheries and aquaculture practitioners wishing to incorporate adaptation planning into the sector's management and development.

WHY A VULNERABILITY ASSESSMENT

Vulnerability assessments (VAs) can be used for many different purposes, including improving adaptation planning (designing of policies and interventions), raising awareness of risks and opportunities, and advancing scientific research (Patt *et al.*, 2009). This document assumes that the main purpose of understanding vulnerability and, therefore, of undertaking a VA is to **improve the targeting and effectiveness of adaptation actions**.

Through a VA, one seeks to answer the basic question of "who (or what) is vulnerable to what?" by asking:[1]

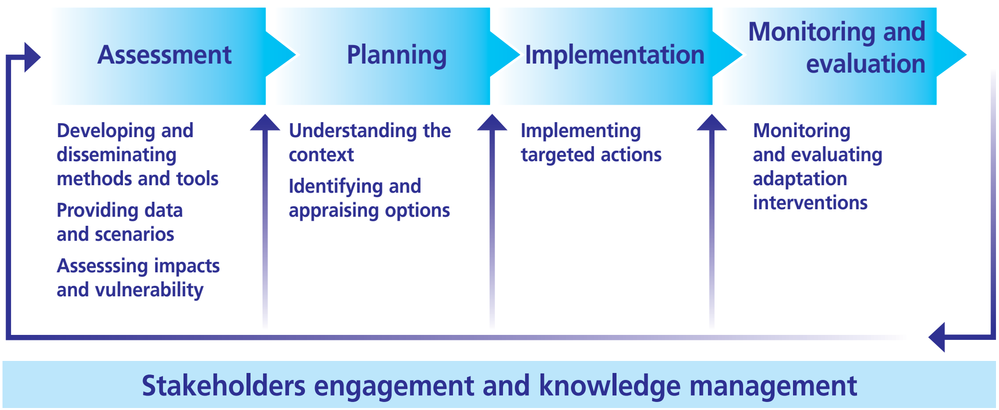
- **Who** are the vulnerable **people / species / production systems** and how can their vulnerability be reduced?
- **Where** are the vulnerable **ecosystems**? Can their capacity to adapt be supported by resource management?
- **Where** will the **economic and social** consequences of vulnerability of fishery or aquaculture systems be felt most? How can one plan to minimize those consequences?
- **Where** will climate change create new opportunities and bring benefits? For whom? How can one ensure these opportunities improve human well-being?

Depending on the context, a VA may be concerned about the vulnerability of **people** at different scales (individuals, social groups, households, communities, provinces, nations, regions) or the vulnerability of different **human activities** (e.g. agriculture, fisheries, aquaculture, tourism, transport, habitation). In addition, a vulnerability assessment may be concerned with specific **places** (e.g. lake and river basins, low-lying coasts, enclosed seas, deltas, upwelling systems) or vulnerabilities to particular **stressors/ hazards** (i.e. natural disasters, global environmental change, or change in general).

[1] Revised from a presentation made by Edward Allison (FAO, 2013a).

This report assumes that VAs are not stand-alone activities. If their specific place within a continuum of activities is sometimes debated, they are usually found at the outset of the adaptation process. Lim and Spanger-Siegfried (2004), for example, place VAs after considering a project design and scope, and before assessing the impacts of future climate variability. The United Nations Framework Convention on Climate Change (UNFCCC), on the other hand, places vulnerability assessment among the first stages of the adaptation process (Figure 1).[2]

FIGURE 1
The adaptation process and its four key components



Source: UNFCCC (2011).

VULNERABILITY IN FISHERIES AND AQUACULTURE

Many economies and people are dependent on fisheries and aquaculture for food, livelihoods and revenue generation. Greenhouse gas accumulation, climate change and the associated impacts in terms of sea-level rise, ocean acidification and changes in salinity, precipitation, groundwater and river flows, water stresses and extreme weather events are changing the productivity of aquatic habitats, modifying the distribution and productivity of both marine and freshwater fish species. Such changes are affecting the seasonality of biological and biophysical processes as well as increasing direct risks to human well-being, infrastructure and processes throughout the fisheries and aquaculture production chain.[3]

These changes are in addition to the multiple drivers of change already faced within the sector, such as changes in markets, management frameworks, fishing practices and demographics. However, it may not always be possible to associate a given driver of change (such as increases in water temperatures) to perceived or documented changes (such as decreases in fish stocks) given the current state of knowledge of the social–ecological system and unknown cumulative impacts of different drivers of change (e.g. overfishing and natural variability). However, even in the face of such uncertainty, a VA may enhance understanding of how the sector and its dependent economies and communities are unable to cope with (or take advantage of) existing and projected changes, so facilitating action to support human and ecosystem well-being.

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[2] The recent "PROVIA Guidance on Assessing Vulnerability, Impacts and Adaptation to Climate Change" provides for a similar adaptation cycle, stressing that real-world adaptation processes are likely to be non-linear, iterative and adaptive, fitting their own situations (PROVIA, 2013). See also "The Vulnerability Sourcebook", which offers step-by-step guidance for designing and implementing a vulnerability assessment that covers the entire life cycle of adaptation interventions (Fritzsche *et al.*, 2014).

[3] See, for example, Cheung *et al.* (2010), Cochrane *et al.* (2009), Duriyapong and Nakhapakorn (2011), Cooley *et al.* (2012) and Barange *et al.* (2014).

Specific adaptation actions will be guided by the VA – depending on the answers to the vulnerability questions asked – and could include actions such as: incorporating uncertainty into decision-making and management process; supporting transitions to alternative species, production and post-harvest processes; supporting the development of alternative or diversified livelihoods; enhancing natural barriers, protecting fish habitats through adaptive spatial management; and incorporating climate change into transboundary water and natural resource planning across sectors.[4]

In recent years, a number of initiatives have implemented different approaches to better characterize and understand the broad threats and underlying issues facing fisheries and aquaculture. Therefore, the purpose of this document is to shed light on the different VA methodologies that have been developed, how these are conditioned by the disciplinary traditions from which they have emerged, and how they have been applied in the context of fisheries and aquaculture.

This review builds on previous work and reviews of vulnerability concepts and approaches for assessments. It is based on extensive searches of the published and grey literature. Preference was given to relatively recent works (2007 onwards), which are themselves building on previously published literature (Janssen, 2007). An annotated bibliography on the application of climate change VA methodologies in fisheries and aquaculture (Barsley, De Young and Brugère, 2013) was developed to support this review. The report may also be seen as a fisheries and aquaculture vulnerability assessment supplement to the PROVIA (2013) document, which presents each stage of an adaptation cycle[5] and a wide array of approaches, methods and tools available for each stage and context.

The document starts with a review of concepts to help understand what vulnerability is and how it can be studied (Chapter 2). Chapter 3 provides information on available methodologies to measure and evaluate vulnerability. Their application in the context of fisheries and aquaculture is detailed in Chapter 4. Chapter 5 proposes a series of practical steps to assess vulnerability in the sector. Further reflections on moving from vulnerability assessment to adaptation interventions are detailed in Chapter 6, and Chapter 7 concludes.

[4] See, for example, Daw *et al.* (2009), Cinner *et al.* (2013), Hammill *et al.* (2013).

[5] The PROVIA guidance is structured along a five-stage iterative adaptation learning cycle: 1) Identifying adaptation needs (What are the impacts and vulnerabilities?); 2) Identifying adaptation options (How can the specific risks and opportunities be addressed?); 3) Appraising adaptation options (What are the pros and cons of the different options?); 4) Planning and implementing adaptation actions (Planning, assigning responsibilities, setting up institutional frameworks, and taking action.); and 5) Monitoring and evaluation of adaptation (Are things going as planned? Identify any problems, document the outcomes achieved, change course as needed, and draw lessons from the experience).

2. Understanding vulnerability: clarifying concepts and perspectives

Vulnerability is a complex and subjective topic, and its etymology has evolved over time. Many scholars from the natural and social sciences have worked on what vulnerability means in particular disciplinary contexts, resulting in interpretations of vulnerability focused on different components of the social–ecological system under study, different physical and time scales, and different methodologies of investigations. Thus, the disciplinary perspectives from which vulnerability is considered shape the questions asked and the methodologies used to answer these questions, conditioning not only the focus of the analysis and enquiry process, but also the interpretation of the findings and subsequent adaptation actions. For those wishing to implement a VA, it is therefore important to understand these disciplinary roots, as this will ultimately influence their understanding of the vulnerability of the system at hand (McLaughlin and Dietz, 2008).

DESCRIBING AND UNDERSTANDING VULNERABILITY

Box 1 outlines the interpretation of vulnerability from the **risk/hazard**, **political economy or ecology**, and **resilience** schools of thought. These are three dominant disciplinary traditions that have a strong influence on how research on vulnerability is carried out (Adger, 2006; Eakin and Luers, 2006; Füssel, 2007; McLaughlin and Dietz, 2008). Table 1 presents some of the differences among the types of questions asked, the

BOX 1

Vulnerability – schools of thought

Political economy perspective on vulnerability
A perspective that emphasizes the sociopolitical, cultural and economic factors that together explain differential exposure to hazards, differential impacts and differential capacities to recover from past impacts and/or cope and adapt to future threats. As the political ecology perspective, it focuses on the political dimension of vulnerability and highlights social inequalities and points of conflicts within societies.

Political ecology perspective on vulnerability
A perspective that explores vulnerability with respect to broad processes of institutional and environmental change and that argues for a balanced consideration of both biophysical and social dynamics in decision-making. As the political economy perspective, it focuses on the political dimension of vulnerability and highlights social inequalities and points of conflicts within societies.

Resilience approach to vulnerability
An approach that gives a predominant weight to the implications of social and environmental change across the broader geographic space, reducing human activity to just one of the driving forces and humans themselves as only one of the affected species.

Risk–hazard approach to vulnerability
An approach that uses a biophysical threat as point of departure and that describes, on a very broad scale: what a unit/system is vulnerable to, what consequences might be expected, and where and when those impacts might occur.

Source: Eakin and Luers (2006).

TABLE 1
Influence of three schools of thought on understanding vulnerability

	Risk–hazard school	Political economy/ecology school	Resilience school
Key focal vulnerability questions	What are the hazards? What are the impacts? Where and when?	How are people and places affected differently? What explains differential capacities to cope and adapt? What are the causes and consequences of differential susceptibility?	Why and how do systems change? What is the capacity to respond to change? What are the underlying processes that control the ability to cope and adapt?
Key elements of vulnerability	Exposure, sensitivity	Capacity, sensitivity, exposure	Thresholds of change, reorganization, capacity to learn and adapt
System to be evaluated (i.e. unit of exposure)	Places, sectors, activities, landscapes, regions	Individuals, households, social groups, communities, livelihoods	Ecosystems, coupled human–environmental system
Scale of evaluation	Regional, global	Local, regional, global	Landscapes, ecoregions, multiple scales

Source: Eakin and Luers (2006).

vulnerability elements focused on, scales of analysis chosen, and types of systems these major schools of thought tend to focus on.

Other perspectives on vulnerability, which either encompass more than one of the three dominant constructs or simply depart from them all, have also been put forward. Two important groupings of different perspectives include whether vulnerability is considered as an **outcome** of a given change (outcome vulnerability) or is determined by current **contextual** underpinnings (contextual vulnerability) (O'Brien *et al*., 2004, 2007). Table 2 summarizes their key features. Put briefly, outcome vulnerability relates to the effects of future climate/environment-related changes as a driver of a system's vulnerability. Contextual vulnerability looks at how the current contextual situation of a system may affect its vulnerability to current and future climate change. Because each perspective considers different elements of vulnerability, each calls for a different set of methodologies, usually borrowing from both the natural and social sciences. For example, the investigation of outcome vulnerability generally relies on *ex ante* assessments with a relatively narrow focus on a limited set of climate change drivers (e.g. temperature-driven changes in species distributions) and tends to use model-based investigation approaches. These assessments mirror the approaches adopted in the risk/hazard literature on climate change. The study of contextual vulnerability aims to provide a holistic understanding of the multiple drivers of vulnerability and tends to use participatory and survey-based approaches. As a consequence, outcome-oriented investigations tend to be linear, as opposed to the iterative process of context-oriented vulnerability investigations (O'Brien *et al*., 2007). By way of example, answering the question "Who is vulnerable to climate change?" from an outcome vulnerability perspective might imply looking at expected net impacts (economic, biological, etc.) in different systems. From a contextual vulnerability perspective, it might imply looking at, for example, differences in ethnicity, social class and gender as indicators of how different groups within a system might be more or less vulnerable to change. In other words, outcome investigations will tend to answer "what" and "who" is vulnerable, whereas contextual investigations will aim to provide insights into "why" who and what are vulnerable. According to this interpretation, the outcome construct of vulnerability is more closely associated with the risk/hazard school of thought on vulnerability, whereas the contextual perspective echoes more closely dimensions of both the political economy/ecology and resilience schools of thought. Although O'Brien *et al*. (2007) recognized that these two perspectives are complementary, they argued that their roots in different discourses and fundamental differences in their

TABLE 2
Key features of the outcome and contextual vulnerability perspectives

Perspectives	Outcome vulnerability	Contextual vulnerability
Root problem	Climate change	Social vulnerability
Policy context	Climate change mitigation, compensation, technical adaptation	Social adaptation
Relationship between vulnerability and adaptive capacity	Adaptive capacity determines vulnerability	Vulnerability determines adaptive capacity
Starting point of analysis	Future climate hazards (scenarios)	Current vulnerability to climate change
Dominant discipline	Natural sciences	Social sciences
Meaning of vulnerability	Expected net damage for a given level of global climate change	Susceptibility to climate change and variability as determined by socio-economic factors

Source: O'Brien *et al.* (2004, 2007).

conceptualization of the character and causes of vulnerability would make it difficult for the two perspectives to be integrated into "one common framework".

McLaughlin and Dietz (2008) proposed an **integrative construct** of vulnerability at the interface of social structure, human agency and the environment (or environments) and their relationships in shaping vulnerability (either as producing or mitigating it). Social structure is understood as any social unit (e.g. household, community, organization) and its functioning (e.g. role, decision-making). Human agency refers to "the capacity of individual and corporate actors, with the diverse cultural meanings that they espouse, to play an independent causal role in history". The term environment (or environments) refers to the multiple biophysical and social dimensions an organism, population or ecosystem is related to (hence the plural form of the word). This description of vulnerability attempts to be at the interface of the three broad conceptual traditions of vulnerability.

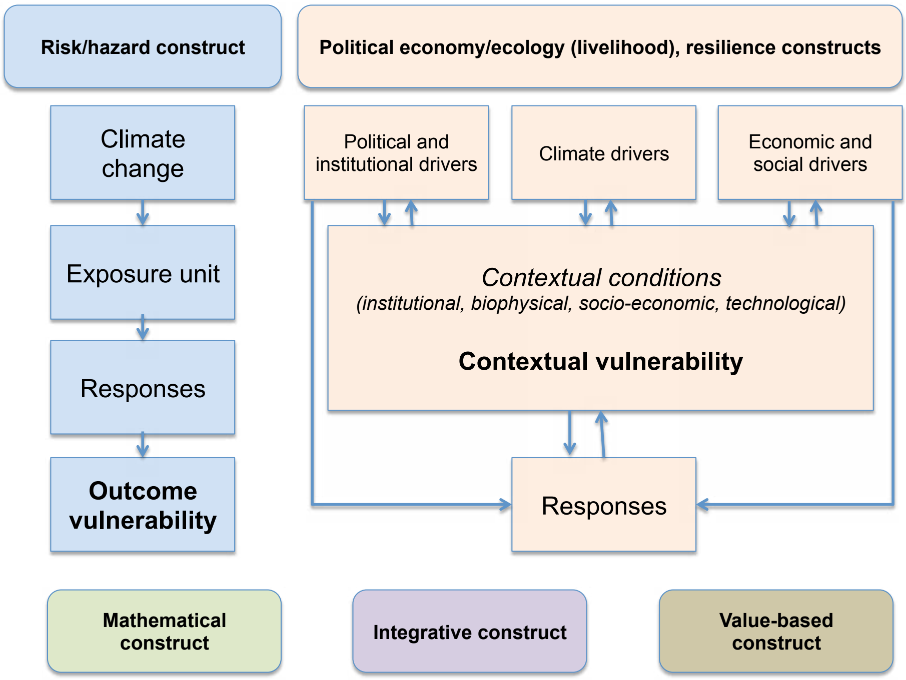
Ionescu *et al.* (2009) proposed a **mathematical construct** of vulnerability grounded in systems theory as a way to overcome, through mathematical notations, conceptual divides and to support rigorous interdisciplinary research. Although this is an innovative way of presenting vulnerability – and the authors noted that "mathematical" does not necessarily imply quantitative – their construct may have limited appeal, in particular among VA practitioners.

More recently, O'Brien and Wolf (2010) have tried to fill a shortcoming in the outcome and contextual vulnerability constructs related to the role human subjectivity plays in the understanding and perception of vulnerability. Placing people's values and perceptions of vulnerability at the centre of their **value-based construct** of vulnerability is an important move forward in conceptual vulnerability debates.

Figure 2 presents the key features of different vulnerability schools of thought and elements, and broadly relates them to one another.

In parallel to these conceptual developments, a number of authors have proposed **frameworks** to capture the linkages between the various elements of vulnerability and to link vulnerability to climate change adaptation. Two of these frameworks, by Turner *et al.* (2003a) and Füssel and Klein (2006), succeed in bridging various schools of thoughts and are of potential relevance to guide an empirical investigation of vulnerability. They are detailed in Appendix 1. However, there is no perfect and comprehensive enough, yet simple and directly applicable, framework. Each framework reflects the perspective on vulnerability its authors have adopted, and each captures to greater or lesser extents the various components of vulnerability discussed above. In addition, none seems to simultaneously capture outcome and contextual vulnerability – a compatibility issue highlighted by O'Brien *et al.* (2007), or the dynamics, multiple dimensions and scale dependence of vulnerability (Vogel and O'Brien, 2004). Another of their main shortcomings for practical applications relates

FIGURE 2
A broad categorization of vulnerability perspectives and their key features



Source: UNFCCC (2011).

to the fact that no methodology (or mix of methodologies) of investigation clearly emerges from any of the frameworks; leaving this choice open – and problematic – to framework users.

The IPCC model of vulnerability

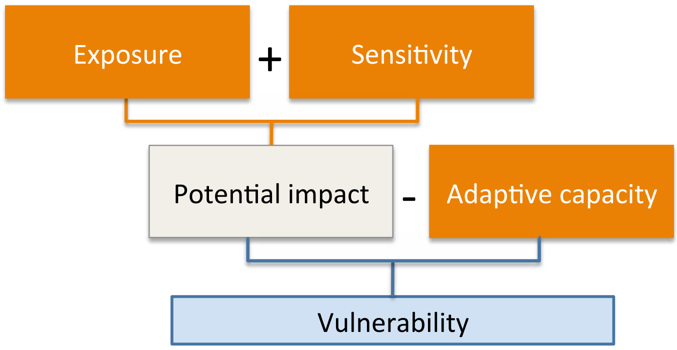
In 2001, in its Third Assessment Report, and again in 2007 in the Fourth Assessment Report, the Intergovernmental Panel on Climate Change (IPCC) took stock of these conceptual developments to define vulnerability. Thus, combining the key elements of vulnerability from the various schools of thought, it defined vulnerability as a function of a system's exposure to change, its sensitivity to such change and its capacity to adapt to it (see Box 2). This simple generic definition provides flexibility to allow different disciplinary perspectives to enter into this definition with their particular biases, while promoting the inclusion of additional perspectives. For example, the exposure elements tend to link well to the outcome perspectives on vulnerability, and the sensitivity and adaptive capacity elements allow for an understanding of contextual vulnerability.

Owing to its generic yet encompassing nature, the IPCC definition is usually found as the starting point of studies on vulnerability, and in both conceptual and empirical analyses of the relationships between its different components.

Figure 3 presents the IPCC conceptual model of vulnerability as a function of exposure, sensitivity and adaptive capacity.

More recently, in its 5th Assessment Report (AR5) (Oppenheimer *et al*., 2014), the IPCC endeavored to underline the importance of "Contextual vulnerability" in understanding the risks faced by nature and society by expressing contextual vulnerability as a determining factor of risk. Risk, according to the AR5, is evaluated by a combination of the likelihood or probability that an event will happen and the consequences if that event were to occur. According to this interpretation, and depending on how factors of risk are interpreted, a risk assessment can provide the similar information as a vulnerability assessment – the event and its likelihood can be

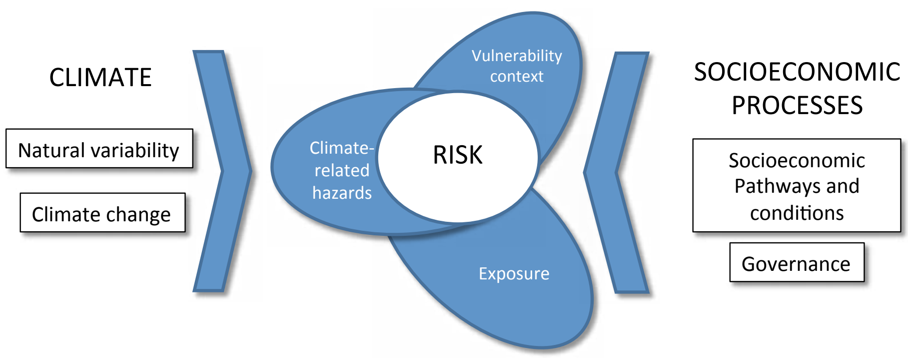
FIGURE 3
IPCC-derived conceptual model of vulnerability



Source: Adapted from McCarthy *et al.* (2001).

interpreted as the exposure to an event and the consequences of an event can be linked to the sensitivity and adaptive capacity of the system, for example. As noted above, however, the risk/hazard approach tends to focus on the driver of change as the main determinant of vulnerability – that is to say the "Outcome vulnerability" – and does not sufficiently explain why given different systems may or may not be vulnerable in the face of the same event (i.e. the "Contextual vulnerability"). Acknowledging this potential limitation, the AR5 provides an interpretation of risk (Figure 4) that explicitly links 1) the likelihood of impacts of climate-related hazards (single events or trends), such as sea level rise, acidification, increases in water temperatures, 2) an understanding of how exposed the system is to the hazard, such as the number of coastal communities in a region, the number of commercially important fish species in a lake, the existence of coral reefs, and 3) an understanding of the vulnerability context[6] existing within the system. This latter element enables to bridge the previous IPCC definition of vulnerability (AR4, 2007) with the concept of risk put forth in the AR5 (2014). Thus, the vulnerability context in the AR5 focusses in particular on the sensitivity to change and the adaptive capacity of the system. The AR5 goes on to acknowledge that many socioeconomic factors (demographics, governance frameworks, etc.) may determine how a system is exposed to climate-related drivers, how it is sensitive to such drivers

FIGURE 4
How hazards, exposure and vulnerability contexts determine risk



Source: Adapted from Oppenheimer *et al.*, 2014.

[6] The term context has been added by the authors to minimize confusion stemming from a different definition of the term "vulnerability" as described in the IPCC AR5.

and whether or not the system is able to adjust, cope or take advantage of change. Essentially, a change is important (i.e. high risk) if nature or society is exposed to and affected by it and if nature or society is unable to adapt to this change.

Readers may refer to the Glossary in this publication for a list of the key vulnerability terms and concepts discussed thus far.

LINKS TO OTHER CONCEPTS AND FRAMEWORKS

A number of other concepts and frameworks complement the IPCC vulnerability model. Although sometimes differing in vocabulary or methodologies, all these concepts and frameworks ultimately aim to support sustainable development. Understanding what each concept or framework has to offer in terms of perspectives, tools and methodologies, and how these can be used complementarily to improve human and ecosystem well-being in the face of change is therefore of fundamental importance.

Resilience

The term "resilience", which did not appear in direct relation to the IPCC vulnerability definition, has grown in use and now constitutes a large and influential body of literature. Resilience is the capacity of a system to absorb disturbance and reorganize while undergoing change so as to retain essentially the same function, structure, identity and feedbacks (Holling, 1973; Walker *et al*., 2004). It is concerned with "the magnitude of disturbance that can be absorbed or buffered without the system undergoing fundamental changes in its functional characteristics" and characterized by a system's ability to adapt, learn and self-organize (Berkes, Colding and Folke, 2003). Initially used to characterize ecosystems, the concept of resilience has since been broadened to encompass human systems and become a school of thought in its own right (Walker *et al*., 2006). Adaptability, transformation, regime shifts, tipping points, thresholds and non-linearity are all underlying dimensions of resilience. The desired outcome of the analysis of a system's resilience is to propose actions that will restore the resilience lost in a system, or enhance its functioning to allow a greater array of safe and acceptable resource-use options (Walker *et al*., 2002). Although interpretations of resilience vary, the characteristics of resilient systems have been described in an increasingly wide range of contexts in recent years, for example, in relation to: food production systems (Meybeck *et al*, 2012; Naylor, 2008); climate change and the Peruvian anchovy fishery (Badjeck *et al*., 2009); impact of development projects on community resilience (Bunce, Brown and Rosendo, 2010); post-disaster recovery for aquaculture-dependent livelihoods (Mills *et al*., 2011); and an objective for natural resources research and management (Walker *et al*., 2010).

If the incorporation of time in resilience and vulnerability is sometimes seen as a differentiating dimension between the two concepts (Gitz and Meybeck, 2012), resilience and vulnerability are closely related, and it is difficult to talk about one without talking about the other (Adger, 2006; Füssel, 2007; Miller *et al*., 2010). Table 1 underscored the perspective brought by the resilience school of thought on vulnerability questions. Methodologically, studying resilience raises many conceptual debates and practical issues (Strunz, 2012). The authoritative resilience assessment guidelines that have been developed for both practitioners and scientists[7] could be consulted by those implementing VAs to assist them in assessing particular dimensions of vulnerability such as thresholds, capacity to reorganize, adapt and learn.

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[7] *Assessing resilience in social-ecological systems: Workbook for practitioners* (revised version 2), *Assessing resilience in social-ecological systems – A workbook for scientists* are available from www.resalliance.org/index.php/resilience_assessment

Sustainable livelihoods

The sustainable livelihoods (SL) framework (Scoones, 1998; DFID, 1999), which was developed to guide interventions aimed at alleviating poverty though the development of sustainable livelihoods, includes vulnerability as one of its key features. Livelihood vulnerability is seen as stemming from shocks and trends of any kind, and from seasonality. It is both influenced by broader governance processes and affects the natural, human, financial, social and physical capital assets that underpin livelihoods. More than a decade of implementation of the SL framework in a variety of contexts shows that vulnerability has rarely been studied in the depth that the IPCC model suggests, but has enabled it to be embedded among other livelihood components, i.e. study and understand it as an evolving and integral aspect of livelihood dynamics. Insights gained on the cause-and-effect relationships of vulnerability with the other components of the livelihood framework are complementary to those to be gained from the study of exposure, sensitivity and adaptive capacity. Vice versa, the knowledge gained from the study of the three components of the IPCC model will benefit from being placed in a broader livelihood context.

Institutional analysis and development framework

The institutional analysis and development framework, stemming from political theory and collective action analysis, aims to document how individuals behave in collective action settings and the institutional foundations that inform such arrangements (Ostrom, 2011). The framework identifies key variables that are important in evaluating the role of institutions in shaping social interactions and decision-making processes. These variables are: institutions or rules that govern the action arena; the characteristics of the community or collective unit of interest; and the attributes of the physical environment within which the community acts (Ostrom, 1990, 2005). Understanding the interplay between these variables is of particular importance from a vulnerability point of view because of their weight on the capacity of people – and people within systems – to cope, respond and evolve in the short and longer terms to external stressors, be these climate-related or not.

Sendai Framework for Disaster Risk Reduction

The Sendai Framework for Disaster Risk Reduction (2015-2030), a successor to the ten-year Hyogo Framework for Action (UN/ISDR, 2007), is a fifteen-year plan to explain, describe and detail the work that is required from all different sectors and actors to reduce disaster losses (UN/ISDR, 2015). It was developed with and agreed upon by the many partners needed to reduce and manage disaster risk – governments, international agencies, disaster experts and many others – bringing them into a common system of coordination. The framework outlines four priorities for action,[8] and offers guiding principles and practical means to reduce disaster losses substantially by building the resilience of nations and communities to disasters. This means reducing loss of lives and social, economic, and environmental assets when hazards strike.

The Sendai Framework maintained the Hyogo Framework contextual perspective on vulnerability by defining it as: "The conditions determined by physical, social, economic, and environmental factors or processes, which increase the susceptibility of a community to the impact of hazards", whereas its view of hazards as "A potentially damaging physical event, phenomenon or human activity that may cause the loss of

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[8] Priority actions are:
1. Understanding disaster risk.
2. Strengthening disaster risk governance to manage disaster risk.
3. Investing in disaster risk reduction for resilience.
4. Enhancing disaster preparedness for effective response and to "Build Back Better" in recovery, rehabilitation and reconstruction.

life or injury, property damage, social and economic disruption or environmental degradation" also anchors it in the risk/hazard and outcome vulnerability perspective – although broader than just to climate change. The scope of the Sendai Framework encompasses small-scale and large-scale, frequent and infrequent, sudden and slow-onset disasters, caused by natural or manmade hazards as well as related environmental, technological and biological hazards and risks. It thus reflects a holistic and multihazard approach to vulnerability and disaster risk management that encompasses impacts on social, economic, cultural and environmental systems.

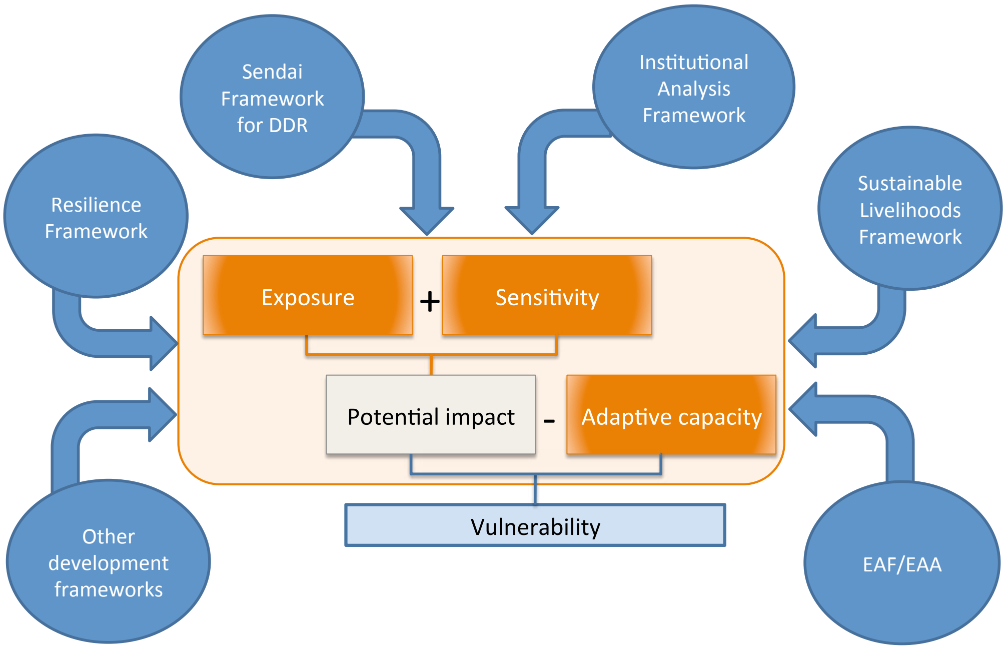
Ecosystem approach to fisheries/aquaculture (EAF/EAA)

The ecosystem approach to fisheries (Garcia *et al*., 2003, FAO, 2003) and the ecosystem approach to aquaculture (FAO, 2010) provide a particular focus on the management and governance of aquatic food systems for human and ecosystem well-being that the frameworks described above lack. Both approaches stress the need for holistic, integrated and participatory processes to achieve sustainable development in fisheries and aquaculture. The purpose of an EAF is to: "plan, develop and manage fisheries in a manner that addresses the multiple needs and desires of societies, without jeopardizing the options for future generations to benefit from the full range of goods and services provided by the aquatic ecosystems". Similarly, the EAA is seen as "a strategy for the integration of the activity within the wider ecosystem such that it promotes sustainable development, equity, and resilience of interlinked social–ecological systems". From a vulnerability point of view, both the EAF and the EAA can be used to identify key climate change issues that affect, or are likely to affect in the future, the ecological well-being of the system under consideration, the well-being of the people it supports, and, *inter alia*, its ability to achieve this. From an adaptation point of view, they can also be used to address climate change: either through the promotion of interventions that capitalize on the role of aquatic systems and fish production activities in climate mitigation (i.e. increasing carbon sequestration and decreasing emissions), in community and livelihood adaptation, and/or the promotion of a better understanding of the synergies and trade-offs between the two.[9]

Figure 5 shows the relationship between the IPCC model of vulnerability and the complementary frameworks discussed above. As was the case for the different perspectives on vulnerability, each of the development frameworks discussed above has strengths and weaknesses, but considering these frameworks together would enrich a given vulnerability assessment. By doing so, it would provide the option to build a layer of complexity over the basic IPCC vulnerability components with complementary considerations and perspectives that might have been missed otherwise.

[9] For a discussion on how the EAF and climate change are linked, see De Young *et al*. (2012).

FIGURE 5
Complementary frameworks for the study of vulnerability



Source: FAO (2013b).

3. Capturing and measuring vulnerability: available methodologies for vulnerability assessments

Chapter 2 highlighted the complexity of vulnerability as a concept. This complexity, combined with the wide range of contexts in which VAs have been implemented, has resulted in a large and disparate body of empirical work on vulnerability that is inadequately linked to the conceptual developments that underpin it (Miller *et al*., 2010). This section aims to provide clarity on the various ways vulnerability can be captured and measured. In order to help those responsible for implementing VAs to choose the most appropriate methodologies among those available, it provides a broad classification of vulnerability methodologies available and relates them, where possible, to the conceptual constructs presented above.

CLASSIFICATION OF METHODOLOGIES FOR VULNERABILITY ASSESSMENTS

One way to distinguish VA methodologies is to consider whether they are **quantitative** or **qualitative**. Qualitative analyses are in general based on qualitative information such as case studies and comparative analyses, while quantitative analyses are those combining economic and social data such as statistics with climate models (O'Brien and Leichenko, 2000). Both types of methodologies have been advocated to study vulnerability (Turner *et al*., 2003a, O'Brien and Leichenko, 2000), yet not always in relation to any particular of its conceptual components.

Vulnerability assessment methodologies have also traditionally been categorized as **top-down** and **bottom-up**. Top-down methods can be seen as those methods based on the handling of data by scientists, with no direct inputs from beneficiaries (e.g. statistical analysis, modelling, downscaling), and bottom-up methods as those relying on iterative and participatory processes through which information inputs are made by, and for, beneficiaries themselves. While top-down approaches are closely associated to climate change impact assessment and emerge in large part from the risk/hazard school of thought on vulnerability, bottom-up approaches are closely associated with the political economy/ecology tradition and the livelihoods perspective on vulnerability. However, their convergence, in particular in relation to the study of resilience and human–environment interactions, has prompted the use of a mix of methods of enquiry that span quantitative and qualitative methodologies and include stakeholder engagement, action research, and social learning (Miller *et al*., 2010).

Broadly speaking, quantitative methodologies tend to be more closely related to top-down ones, while qualitative ones are in closer relation to bottom-up methodologies of investigation. However, by being clearly (and historically) associated with conceptual traditions, the distinction between top-down and bottom-up methodologies is felt to be more illuminating than the conventional quantitative versus qualitative one for the purpose of the present review.

Top-down/quantitative methodologies

In this category fall quantitative/statistical downscaling approaches that have been proposed to assess vulnerability because vulnerability is viewed in connection to the quantified probabilities of a risk occurring. These probabilities, and related confidence, can refer to either the likelihood of occurrence of climatic changes and events (Solomon *et al*., 2007) or to socio-economic ones, for example, the likelihood of a household falling in and out of poverty over time (Alwang, Siegel and Jorgensen, 2001; Heitzmann, Canararajah and Siegel, 2002). Quantitative/statistical downscaling approaches are closely associated with the risk/hazard school of thought on vulnerability and with the study of outcome vulnerability (through the use of modelling).

In this category of methodologies would also fall indicator-based and modelling-based assessment methodologies (Fellmann, 2012). For example, indicators can link some of the biophysical and economic attributes of systems to vulnerability outcomes via a quantitative function (e.g. a variation in yield, resource quality, land value and/or economic returns). Typically, quantitative indicators tend to be chosen as proxies for the exposure, sensitivity and adaptive capacity components of the IPCC vulnerability model, and are then compiled into a relative measure of vulnerability. Modelling methodologies have traditionally focused on biophysical systems, following a reductionist and dose-response logic to forecast or simulate the impacts of one or a mix of climate variables on a particular system. However, more recent developments in agriculture have enabled the integration of economic simulations in biophysical modelling outcomes, allowing an evaluation of the costs of climate change adaptation in agriculture (Nelson *et al*., 2009), of the influence of farm socio-economic characteristics in shaping climate adaptation responses (Reidsma *et al*., 2010) and of the economic losses resulting from the impacts of climate change on Western African fisheries (Lam *et al*., 2012).

The temporal and spatial scales of top-down modelling-based methodologies tend to be longer and larger than bottom-up/qualitative methodologies – reviewed below – which tend to focus on local spatio-temporal scales and contexts.

Bottom-up/qualitative methodologies

Participatory stakeholder-based methodologies typically exemplify bottom-up/qualitative methodologies. In direct connection with the livelihood perspective on vulnerability, these methodologies often provide a means to study one or more components of livelihoods in relation to vulnerability, and constitute an ideal entry point for the involvement of target groups and beneficiaries themselves in assessments (Fellmann, 2012). For example, Preston and Stafford-Smith (2009) tested an assessment approach heavily inspired by the SL framework (Scoones, 1998; DFID, 1999). They broadened the study of vulnerability beyond the sole study of shocks, trends and seasonality, which are the three components of the "vulnerability context" box of the SL framework. Vulnerability in a livelihood context is multidimensional, touching upon the human, social, financial, natural and physical capital upon which livelihoods are built. Its study in a livelihood context is also an integral part of disaster and risk preparedness against natural hazards (Birkmann, 2006a).

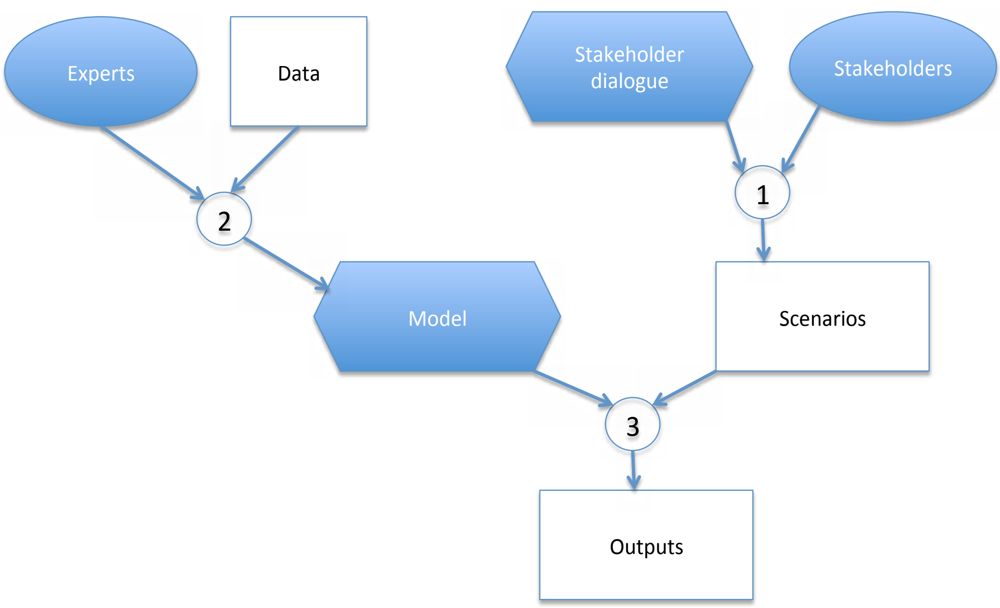
Integrative methodologies

Vulnerability mapping exercises have been widely carried out, in particular in the context of food security/insecurity, often driven by a policy/donor motivation to identify famine-prone areas and households or areas to target for food aid, and in the context of disaster management to prioritize needs and assistance (Alwang, Siegel and Jorgensen, 2001). They have also been conducted to map coastal vulnerability to climate change (Szlafsztein and Sterr, 2007; Torresan *et al*., 2012) or the vulnerability of national economies dependent on fisheries and aquaculture to the impacts of climate change (Allison *et al*., 2009). Indices used in mapping have tended to rely on statistical analysis (e.g. principal component analysis, cluster analysis), although simple rankings across components of the index have also been reported (Alwang Siegel and Jorgensen, 2001). Thanks to recent developments in participatory geographic information systems (P–GIS) that enable stakeholder involvement in decision-making to be increased (Cinderby, Snell and Forrester, 2008), GIS overall appears to offer potential for adequately integrating quantitative and qualitative data, as well as top-down and bottom-up approaches. In addition, maps, in particular where complemented with visual imagery, are powerful communication tools with local stakeholders and policy-makers alike (Sheppard, 2005). O'Brien and Leichenko (2000) had already noted the integrative usefulness of GIS as a tool combining multiple variables and scales.

The application of **agent-based modelling** methodologies to understanding and simulating vulnerability and adaptation from stakeholders' perspectives is emerging as holding potential for integrating different types of data and capturing complex system dynamics (Miller *et al.*, 2010). When incorporating participatory bottom-up data, agent-based models enable the close coupling of people with their natural and social environment, while simultaneously allowing superseding disciplinary barriers and uncertainty, non-linearity and data imperfections as inherent modelling limitations. Such an integration of methodologies was successfully piloted for the exploration of agricultural adaptation strategies to climate vulnerability in the context of multiple social and environmental stresses (Bharwani *et al.*, 2005; Ziervogel, Bharwani and Downing, 2006).

Figure 6 shows a generic model of VA that combines different methods to document climate change vulnerability. Hexagons represent methods, rectangles represent data or outputs, ovals represent actors, and circles activities. In the example here, Activity 1 is method-driven (development of scenario), Activity 2 is actor-driven (development of a model), and Activity 3 is objective-driven (application of model on scenarios). Box 3 provides a case-study application of how the application of a mix of methodologies can shed light on various aspects of vulnerability and adaptation strategies to climate variability. Appendix 2 provides additional information on available analytical tools for assessments.

FIGURE 6
A generic methodology for vulnerability assessment



Source: Adapted from Hinkel (2009).

BOX 3

An illustration of the complementarity and integration of methodologies to document climate vulnerability and adaptation decision-making

Case study

The topic of this case study is agricultural decision-making in a communal irrigation scheme in South Africa, an area where climate variability is high and where other stressors such as restricted land availability, political instability, market fluctuations, globalization and HIV/AIDS place additional strains upon agricultural production. This case study illustrates how the interplay and integration of methodologies can shed light on the range of stresses that communities are adapting to and, thus, on the need to consider the complex nature of vulnerability, rather than a single stress such as climate, when developing strategies for intervention. It is also a good example of gender-sensitive data elicitation and vulnerability analysis. Surveys were implemented two years apart, and data were collected from farmers and other household members involved in the communal irrigation scheme.

Participatory data collection

Participatory approaches – including focus groups, timelines, ranking, matrices and mapping – were used with groups of farmers. Some exercises were undertaken with single-sex groups and others with mixed groups. The perceptions of the community members, as gathered from a focus group, about the positive and negative aspects of the irrigation scheme helped to contextualize farmers' experiences. These exercises enabled group perspectives to be captured around the impact of climate variability and climate information, environmental and socio-economic stress, and response to these stresses.

Structured surveys

Structured quantitative surveys were also implemented with sampled farmers in order to collect data on income and household assets. This information was subsequently used to stratify respondents in the follow-steps of data collection and analysis.

Knowledge elicitation tools (KnETs)

KnETs is an experimental computer-based interview method. It is an interactive activity that represents various environmental, socio-economic and climate scenarios in order to identify the specific variables required for the farmers' process of decision-making about adaptation to proceed. The selection of participants aimed to obtain a distribution of profiles in terms of the gender of the head of household, age and wealth groups (poor, average and better-off farmers) that had been established using the survey data on income and household assets. This process was used to identify drivers and possible heuristics or decision-making rules, particularly as responses to seasonal forecast information. This is essentially a method that allows one to "tune in" to tacit knowledge that is otherwise difficult to access. It also provides robustness to the collection of qualitative data, by providing processes of verification and validation of knowledge as it is collected. The scenarios and actions presented in the knowledge elicitation activity were based on the outputs from the participatory exercises above.

Climate and agricultural data

Data from the Hadley Centre for Climate Prediction and Research model in the United Kingdom of Great Britain and Northern Ireland were used to generate a baseline climatology (from the control run, without greenhouse gas forcing) and a scenario of future climate change for the region under study. Precipitation and potential evapotranspiration (PET), calculated in the Hadley Centre model, were used to establish annual rainfall variability and climate change trends. A crop–water balance module, based on the FAO Water Requirements Satisfaction Index, was used to calculate potential yields with the rainfall and PET as inputs. Seasonal climate forecast information was collected from the South African Weather Service (SAWS). Farmers usually receive this information through radio channels and are known to trust it and use it in their cropping decisions.

BOX 3 (CONTINUED)

Agent-based modelling

An agent-based model (ABM) was developed to represent this farming community at an abstract level and to examine some of the responses to the forecasts as an adaptation to climate variability over time. The model enabled acknowledgement that vulnerability is dynamic and its salient processes to be captured. Farmers' responses and perceptions of the reliability of the weather information provided by the SAWS were gathered during individual interviews and incorporated in the ABM through a learning component. A market module was also integrated in the model, creating reserves of capital that affect long-term strategies and investment in agriculture. The market module was designed such that there were differing dynamics for poor and better-off households. The market module was also coupled to climate, in that prices were sensitive to climate events (if the forecast was below normal, market demand was expected to be high and crops were becoming high-value commodities owing to increased demand, therefore commanding higher prices). The output from the model was a relative sense of how successful farmer-agents might be in using seasonal climate forecasts in their agricultural decision-making. The results of the ABM illustrate the impacts of such short-term adaptation strategies, which contribute to long-term resilience under certain climate change conditions or conditions of climate variability.

Lessons learned from the combination of methodologies

The limitations and assumptions of the model have to be considered when deriving specific conclusions from the results. The combination of intensive field surveys (and long-term community engagement) with formal modelling allows the analyst to experiment with scenarios that do not exist at present (long-term climate change being the most obvious one). In the context of this hybrid methodology and exploratory modelling, some key lessons can be learned:

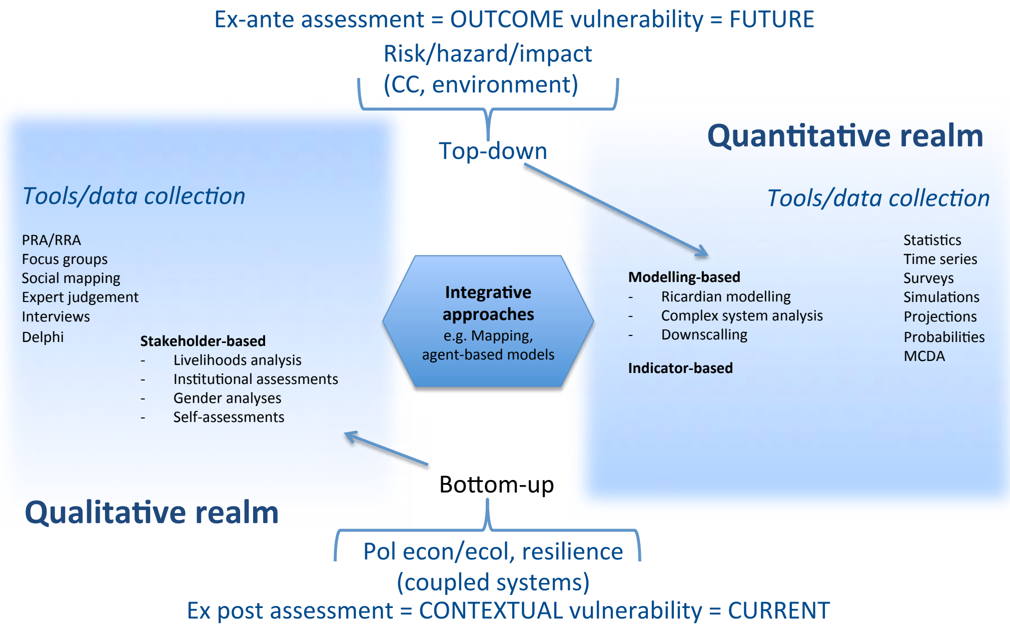
1. ***Linkages among different types of information are paramount:***
   Seasonal climate forecasts are one tool in managing climatic and economic risks, and even more so for taking advantage of opportunities. Market strategies link to climatic risks and opportunities, with different linked strategies appropriate for different types of farmers. A simple overlay of climatic risks (such as drought-prone areas) with economic systems (perhaps indicators based on household income and dependence on non-farm sources) is unlikely to capture the complexity of real household strategies.
2. ***Findings are context-specific but a generic approach is possible:***
   The context of vulnerability and adaptation is important. The situation in a neighbouring country or region may not be the same, although both may be under similar climatic stresses. A fishing livelihood system is unlikely to pursue the same strategies as an irrigated agricultural economy. While such place determinism is clear, a generic methodological approach, such as the one outlined here, may be possible.

Sources: Bharwani *et al.* (2005); Ziervogel, Bharwani and Downing (2006).

Figure 7 maps out the different approaches and the tools upon which they tend to rely[10] in relation to the epistemology of vulnerability. By doing so, it links assessment methodologies with the conceptual perspectives and schools of thought on vulnerability discussed above. Tools and data collection methods listed are borrowed from the adaptation assessment sphere and are applicable at different scales. The rationale behind this methodological "map" is to help the researchers or practitioners responsible for a VA know where each type of methodology they may consider using stands in relation to the various constructs of vulnerability, and what each will

[10] Indicative list. See also Downing and Patwardhan (p. 86, 2004) for a list of tools to apply at various stages of their activities, and also the list in Winograd (2004).

FIGURE 7
Layout of vulnerability assessment methodologies in relation to schools of thoughts and perspectives on vulnerability



Notes:
CC: Climate change.
GIS: Geographic information systems.
PRA/RRA: Participatory rural appraisal / rapid rural appraisal.
MCDA: Multicriteria decision analysis.

Additional information on the tools listed here is provided in Appendix 2.

help to investigate. Some approaches are more integrative than others, but areas of complementarity between quantitative and qualitative, and top-down and bottom-up, approaches can be found. A comprehensive assessment of vulnerability will most probably rely on a mix of all these approaches.

METHODOLOGICAL ISSUES

Vulnerability assessments are laden with methodological issues. These are related to choosing methodologies that can: encompass multiple interacting stressors; capture socio-economic and biophysical uncertainty; account for cross-scale influences and outcomes; and emphasize equity and social justice in the VA outcome (Eakin and Luers, 2006). In addition, VAs are confronted with practical issues such as data availability and confidence, choice of measures, indicators and indices, identification of beneficiaries and scale issues, and reporting and communication issues.

Data availability and confidence

Availability of data, as well as lack of confidence in them, whether they are primary or secondary and collected either through top-down or bottom-up methods, is systematically reported in the literature as a major problem in understanding vulnerabilities, and as such is perhaps the largest constraint to the rigour and reliability of VAs and their findings. This is further confounded by uncertainty and non-linearity in the causes and effects relationships occurring within complex coupled human–environmental systems (Folke, 2006). There are many ways in which these shortcomings can be partially overcome – through mixed approaches, cross-referencing or alternative means of information collection – but data quality will be a critical issue in the use of quantitative methodologies in particular.

Vulnerability measures, indicators and indices

As vulnerability is a complex issue, there is consensus that a single aggregate measure of vulnerability will probably not provide useful information for adaptation planning because it is not possible to disaggregate precise factors leading to vulnerability (Alwang, Siegel and Jorgensen, 2001; Schröter, Polsky and Patt, 2004; Hinkel, 2011). For example, Adger (2006) suggested that measures of vulnerability should strive to simultaneously capture:

- the dynamic nature of vulnerability (changes over time and places);
- the severity of vulnerability (includes risk and thresholds);
- the perception of vulnerability.

Innovations have been made to capture such complexity through the development of composite indices (Table 3). More information on the development and use of these indices is provided in an annotated bibliography on the application of climate change vulnerability assessment methodologies in fisheries and aquaculture (section 2.1 in Barsley, De Young and Brugère, 2013) to which the reader is invited to refer. For illustration purposes, Box 4 provides more information on the construction of a social vulnerability index (SVI) developed by Adger and Vincent (2005). However, these authors note that their choice of indicators is underpinned by their own assumptions. They also caution that if some of the indicators they have used as proxies for vulnerability components in the composition of their vulnerability index are fairly uncontroversial (e.g. those relating economic growth to decreased vulnerability in the case of environmental risk), others may be more contested (e.g. those relating resource dependence to vulnerability).

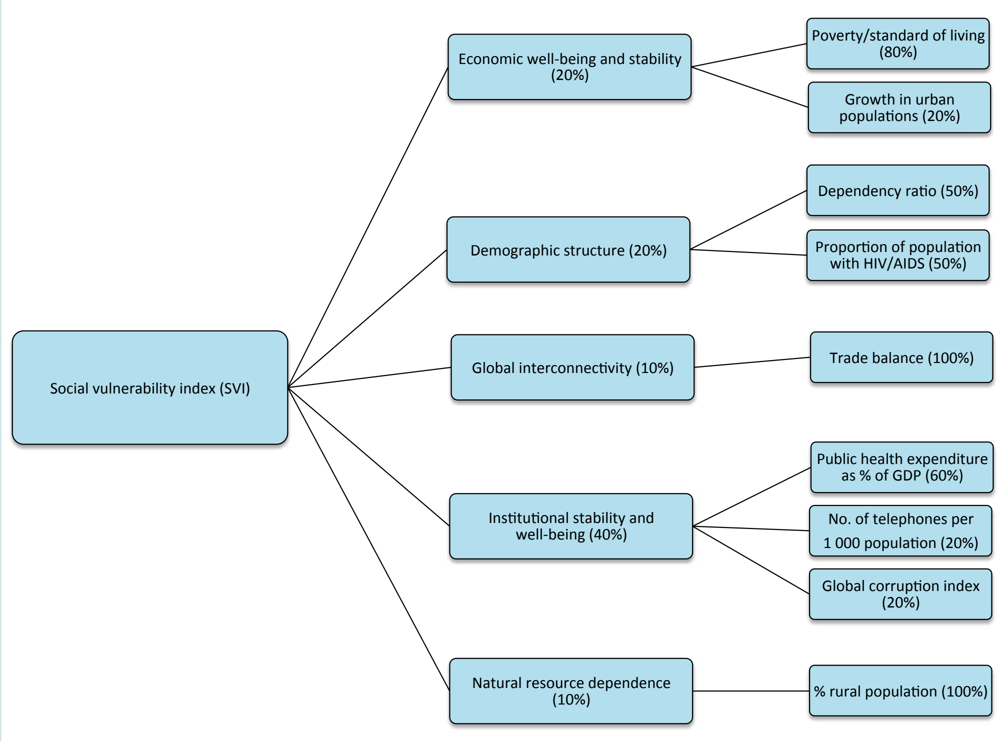
However, capturing cause-and-effect relationships between vulnerability variables and their consequences on social–ecological systems and well-being remains a challenge, along with the determination of thresholds and the influence of institutional set-ups (governance), all of which are compounded by culture and context-specific perceptions (Adger, 2006) as well as disciplinary perspectives (Alwang, Siegel and Jorgensen, 2001).

TABLE 3
Example vulnerability indices

Index name	Description, components	Origin and example reported applications
Livelihood Vulnerability Index (LVI)	Combines seven components: livelihoods, sociodemographics, social networks, health, natural disasters and climate variability, food and water security.	Hahn, Riederer and Foster (2009)
Coastal Vulnerability Index (CVI)	Incorporates geological and physical indicators (geomorphology, shoreline change rate, mean significant wave height, mean tide range, coastal slope and sea-level rise) to identify risks related to sea-level rise.	Gornitz (1990) ; McLaughlin, McKenna and Cooper (2002); Dwarakish *et al*. (2009); Duriyapong and Nakhapakorn (2011)
Multiscale CVI	Integrates the impacts of coastal erosion in the CVI. Uses indicators of coastal characteristics, coastal forcing and socio-economic status.	Mclaughlin and Cooper (2010)
Climate Sensitivity Index (CSI)	Includes two components that represent the influence of extreme events on agriculture (dryness and monsoon dependence) in order to measure sensitivity under exposure to climate change.	O'Brien *et al*. (2004)
Physical Process Vulnerability Index (PVI)	Formed by four variables: coastal erosion rate, coastal slope, mean tidal range, and mean wave height. Used combined with the SVI to assess coastal vulnerability.	Duriyapong and Nakhapakorn (2011)
Composite vulnerability index	Incorporates 16 separate natural and socio-economic variables to measure the disparity between communities and regions exposed to related hazards.	Szlafsztein and Sterr (2007)
Socio-economic Vulnerability Index (SVI)	Composed of four variables: land use, population density, roads/railways, and cultural heritage. Used combined with the PVI to assess coastal vulnerability.	Ebert *et al*. (2008); Duriyapong and Nakhapakorn (2011)

BOX 4

Structure of the aggregate social vulnerability index (SVI), its composite subindices and component indicators



The social vulnerability index (SVI) outlined here uses a theory-driven approach where relevant indicators are developed based on hypothesized links between development, environment and resilience. The key challenge is to derive simple and easily comprehensible indicators or proxy indicators from these hypothesized links, bearing in mind that there may be much uncertainty about the validity of these hypothesized links.

Standardization and aggregation of the indices use a variety of methods that can further increase the uncertainty in the resulting measure of adaptive capacity. Indices are usually either composite (their constituent parts are recognizable) or aggregate (their constituent parts cannot be distinguished). The SVI is designed to combine both approaches and create a single aggregate score, but reveals the composite make-up of that score as its commitment to transparency. Weights (the percentage values in the figure) are applied to the indicators in forming the subindices, and then when aggregating the subindices to form the aggregate index, in keeping with the theory-driven nature of the index, and based on expert judgement.

Sources: Adger and Vincent (2005).

For vulnerability researchers and practitioners, this raises issues of objectivity and transparency (justifying action based on a subjectively deduced state of vulnerability) as well as of transferability (tailoring actions and policies based on location and scale-specific measures of vulnerability).

Barsley, De Young and Brugère (2013) also described a range of context or project-specific indicators elaborated to characterize vulnerability. Birkmann (2006b) listed criteria and functions that vulnerability indicators should seek to fulfil (Table 4).

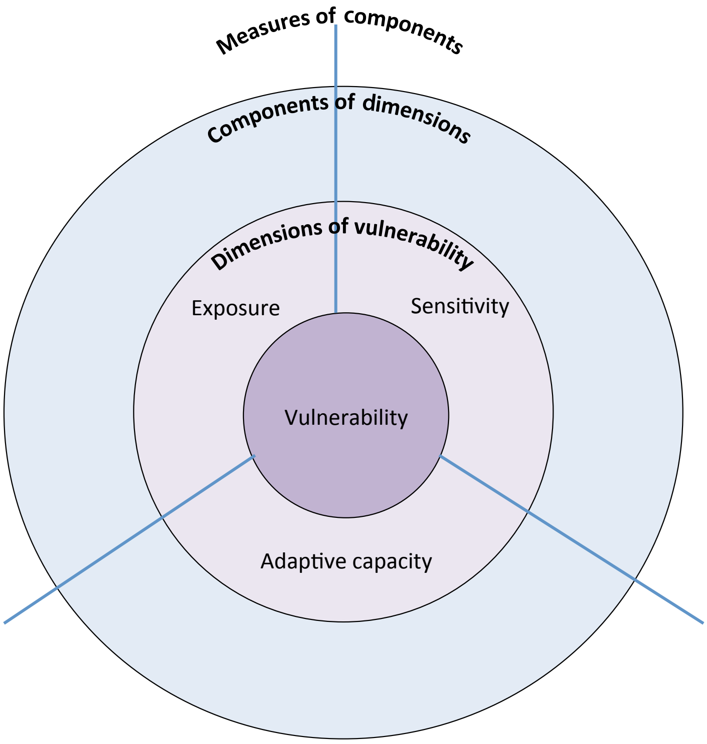
TABLE 4
Eight priority criteria and functions for climate change vulnerability indicators

Criteria that a vulnerability indicator should meet	Functions that a vulnerability indicator should serve
1. Be understandable	Set priorities
2. Be policy-relevant	Provide a background for action
3. Be based on available data	Raise awareness
4. Capture root causes of vulnerability	Analyse trends
5. Be reproducible	Empower people
6. Use representative data	Be relevant for evaluation
7. Be statistically sound	Specify targets
8. Be cost-effective and easy to collect	Compare situations and trends

Source: Adapted from Birkmann (2006b).

In some instances, comparing findings across VAs is important, especially when prioritizing allocation of funding for interventions across areas or sectors. To overcome the disparities in indicators or unreliability in data that may hamper such a process, Polsky, Neff and Yarnal (2007) proposed a vulnerability scoping diagram (VSD) that enables an extrapolation of exposure, sensitivity and adaptive capacity into measurements of the context-specific components of these dimensions of vulnerability (Figure 8). This analytical process serves two functions: "(1) to build a basis for making comparisons of vulnerability from assessments performed at different places and times, and (2) to provide a starting point for understanding the details of vulnerability in a single exposure unit that may be examined in greater detail using additional research".

FIGURE 8
General form of a vulnerability scoping diagram



Notes: The centre of the diagram represents the vulnerability of a given human–environment system. The first ring parses vulnerability into its three fundamental dimensions, or primary axes along which vulnerability is defined: exposure, sensitivity and adaptive capacity. The intermediate ring represents the components, or the abstract features on which to evaluate each of the three vulnerability dimensions for a given human–environment system. The outer ring includes the measurements, or the observable characteristics of the components of the dimensions.

Source: Polsky, Neff and Yarnal (2007).

Identification of winners and losers and scale issues

Identifying who the winners and losers to change might be, and how this may change over time and across scales is a challenge for any VA. The questions that follow (from O'Brien and Leichenko, 2000) highlight the subjectivity involved in answering them, but could nonetheless serve as a guide to discuss and identify winners and losers in VAs:

- What is meant by a win or a loss?
- What factors must be taken into account in labelling a region, an activity, an economic sector or a country a winner or a loser?
- Can wins and losses be objectively and reliably identified and measured?
- How do perceptions of winning or losing capture reality?

Scale issues also arise in the identification of winners and losers from climate change and other drivers of change as, by focusing on particular unit (regional, sectoral, ecosystem) or social group, analyses tend to aggregate them and overlook inequalities among subsets of winners and losers (O'Brien and Leichenko, 2000). In addition, it has been found that aggregating vulnerability across scales is not always meaningful as the processes that cause vulnerability are different at each scale (Adger *et al.*, 2004).

Communicating results of vulnerability assessments

As mentioned above, VAs should be designed for a particular purpose, e.g. raising awareness, designing policies, adaptation planning and furthering scientific knowledge. Communication of the results of a VA will depend on this purpose and intended audiences. Vulnerability assessments to support adaptation planning at the community level will require very different means of communication (e.g. community meetings) to VAs to advance scientific knowledge (e.g. through scientific journals) and to those assessments to raise awareness at high policy levels (e.g. short briefs). To ensure that a VA fulfils its purpose, communicating and reporting results should be a well-planned and integral part of the assessment process.

Schröter, Polsky and Patt (2004) gave particular attention to the "creative" communication that vulnerability researchers and practitioners should engage with to communicate their results and ensure their intended impact. By "creative" they emphasize that communication of the results of VAs should be a two-way flow of information between researchers and practitioners. For example, discussing openly uncertainty associated with the assessment's results should be part of this two-way flow. Sustained communication and dialogue leading to the progressive ownership of the assessment process by the stakeholders should also be part of it, and in practice it should mean more than a one-day workshop at the end of a research process. Information flows between all stakeholders and researchers will strengthen social learning as well as buy-in to follow-up actions. In this regard, achieving trust and credibility is likely to be pivotal, as highlighted in risk communication literature (e.g. Peters, Covello and McCallum, 1997; Covello and Sandman, 2001).

Good practices and principles for vulnerability assessments

In addition to overcoming the methodological challenges listed above, VAs should satisfy two broad requirements – or principles – that will guarantee their relevance, robustness and credibility.

First, vulnerability analysis should be **consistent with the principles of sustainability science**. This means (after Turner *et al.*, 2003a; Schröter, Polsky and Patt, 2004; Adger, 2006):

- Call upon varied, flexible and multidisciplinary inputs while integrating local knowledge.
- Be specific to a place and its related context, while paying attention to scale issues and interactions.

- Recognize multiple and interacting drivers of change (and thus of potential vulnerability).
- Account for differential adaptive capacities.
- Be based on both prospective and historical information.
- Incorporate a significant range of parameters in building quantitative and qualitative pictures of the processes and outcomes of vulnerability.

Second, VAs should **focus on people** to identify "winners" and "losers" of climate and other drivers of change (O'Brien and Leichenko, 2000) and frame actions targeted at the groups who risk losing out. Gender, equity and social justice are issues of critical importance to vulnerability reduction, and as such should be incorporated in assessments (Otzelberger, 2011; Eakin and Luers, 2006).

The due consideration of these principles at the time of the design and implementation of the assessment will influence the quality and relevance of the VA outcomes. From a methodological point of view, this implies carefully considering which vulnerability questions need to be asked (and answered – cf. Chapter 1), as well as developing flexible and creative methods of investigation that are suited to the purpose and context of the vulnerability assessment. .

Table 5 outlines good practices in the implementation of VAs. Examples of this are provided in the next chapter in the context of fisheries and aquaculture.

TABLE 5
Good practices and lessons learned in assessing climate change impacts and vulnerability

Scope	Up front efforts to engage all relevant stakeholders, analyse the natural and social contexts, and determine the focus and expected outputs of the assessment will prove time well spent.
Selection of methods and tools	The selection of assessment approaches, methods and tools needs to be guided by the purpose of the assessment, the availability of resources and time, as well as pragmatism.
Qualitative versus quantitative	Both qualitative and quantitative analyses are helpful. This is particularly important when traditional knowledge and inputs from indigenous communities are incorporated into the assessment process.
Present versus future	Detailed analyses on current trends in climatic patterns, socio-economic trends and adaptation responses could provide many insights into how changes in the future may affect the natural and social systems, and which adaptation options may help to reduce vulnerability. This is particularly important to bear in mind if analyses on future impacts and vulnerability are impeded by uncertainties associated with, among others, climatic and socio-economic scenarios.
Stakeholders	Key stakeholders need to be involved throughout the entire assessment process – they can provide important inputs to the assessment process, as well as validate the interim results.
Collaboration	Inputs from a wide range of disciplines (e.g. science, social science, engineering, economics) are often required. Effective collaboration among experts and stakeholders from different disciplines/sectors is important to ensure the credibility of the assessment results.
Transparency	For the results of assessments to be used effectively and appropriately in adaptation decision planning, it is important to be transparent about the underlying assumptions and caveats of the assessment process and its results.
Disaggregation	Vulnerability and adaptation options will differ by gender, age, and demographic groups, and, therefore, assessments will need to allow for such differences

Source: Adapted from UNFCCC (2011).

Based on the above, the following 11 principles support a "good" VA (FAO, 2013b):

1. Be linked to concrete adaptation actions, leading to the achievement of societal objectives.
2. Acknowledge that climate change is typically one among many risks and drivers of change (it may be an amplifier of existing changes) and that its compounded effects may be difficult to single out from these other drivers, or to quantify and predict clearly.

3. Be based on an established and agreed-upon framework.
4. Use an approach that relies on established and robust methodologies (to ensure accountability and replicability), while allowing for uniqueness inherent to each context.
5. Consider combining and reconciling the strengths of top-down and bottom-up approaches.
6. Be based on best available information (evidence-based / objective data, models) but also consider/include perceptions/subjective information from stakeholders.
7. Be a transparent process, acknowledging limitations and uncertainties as well as disciplinary biases.
8. Be aware that there may be winners and losers who need to be identified at different (time, geographical) scales.
9. Acknowledge the benefits and limitations of working at any particular scale and that VA findings might be limited to a predetermined scale deemed of relevance to the assessment itself.
10. Account for the different needs of end users and use context-relevant communication channels.
11. Be an iterative, participatory and multistakeholder process.

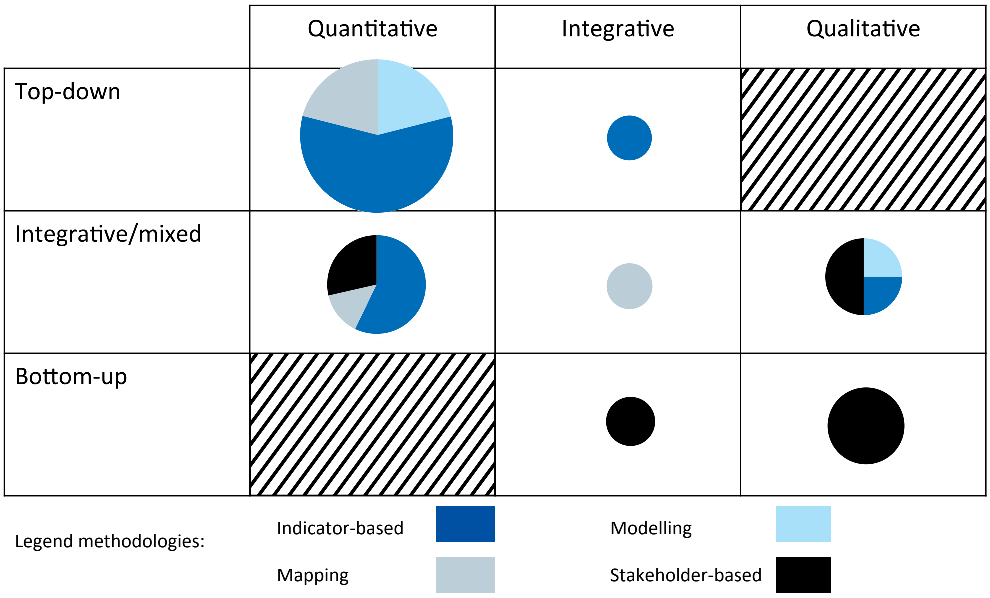
4. Vulnerability assessments in fisheries and aquaculture

A number of VAs have been implemented to better characterize and understand the broad climate change threats and underlying issues facing fisheries and aquaculture. This chapter aims to illustrate how the methodologies described above have been applied to do this, so that fisheries and aquaculture managers and decision-makers can decide on the relevance of a VA and how to broach it. Both the overview of the application of VAs to aquatic and land-based systems and the practical examples of assessments that follow provide a starting point for considering the vulnerability "variables" requiring examination and the methodologies needed to do so.

OVERVIEW OF THE APPLICATION OF VULNERABILITY ASSESSMENTS IN AQUATIC AND LAND-BASED SYSTEMS

Barsley, De Young and Brugère (2013) have gathered an extensive collection of experiences in the implementation of various VA methodologies in the context of fisheries, aquaculture and other sectors (Sections 3, 4, 5 and 6 of the annotated bibliography in Barsley, De Young and Brugère, 2013). Figure 9, elaborated on the basis of the information provided in Appendix 3, organizes the assessment methodologies used in fisheries and aquaculture between 1995 and 2012 according to whether they were quantitative, qualitative or mixed, top-down, bottom-up or integrated. It also indicates the tools and data collection methods upon which these methodologies relied (cf. Figure 7).

FIGURE 9
Types of vulnerability assessment methodologies applied to fisheries and aquaculture

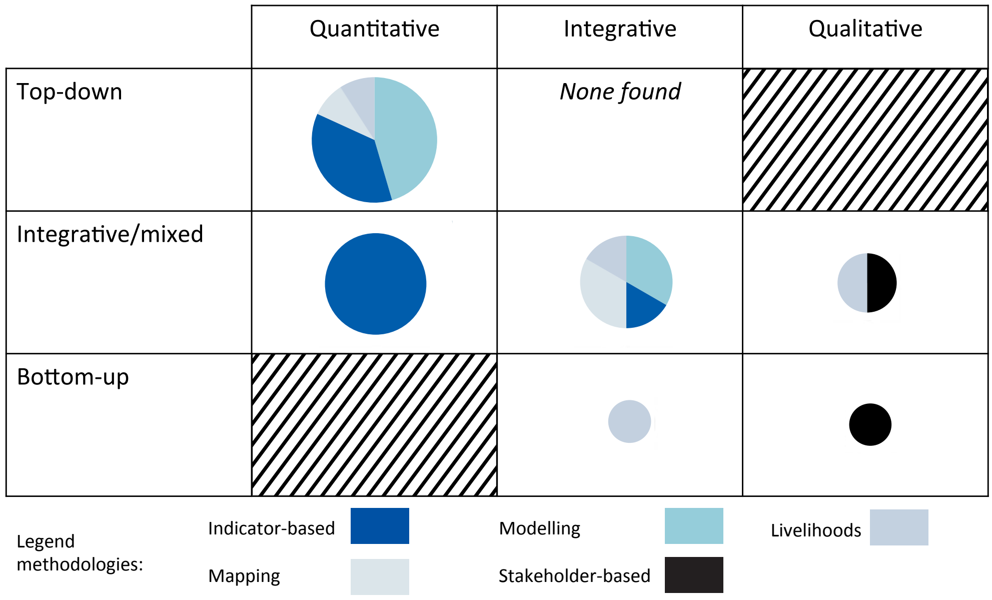


Notes:
Total number of published studies identified (based on Barsley, De Young and Brugère, 2013): 24 from 1995 to 2012.
The size of the pies is proportional to the number of studies found using these methodologies, whereas sections of the pie indicate the nature of the methods used.

Figure 9 indicates a reliance on quantitative top-down assessment methodologies in the context of fisheries and aquaculture to investigate climate risk impacts and outcome vulnerability. The imbalance with VAs based on contextual vulnerability in fisheries and aquaculture suggests that more research and pilot implementations of this type of assessments are needed.

A similar review of VAs undertaken in other sectors (e.g. agriculture and pastoralism, natural resources, food security, poverty, rural development) from 1995 to 2012 is shown in Figure 10 on the basis of the information provided in Appendix 3.

FIGURE 10
Types of vulnerability assessment methodologies applied in other sectors



Notes:
Total number of published studies identified (based on Barsley, De Young and Brugère, 2013): 19 from 1995 to 2012.
The size of the pies is proportional to the number of studies found using these methodologies, whereas sections of the pie indicate the nature of the methods used.

The conclusion reached is somewhat similar to that for fisheries and aquaculture: most VAs have been quantitative, using top-down indicator-based approaches. However, contrasting with the more conventional natural-resource orientation of fisheries and aquaculture assessments, the "human" nature of the fields of application of these other VAs (e.g. food security, poverty) has opened the door to a larger use of integrative, mixed approaches. For example, methods based on the SL framework comprising rapid rural appraisals (RRAs) and studies of households' assets, access and activities were piloted in a number of instances. Therefore, the fisheries and aquaculture sectors may learn from the implementation of integrative and bottom-up methodologies in other fields.

This brief analysis of the application of VA methodologies indicates that those studies focusing on "human system" vulnerabilities (i.e. people, activities) lend themselves more naturally to bottom-up, qualitative, stakeholder-based methodologies, than those focusing on "natural system" vulnerabilities (i.e. places, ecosystems, species). However, if the "system" under investigation is broadened to encompass both its social and ecological dimensions, quantitative/qualitative, top-down/bottom up methodologies tend to be used complementarily. Such mixes are arguably a step forward in the more holistic capture of the multiple dimensions of vulnerability. In this regard, mapping and P–GIS-based approaches appear to hold potential in working towards the further integration of perspectives on vulnerability.

EXAMPLES OF VULNERABILITY ASSESSMENTS IN FISHERIES AND AQUACULTURE

Six vulnerability studies are outlined briefly in this section to illustrate how VAs in fisheries and aquaculture have been carried out. The summaries of these studies are organized according to the following five aspects:

- What was the purpose of the assessment (adaptation planning, awareness raising, etc.)?
- What vulnerability question was asked as the starting point of the assessment?
- How was vulnerability defined and interpreted?
- What tools, data collection, vulnerability analysis methods were used?
- How were the vulnerability findings presented and communicated?

The case studies provide examples at different scales (from communities to national to region), using different methodologies (perceptions-based to model-based, indicators to open-ended) and having different objectives (to advance VA methodology, to raise awareness, to support direct adaptation planning).

These case studies are not in-depth reviews of the work undertaken but aim to trigger ideas for those wanting to undertake VAs. The reader is invited to refer to the original work for further information on the methodology and detailed results of the assessments themselves. Additional examples or reviews of VAs in fisheries and aquaculture are also available through Barsley, De Young and Brugère (2013).

CASE STUDY 1 – VULNERABILITY OF NATIONAL ECONOMIES TO GLOBAL CLIMATE CHANGE THROUGH FISHERIES AND AQUACULTURE

References

Allison *et al.* (2005, 2009).[11]

Purpose of assessment

As the first global assessment for the fisheries sector, the purpose of this assessment was to raise general awareness within the sector and within the climate change world of potential impacts from increasing temperatures. It also aimed to show how vulnerability of national economies to changes stemming from the fisheries sector is not limited to areas of greatest temperature changes but also to those economies with high dependence on the sector and low adaptive capacity.

Vulnerability question

How are national economies vulnerable to potential climate change impacts stemming from changes in their fisheries?

Scale of assessment

Global with national indicators.

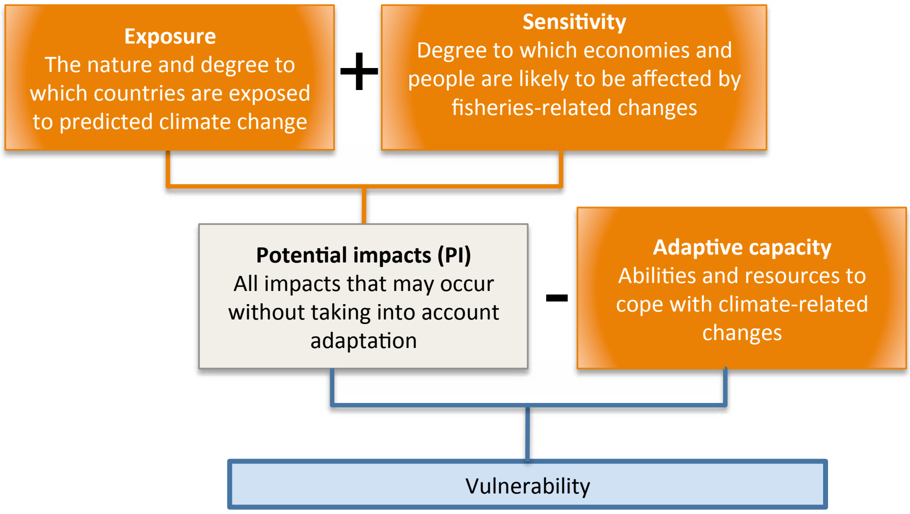
Definition and interpretation of vulnerability

The basic IPCC model of vulnerability was adapted to the context of fisheries as shown in Figure 11. **Vulnerability** = Exposure + Sensitivity – Adaptive Capacity.

[11] Note that this work has been updated by Monnerau *et al.* (2015) particularly to include small island developing States (SIDS) for which data were not available for the original study.

FIGURE 11

Interpretation and adaption of the IPCC model of vulnerability to the context of fisheries



Data and methods

The authors used composite indicators to quantify each component of the IPCC model of vulnerability and then ranked the countries according to their resulting vulnerability scores.

Exposure of the economy was captured through projected changes in surface temperatures to 2050 as a proxy of expected impacts on fish species targeted by countries (Table 6).
Data: temperature results from the Hadley Centre for Climate Prediction and Research model (HadCM3), two scenarios.

Sensitivity of the economy was captured through proxies for national dependency on marine and inland fisheries.
Data: Landings and contribution of fisheries to employment, exports and dietary protein (sources of data: FAO and World Bank).

Adaptive capacity was captured through general national-level human development indices as proxies.
Data: national-level indicators of health, education, governance, economy size.

Sufficient data were available to calculate relative vulnerability rankings for 132 countries, and results were found to be robust to different methods of weighting.

Presentation of vulnerability assessment findings

To enable uptake by different audiences, results of the VA were published in three ways: a technical document with detailed methodology and data; a journal article; and a policy brief. The visual representation (Figure 12) of the relative vulnerability rankings strengthened the awareness raising aspects of the assessment.

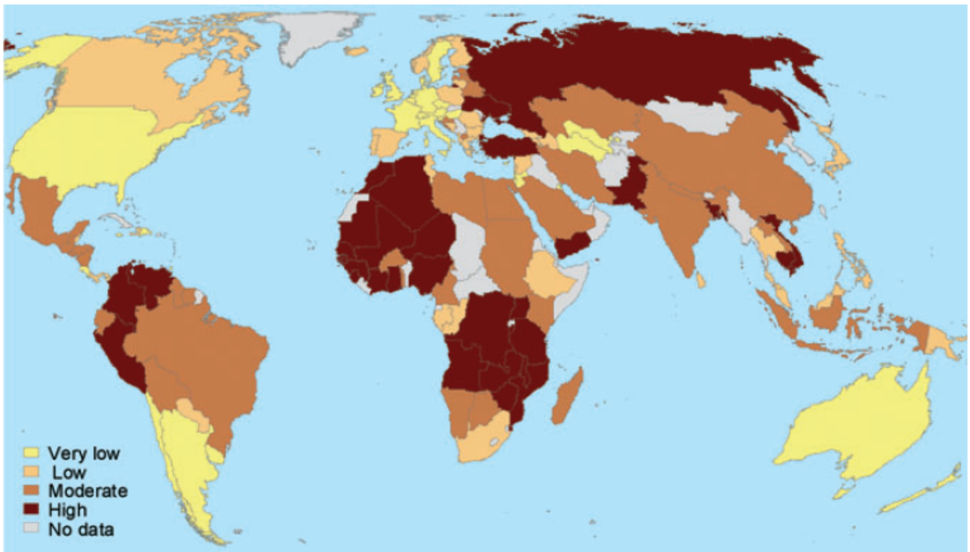
TABLE 6

Summary of variables used to calculate exposure, sensitivity (as fisheries dependence) and adaptive capacity, and their interpretation

Component	Interpretation	Variables	Source
Exposure	Gross indicator of projected levels of climate change	Mean project surface temperature increase (°C at 1.5 m altitude) by 2050	Mitchell *et al.* (2004)
Sensitivity	Composite index of employment and economic dependence on the fisheries sector	Number of fishers (most recent year 1990–96)	FAO (1999), World Bank (2003), FAOSTAT (2004)
		Fisheries export value as proportion (%) of total export value (averaged over 1998–2001)	
		Proportion (%) of economically active population (1990) involved in the fishery sector	
		Total fisheries landings (tonnes, averaged over 1998–2001)	
	Index of nutritional dependence	Fisher protein as proportion of all animal protein (% g/person/day, averaged over 1998–2001)	FAOSTAT (2004)
Adaptive capacity	Health	Healthy life expectancy (years, 2000)	Kaufmann, Kraay & Zoido-Lobate´n (2002), FAOSTAT (2004), CAIT (2005)
	Education	Literacy rates (% of people ≥ 15 years, 2000–01)	CAIT (2005)
		School enrolment ratios (% in primary, secondary and tertiary education, 2000–01)	
	Governance	Political stability	UNDP (2003), CAIT (2005)
	(2000–01)	Governance effectiveness	
		Regulatory quality	
		Rule of law	
		Voice and accountability	
		Corruption	
	Size of economy	Total GDP (2000)	CAIT (2005)

FIGURE 12

World map of the relative vulnerabilities of economies to the impacts of climate change on their fisheries sectors



Source: Allison *et al.* (2005, 2009).

CASE STUDY 2 – Vulnerability of Pacific Island counties and territories to climate change

Reference

Bell *et al*., 2011.

Purpose of assessment

One of a series[12] of VAs for the region, which had several intentions. The first was to provide information to fisheries managers and policy-makers on the vulnerability of fisheries and aquaculture resources to climate change in the Pacific in order provide recommendations on how best to adapt and ensure that the benefits from fisheries and aquaculture are maintained in years to come. Its second intention was to be a valuable resource for anyone wanting to learn about the diverse oceanic, coastal and freshwater fisheries and aquaculture activities of the Pacific Islands region, and the environmental conditions and habitats that support them, thus raising awareness about the immense value of this social–ecological system.

Vulnerability question 1

How is the fish-based food security of nine Pacific Island countries and territories (PICTs) vulnerable to climate change?

Vulnerability question 2

How are the economic development and government revenue of PICTs vulnerable to climate change through potential changes in their skipjack tuna fisheries?

Scale of assessments

Regional with national indicators.

Definition and interpretation of vulnerability

The definitions of vulnerability adopted for the studies were based on the IPCC model of vulnerability tailored to the fisheries sector (Figure 13).

Data and methods

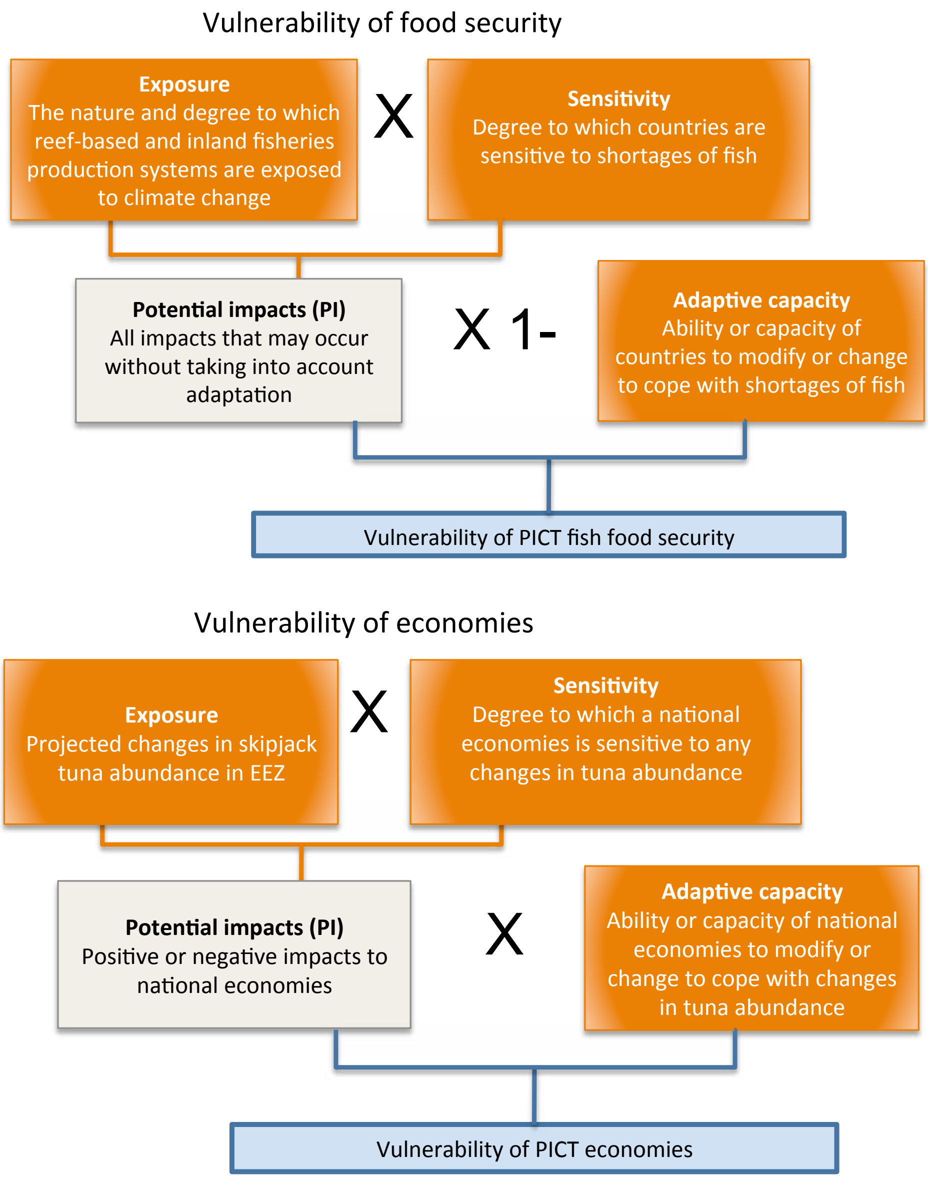
Food security vulnerability

Potential impact = Exposure × Sensitivity (PI = E × S) and then standardized and normalized.

Exposure: Exposure to shortages of fish in each PICT for the B1 and A2 scenarios in 2035, A2 in 2050, and B1 and A2 in 2100, using an index based on the availability per person (kilograms) of: (i) demersal fish, non-tuna nearshore pelagic fish and shallow subtidal and intertidal invertebrates in proportion to their contributions to the estimated annual production of 3 tonnes/km^2; and (ii) freshwater fish based on current national catches. The availability of all reef-associated fish and invertebrates, and freshwater fish, was modified by the projected changes to their production under each scenario. The resulting total availability of fish per person was then deducted from the assumed 35 kg per person required for good nutrition to estimate the exposure of each PICT.

[12] The authors also evaluated the vulnerability of fisheries-dependent livelihoods through projected effects of climate change on all fisheries resources and aquaculture.

FIGURE 13
Definitions of vulnerability adopted by Bell *et al.*, 2011



Sensitivity: Sensitivity to a shortage of fish was estimated as the recommended level of fish consumption for good nutrition (35 kg/person per year) or higher national levels of consumption where these occur.

Adaptive capacity: The adaptive capacity index of PICTs to adapt to shortages in the supply of fish was estimated by weighting values for the size of the economy (purchasing power) by 0.5, and indices for health, education and governance each by 0.167.

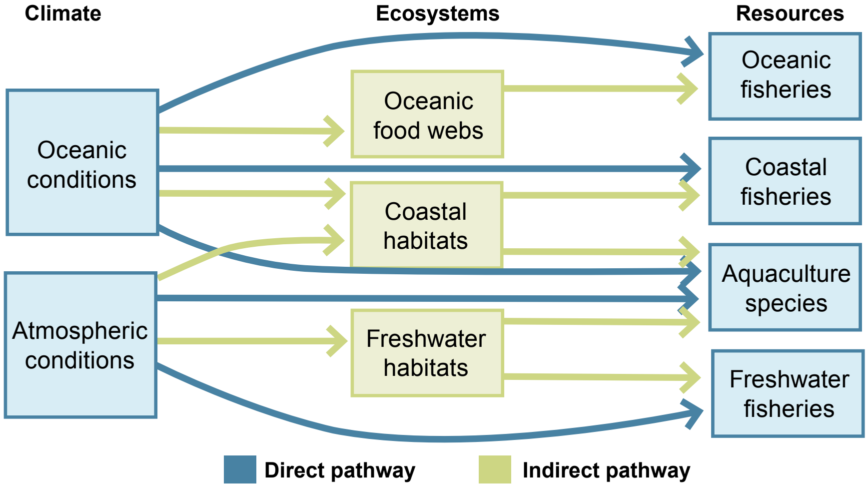
Food security vulnerability: Vulnerability was estimated by multiplying PI × (1 – AC), so that the potential impact on PICTs in Group 3 with the greatest adaptive capacity was reduced relative to PICTs with poor adaptive capacity.

Vulnerability of economies

Potential impact = Exposure × Sensitivity (PI = E × S)

FIGURE 14

Pathways to estimate exposure of the various fisheries resources and aquaculture species in the tropical Pacific to climate change adopted by Bell *et al.*, 2011



Exposure: Projected changes to oceanic conditions and projected effects on skipjack tuna catches within the exclusive economic zone (EEZ) of each PICT were quantified and modelled[13] with secondary scenario-based information (to 2050). Changes are relative to the 20-year average catches for 1980–2000 and for the B1 and A2 emissions scenarios by 2035 and 2050.

Sensitivity: Estimated as the average contributions (1999–2008) to government revenue (value of payment of access fees by distant-water fishing nations) and to gross domestic product (GDP) (value of fishing operations).

Adaptive capacity: Estimated from four composite indicators: health (infant mortality rate and life expectancy); education (literacy rate and students enrolled in primary education); governance (political stability, government effectiveness, regulatory quality, rule of law, voice and accountability, and corruption); and the size of the economy (GDP/person), on the assumption that PICT with higher levels of human and economic development are in a better position to undertake planned adaptation. These were standardized and normalized to range from 0 to 1 and then averaged to produce a composite adaptive capacity index.

Vulnerability of economies

In PICTs where contributions from tuna are expected to **decrease**: Vulnerability = PI × (1 – AC), so that PICTs with the greatest adaptive capacity had reduced vulnerability to lower catches of tuna.

In PICTs where contributions from tuna are expected to **increase**: Vulnerability = PI × AC, to reflect the likelihood that the PICT with the greatest adaptive capacity would be more capable of maximizing benefits from the increased resource.

Presentation of vulnerability assessment findings

Results of the VA were summarized in tabular form, for each PICT (Tables 7 and 8), reflecting the relative "winners" and "losers" of climate change. They were published in different outlets, which included policy briefs,[14] a book (Bell *et al*, 2011), an FAO Fisheries and Aquaculture Proceedings (Johnson, Bell and De Young, 2013) report, and

[13] SEAPODYM model indicative results.
[14] Series available at www.spc.int/coastfish/en/publications/brochures/policy-briefs.html

a number of academic journal articles. Their differentiated scientific and policy emphases have enabled them to reach a wide audience and bridge the science and policy realms.

TABLE 7

Relative vulnerability of fish-based food security to climate change in nine Pacific Island Countries and Territories (PICTS)

PICT	Emissions scenarios		
	B1/A2 2035	A2 2050	A2 2100
Melanesia			
Fiji	Very low	Very Low	Very Low
PNG	Very High	Very High	Very High
Solomon Islands	Low	Moderate	Moderate
Vanuatu	Very High	Very High	High
Micronesia			
Guam	Moderate	Moderate	Low
Nauru	Very high	Very high	Very high
CNMI	High	High	High
Polynesia			
American Samoa	Very high	Very high	Very high
Samoa	Moderate	Moderate	High

Notes: Relative vulnerability scores of selected PICTs (countries for which gaps in fish needed for good nutrition per person per year [i.e. 35 kg/person] are projected) to the availability of relative vulnerability scores of PICTs in Group 3 to the availability of coastal (reef-associated) and freshwater fish for food security under the B1/A2 emissions scenarios for 2035, A2 for 2050, and B1 and A2 in 2100. Scores have been classified as very low (0.00–0.05), low (0.06–0.10), moderate (0.11–0.20), high (0.21–0.30) or very high (>0.30). See Supplementary Tables 12.23–12.26 (www.spc.int/climate–change/fisheries/assessment/chapters/12–supp–tables.pdf) for exact vulnerability scores and the values of indices for exposure, sensitivity, potential impact and adaptive capacity used to calculate the scores.

Source: Bell *et al*. (2011).

TABLE 8

Relative vulnerability or benefit for PICT economics to changes in tuna fisheries

PICT	Surface fishery			Longline fishery		
	B1/A2 2035	B1 2100	A2 2100	B1/A2 2035	B1 2100	A2 2100
Melanesia						
Fiji*				- Very low	- Very low	- Very low
New Caledonia*				+ Very low	+ Very low	+ Very low
PNG	+ Very low	- Very low	- Very low	- Very low	- Very low	- Very low
Solomon Islands	+ Very low	- Very low	- Low	- Very low	- Very low	- Very low
Vanuatu	+ Very low	+ Very low	+ Very low	- Very low	- Very low	- Very low
Micronesia						
FSM	+ Low	+ Very low	- Low	- Moderate	- High	- Moderate
Kiribati	+ Very high	+ Very high	+ Very high	- Moderate	- Very high	- Very high
Marshall Islands	+ Low	+ Low	+ Low	- High	- Very high	- Very high
Nauru**	+ Moderate	+ Moderate	- Very low			
Palau	+ Very low	+ Very low	- Very low	- High	- Very high	- Very high
Polynesia						
American Samoa*				- Low	- Low	- Very low
Cook Islands	+ Very low	+ Very low	+ Very low	- Low	- Moderate	- Very low
French Polynesia				- Very low	- Very low	- Very low
Niue*				- Very high	- High	- Moderate
Samoa	+ Very low	+ Very low	+ Very low	- Very low	- Very low	- Very low
Tokelau**	+ High	+ High	+ Very high			
Tonga	+ Very low	+ Very low	+ Very low	- Very low	- Very low	- Very low
Tuvalu	+ Moderate	+ Moderate	+ Moderate	- Low	- Low	- Very low

Notes: Relative vulnerability (–) or benefit (+) for economies of PICTs to projected changes in the surface fishery and longline fishery for tuna under the B1/A2 emissions scenarios for 2035, B1 for 2100 and A2 for 2100. Scores have been classified as very low (0.00–0.05), low (0.06–0.10), moderate (0.11–0.20), high (0.21–0.30) or very high (> 0.30). See Supplementary Tables 12.5–12.10 (www.spc.int/climate–change/fisheries/assessment/chapters/12–supp–tables.pdf) for the exposure, sensitivity, potential impact and adaptive capacity indices used to calculate the scores.

(+) benefit, (–) vulnerability to negative economic impacts.

* PICTs where the surface fishery contributes < 0.01% of GDP.

** PICTs where the longline fishery contributes <0.01% of GDP.

Source: Bell *et al.* (2011).

CASE STUDY 3 – SOCIAL–ECOLOGICAL VULNERABILITY OF CORAL REEF FISHERIES TO CORAL BLEACHING IN KENYA

Reference

Cinner *et al*. (2013).

Purpose of assessment

This study piloted a VA method to help countries, development agencies and their staff, researchers and fisheries professionals in understanding how to define and measure vulnerability within complex fisheries systems, using risks of coral reef bleaching in Kenyan reef-dependent fishing communities as an example. Ultimately, the scope of this work was to improve resilience of fisheries systems and dependent communities to multiple drivers of change including climate change and ocean acidification.

Vulnerability question

What is the social–ecological vulnerability of coral reef fisheries to climate change?

Definition and interpretation of vulnerability

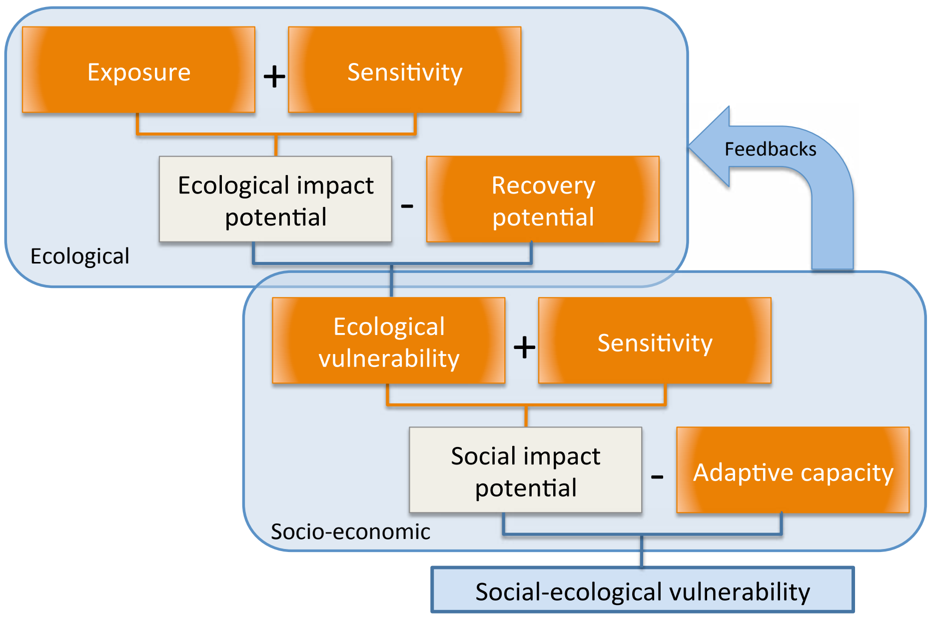
The IPCC model of vulnerability was extended to capture ecological vulnerability nested in social vulnerability as in the following equation and Figure 15.

$V_{S.E} = E_s + S_S – AC_S$

where $E_S = V_E = E_E + S_E – AC_E$

and $_S$ = social, $_E$ = ecological

FIGURE 15
Heuristic framework for linked social–ecological vulnerability



Source: Adapted from Marshall *et al*. (2010).

Data and methods

1. Ecological vulnerability

- Ecological exposure: based on temperature, currents, light, tidal variation, chlorophyll, water quality, site-specific index of coral bleaching stress.
- Ecological sensitivity: based on two indicators.
  1. Susceptibility of coral community to bleaching, using genus-specific bleaching sensitivity (McClanahan *et al*., 2005, 2007).

  2. Susceptibility of fish community to population declines associated with coral habitat loss from bleaching, using species-specific climate vulnerability index (Graham *et al*., 2011).
- Ecological recovery potential: five indicators for corals, six indicators for fish species, from the literature.
- Ecological vulnerability = (Exposure + Sensitivity) – Recovery potential, using the composite metrics developed for these variables.

How was ecological vulnerability to climate change estimated?
Ecological vulnerability includes the potential impact on the ecosystem (i.e. exposure plus sensitivity) minus the recovery potential. For the exposure metric, this study used an existing spatial model that examines the environmental conditions (tides, temperature variability, etc.) that predispose a particular location to mortality from coral bleaching. The literature was then reviewed to find the scientific evidence behind 13 potential indicators of sensitivity and recovery potential for corals and fish assemblages. Each of these indicators was normalized (i.e. put on a scale of 0–1) and then weighted based on the scientific evidence supporting its importance. To ensure that the normalization used appropriate bounding (i.e. high and low values), national and regional variation in the indicators was examined. These indicators were then combined to create metrics for ecological sensitivity and recovery potential.

2. Social vulnerability
- Social exposure = ecological vulnerability.

How was the exposure of social systems to climate change estimated?
Social systems dependent on coral reefs are vulnerable to climate changes (such as increases in temperature and extreme events) through the extent to which ecological components are vulnerable (Ve). Hence, assessing the extent to which ecological components are vulnerable is a matter of understanding how coral reefs are sensitive to climate changes (S) and knowing their capacity to recover from potential impacts (AC).
- Social sensitivity: based on two indicators.
  1. Livelihood sensitivity: dependence on marine resources.
  2. Fishing gear sensitivity: data on how susceptible the catch composition of different gear types is to coral bleaching.

How was the sensitivity of marine-dependent communities estimated?
Coastal communities that are dependent on coral reefs will be sensitive to changes in the coral reef. People can be dependent on coral reefs if their livelihoods are reliant on fishing and depending on what fish they target. This study shows how to develop an occupational sensitivity score based on two measures:
  1. Livelihood sensitivity: Dependence can be assessed through identifying livelihoods within a household or community, and the importance of each livelihood in the household or community
  2. Gear sensitivity: Target species and catch composition can be assessed through observing the specificity of gear used. Different gear will target different species, and some species are more susceptible to climate changes. This study showed how to develop a single value of mean expected decline for each gear.

By providing knowledge of the factors that contribute to sensitivity, decision-makers can prioritize their efforts and provide a basis for early engagement with reef users.
- Social adaptive capacity: based on eleven indicators:
  1. Human agency (i.e. recognition of causal agents impacting marine resources).
  2. Access to credit.

3. Occupational mobility.
4. Occupational multiplicity.
5. Social capital.
6. Material assets.
7. Technology.
8. Infrastructure.
9. Debt level.
10. Trust of community members, local leaders, police, etc.
11. Capacity to anticipate change and to develop strategies to respond.

How was adaptive capacity of social systems estimated?
By providing knowledge of the factors that contribute to adaptive capacity, decision-makers can prioritize their efforts and provide a basis for early engagement with reef users. This study showed how to develop a single metric to assess adaptive capacity based on the 11 indicators shown above. Data for each indicator can be collected through household surveys and/or key informant interviews. To create a metric of adaptive capacity, these indicators then need to be bounded (i.e. placed on a scale of 0–1), weighted (to reflect that some indicators may contribute more to adaptive capacity than others), and combined. It is absolutely critical to examine the data after they are bounded to ensure that there is enough variation (i.e. that some values are at or close to 0 and other values are at or close to 1). If the choice of how to bound the indicators does not allow for sufficient variation, then the indicator will simply not contribute much to the overall adaptive capacity score. There is no hard-and-fast rule about exactly how much variation is enough, so it is advisable to try a couple of different bounding options to see how they influence the adaptive capacity score.

3. Social–ecological vulnerability

- Social–ecological vulnerability = ecological vulnerability (= social exposure) + social sensitivity – adaptive capacity.

Data were collected in ten Kenyan fishing communities, and a quantitative vulnerability score was developed for each community using an equation to combine the three contributing indices (each normalized to 0–1 scale).

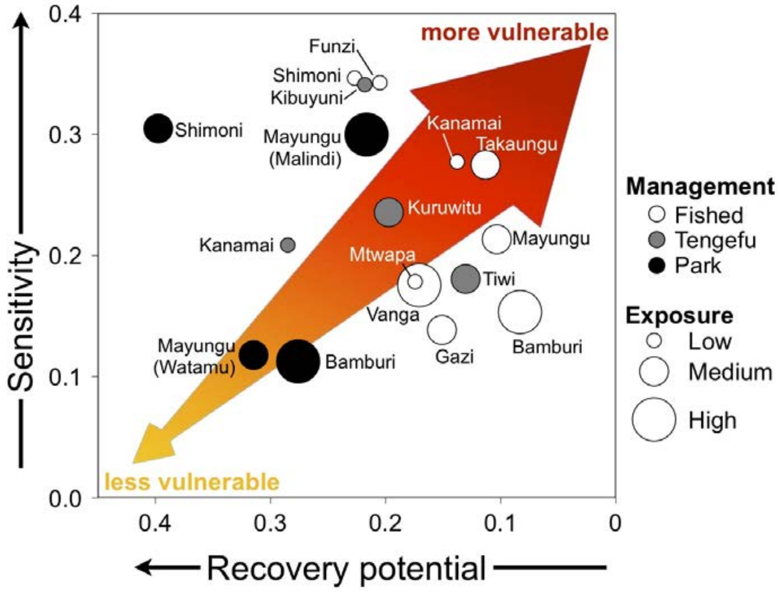
Presentation of the results
Results for ecological vulnerability were provided through the vulnerability scores. Results were also shown graphically – first plotted on a graph showing recovery potential against ecological sensitivity, with ecological exposure indicated by bubble size (Figure 16). In a second step, adaptive capacity was plotted against social sensitivity, with social exposure (= ecological vulnerability) indicated by bubble size, in order to represent social–ecological vulnerability (Figure 17).

CASE STUDY 4 – SOCIAL–ECOLOGICAL VULNERABILITY OF FISHERIES-DEPENDENT COMMUNITIES IN THE BENGUELA CURRENT REGION

References
Raemaekers and Sowman (2015).

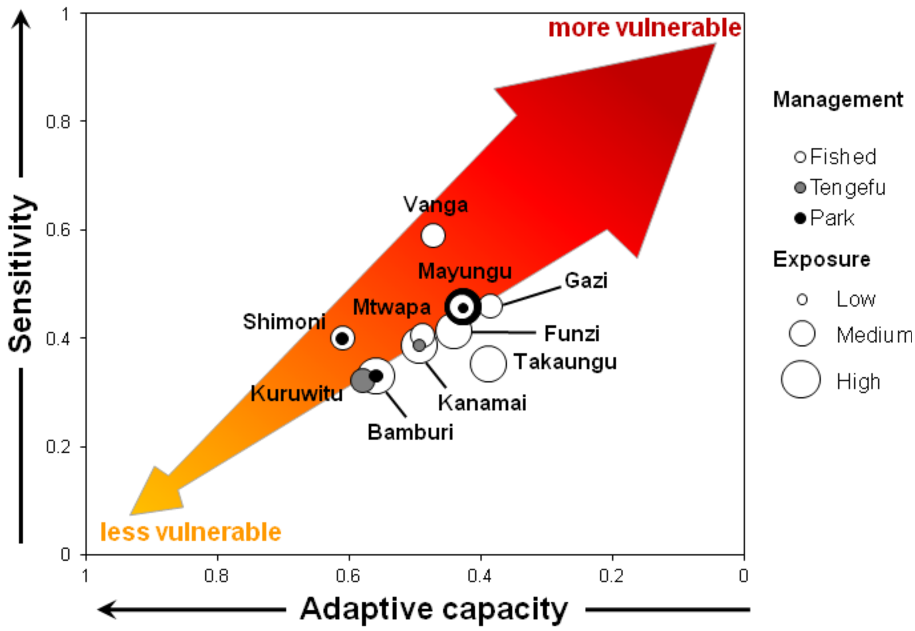
Purpose of assessment
The rapid assessment allowed communities to identify potential threats, strengths and opportunities as well as existing coping mechanisms and adaptation strategies as part of an adaptation process.

FIGURE 16
Ecological vulnerability of Kenyan coastal communities to the impacts of coral bleaching on reef fisheries



Note: The arrow highlights less-vulnerable to more-vulnerable communities.

FIGURE 17
Social–ecological vulnerability of Kenyan coastal communities to the impacts of coral bleaching on reef fisheries



Note: The arrow highlights less-vulnerable to more-vulnerable communities.

Vulnerability question

What are the socio-ecological vulnerabilities of fisheries-dependent communities in relation to climate change and environmental variability, including impacts of other sector activities that may exacerbate vulnerability?

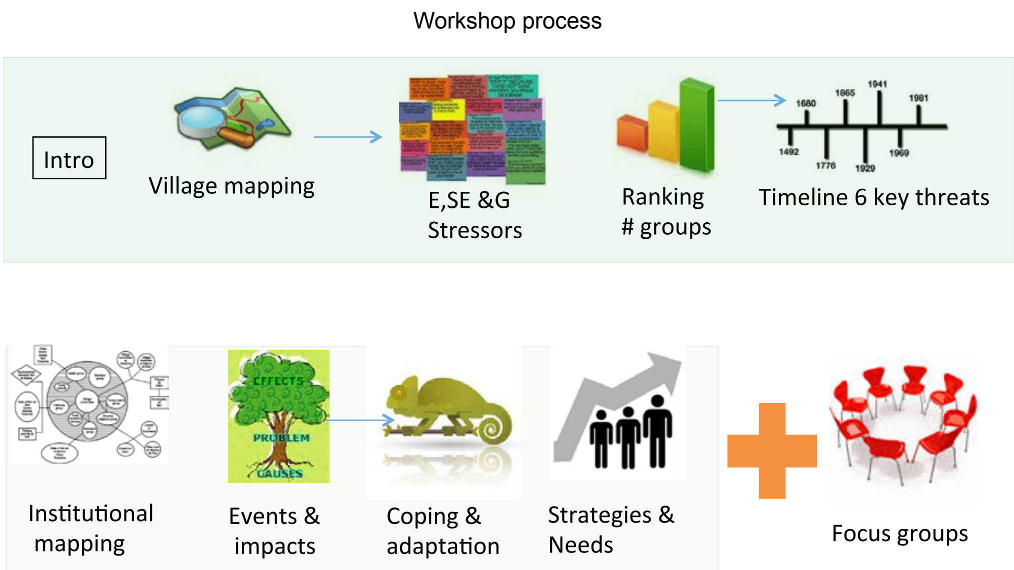
Definition and interpretation of vulnerability

Vulnerability is defined as the extent to which a socio-ecological system (coastal fishery system) is susceptible to various socio-ecological changes (including the effects of climate change) and the system's capacity to adapt to and cope with these changes and effects from the viewpoint of local communities. Here, vulnerability is inherent to a social system, i.e. social conditions, historical circumstances and political economy of groups, and is in effect independent of climate aspects. However, climate change impacts will interact with changes in demographics, markets, technology, social pressures and many other factors that cannot always be anticipated. Social vulnerability will affect the ability of a community to cope with change, whether social or environmental. The conceptual framework used is the "360° degree integrated assessment" to assess vulnerability to different social and ecological stressors, and to map out linkages between these factors, i.e. influence of one factor on another.

Data and methods

In each community, using participatory assessment tools, a profile and map of the socio-ecological system were drawn up, perceptions on threats from all sources were identified, and vulnerabilities were assessed in terms of geographical location, fishery, and post-harvest activities as well as the different groups affected such as children, women groups, and institutions. Coping and adaptation mechanisms were then discussed, and key adaptation options were highlighted. This rapid assessment was done during a two-day workshop consisting of several dedicated plenary discussions, group exercises and key informant interviews or focus group meetings (Figure 18).

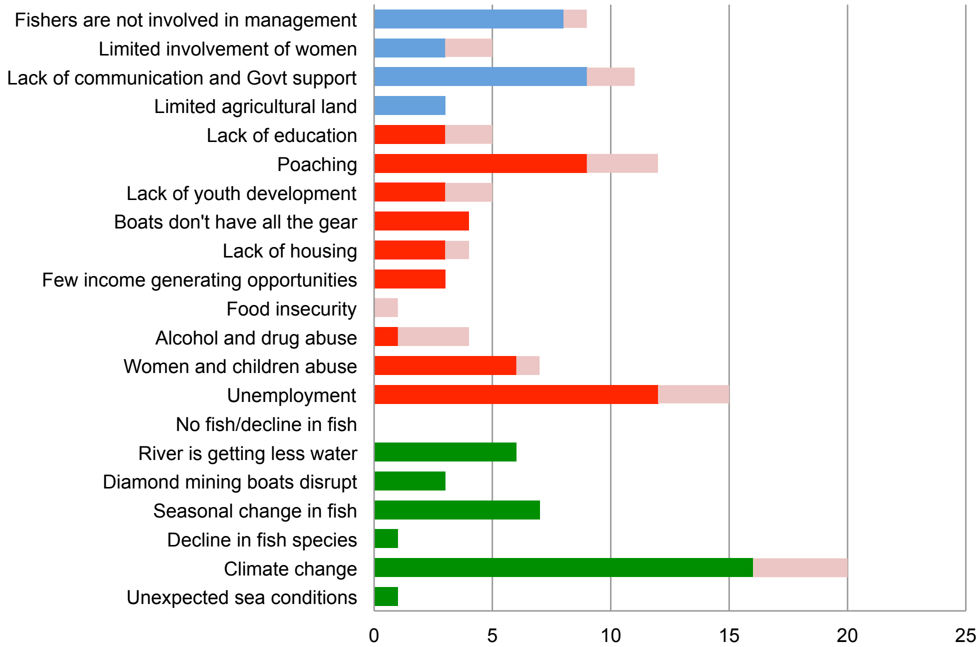
FIGURE 18
Schematic representation of the rapid vulnerability assessment process applied in the Benguela Current region



Presentation of vulnerability assessment findings

Results of each step in the assessment are compiled through graphics, such as Figure 19 of ranked stressors, or as tables such as Table 9 of current and needed adaptation strategies.

FIGURE 19
Example stressors and their relative importance



Notes: Women votes = pink; ecological stressors = green; socio-economic stressors = red; governance stressors = blue.

TABLE 9
Example current and additional adaptation strategies

What strategies are working?	What supported is needed?
Local-level organizations (fisher cooperatives, associations)	Improved financial skills, networking, work ethics, collaboration among cooperatives, better governance
Improved fishing and post-harvest technologies (e.g. GPS, cooling pumps, engines)	Training to use and manage equipment, fisheries management plan, sea rescue unit for area
Improved stock monitoring	Better monitoring and management, safer boats, more research and information and feedback
Exploring new fishing grounds	Safer boats, better technology, more research with local fishers
Supplementary livelihoods (e.g. farming)	Explore and develop fish farming (abalone, mussels, kelp), access to better markets, whale watching
Working closely with NGOs, religious groups, universities and others	Counselling/mentoring, communication, training

CASE STUDY 5 – VULNERABILITY OF FISHERIES AND AQUACULTURE SPECIES AND PRODUCTION SYSTEMS IN THE LOWER MEKONG BASIN

Reference

ICEM (2013).

Purpose of assessment

Under the Mekong Adaptation and Resilience to Climate Change (ARCC) project (funded by the United States Agency for International Development [USAID]), a series of climate change vulnerability and adaptation studies were undertaken for the water resources, food security, livelihoods, and biodiversity of the Lower Mekong Basin (LMB). The studies laid the foundation for the whole USAID Mekong ARCC project by providing the scientific evidence base for identifying highly vulnerable and valuable agricultural and natural systems assets in the LMB, defining adaptation options and priorities, and guiding the selection of focal areas for enhancing existing adaptation strategies and demonstrating and testing new approaches. The studies focused on five themes: (i) agriculture; (ii) capture fisheries and aquaculture; (iii) livestock; (iv) natural systems; and (v) socio-economics. This fisheries study presented a methodology and results for vulnerability assessments using the Climate Change Vulnerability Assessment and Adaptation Methodology (CAM) (ICEM, 2011) to provide adaptation approaches for the ARCC project.

Vulnerability questions

How are LMB fisheries and aquaculture species and production systems vulnerable to predicted climate change impacts?

Scale of assessment

Based on a sector-independent assessment of predicted climate change in the LMB, the assessment took place in six climate change hotspots (Chiang Rai, Khammoun, Gia Lai, Mondulkiri, Kien Giang, and Stung Treng). Indicator species representing a range of fish types can be used as proxies to visualize what specific climate change threats might mean for the wider group of species.

Definition and interpretation of vulnerability

The definitions of vulnerability adopted for the studies were based on the IPCC model of vulnerability tailored to the fisheries and aquaculture species and production systems.

Data and methods

Drivers of change included, depending on the eco-zone: increased temperatures, increased or decreased precipitation, decreased water availability, drought, flooding, storms and flash flooding, sea-level rise, and increased salinity. These exposure variables, using available projection to 2050 for each zone, were matched to information, such as: status of the species (IUCN red list status – invasive, least concern, vulnerable, endangered); water quality requirements and tolerances; migratory patterns; breeding season; diet; current trends and threats. Expert judgement was used to examine exposure, sensitivity and adaptive capacity of capture fisheries species and aquaculture systems (e.g. extensive pond culture, semi-intensive pond culture, cage culture) and related species (e.g. tilapia, silver barb and carps).

Presentation of vulnerability assessment findings

For each eco-zone, results of information compilations were provided in tables listing evaluations (high, medium, low rankings) of the exposure, sensitivity and adaptive capacity of species and processes to each environmental threat (see examples in Tables 10 and 11). Vulnerability assessments for evaluated species and systems were then presented for comparison based on low, medium, high, and very high vulnerability rankings (see examples in Tables 12 and 13). Adaptation options were then proposed for species/production system relative to their relevance in each eco-zone studied (see Table 14).

TABLE 10
Capture fish CAM example results for Chiang Rai

System component or assets	Thread	Interpretation of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
		Written description of how the threat relates to the system component				*Written explanation of what the impact is, and why it was scored (high, med, low)*		
1. *Tor tambroides* UPLAND FISH, SOME MIGRATION, IMPORTANT FOR FOOD SECURITY IN SOME AREAS	Increase in temperature	Maximum temperatures increases of up to 10% in the wet season. 5-7% during other seasons. Even higher relative changes in minimum temps 3-27%, highest in the cool season.	Very high	Very high	Very high	This upland fish favours cooler waters. Increased temps may resul in its disappearance from some lower stream reaches. This species spawns during November and December. Temperature increases at this time may result in changes in reproductive success. May also affect fish biology (maturation, hatching periods, etc).	Low	Very high
	Increase in precipitation	Increased precipitation in the period March-December, highest in the months of Aug & Sept and Oct. Highest percentage increase in precipitation occurs in December (40%).	Medium	High	Medium	This fish favours dear flowing waters and spawns on gravel substrates. Increased turbidity will not favour this fish and may result in the siltation of spawning grounds. High turbidity may impact to availabilty of natural food for fry as well.	Low	Medium
	Decrease in precipitation	Decreases in precipitation are projected to occur duing the months of Jan & Feb, (although these are low rainfall months they are not the driest months).	High	Medium	High	Affects on movement of stocks between pools, compounded by increase in temperature. Lower survival of fish during drier months. Lower stream flows. Affect to their habitats (streams in the mountain) during Jan & Feb affecting, availability of food. Lost connectivity of stream pools.	Low	High
	Decrease in water availability	Reduced soil water availability in period Feb-May and Aug & Sept. The dry season decrease may affect stream water flows.	Low	High	Medium	Reduced capacity of fish to move from pool to pool and onto floodplain. Availability of food. Reduced access to food. Increased fishing pressure.	Low	Medium
	Increase in water availability	No negative effect.	-	-		-	-	-
	Drought	Droughts (>60% of years for 6 months) resulting in poorer water quality, increased fishing pressure in refuge areas. Negative effects compounded by temperature increase.	Low	High	Low	Reduced surVival, Increased fishing pressure on stocks trapped in pools.	Very low	Medium
	Flooding	No negative effects anticipated	-	-	-		-	-
	Storms and Flash floods	Increase in the number of days with daily precipitation above 100 mm, from 7-10 days. Increase in the highest single daily precipitation; 160mm	Medium	Medium	High	Possible effect on migration patterns. Poor water quality from erosion and pesticide from agricultural area nearby. Reduced survival of juveniles. Negative effects on food availability. Physical damage to adults.	Medium	High
	Sea level rise	n/a	-	-	-	-		
	Increasing salinity	n/a	-	-	-	-		

TABLE 11
Aquaculture CAM example results for Chiang Rai

System component or assets	Thread	Interpretation of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
		Written description of how the threat relates to the system component				*Written explanation of what the impact is, and why it was scored (high, med, low)*		
SEMI INTENSIVE POND POLYCULTURE OF TILAPIA, SILVER BARB AND CARPS	Increase in temperature	Maximum temperatures increases of up to 10% in the wet season. 5-7% during other seasons. Even higher relative changes in minimum temps 3-27%, highest in the cool season.	High	High	High	Reduced oxygen levels. Poorer water quality. Disease incidence. Reduced survival rate and growth of fish.	Low	High
	Increase in precipitation	Increased precipitation in the period March-December, highest in the months of Aug & Sept and Oct. Highest percentage increase in precipitation occurs in December (40%).	Medium	Low	Medium	Reduced water quality through turbidity. Reduced productivity of pond and growth of fish	High	Medium
	Decrease in precipitation	Decreases in precipitation are projected to occur duing the months of Jan & Feb, (although these are low rainfall months they are not the driest months).	Medium	Very high	High	Stagnation of pond water. Ammonia accumulation. Water column stratification. Potential die offs.	Very low	Very high
	Decrease in water availability	Reduced soil water availability in period Feb-May and Aug & Sept. The dry season decrease may affect stream water flows.	Low	Medium	Medium	Accumulation of wastes in pond. Poorer water quality. Capacity to fill ponds. Reduced survival and growth of stock.	Medium	Medium
	Increase in water availability	No negative effect.	-	-				
	Drought	Droughts (>60% of years for 6 months) resulting in poorer water quality, increased fishing pressure in refuge areas. Negative effects compounded by temperature increase.	Medium	Very high	High	Difficulty in maintaining pond water levels. Stratification. Reduced survival and growth of stock.	Low	High
	Flooding	No negative effects anticipated	High	Very high	Very high	Control of pond water levels. Maintenance of pond fertility. Loss of stock from pond.	Medium	Very high
	Storms and Flash floods	Increase in the number of days with daily precipitation above 100 mm, from 7-10 days. Increase in the highest single daily precipitation; 160 mm	Medium	Very high	High	Control of pond water. Maintenance of pond fertility in pond. Loss of stock from pond. Damage to pond infrastructure.	Low	High
	Sea level rise	n/a						
	Increasing salinity	n/a						

TABLE 12
Capture fisheries and aquaculture summary vulnerability results for Chiang Rai

Species	Threat	Vulnerability
1. *Tor tambroides* UPLAND FISH, SOME MIGRATION, IMPORTANT FOR FOOD SECURITY IN SOME AREAS	Increase in temperature	Very high
	Increase in precipitation	Medium
	Decrease in precipitation	High
	Decrease in water availability	Medium
	Increase in water availability	-
	Drought	Medium
	Flooding	-
	Storm and Flash floods	High
	Sea level rise	-
	Increasing salinity	-
2. *Cyclochcilichthys enoptos* MIGRATORY, MEDIUM, WHITE FISH IMPORTANT FOR FOOD SECURITY	Increase in temperature	Very high
	Increase in precipitation	Medium
	Decrease in precipitation	High
	Decrease in water availability	Medium
	Increase in water availability	-
	Drought	Medium
	Flooding	-
	Storm and Flash floods	Medium
	Sea level rise	-
	Increasing salinity	-
3. *Trichogaster pectoralis* NON MIGRATORY, SMALL BLACK FISH, IMPORTANT FOR FOOD SECURITY	Increase in temperature	Medium
	Increase in precipitation	Medium
	Decrease in precipitation	Low
	Decrease in water availability	Medium
	Increase in water availability	-
	Drought	Medium
	Flooding	-
	Storm and Flash floods	Medium
	Sea level rise	-
	Increasing salinity	-

System & species	Threat	Vulnerability
INTENSIVE POND MONOCULTURE OF CLARIAS CATFISH	Increase in temperature	High
	Increase in precipitation	Low
	Decrease in precipitation	Medium
	Decrease in water availability	Very high
	Increase in water availability	-
	Drought	Very high
	Flooding	Very high
	Storm and Flash floods	High
	Sea level rise	-
	Increasing salinity	-
SEMI-INTENSIVE POND POLYCULTURE OF TILAPIA, SILVER BARB AND CARPS	Increase in temperature	High
	Increase in precipitation	Medium
	Decrease in precipitation	Very high
	Decrease in water availability	Medium
	Increase in water availability	-
	Drought	High
	Flooding	Very high
	Storm and Flash floods	High
	Sea level rise	-
	Increasing salinity	-
EXTENSIVE POND POLYCULTURE OF CARPS & TILAPIA	Increase in temperature	Medium
	Increase in precipitation	Low
	Decrease in precipitation	Medium
	Decrease in water availability	High
	Increase in water availability	-
	Drought	High
	Flooding	High
	Storm and Flash floods	Medium
	Sea level rise	-
	Increasing salinity	-

TABLE 13
Example capture fisheries proposed adaptation options – upland/forest stream fish

Thread	Proposed adaptation	CR	GL	KH	KG	MK
Increased temperature	Plant forest cover along upland streams	✓	✓			✓
	Create fast-flowing, shallow water areas to increase oxygen levels and improve spawning grounds	✓	✓			✓
	Remove silt from deeper pools to reduce BOD and enhance DO	✓	✓			✓
	Ensure that streams have variable habitats (sunken trees, undercut banks, etc.) that allow fish to move easily from one area to the next	✓	✓			✓
Increase in precipitation	Improve forest cover to reduce levels of soil erosion from heavy rain					✓
Decrease in precipitation	Create connections between pools that allow for fish to move through the stream during low water conditions	✓	✓			
	Create low weirs to retain water during the dry season. However, these weirs must not create obstacles to migrating white fish intending to spawn in the upper river reaches	✓	✓			
	The establishment of conservation areas where adult and juvenile stocks of key species can be protected and their	✓	✓			

Note: CR = Chiang Rai; GL = Gia Lai; KH = Khammoun; KG = Kien Giang; MK = Mondulkiri.

TABLE 14
Example capture fisheries proposed adaptation options – upland/forest stream fish

Thread	Adaptation	CR	GL	KH	KG	MK
Decrease in water availability	Reduce seepage from ponds through embankment repair and maintenance	✓				
	Excavate on-farm reservoir ponds to aid dry season supplies	✓				
	Treatment and re-use of water on the farm rather than discharge of polluted water into watercourses	✓				
Drought	Excavate on-farm reservoir ponds to aid dry season supplies	✓				
	Reductions in fish stocking densities and farm biomass in advance of expected drought periods	✓				
Floods	Increase the height of embankments	✓	✓			
	Change management cycles so that farms have low stocking rates during high-risk periods	✓	✓			
Storms and flash floods	Do not build ponds on the side of stream valleys	✓	✓			
	Ensure that excess water can be more easily diverted away from pond areas	✓	✓			
	Ensure that embankments are maintained to a high standard.	✓	✓			

Note: CR = Chiang Rai; GL = Gia Lai; KH = Khammoun; KG = Kien Giang; MK = Mondulkiri.

CASE STUDY 6 – UNITED STATES NATIONAL MARINE FISHERIES SERVICE METHODOLOGY FOR ASSESSING THE VULNERABILITY OF MARINE FISH AND INVERTEBRATE SPECIES TO CLIMATE CHANGE

References

Morrison *et al.* (forthcoming); Hare *et al.* (forthcoming) www.st.nmfs.noaa.gov/ecosystems/climate/activities/assessing–vulnerability–of–fish–stocks

Purpose of assessment

A VA methodology was created to be applicable across marine ecosystems of the United States of America. The results provide insight into which species are likely to be the most vulnerable to climate change and identify the key drivers behind the vulnerability. Scientists, managers and fishers are expected to use this information as they prepare for and adapt to future conditions.

Vulnerability questions

Which species have life histories and exposures that may leave them vulnerable to large changes in abundance or productivity?

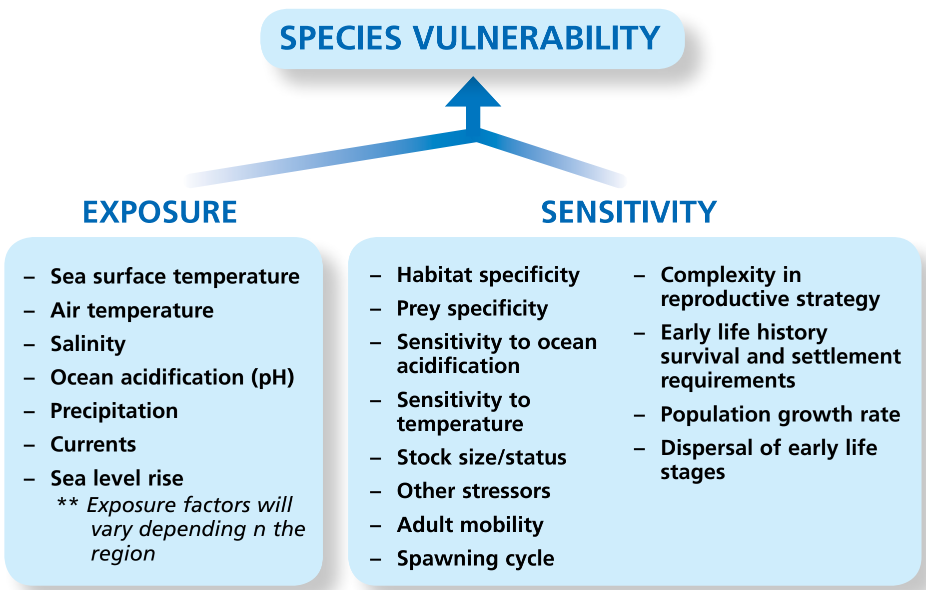
Scale of assessment

The methodology was created to be applicable across different conditions – tropical, temperate, and arctic, as well as data rich and data poor. The first implementation of the assessment was completed for the Northeast United States Continental Shelf Large Marine Ecosystem, and included 82 species of fish and invertebrates.

Definition and interpretation of vulnerability

The basic IPCC model of vulnerability was modified such that vulnerability is a combination of exposure and sensitivity, where sensitivity includes the adaptive capacity of the species. The sensitivity component was divided into 12 sensitivity attributes and the exposure component was divided into a number of exposure factors (Figure 20).

FIGURE 20
General vulnerability assessment framework



Climate exposure was defined as the overlap between the species distribution and the magnitude of the expected environmental change. Exposure factors considered varied depending on what environmental factors are important to the region of interest, but included sea surface temperature, air temperature, pH, salinity, precipitation, currents and sea-level rise. The authors defined sensitivity as the inherent biological attributes of a species that are predictive of their ability/inability to respond to potential environmental changes. The authors chose to base the sensitivity attributes on current biological parameters, rather than projected future changes because there is more certainty around current life-history parameters compared with conjecture about future conditions (Table 15).

TABLE 15
A summary of 12 species sensitivity attributes

Attribute	Goal	Low score	High score
Stock size/status	To determine whether the stock's resilience is compromised owing to low abundance	High abundance	Low abundance
Other stressors	To account for other factors that could limit population responses to climate change	Low levels of other stressors	High levels of other stressors
Population growth rate	Estimate the productivity of a stock	High productivity	Low productivity
Complexity in reproductive strategy	Identify reproductive strategy that may be disrupted by climate change	Low complexity	High complexity
Spawning cycle	Identify spawning strategies that are more sensitive to changes	Year-round spawners	Short-duration aggregate spawners
Early life history Survival and settlement requirements	Determine the relative importance of early life-history requirements for a stock	Larval requirements are relatively resistant to environmental change	Larval requirements are specific and likely to be affected by environmental change
Sensitivity to ocean acidification	Determine the stock's relationship to "sensitive taxa"	Is not a sensitive taxa or reliant on a sensitive taxa for food or shelter	Stock is a sensitive taxa
Habitat specificity	Determine the relative dependence a stock has on habitat and the abundance of the habitat	Habitat generalist with abundant habitat available	Habitat specialist on a limited habitat type
Prey specificity	Determine whether the stock is a prey generalist or a prey specialist	Prey generalist	Prey specialist
Sensitivity to temperature	Known temperature of occurrence or distribution as a proxy for sensitivity to temperature	Species found in wide temperature range or has a distribution across wide latitudinal range and depths	Species found in limited temperature range or has a limited distribution across latitude and depths
Adult mobility	Determine the ability of the stock to move if its current location becomes unsuitable	Highly mobile adults	Sessile adults
Dispersal of early life stages	Estimate the ability of the stock to colonize new habitats	High dispersal	Low dispersal

Note: Detailed attribute definitions can be found in the supplemental information of the original sources.

Data and methods

The methodology relied on technical experts using species profiles, based on scientific literature, and general knowledge to provide a score for each species for each sensitivity attribute and for each exposure factor. Both individual and group expert elicitation practices were used to minimize bias and increase precision of the results. The methodology allowed experts to account for their uncertainty when assigning a score. Experts had five "tallies" for each sensitivity attribute and exposure factor, which they distributed among four scoring bins (low, moderate, high or very high) depending on their confidence in the score. This is a transparent method that clearly shows the expert's uncertainty about each score. In addition, uncertainty across experts can also be informative. Experts also provided a data quality score for each attribute.

The authors used three steps to combine expert tallies into a final vulnerability rank for each species. First, they calculated the sensitivity attribute and exposure factor means based on the distribution of all expert tallies across the four scoring bins. Second, they calculated component scores for exposure and vulnerability based on a logic model. Finally, exposure was multiplied by sensitivity to calculate the overall vulnerability score.

Presentation of vulnerability assessment findings

Results of the first implementation of the assessment for 82 species found in the Northeast United States Continental Shelf Large Marine Ecosystem will be available as a scientific publication (Hare *et al*., forthcoming), as well as available from the website of the National Marine Fisheries Service. Visual presentations of the results will be provided to summarize results as a whole as well as for individual species (e.g. Figure 21). Species narratives will be available for each species detailing overall vulnerability rank, the exposure factors and life-history attributes that led to that rank, as well as a discussion of data quality and future research priorities.

FIGURE 21
Example vulnerability assessment output for one species (Spanish mackerel)

Scomberomorus maculatus	*Expert scores*	*Data quality*	*Expert scores plots (Portion by category)*
Stock status	1.9	2.2	
Other stressors	2.1	1.8	
Population growth rate	1.7	2.6	
Spawning cycle	2.4	2.8	
Complexity in reproduction	2.1	2.6	
Early life history requirements	2.3	1.2	
Sensitivity to ocean acidification	1.1	2.2	
Prey specialization	1.3	2.8	
Habitat specialization	1.6	3.0	
Sensitivity to temperature	1.3	3.0	
Adult mobility	1.3	2.4	
Dispersal & early life history	2.0	2.6	
Sensitivity score	**Low**		
Sea surface temperature	4.0	3.0	
Variability in sea surface temperature	1.1	3.0	
Salinity	3.2	3.0	
Variability salinity	1.2	3.0	
Air temperature	4.0	3.0	
Variability air temperature	1.0	3.0	
Precipitation	1.2	3.0	
Variability in precipitation	1.3	3.0	
Ocean acidification	4.0	2.0	
Variability in oa	1.0	2.2	
Currents	2.0	1.0	
Sea level rise	1.2	1.5	
Exposure score	**Very high**		
Overall vulnerability rank	**Moderate**		

Spanish mackerel – *Scomberomorus maculatus*

Overall Vulnerability Rank = Moderate

Biological Sensitivity = Low

Climate Exposure = Very High

Data Quality = 83% of scores ≥ 2

Low
Moderate
High
Very High

Notes:
Expert vulnerability scores: 1 = low, 2 =medium, 3 = high, 4 = very high.
Data quality scores: 0 = no data, 1 = expert judgement, 2 = limited data, 3 = adequate data.

5. A harmonized vulnerability assessment process for fisheries and aquaculture

A framework for assessing vulnerability in fisheries and aquaculture has recently been elaborated by a group of experts (FAO, 2013b). This framework was inspired by the earlier works of Schröter, Polsky and Patt (2004) and Lim and Spanger-Siegfried (2004) towards the elaboration of a robust VA process[15] and refined on the basis of a number of experiences of VAs in fisheries and aquaculture, including those illustrated in the previous chapter.

STEPS FOR VULNERABILITY ASSESSMENTS IN FISHERIES AND AQUACULTURE

The steps proposed below are aimed at being used as a practical "how to" guide to assist VA practitioners in the development and application of a VA. The level of detail and language used in the process will depend on the information available, the stakeholders involved and the end users of the results (FAO, 2013b).

Step 1: Why a vulnerability assessment? – assessment "warm-up"

This step enables defining the broad context within which the assessment will take place. It is essential to reflect and decide on why a VA is needed:

- Who is driving/requesting the assessment and why?
- Define the objective (or objectives) of the assessment: What are its immediate objective and links to longer-term/higher level goals? This implies distinguishing between the specific output (product) of the assessment and the outcomes (changes) the assessment will lead to.
- To what extent is the assessment anticipatory (*ex ante*), reactive (*ex post*) or a mix of both?
- Who are going to be the users of the assessment? (direct and indirect users, at several possible levels)
- Who will undertake the VA? What is their expertise/disciplinary background?

Operational constraints also need to be identified:

- What issues need to be considered relating to the funding source for the assessment?
- Are there time constraints for the assessment?
- Are there financial and human constraints?

Step 2: Identify the system and drivers – "scoping" activity

This step enables an **initial** scoping of who/what is vulnerable to what and why, within the context determined under Step 1. It is **not** the assessment as such, but it should enable a broad picture of vulnerability to be obtained in order to help define the scope, range and possible methods of the detailed VA to be undertaken.

a) Important things to consider are:

- What is the specific system/sector/group at stake: socio-economic, biophysical, combined human–environmental?

[15] A summary of these earlier works is provided in Appendix 4.

- What are the major drivers of change in the system: climate change, economic, social, policies, micro/macro? A rapid analysis of impact pathways may be useful here and will provide the broad picture of changes in the system.
- What is the temporal scale to be considered: long-term, short-term, past history, projections?
- What is the spatial scale of the assessment: national, local, regional, ecological scales, combination of scales?
- Can some thresholds/tipping points be identified at this stage, i.e. up to what point will a system people need to change?
- Who are stakeholders to involve in the assessment? At this stage, a rapid stakeholder analysis, including considerations of their likely perceptions and of external stakeholders may be useful.

Box 5 provides examples of initial vulnerability questions and issues specific to fisheries and aquaculture. At this point, future projections of climate and vulnerability are not necessarily required, as it is mostly contextual vulnerability that is focused upon.

BOX 5

Example questions and issues specific to fisheries and aquaculture in a vulnerability scoping exercise

Understanding the **exposure** of the human and aquatic system to change: Identification of the biophysical changes expected over different time scales (year, decade and century) and their impacts on the system under evaluation and the larger communities dependent on the system.

- Review of any existing climatic, oceanographic, etc. models predicting biophysical changes and system (ecosystem) impacts within the context of other drivers of change on the system (e.g. pollution, irrigation, land use, other users of the aquatic system, fishing).
- Analysis of the various pathways to impacts on the fisheries/aquaculture system and communities within the context of other drivers of change (e.g. globalization, changes in markets, war, policies). For example, fisheries management, use of resources by other sectors, pollution and runoff all affect the fisheries resources and environments. Social, political and economic drivers also affect fisheries and their communities.
- It would help to know to what extent changes are climate-change-driven and, further down, how sensitive the system is to the various drivers.
- How likely are these changes to occur?
- If no formal information is available, opinion and perceptions would be useful.

Understanding the **sensitivity** of the human and aquatic system to change.

- Description of the biological and ecological state of the resources in the system:
  How sensitive are the ecosystem and fisheries species to changes in temperatures, sea level, salinity, precipitation, ocean circulation and other predicted impacts? What are the consequences to ecosystem well-being if the change comes about?
- Description of the social and economic contributions to, for example, food/nutrition security, livelihoods, employment, export earnings, social stability, and dependence of the relevant communities (local, regional, national) on the system:
  How sensitive are these to changes in the various drivers, including climate change? What are the consequences to human well-being if the change comes about?

Evaluating the current **adaptive capacity** of the human and aquatic system.

- Description of the resilience and adapting capabilities of the aquatic system, such as through indicators on biodiversity within the ecosystem, genetic diversity of species, biomass, age and size structures, water quality, amount of habitat destruction/rebuilding, proximity to threshold limits.

BOX 5 (CONTINUED)

- Description of the adaptive capacity of the human economic–social system, such as:
  - The ability of institutions, communities and individuals to learn, use and store knowledge and experiences:
    - How is (market, climate, policy) information shared at the local level? National level?
    - What information is collected and how/when is it collected (e.g. research surveys, local knowledge surveys)?
    - How is this information used to assist management and manage uncertainty and change?
    - Etc.
  - Flexibility in decision-making and problem-solving:
    - Are adaptive, participatory, integrated approaches to management in place?
    - Etc.
  - Existence of power structures that are responsive, effective and consider the needs of all stakeholders:
    - Who is responsible for fisheries management?
    - Who is responsible for disaster risk management, general aquatic health, water management, coastal/lake/river/basin management?
    - Is it the same agency for the above items?
    - Do relevant plans exist and are they coordinated across institutions (e.g. does an integrated coastal management plan exist that incorporates disaster risk management)?
    - Who takes the decisions?
    - What are the consultation processes?
    - How is uncertainty built into the decision-making process?
    - Etc.
  - Existence of alternatives and access to services:
    - Are there social safety net systems in place (e.g. community-level insurance, shared recovery costs)?
    - Alternative livelihoods availability? Job mobility? Training?
    - Access to alternative markets?
    - Alternative sources of food and nutrition?
    - Access to public services (potable water, health systems, education)?

b) Methods to organize information from point 2.a.

Organizing the information gathered from point 2a will depend on the preferences of the stakeholders defining and working on the VA. Some possibilities include structuring information in:

- matrix/table form,
- decision tree,
- axis/gradients,
- maps,
- freely, in narratives
- according to the five livelihood capitals (natural, physical, financial, social, human)

It may also be useful to organize the information according to the IPCC model of vulnerability (exposure, sensitivity, adaptive capacity – Figure 3) for different types of stakeholders, or scales (spatial and/or temporal).

Step 3: Choosing a framework of analysis

From the broad picture and initial scoping of drivers and vulnerabilities drawn from step 2, stakeholders will need to agree upon a particular framework for the vulnerability analysis. The choice of framework will depend on the questions to be asked by the VA, how and to whom the VA and its findings will be communicated, operational constraints, and what people need and want from the VA.

It may be useful to consider at this point the IPCC model of vulnerability complemented by other frameworks, as shown in Figure 5, as this will allow for drivers other than climate change to be encompassed in the assessment. This enables not only acknowledgement of the existence and relevance of these other frameworks, but also the option to build a layer of complexity over the basic IPCC vulnerability components with complementary considerations and perspectives.

Step 4: Identify data/information needed to answer the vulnerability questions

Having established the questions that the VA is to answer, depending on its purpose, objective and time/financial/human constraints, this step should establish which information and data are needed, which are already available and which need to be collected.

Depending on the various elements underlying the vulnerability questions, the assessment may consider using a mix of various types of data: qualitative, quantitative, primary (gathered at the source), and secondary (derived from other sources) of any kind (e.g. scientific climatic, biological, socio-economic data, perceptions information).

This inventory of data/information can be organized according to the method used in step 2.

Step 5: Identify how to get these data and information

There are many methodologies available for collecting data and information on the vulnerability components. The choice of these methods will depend on issues such as the scale of the assessment, resource constraints, as well as whether participatory approaches or other approaches to collecting information are to be used.

Some questions to consider include:

- How to obtain the missing data/information: reviews, secondary data (e.g. census), surveys, expert or stakeholder workshops, etc.?
- Who can collect it?
- Where/whom from?
- Are present data, future projections, historical information included?

Links to guidance on information-gathering methodologies that could be adapted to the context of a VA include the online EAF Toolbox[16] and the list of process-oriented methodologies and information management tools for use in the implementation of the EAF. More information on these methodologies, as well as those included in Figure 7, is provided in Appendix 2.

Step 6: Analysing the data/information within the chosen framework

This step is about analysing the collected data and information according to the framework chosen for the assessment. There are many methodologies available for pulling together the information on the vulnerability components, such as modelling-based (e.g. downscaling, modelling), indicator-based (computation of indices and indicators), and stakeholder-based (livelihood narratives, institutional analyses, etc.) methods. The choice between these methods will depend on the scale, information collected and available, and the purpose of the assessment itself.

The results of this step should provide refined answers to the questions: Who and/or what is vulnerable to what? (step 2). They should also clearly point to the causes or reasons for vulnerability, i.e. answer why systems or people are unable to adapt and vulnerable, in such a way that recommendations and priorities for action become clear.

[16] Available at www.fao.org/fishery/eaf-net/topic/166272/en

Step 7: Report and communicate findings

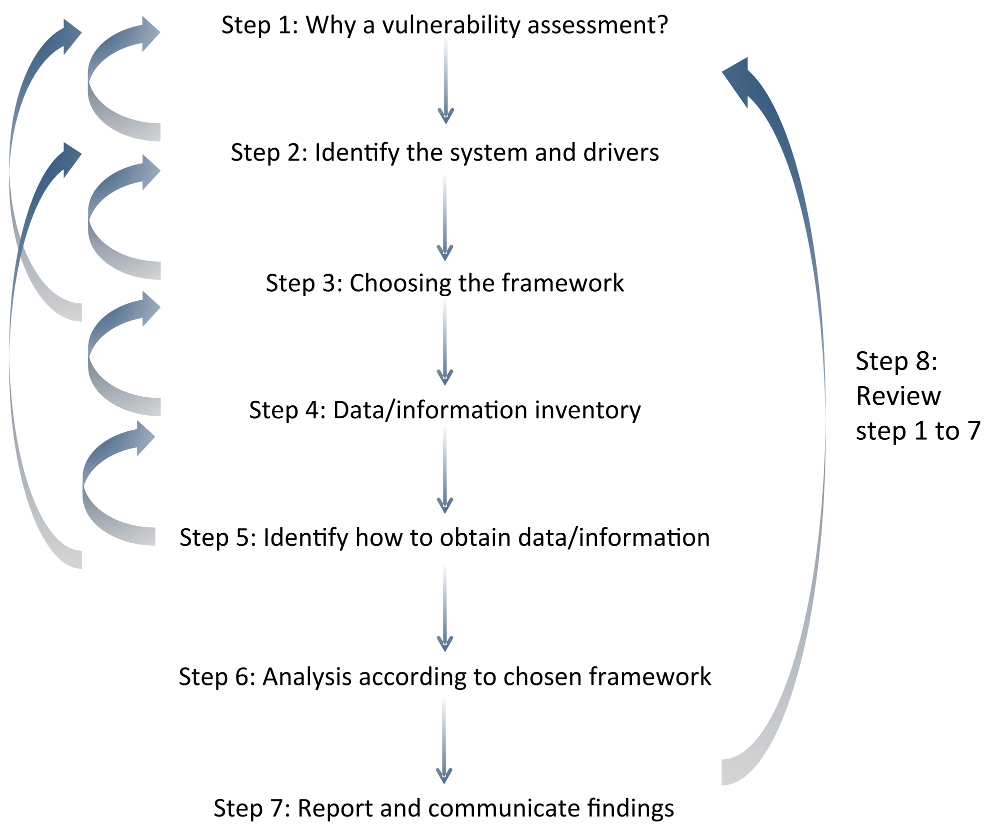
Depending on the objectives and users of the findings, this step considers how and in what forms the findings of the VA should be communicated for adaptation planning and used to influence decision processes.

It is essential to decide upon target audiences and users and the most appropriate communication channels for these audiences.

Step 8: Review steps 1–7

As the vulnerability questions may evolve during the VA process (steps 1 to 7), this step is to remind the assessor to continuously review each step along the way and make the necessary adjustments to the VA methodologies followed (see Figure 22).

FIGURE 22
Proposed vulnerability assessment process for fisheries and aquaculture



Source: FAO (2013b).

6. Beyond vulnerability assessments: some reflections

FROM VULNERABILITY ASSESSMENT TO DECISION-MAKING: TURNING FINDINGS INTO ACTIONS AND POLICIES

Vulnerability assessments are often part of a continuum of activities that, together, enable adaptive capacity and resilience to be assessed and enhanced (Lim and Spanger-Siegfried, 2004; UNFCCC, 2011). Findings from VAs can be used in adaptation projects to describe potential future vulnerabilities, to compare vulnerability under different socio-economic and climatic futures, or to identify key options for adaptation, for example.

Assessing vulnerability is not only a scientific exercise. It carries an important political dimension that is likely to encroach upon the domain of policy analysis (Patt *et al.*, 2009; Klein and Möhner, 2011). For example, identifying winners and losers of climate change can have important policy implications, notably in the design of economic development strategies (O'Brien and Leichenko, 2000).

If VAs relating to global change are to "inform the decision-making of specific stakeholders about options for adapting to the effects of global change" (Schröter, Polsky and Patt, 2004: 3), they should be scientifically valid, as well as useful and credible to all stakeholders (both those involved in the assessment and beyond) (Schröter, Polsky and Patt, 2004; Polsky, Neff and Yarnal, 2007). However, there is still a gap between the findings of VAs and their translation into adaptation policies. Füssel and Klein (2006), for example, tried to fill this gap with a particular framework for an "adaptation policy assessment" that builds on their "second generation" VA framework but provides a stronger focus on the implementation and facilitation of measures to increase mitigative and adaptive capacities.

In order to bridge the gap between what stakeholders, scientists and practitioners can provide in their study and assessments of vulnerability, and what policy-makers need to base their decisions upon, the following questions should be carefully considered:

- Regarding the prioritization for interventions: Which vulnerability elements should be addressed first, or simultaneously? How to decide which countries, systems or areas are more or "particularly" vulnerable and need targeting in priority? (Klein, 2009). On which basis should short-term versus long-term interventions and policies be prioritized? What are the estimated costs and benefits of the potential interventions?
- Regarding the scales of intervention (macro/meso/micro): What are the linkages between them?
- Regarding interventions: Could some "standard"/minimum or "no regrets" adaptation measures or policies be recommended? Is some "tailoring" imperative?
- Regarding the place of climate change in relation to other drivers of change: Could climate change adaption be used as a vehicle to address other forms of vulnerabilities and vice versa? (e.g. gender inequality).
- Regarding the relevance of a VA: What is the usefulness of the assessment methodologies proposed for other purposes than adaptation planning? Is a VA justified and necessary if "no regrets" adaptation actions can be done with the time and expense of a VA (e.g. better fisheries and aquaculture management)?

In order to make a VA useful, it is also important to (after Turner *et al.*, 2003a):

- decide what one wants to achieve with the VA at hand (it gives an idea of what could be achieved through a VA, if one needs to focus on specific aspects); or

- have a checklist while carrying out a (large) VA to ensure that nothing has been completely overlooked.

This latter point forces the assessors to think holistically about vulnerability and provides a starting point of analysis that also allows gaps in understanding to be identified (Turner *et al*. 2003b). It echoes the emphasis placed on the need for holistic thinking to capture the multiple facets of vulnerability indicated in the broader IPCC model (5). This is particularly important so that adequate attention is paid to the "so what?" question that should be asked at the end of any VA and guide follow-up vulnerability reduction initiatives.

Box 6 describes the process followed by a Caribbean country to move from a VA to the elicitation of suitable adaptation options to climate change for its fisheries sector.

BOX 6

The Grenada case: from vulnerability assessment to adaptation actions

Grenada comprises the main island of Grenada, two smaller islands (Petite Martinique and Carriacou), and a number of smaller uninhabited and semi-inhabited cays. It marks the southern end of the Caribbean's Windward Islands and is among the youngest islands in the Insular Caribbean. This island nation is among the countries emitting the least amount of climate-changing greenhouse gasses. However, its high coastal population densities, limited land space, geographic location, scarce freshwater supplies, and high dependence on natural-resource-based livelihoods (specifically tourism, fisheries, and agriculture) make it one of the countries most vulnerable to climate change impacts. The government of Grenada is actively working to develop responses to climate change. Although capacity has been evolving rapidly, the individuals, agencies and local organizations charged with developing adaptation strategies have limited access to information and tools needed to help articulate current impacts, visualize likely future events, understand the socio-economic implications of those events, and take action to protect people and the environment.

To help decision-makers identify vulnerable areas and develop adaption strategies, a spatial analysis was conducted to identify those communities most vulnerable to inundation from sea-level rise and storm surge in Grenada. The IPCC (2007) vulnerability (VA) framework that describes the vulnerability of coastal communities as a function of exposure, sensitivity and adaptive capacity was applied. This framework helped organize, synthesize and communicate information about the climate and disaster risks to fisheries. Fisheries indicators across a suite of both ecological as well as socio-economic characteristics were estimated for those which could be rapidly collected and embedded in an overall coastal VA. This helped highlight the key role that fisheries play in the overall coastal vulnerability of Grenada.

Decisions on what information to use to populate the framework with the appropriate social and ecological indicators were made by examining the availability of fisheries information and existing gaps at the national, subnational and site level. The aim was to find information to describe the following areas: (i) resource characteristics, (ii) governance, (iii) livelihood, (iv) infrastructure (social and physical), and (v) economics. For each of these areas, the following question was asked: What are the key pieces of information necessary and accessible to describe a place (be it a section of the nation's coastline or a section of a site's bay)?

In order to build an information base for Grenada without conducting extensive field surveys, various information types were accessed and drawn from the following sources to generate indicators: information collected from government programmes (fisheries, physical planning and government census departments), and stakeholder-based methodologies (fisher focus group surveys, and participatory mapping). Information from government programmes was especially useful for national and subnational-level assessment, while stakeholder-based methodologies proved to be the most useful for site-level assessments.

The next step was to use the outputs of the VAs to design actions that would help reduce the vulnerability of coastal communities. A site-specific approach was implemented with

BOX 5 (CONTINUED)

local non-governmental organizations (NGOs), community and government to design a suite of adaptation actions for Grenville, a coastal community in Grenada identified by the assessment and local partners as one of the most vulnerable communities. The stakeholder-based methodologies described above provided an excellent entry point to engage the community. Following fisher and household surveys conducted in partnership with the Red Cross of Grenada, a series of community meetings (including a 3D participatory mapping exercise) were held to design a series of adaptation actions that could help reduce the vulnerability of the Grenville community to climate change. Given the reliance of the Grenville community on fisheries as the main source of livelihood, a suite of fisheries-specific actions was included. These actions included: a series of activities to enhance the cohesiveness of the fisher community that would help strengthen their adaptive capacity; the development of a fisher village along the southern end of the Grenville Bay that incorporates and leverages natural infrastructure and is designed to withstand the impacts of flooding from sea-level rise and storm surge; and the restoration and enhancement of natural habitat to help decrease erosion and protect coastal (including fisheries related) infrastructure from storm surge. A subset of the activities identified is currently being implemented in partnership with local NGOs, community and government. Implementing the full suite very much depends on the willingness of the Government of Grenada and the international community to invest in Grenville in the long term, but some important building blocks have been laid via these efforts.

It is important to remember that, given the degree to which tropical coastal communities rely on fish for food security and livelihoods, the investments made to increase the resilience of small-scale fisheries will benefit resilience of coastal communities overall.

Many small fishing communities such as Grenville are economically, socially, and politically marginalized owing to poor access to infrastructure, markets and social services. As climate and disaster risk jeopardize that access, addressing these multiple stresses using cross-sectoral approaches becomes critical. Vulnerability assessments provide a solid foundation for cross-sectoral collaboration. If well executed, they can also help decide where to focus limited resources and be a strong vehicle for community engagement. The sustainability and, ultimately, the effectiveness of solutions to help decrease vulnerability of small-scale fisheries depend on all of the above. The Grenville efforts described above provide a good example of the steps involved in taking a vulnerability assessment through to implementation.

The literature on adaptation decision-making may yield interesting insights on how to ensure that VAs – especially those stemming from quantitative and top-down approaches – can go that step further in informing policies and guiding action. However, Ribot (2011, p. 1161) warns that a sole focus on climate adaptation (and indirectly on climate hazards instead of a broader range of stressors) can obscure causality and the understanding of why people are vulnerable in the first place: “The word adaptation does not preclude vulnerability analysis. Indeed, actions labeled adaptation should be based on deep knowledge of vulnerability. Such analysis does not just mean identifying vulnerability indicators – to which vulnerability analysis is often reduced. Indicators are important for identifying who is at risk so interventions can be well targeted. But it is analysis of why they are at risk that tells us what can be done about it. Insisting on causal analysis as a prerequisite of any climate risk-reduction approach, ensures that the broadest range of factors is taken into account for guiding action. While adaptation may seem urgent and rigorous causal analysis takes time, skipping this step limits options.”

Vulnerability research has long been closely linked to disaster risk reduction and has informed many interventions towards it (Miller *et al*., 2010). Given their numerous cross-overs, vulnerability and resilience research ought to inform actions and policies towards adaptation and transformation. However, translating local findings to larger scales is likely to remain problematic.

Finally, estimating the consequences of interventions, considering their distributional aspects and weighing their pros and cons, needs to be encompassed in VAs. While a "no regrets" approach that mixes social risk management and asset-based vulnerability information has been proposed to guide interventions (Heltberg, Siegel and Jorgensen, 2009, although with more specific reference to the disaster context), in-adapted policies can also lead to "maladaptations" and undermine the very capacity of people they intend to help (Bunce, Brown and Rosendo, 2010).

FURTHER REFLECTIONS ON VULNERABILITY ASSESSMENTS

Can the methodology wilderness be tamed?

The terminology used in vulnerability research remains rather complicated, if not confusing for a non-academic audience, not only because of semantics, but also because of the many interpretations of the vulnerability question. For example, "outcome" and "contextual" vulnerability terms may not make immediate intuitive sense. However, these terms, and many others used in this document to depict vulnerability constructs, seem to have now been widely adopted by vulnerability experts, and are starting, often implicitly, to be mainstreamed in the wider climate adaptation and development policy literature.

Overall, the review of the literature has shown that two broad categories of constructs of vulnerability can be distinguished: one related to the "natural" world (risk/hazard construct and outcome vulnerability), and one related to the "human" world (political economy/ecology and resilience constructs, and contextual vulnerability). Although the former seems to have guided vulnerability investigations in both fisheries and non-fisheries contexts to a greater extent, the latter has received increasing attention over the years thanks to the regain in holistic thinking brought about by the consideration of coupled social-ecological systems.

Within each vulnerability perspective, a range of methodologies of assessment is available. In real-world assessments, they are often used in a complementary way, or integrated through the use of methods enabling this to happen. In the context of fisheries and aquaculture, as in other contexts, a focus on a biophysical exposure unit will prompt an affiliation with outcome vulnerability and the use of top-down methods, whereas a focus on a human exposure unit will prompt an affiliation with contextual vulnerability and the use of bottom-up investigation approaches. A larger number of experiences are found in relation to the former, although the use of stakeholder-based approaches is on the increase.

Figure 7 has attempted to put some order in the methodologies that have been proposed, and the tools needed for implementing VAs, while relating them explicitly to the perspective on vulnerability they are meant to help document.

However, some questions remain:

- Which methodologies or mix of methodologies have demonstrated success when implemented in fisheries and aquaculture, according to which criteria and in which contexts and circumstances?
- Which methodological gaps remain and which new methodological developments need to be considered to ensure the relevance of generic VA approaches to the specific context of fisheries and aquaculture?

Vulnerability perspectives, methodologies and investigation tools remain tightly intertwined. Deciding on the objective of the assessment from the outset, whether it is located at the research or at the development ends of the vulnerability continuum can help in seeing through this complexity, and guide towards the choice of suitable investigation approaches.

Searching for clarity in the vulnerability "jungle" will lead to inevitable simplifications that vulnerability experts may resent, but that practitioners may appreciate. Similarly, being overprescriptive in the way VAs should be conducted may be counterproductive, although conclusions deducted from VAs about the status or degree of vulnerability of a particular ecosystem or human group will be more reliable if they stem from an agreed-upon framework of enquiry, itself grounded in the conceptual underpinnings of vulnerability. Recognizing the importance of values and perceptions of both vulnerability experts and vulnerable groups is to be emphasized here, as they will tint findings and influence subsequent decision-making.

Finally, although only alluded to in earlier sections, vulnerability and resilience are different, and yet closely intertwined (Miller *et al.*, 2010). Their dual consideration can advance a more integrated understanding of social–ecological change, and thus better guide interventions supporting long-term (positive) adaptations to climate change. Indeed, as much uncertainty is inherent to this process, increasing resilience is generally thought of as a robust and "safe" approach to decreasing vulnerability.

7. Conclusion

Vulnerability assessments are usually not stand-alone exercises, but often placed in a continuum of activities that are carried out together for specific ends. Vulnerability assessments can therefore be carried out to suit different purposes, and these are key determinants of the vulnerability questions asked and the methodologies that will be chosen to undertake the assessment. However, it is often the case that not all information is available when the VA is carried out. Therefore, findings at various stages of assessment should be revisited when new or complementary information becomes available or when some uncertainty is reduced.

The relatively simple IPCC model of vulnerability, which has guided most VAs to date, is still evolving. Its refined applications in the context of fisheries and aquaculture have made important contributions in this regard. It has enabled both ecological and social vulnerability to be captured, and the characterizing of the circumstances under which climate change is anticipated to generate losses and hardship, as well as bring about benefits and decrease vulnerability.

Vulnerability has multiple facets. Methods of analysis and assessment need to embrace this complexity. They can be quantitative, qualitative, relative and absolute, global, local, expert-driven or stakeholder-driven, or a combination of all. Deciding on the type of vulnerability analysis (its scale, methods, data) should however be determined by the purpose of the assessment. Available resources, time, expertise and data are also important constraints that will also influence the choice of assessment methodology (or methodologies).

Finally, interpretation of vulnerability analysis requires careful attention regarding the assumptions and choices of indicators and models used, particularly where multiple indicators of each component are used. Stakeholder values and perceptions of vulnerability, as well as the background and perspectives of the vulnerability assessors, need to be recognized and made explicit as they are likely to influence the assessment conclusions and adaptation priorities.

References

Adger, W.N. 2006. Vulnerability. *Global Environmental Change*, 16(3): 268–281.

Adger, W.N. & Vincent, K. 2005. Uncertainty in adaptive capacity. *C. R. Geoscience*, 337: 399–410.

Adger, W.N., Brooks, N., Bentham, G., Agnew, M. & Eriksen, S. 2004. *New indicators of vulnerability and adaptive capacity*. Technical Report 7. Norwich, UK, Tyndall Centre for Climate Change Research.

Allison, E.H., Adger, W.N., Badjeck, M.-C., Brown, K., Conway, D., Dulvy, N.K., Halls, A., Perry, A. & Reynolds, J.D. 2005. *Effects of climate change on the sustainability of capture and enhancement fisheries important to the poor: analysis of the vulnerability and adaptability of fisherfolk living in poverty*. Final technical report. Fisheries Management Science Programme MRAG/DFID, Project no. R4778J. London.

Allison, E.H., Perry, A.L., Badjeck, M.C., Adeger, W.N., Brown, K. Conway, D., Halls, A.S., Pilling, G.M., Reynolds, J.D., Andrew, N.L. & Dulvy, N.K. 2009. Vulnerability of national economies to the impacts of climate change on fisheries. *Fish and Fisheries*, 10(2): 173–196.

Alwang, J., Siegel, P. & Jorgensen, S. 2001. *Vulnerability: a view from different disciplines*. Social Protection Discussion Paper Series. Washington, D.C., World Bank.

Badjeck, M.-C., Mendo, J., Wolff, M. & Lange, H. 2009. Climate variability and the Peruvian scallop fishery: the role of formal institutions in resilience building. *Climatic Change*, 94: 211–232.

Barange, M., Merino, G., Blanchard, J.L., Scholtens, J., Harle, J., E.H. Allison, E.H., Allen, J.I., Hold, J. & Jennings, S. 2014. Impacts of climate change on marine ecosystem production in societies dependent on fisheries. *Nature Climate Change*, 4:211–216.

Barsley, W., De Young, C. & Brugère, C. 2013. *Vulnerability assessment methodologies: an annotated bibliography for climate change and the fisheries and aquaculture sector*. FAO Fisheries and Aquaculture Circular No. 1083. Rome, FAO. (also available at www.fao.org/3/a-i3315e/index.html).

Berkes, F., Colding, J. & Folke, C. 2003. *Navigating social–ecological systems: building resilience for complexity and chance.* Cambridge, UK, Cambridge University Press.

Bharwani, S., Bithell, M., Downing, T.E., New, M., Washington, R. & Ziervogel, G. 2005. Multi–agent modelling of climate outlooks and food security on a community garden scheme in Limpopo, South Africa. *Philosophical Transactions of the Royal Society B*, 360: 2183–2194.

Bell, J.D., Johnson, J.E., Ganachaud, A.S., Gehrke, P.C., Hobday, A.J., Hoegh–Guldberg, O., Le Borgne, R., Lehodey, P., Lough, J.M., Pickering, T., Pratchett, M.S. & Waycott, M. 2011. *Vulnerability of tropical Pacific fisheries and aquaculture to climate change: summary for Pacific island countries and territories*. Noumea, Secretariat of the Pacific Community .

Birkmann, J. 2006a. Measuring vulnerability to promote disaster–resilient societies: Conceptual framework and definitions. *In* J. Birkmann, ed. *Measuring vulnerability to natural hazards: towards disaster resilient societies*, pp. 7–54. Tokyo, United Nations University.

Birkmann, J. 2006b. *Measuring vulnerability. Report of the First Meeting of the Expert Working Group "Measuring Vulnerability" of the UNI–EHS, Kobe, Japan, 23–24 January 2005*. Working Paper 1. Bonn, Germany, United Nations University.

Bunce, M., Brown, K. & Rosendo, S. 2010. Policy misfits, climate change and cross-scale vulnerability in coastal Africa: how development projects undermine resilience. *Environmental Science and Policy*, 48: 485–497.

CAIT. 2005. Climate Analysis Indicators Tool (CAIT) Version 2.0. (available at http://cait.wri.org/)

Cheung, W.W.L., V.W.Y. Lam, J.L. Sarmiento, K. Kearney, R. Watson, D. Zeller, and D. Pauly. 2010. Large-scale redistribution of maximum fisheries catch in the global ocean under climate change. *Global Change Biology*, 16(1): 24-35.

Cinderby, S., Snell, C. & Forrester, J. 2008. Participatory GIS and its application in governance: the example of air quality and the implications for noise pollution. *Local Environment*, 13(4): 309–320.

Cinner, J., McClanahan, T., Wamukota, A., Darling, E., Humphries, A., Hicks, C., Huchery, C., Marshall, N., Hempson, T., Graham, N., Bodin, Ö., Daw, T. & Allison, E. 2013. *Social–ecological vulnerability of coral reef fisheries to climatic shocks*. FAO Fisheries and Aquaculture Circular No. 1082. Rome, FAO. (also available at www.fao.org/docrep/018/ap972e/ap972e00.htm)

Cochrane, K., C. De Young, D. Soto & T. Bahri, eds. 2009. *Climate change implications for fisheries and aquaculture: overview of current scientific knowledge*, pp. 107–150. FAO Fisheries and Aquaculture Technical Paper No. 530. Rome, FAO. 212 pp. (also available at www.fao.org/docrep/012/i0994e/i0994e00.htm).

Cooley, S.R., Lucey, N., Kite–Powell, H. & Doney, S.C. 2012. Nutrition and income from molluscs today imply vulnerability to ocean acidification tomorrow. *Fish and Fisheries*, 13(2): 182–215.

Covello, V. & Sandman, P.M. 2001. Risk communication: evolution and revolution. *In* A. Wolbarst, ed. *Solutions to an environment in peril*, pp. 164–178. Baltimore, USA, Johns Hopkins University Press.

Daw, T., Adger, W.N., Brown, K., Badjeck, M.-C. 2009. Climate change and capture fisheries: potential impacts, adaptation and mitigation. *In* K. Cochrane, C. De Young, D. Soto & T. Bahri, eds. *Climate change implications for fisheries and aquaculture: overview of current scientific knowledge*, pp. 107–150. FAO Fisheries and Aquaculture Technical Paper No. 530. Rome, FAO. 212 pp. (also available at www.fao.org/docrep/012/i0994e/i0994e00.htm).

De Young, C., Charles, A. & Hjort, A. 2008. *Human dimensions of the ecosystem approach to fisheries: an overview of context, concepts, tools and methods*. FAO Fisheries Technical Paper No. 489. Rome, FAO. 152 pp. (also available at www.fao.org/docrep/010/i0163e/i0163e00.htm).

De Young, C., Soto, D., Bahri, T. & Brown, D. 2012. Building resilience for adaptation to climate change in the fisheries and aquaculture sector. *In* A. Meybeck, J. Lankoski, S. Redfern, N. Azzu & V. Gitz. *Building resilience for adaptation to climate change in the agricultural* sector – *Proceedings of a Joint FAO/OECD Workshop 23–24 April 2012*. Rome, FAO. 346 pp. (also available at www.fao.org/docrep/017/i3084e/i3084e.pdf).

DFID. 1999. Sustainable Livelihoods Guidance Sheets. UK Department for International Development (also available at www.eldis.org/vfile/upload/1/document/0901/section2.pdf).

Dougill, A.J., Fraser, E.D.G. & Reed, M.S. 2010. Anticipating vulnerability to climate change in dryland pastoral systems: using dynamic systems models for the Kalahari. *Ecology and Society*, 15(2): 17.

Downing, T.E. & Patwardhan, A. 2004. *Assessing vulnerability for climate adaptation*. Technical Paper 3. IPCC.

Duriyapong, F. & Nakhapakorn, K. 2011. Coastal vulnerability assessment: a case study of Samut Sakhon coastal zone. *Songklanakarin Journal of Science and Technology*, 33(4): 469–476.**Dwarakish, G.S., Vinay, S.A., Natesan, U., Asano, T., Kakinuma, T., Venkataramana, K., Jagadeesha Pai, B. & Babita, M.K.** 2009. Coastal vulnerability assessment of the future sea level rise in Udupi coastal zone of Karnataka state, west coast of India. *Ocean & Coastal Management*, 52(9): 467–478.

Eakin, H. & Luers, A.L. 2006. Assessing the vulnerability of social–environmental systems. *Annual Review of Environment and Resources*, 31: 365–394.

Ebert, A., Kerle, N. & Stein, A. 2008. Urban social vulnerability assessment with physical proxies and spatial metrics derived from air- and spaceborne imagery and GIS data. *Natural Hazards*, 48(2): 275–294.

FAO. 1999. *Number of fishers 1970–1996*. FAO Fisheries Circular No. 929. Rome. 124 pp. (also available at ftp://ftp.fao.org/docrep/fao/009/x4193t/x4193t.zip).

FAO. 2003. *Fisheries management. 2. The ecosystem approach to fisheries*. FAO Technical Guidelines for Responsible Fisheries No. 4, Suppl. 2. Rome, FAO. 112 pp. (also available at www.fao.org/docrep/005/y4470e/y4470e00.htm).

FAO. 2010. *Aquaculture development. 4. Ecosystem approach to aquaculture*. FAO Technical Guidelines for Responsible Fisheries No. 5, Suppl. 4. Rome. 53 pp. (also available at www.fao.org/docrep/013/i1750e/i1750e00.htm)

FAO. 2013a. *FAO/BCC Regional Workshop on Assessing Climate Change Vulnerability in Benguela Fisheries and Aquaculture, Windhoek, Namibia, 11–13 April 2013*. FAO Fisheries and Aquaculture Report No. 1051. Rome. 66 pp. (also available at www.fao.org/docrep/018/i3389e/i3389e.pdf).

FAO. 2013b. *Report of the FAO/PaCFA Expert Workshop on Assessing Climate Change Vulnerability in Fisheries and Aquaculture: Available Methodologies and their Relevance for the Sector, Windhoek, Namibia, 8–10 April 2013*. FAO Fisheries and Aquaculture Report No. 1047. FAO, Rome. 29 pp. (also available at www.fao.org/docrep/018/i3357e/i3357e.pdf).

FAOSTAT. 2004. FAO Statistical Databases. (available at http://faostat.fao.org/).

Fellmann, T. 2012. The assessment of climate change related vulnerability in the agricultural sector: Reviewing conceptual frameworks. *In* A. Meybeck, J. Lankoski, S. Redfern, N. Azzu & V. Gitz. *Building resilience for adaptation to climate change in the agricultural sector – Proceedings of a Joint FAO/OECD Workshop 23–24 April 2012*. Rome, FAO. 346 pp. (also available at www.fao.org/docrep/017/i3084e/i3084e.pdf).

Folke, C. 2006. Resilience: The emergence of a perspective for social–ecological systems analyses. *Global Environmental Change*, 16: 253–267.

Fritzsche, K., Schneiderbauer S., Bubeck, P., Kienberger, S., Buth, M., Zebisch, M. & Kahlenborn, M. 2014. *The vulnerability sourcebook concept and guidelines for standardised vulnerability assessments*. Bonn, Germany, Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH. (also available at https://gc21.giz.de/ibt/var/app/wp342deP/1443/index.php/knowledge/vulnerability–assessment/vulnerability–sourcebook/).

Füssel, H.M. 2007. Vulnerability: a generally applicable conceptual framework for climate change research. *Global Environmental Change*, 17(2).

Füssel, H.M. & Klein, R. 2006. Climate change vulnerability assessments: an evolution of conceptual thinking. *Climatic Change,* 75(3): 301–329.

Garcia, S.M., Zerbi, A., Aliaume, C., Do Chi, T. & Lasserre, G. 2003. *The ecosystem approach to fisheries. Issues, terminology, principles, institutional foundations, implementation and outlook*. FAO Fisheries Technical Paper No. 443. Rome, FAO. 71 pp. (also available at www.fao.org/3/a-y4773e.pdf).

Gitz, V. & Meybeck A. 2012. Risks, vulnerabilities and resilience in a context of climate change. *In* A. Meybeck, J. Lankoski, S. Redfern, N. Azzu & V. Gitz, eds. *Building resilience for adaptation to climate change in the agriculture sector. Proceedings of a Joint FAO/OECD Workshop, 23–24 April 2012*. Rome, FAO. 346 pp. (also available at www.fao.org/docrep/017/i3084e/i3084e.pdf).

Gornitz, V. 1990. Vulnerability of the East Coast, USA to future sea level rise. *Journal of Coastal Research*, 9: 201–237.

Graham, N.A.J, Chabanet, P., Evans, R.D., Jennings, S., Letourneur, Y., MacNeil, M.A., McClanahan, T.R., Öhman, M.C., Polunin, N.V.C. & Wilson, S.K. 2011. Extinction vulnerability of coral reef fishes. *Ecology Letters*, 14(4): 341–348.

Hahn, M.B., Riederer, A.M. & Foster, S.O. 2009. The Livelihood Vulnerability Index: A pragmatic approach to assessing risks from climate variability and change—A case study in Mozambique. *Global Environmental Change*, 19(1): 74–88.

Hammill, A., Bizikova, L., Dekens, J. & McCandless, M. 2013. *Comparative analysis of climate change vulnerability assessments: lessons from Tunisia and Indonesia*. Bonn, Germany, Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH.

Hare, J.A., Morrison, W.E., Nelson, M.W., Stachura, M.M., Teeters, E.J., Griffis, R.B., Alexander, M.A., Scott, J.D., Alade, L., Bell, R.J., Chute, A.S., Curti, K.L., Curtis, T.H., Kircheis, D., Kocik, J.F., Lucey, S.M., McCandless, C,.T., Milke, L.M., Richardson, DE., Robillard, E., Walsh, H.J., McManus, M.C. & Marancik, K.E. Forthcoming. *Northeast Fisheries Climate Vulnerability Assessment (NEVA): an application of the NMFS fisheries climate vulnerability assessment methodology*. NMFS Draft document.

Heitzmann, K., Canararajah, R.S. & Siegel, P.B. 2002. *Guidelines for assessing the sources of risk and vulnerability*. Social Protection Discussion Paper 0212, Social Protection Unit, Human Development Network. Washington, DC, World Bank.

Hellebrandt, D., Hellebrandt, L. & Abdallah, P.R. 2009. Vulnerability of small-scale fisherfolk in Southern Brazil: context and perceptions. Apresentação oral, Agropecuária, Meio–Ambiente e Desenvolvimento Sustentável, Porto Alegre, 26–30 July 2009, Sociedade Brasileira de Economia, Administração e Sociologia Rural.

Heltberg, R., Siegel, P.B. & Jorgensen, S.L. 2009. Addressing human vulnerability to climate change: toward a 'no-regrets' approach. *Global Environmental Change*, 19: 89–99.

Hinkel, J. 2009. A framework for analyzing methodologies of vulnerability assessments. *In* G.P. Patt, D. Schröter, R.J.T. Klein & A.C. de la Vega–Leinat, eds. *Assessing vulnerability to global environmental change. Making research useful for decision making and policy*, pp. 321–249. London, Earthscan.

Hinkel, J. 2011. Indicators of vulnerability and adaptive capacity: towards a clarification of the science–policy interface. *Global Environmental Change*, 21(1): 198–208.

Holling, C.S. 1973. Resilience and stability of ecological systems. *Annual Review of Ecology and Systematics*, 4: 1–23.

Intergovernmental Panel on Climate Change (IPCC). 2001. – see McCarthy *et al*. (2001).

Intergovernmental Panel on Climate Change (IPCC). 2007. *Climate Change 2007 – Working Group II: Impacts, Adaptation, Vulnerability. Appendix 1: Glossary*. (also available at www.ipcc.ch/publications_and_data/ar4/wg2/en/annexessannex–i.html)

International Centre for Environmental Management (ICEM). 2011. *Climate change adaptation and mitigation (CAM) methodology brief*. Hanoi. (also available at www.icem.com.au/).

International Centre for Environmental Management (ICEM). 2013. *USAID Mekong ARCC climate change impact and adaptation on fisheries*. Prepared for the United States Agency for International Development. (also available at www.mekongarcc.net/sites/default/files/mekong_arcc_theme_report_–_fisheries–press–forweb.pdf).

Ionescu, C., Klein, R.J.T., Hinkel, J., Kumar, K.K.S. & Klein, R. 2009. Towards a formal framework of vulnerability to climate change. *Environmental Modelling and Assessment*, 14: 1–16.

Janssen, M.A. 2007. An update on the scholarly networks on resilience, vulnerability, and adaptation within the human dimensions of global environmental change. *Ecology and Society*, 12(2): 9–27.

Johnson, J., Bell, J. & De Young, C. 2013. *Priority adaptations to climate change for Pacific fisheries and aquaculture: reducing risks and capitalizing on opportunities. FAO/Secretariat of the Pacific Community Workshop, 5–8 June 2012, Noumea, New Caledonia*. FAO Fisheries and Aquaculture Proceedings No. 28. Rome, FAO. 109 pp. (also available at www.fao.org/docrep/017/i3159e/i3159e.pdf)

Kaufmann, D., Kraay, A. & Zoido–Lobate´n, P. 2002. *Governance Matters II: Updated Indicators for 2000/1*. World Bank Policy Research Working Paper No. 2772. Washington, DC. 60 pp.

Klein, R.J.T. 2009. Identifying countries that are particularly vulnerable to the adverse effects of climate change: an academic or a political challenge? *Carbon and Climate Law Review*, 3(3): 284–291.

Klein, R.J.T & Möhner, A. 2011. The Political Dimension of Vulnerability: Implications for the Green Climate Fund. *IDS Bulletin*, 42(3): 15-22.

Lam, V.W.Y., Cheung, W.W.L., Swartz, W. & Sumaila, U.R. 2012. Climate change impacts on fisheries in West Africa: implications for economic, food and nutritional security. *African Journal of Marine Science*, 34(1): 103–117.

Lim, B. & Spanger-Siegfried, E., eds. 2004. *Adaptation policy frameworks for climate change: developing strategies, policies and measures*. Cambridge, UK, UNDP/Cambridge University Press.

Marshall, N.A., Marshall, P.A., Tamelander, J., Obura, D.O., Mallaret–King, D. & Cinner, J.E. 2010. *A framework for social adaptation to climate change: sustaining tropical coastal communities and industries*. Gland, Switzerland, IUCN. 36 pp.

McCarthy, J.J., Canziani, O.F., Leary, N.A., Dokken, D.J. & White, K.S., eds. 2001. *Climate Change Third Assessment Report 2001: Impacts, Adaptation and Vulnerability*. Intergovernmental Panel on Climate Change. Cambridge, UK, Cambridge University Press.

McLaughlin, P. & Dietz, T. 2008. Structure, agency and environment: Toward an integrated perspective on vulnerability. *Global Environmental Change*, 39(4):99-111.

McLaughlin, S. & Cooper, J.A.G. 2010. A multi-scale coastal vulnerability index: a tool for coastal managers? *Environmental Hazards*, 9(3): 233–248.

McLaughlin, S., McKenna, J. & Cooper, J.A.G. 2002. Socio-economic data in coastal vulnerability indices: constraints and opportunities. *Journal of Coastal Research*, 36: 487–497.

McClanahan, T.R., Maina, J., Moothien–Pillay, R. & Baker, A.C. 2005. Effects of geography, taxa, water flow, and temperature variation on coral bleaching intensity in Mauritius. *Marine Ecology Progress Series*, 298: 131−142.

McClanahan, T.R., Graham, N.A.J., Maina, J., Chabanet P., Bruggemann, J.H. & Polunin, N.V.C. 2007. Influence of instantaneous variation on estimates of coral reef fish populations and communities. *Marine Ecology Progress Series*, 340: 221−234.

Meybeck, A., Lankoski, J., Redfern, S., Azzu, N. & Gitz, V. 2012. *Building resilience for adaptation to climate change in the agricultural sector – Proceedings of a Joint FAO/ OECD Workshop 23–24 April 2012*. Rome, FAO. 346 pp. (also available at www.fao.org/ docrep/017/i3084e/i3084e.pdf).

Miller, F., Osbahr, H., Boyd, E., Thomalla, F., Bharwani, S., Ziervogel, G., Walker, B., Birkmann, J., Van der Leeuw, S., Rockström, J., Hinkel, J., Downing, T., Folke, C. & Nelson, D. 2010. Resilience and vulnerability: complementary or conflicting concepts? *Ecology and Society*, 15(3): 11–36.

Mills, D.J., Adhuri, D.S., Phillips, M.J., Ravikumar, B. & Padiyar, A.P. 2011. Shocks, recovery trajectories and resilience among aquaculture–dependent households in post–tsunami Aceh, Indonesia. *Local Environment*, 16 (5): 425–444.

Mitchell, T.D., Carter, T.R., Jones, P.D., Hulme, M. & New, M. 2004. *A comprehensive set of high resolution grids of monthly climate for Europe and the globe: the observed record (1901–2000) and 16 scenarios (2001–2100)*. Tyndall Centre Working Paper 55. Norwich, UK, Tyndall Centre for Climate Change Research.

Monnereau, I., Mahon, R., McConney, P., Nurse, L., Turner, R. & Vallès, H. 2015. Vulnerability of the fisheries sector to climate change impacts in Small Island Developing States and the Wider Caribbean. *CERMES Technical Report* No 77. Centre for Resource Management and Environmental Studies (CERMES).

Morrison, W. Forthcoming. Methodology for Assessing the Vulnerability of Fish Species to a Changing Climate. NMFS Draft document.

Naylor, R.L. 2008. Managing food production systems for resilience. *In* F.S. Chapin, G.P. Kofinas & C. Folke, eds. *Principles of natural resource stewardship: resilience–based management in a changing world*, Chapter 12. New York, USA, Springer.

Nelson, G.C., Rosegrant, M.W., Koo, J., Robertson, R., Sulser, T., Zhu, T., Ringler, C., Msangi, S., Palazzo, A., Batka, M., Magalhaes, M., Valmonte–Santos, R., Ewing, M. & Lee, D. 2009. *Climate change: impact on agriculture and costs of adaptation*. Food Policy Report. Washington, DC, International Food Policy Research Institute.

O'Brien, K.L. & Leichenko, R.M. 2000. Double exposure: assessing the impacts of climate change within the context of economic globalisation. *Global Environmental Change*, 10(3): 221–232.

O'Brien, K. & Wolf, J. 2010. A values–based approach to vulnerability and adaptation to climate change. *WIREs Climate Change*, 1 (2): 232–242.

O'Brien, K., Eriksen, S., Nygaard, L.P. & Schjolden, A. 2007. Why different interpretations of vulnerability matter in climate change discourses. *Climate Policy*, 7(1): 73–88.

O'Brien, K., Eriksen, S., Schjolen, A. & Nygaard, L. 2004. *What's in a word? Conflicting interpretations of vulnerability in climate change research*. CICERO Working Paper 2004:04. Oslo, Oslo University.

Oppenheimer, M., M. Campos, R.Warren, J. Birkmann, G. Luber, B. O'Neill, and K. Takahashi. 2014. Emergent risks and key vulnerabilities. *In* Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L.White eds. *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, pp. 1039-1099. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Ostrom, E. 1990. Governing the commons: the evolution of institutions for collective action. Cambridge, UK, and New York, USA, Cambridge University Press.

Ostrom, E. 2005. Understanding institutional diversity. Princeton, USA, Princeton University Press.

Ostrom, E. 2011. Background on the institutional analysis and development framework. *The Policy Studies Journal*, 39(1): 7–27.

Otzelberger, A. 2011. *Gender–responsive strategies on climate change: progress and ways forward for donors*. Sussex, UK, BRIDGE, Institute of Development Studies.

Patt, G.P, Schröter, D., de la Vega–Leinat, A.C. & Klein, R.J.T. 2009. Vulnerability research and assessment to support adaptation and mitigation: common themes from the diversity of approaches. *In* G.P. Patt, D. Schröter, R.J.T. Klein & A.C. de la Vega–Leinat, eds. *Assessing vulnerability to global environmental change. Making research useful for decision making and policy*, pp. 1–25. London, Earthscan.

Peters, R.G., Covello, V.T. & McCallum, D.B. 1997. The determinants of trust and credibility in environmental risk communication: an empirical study. *Risk Analysis*, 17(1): 43–54.

Polsky, C., Neff, R & Yarnal, B. 2007. Building comparable global change vulnerability assessments: the vulnerability scoping diagram. *Global Environmental Change*, 17: 472–485.

Preston, B. & Stafford–Smith, M. 2009. *Framing vulnerability and adaptive capacity assessment: discussion paper*. CSIRO Climate Adaptation Flagship Working paper No. 2. (also available at www.csiro.au/org/ClimateAdaptationFlagship.html).

PROVIA. 2013. *PROVIA guidance on assessing vulnerability, impacts and adaptation to climate change*. Consultation document. Nairobi, United Nations Environment Programme. 198 pp. (also available at www.unep.org/provia).

Raemaekers, S. & Sowman, M. (2015). *Community-level socio-ecological vulnerability assessments in the Benguela Current Large Marine Ecosystem*. FAO Fisheries and Aquaculture Circular No. 1110. Rome, FAO.

Reidsma, P., Ewert, P., Lansink, A.O. & Leemans, R. 2010. Adaptation to climate change and climate variability in European agriculture: the importance of farm level responses. *European Journal of Agronomy*, 32: 91–102.

Ribot, J. 2011. Vulnerability *Before Adaptation: Toward Transformative Climate Action*. Editorial. *Global Environmental Change*, 21(4): 1160–1162.

Schröter, D., Polsky, C. & Patt, A.G. 2004. Assessing vulnerabilities to the effects of global change: An eight–step approach. *Mitigation and Adaptation Strategies for Global Change*, 10(4): 573–595.

Scoones, I. 1998. *Sustainable rural livelihoods: a framework for analysis*. IDS Working Paper 72. Sussex, UK, Institute of Development Studies.

Sheppard, S.R.J. 2005. Landscape visualisation and climate change: the potential for influencing perceptions and behaviour. *Environmental Science and Policy*, 8: 637–654

Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M. & Miller, H.L., eds. 2007. *Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 2007*. Cambridge, UK, and New York, USA, Cambridge University Press.

Strunz, S. 2012. Is conceptual vagueness an asset? Arguments from philosophy of science applied to the concept of resilience. *Ecological Economics*, 76: 112–118.

Szlafsztein, C. & Sterr, H. 2007. A GIS–based vulnerability assessment of coastal natural hazards, state of Pará, Brazil. *Journal of Coastal Conservation*, 11(1): 53–66.

Torresan, S., Critto, A., Rizzi, J. & Marcomini, A. 2012. Assessment of coastal vulnerability to climate change hazards at the regional scale: the case study of the North Adriatic Sea. *Natural Hazards and Earth System Science*, 12(7): 2347–2368.

Turner, B.L., Kasperson, R.E., Meyer, W.B., Matson, P., McCarthy, J.J., Corell, R.W., Christensen, L., Eckley, N., Kasperson, J.X., Luers, A., Martello, M.L, Polsky, C., Pulsipher, A. & Schiller, A. 2003a. A framework for vulnerability analysis in sustainability science. *Proceedings of the National Academy of Sciences*, 100: 8074–8079.

Turner, B.L., Matson, P.A., McCarthy, J.J., Corell, R.W., Christensen, L., Eckley, N., Hovelsrud–Broda, G.K., Kasperson, J.X., Kasperson, R.E., Luers, A., Martello, M.L., Mathiesen, S., Naylor, R., Polsky, C., Pulsipher, A., Schiller, A., Selin, H. & Tyler, N.· 2003b. Illustrating the coupled human–environment system for vulnerability analysis: three case studies. *Proceedings of the National Academy of Sciences of the United States of America*, 100(14): 8080–8085.

United Nations Development Programme (UNDP). 2003. *Human development indicators 2003*. Human Development Report Office.

United Nations Framework Convention on Climate Change (UNFCCC). 2011. *Assessing climate change impacts and vulnerability, making informed adaptation decisions. Highlights of the contribution of the Nairobi Work Programme*. Nairobi.

United Nations International Strategy for Disaster Reduction (UN/ISDR). 2007. *Hyogo Framework for Action 2005–2015: Building the resilience of nations and communities to disasters*. Extract from the final report of the World Conference on Disaster Reduction (A/CONF.206/6). Geneva, Switzerland.

United Nations International Strategy for Disaster Reduction (UN/ISDR). 2015. *Sendai Framework for Disaster Risk Reduction 2015–2030*. Geneva, Switzerland. (also available at www.unisdr.org)

Vogel, C. & O'Brien, K. 2004. Vulnerability and global environmental change: rhetoric and reality. *AVISO – Information Bulletin on Global Environmental Change and Human Security*, 13: 1–8.

Walker, B., Holling, C.S., Carpenter, S.R. & Kinzig, A. 2004. Resilience, adaptability and transformability in social–ecological systems. *Ecosystems and Society*, 9(2): 5.

Walker, B., Sayer, J., Andrew, N.L. & Campbell, B. 2010. Should enhanced resilience be an objective of natural resource management research for developing countries? *Crop Science*, 50: S–10–S–19.

Walker, B., Gunderson, L., Kinsig, A., Folke, C., Carpenter, S. & Schultz, L. 2006. A handful of heuristics and some propositions for understanding resilience in social–ecological systems. *Ecosystems and Society*, 11(1): 13.

Walker, B., Carpenter, S., Anderies, J., Abel, N., Cumming, G., Janssen, M., Lebel, L., Norberg, Peterson, G. & Pritchard, R. 2002. Resilience management in social–ecological systems: a working hypothesis for a participatory approach. *Conservation Ecology*, 6(1): 14.

Winograd, M. 2004. *Capacity strengthening in climate change vulnerability and adaptation strategy assessments. Background on frameworks, methodologies and tools for vulnerability and adaptation assessments: how to move from reactive to proactive approaches*. C3D/ENDA. (also available at http://c3d–unitar.org/c3d/userfiles/Guide_for_trainers.pdf)

World Bank. 2003. *World Development Indicators*. Washington, D.C. p. 424.

Ziervogel, G., Bharwani, S. & Downing, T.E. 2006. Adapting to climate variability: pumpkins, people and policy. *Natural Resources Forum*, 30: 294–305.

Glossary

Adaptive capacity: Ability or capacity of a system to modify or change to cope with changes in actual or expected climate stress.[17]

Adaptive capacity (in relation to climate change impacts): The ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences.[18]

Bottom-up approaches/methods: Category of analytical methods relying on iterative and participatory processes through which information inputs are made by, and for, beneficiaries.

Contextual vulnerability: A state or condition of being moderated by existing inequalities in resource distribution and access, the control individuals exert over choices and opportunities and historical patterns of social domination and marginalization.[19] Opposed to outcome vulnerability.

Exposure: The nature and degree to which a system is exposed to significant climatic variations.[20]

Outcome vulnerability: The linear result of projected climate change impacts on a specific unit.[21] Opposed to contextual vulnerability.

Political ecology perspective on vulnerability: Perspective that explores vulnerability with respect to broad processes of institutional and environmental change and that argues for a balanced consideration of both biophysical and social dynamics in decision-making. Like the political economy perspective, it focuses on the political dimension of vulnerability and highlights social inequalities and points of conflicts within societies.[22]

Political economy perspective on vulnerability: Perspective that emphasizes the socio-political, cultural and economic factors that together explain differential exposure to hazards, differential impacts and differential capacities to recover from past impacts and/or cope and adapt to future threats. Like the political ecology perspective, it focuses on the political dimension of vulnerability and highlights social inequalities and points of conflicts within societies.[23]

Qualitative approaches/methods: Analytical methods relying on qualitative, non-numerical data.

[17] Allison *et al.* (2005); Daw *et al.* (2009).
[18] IPCC (2007).
[19] Eakin and Luers (2006).
[20] IPCC (2001) available at www.ipcc.ch/pdf/glossary/tar-ipcc-terms-en.pdf
[21] O'Brien *et al.* (2007).
[22] Eakin and Luers (2006).
[23] Eakin and Luers (2006).

Quantitative approaches/methods: Analytical method relying on quantitative, numerical, data.

Resilience: Originally defined in an ecological context as the ability to absorb change and disturbance and still maintain the same relationships that control a system's behaviour.[24] Later broadened to apply to social–ecological systems as the capacity of a system to absorb disturbance and reorganize while undergoing change so as to retain essentially the same function, structure, identity and feedbacks.[25]

Resilience approach to vulnerability: Approach that gives a predominant weight to the implications of social and environmental change across the broader geographic space, reducing human activity to just one of the driving forces, and humans themselves as only one of the affected species.[26]

Risk/hazard approach to vulnerability: Approach that uses a biophysical threat as point of departure and that describes, on a very broad scale: what a unit/system is vulnerable to, what consequences might be expected, and where and when those impacts might occur.[27]

Sensitivity: Degree to which a system is affected, either adversely or beneficially, by climate variability or change. The effect may be direct (e.g. a change in crop yield in response to a change in the mean, range or variability of temperature) or indirect (e.g. damages caused by an increase in the frequency of coastal flooding due to sea-level rise).[28]

In the context of fisheries: degree to which national economics are dependent on fisheries and therefore sensitive to any changes in the sector.[29]

Top-down approaches/methods: Category of analytical methods based on the handling of data by scientists, with no inputs from beneficiaries, e.g. statistical analysis, modelling, downscaling.

Vulnerability: Degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes.[30]

A function of potential impacts resulting from exposure and sensitivity of a system to climate change **and** of its adaptive capacity.[31]

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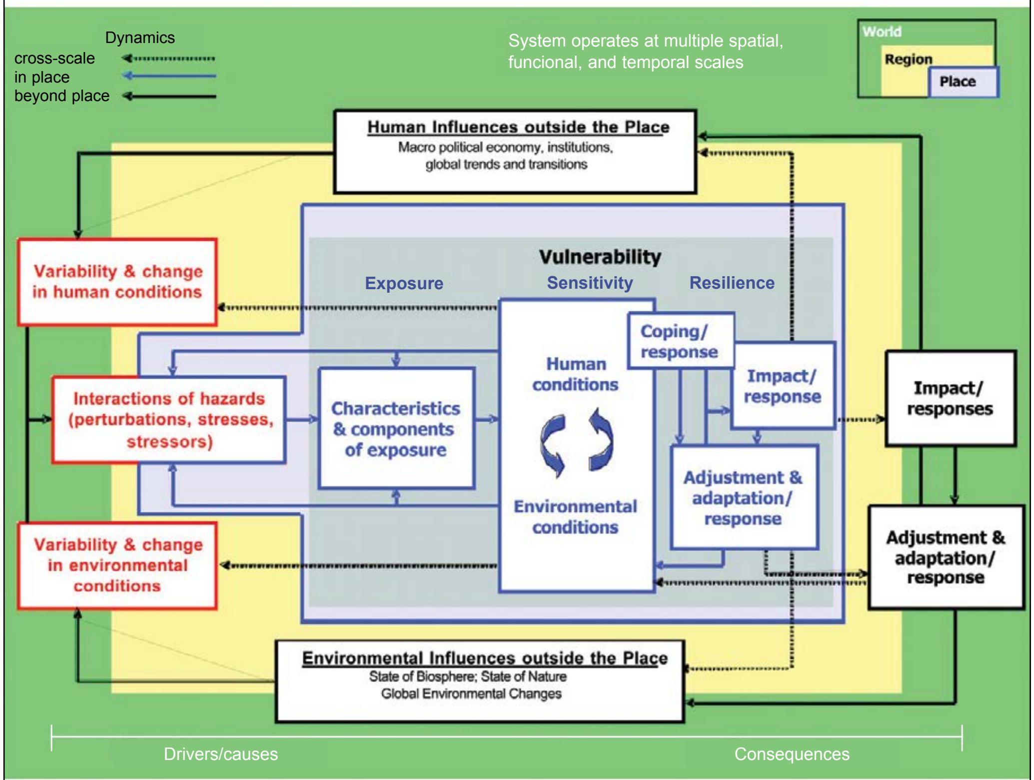
[24] Holling (1973).
[25] Holling (1973); Walker *et al.* (2004).
[26] Eakin and Luers (2006).
[27] Eakin and Luers (2006).
[28] IPCC (2007).
[29] Allison *et al.* (2005); Daw *et al.* (2009).
[30] IPCC (2007).
[31] Allison *et al.* (2005); Daw *et al.* (2009).

APPENDIX 1

Examples of vulnerability frameworks

The framework developed by Turner *et al.* (2003a) (Figure A1.1) was perhaps the most comprehensive and innovative at the time, with its nesting of exposure, sensitivity and resilience within the context of a "place" (human influences) while subjected to outside environmental influences.

FIGURE A1.1
Vulnerability framework developed by Turner *et al.*

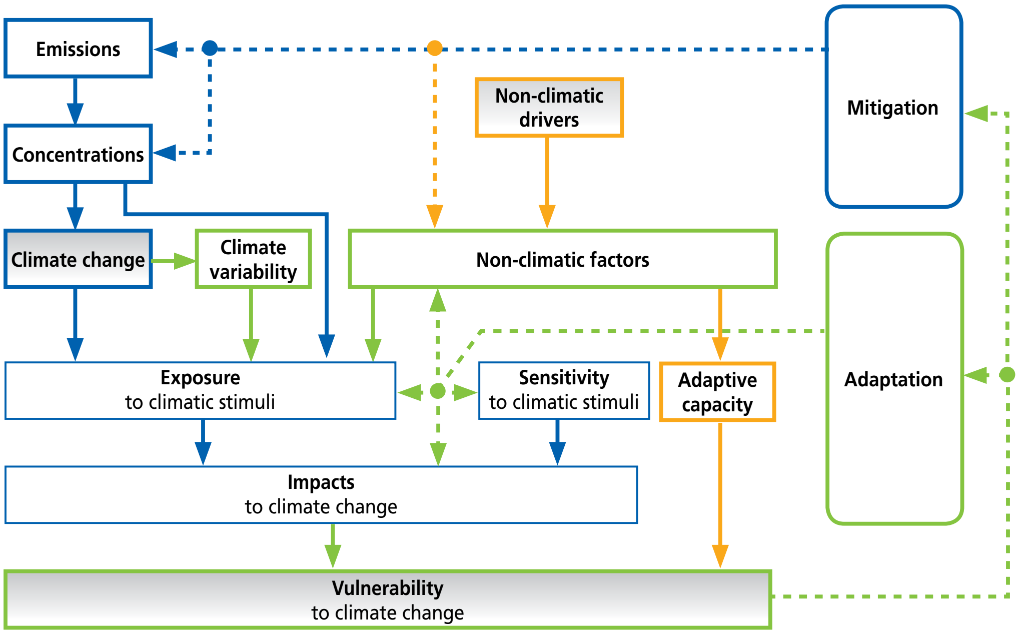


Source: Turner *et al.* (2003a).

The framework developed by Füssel and Klein (2006) (Figure A1.2) includes adaptive capacity, seen as a key determinant of people's vulnerability to climate change, but lacks the nested scales of Turner *et al.* (2003a).

Retaining only key aspects of the framework of Turner *et al.*, and focusing on factors instead of attributes of vulnerability, the framework developed by Füssel (2007) is based on the categorization of vulnerability factors in four groups, which individually or paired through cross-scale effects or integration provide a clear and relatively simple means through which the various components vulnerability of a system can be profiled at a given point in time (Table A1.1).

FIGURE A1.2
Conceptual framework for "second-generation" vulnerability assessment



Source: Füssel and Klein (2006).

TABLE A1.1
Categorization and interferences between vulnerability domains and spheres

Sphere	Domain: Biophysical ⟷ Integration	Socio-economic
External	"Environmental conditions/influences" *E.g. severe storms, earthquakes, sea-level change*	"Human conditions/influences" *E.g. national policies, international aid, economic globalization*
↕ Cross-scale		
Internal	"Sensitivity" *E.g. topography, environmental conditions, land cover*	"Resilience" *E.g. household income, social networks, access to information*

Sources: Adapted from Füssel (2007) and Turner *et al.* (2003a).

APPENDIX 2

Overview of possible methodologies of analysis and information management tools

Methodologies and tools are presented in alphabetical order. For additional information, refer to PROVIA (2013) and the UNFCCC Nairobi Work Programme on impacts, vulnerability and adaptation to climate change compendium of knowledge sources (available at unfccc.int/adaptation/nairobi_work_programme/knowledge_resources_and_publications/items/5457.php).

AGENT-BASED MODELLING

An agent-based model is a programme of self-contained entities called agents each of which can represent real-world objects such as individuals or households. Simulation of social agents is included in the generic term, multi-agent-based simulation (MABS). The data required for such a model are ideally suited to data-intensive fieldwork. Hence, the representation of place-based understanding of the dynamics of vulnerability and adaptation in MABS is a natural yet innovative approach. Participatory techniques provide a robust and effective method to formalize and verify qualitative ethnographic data, for use in an agent-based model. Agent-based modelling illustrates how macro–level behaviour can emerge from various types of rules which inform decisions at the local, individual level. An agent-based model can be used to establish which patterns of strategic behaviour emerge as a result of local responses and whether such emergent phenomena account for a clearer understanding of the original field data.

The adaptive dynamics involved in climate-change-related behaviour within agriculture, human–environment interaction and impacts for the individual and the group can be investigated. MABS can explore social and environmental scenarios that do not exist at present, providing an experimental laboratory on the same level of sophistication as models of the global climate system.

The use of even simple agent-based models can help to illuminate field-based descriptions. The benefits of mapping and modelling a complex adaptive system using this framework lie in the ability to identify characteristics – macrolevel patterns – that are important to the functioning of a successful system and its essential underlying components. Microlevel effects can also be easily identified within an agent-based modelling environment, which can then allow the analysis of the interaction of models of adaptation developed from the social sciences domain with environmental models from the physical sciences domain. That is, simulations illustrate how systems of different orders interact with each other, and one may often be more interested in the structure, organization and interaction of these submodels than in their content.

Furthermore, agent-based models allow examination the consequent behaviours of individual strategies on a group. They permit the representation of incremental complexity (i.e. where models include more and more factors and their contextual interactions) and facilitate the identification of critical situations that can lead to prediction outside the simulation; that is, the ability to demonstrate that some values for the system under study are salient enough to drive phenomena and not simply be a contributing factor.

Nevertheless, a simulation is only a descriptive model and its explanatory power is constrained by the assumptions made, including the researchers' understanding of the field data and the level of implementation of the model. Moreover, such a model will be a simplification of the system under study and in many cases will not represent any "real" system but will be intended to generate model data for an "ideal" world, against which real data can be compared, noting where it corresponds to, and departs from, the ideal world. This can help to establish a sense of important contextual drivers within the domain and new areas for investigation, which can be further validated with the model.

Source: Bharwani, S., Bithell, M., Downing, T.E., New, M., Washington, R. & Ziervogel, G. 2005. Multi-agent modelling of climate outlooks and food security on a community garden scheme in Limpopo, South Africa. *Philosophical Transactions of the Royal Society B*, 360: 2183–2194.

DELPHI METHOD

The purpose of the Delphi technique is to elicit information and judgements from a group to facilitate problem-solving, forecasting, planning, and decision-making (Neuman, 1994). Its name comes from the city of Delphi was where people came to consult the oracle (housed in the temple of Apollo) who forecasted the future. It often involves consulting a group of experts on a particular topic to determine consensus on an issue. This method is used both for information acquisition and in processes.

There are many variations of the Delphi method, and while some can be used in face-to-face meetings, most seek to avoid physically assembling the experts. Instead, information may be exchanged via e-mail. This takes advantage of experts' creativity while facilitating group involvement and interaction. Delphi is designed to reap the benefits, but reduce the liabilities, of group problem-solving. This is important in the ecosystem approach to fisheries (EAF) because ordinary meetings of diverse experts with different disciplinary backgrounds and academic or professional status can be difficult to manage even with a facilitator. Such meetings are expensive to organize if the experts reside in different parts of the world.

Source: De Young, C., Charles, A. & Hjort, A. 2008. *Human dimensions of the ecosystem approach to fisheries: an overview of context, concepts, tools and methods*. FAO Fisheries Technical Paper No. 489. Rome, FAO. 152 pp. (also available at www.fao.org/docrep/010/i0163e/i0163e00.htm).

Additional information: Neuman, L. 1994. *Social research methods: qualitative and quantitative approaches*. Second edition. Boston, USA, Allyn and Bacon.

INSTITUTIONAL ANALYSIS

Institutional analysis is the investigation of how formal and informal social rules (institutions) shape human behaviour. Institutional analyses focus on how individuals and groups construct institutions, how institutions operate by patterns of interaction, how they are linked and the outcomes generated by institutions. Institutional analysis has been employed for example for research into co-management arrangements and conditions for success, through the investigation of the set of contextual variables that describe the fishery system, the influence of external factors on the system, the incentives for fishery actors to interact or not, and the observable outcomes that feed back into a system that is constantly adapting.

Without institutional analysis, a clear understanding of the complex interactions and relationships among the actors in fisheries is not likely to be achieved. This understanding is even more important as the EAF encompasses a greater number of actors, including those in other sectors.

Source: De Young, C., Charles, A. & Hjort, A. 2008. *Human dimensions of the ecosystem approach to fisheries: an overview of context, concepts, tools and methods*. FAO Fisheries Technical Paper No. 489. Rome, FAO. 152 pp. (also available at www.fao.org/docrep/010/i0163e/i0163e00.htm).

The Institutional Analysis and Development (IAD) framework, developed by the Universities of Indiana and Colorado, the United States of America, stems from the works of D. North and E. Ostrom on the how institutions function and structure social order and cooperation mechanisms among individuals. The "Institutional Grammar Tool" offered by the IAD framework is a method for conducting a microlevel analysis of institutions. It can be adapted to a range of contexts and situations where the systematic identification of the rules that govern the behaviour of people in collective action situations is needed in order to further policy design and implementation effectiveness.

Further information on the IAD framework and the Institutional Grammar Tool:

IAD and Institutional Grammar Tool website:

www.ucdenver.edu/academics/colleges/SPA/researchandoutreach/Buechner%20Institute%20for%20Governance/Centers/WOPPR/IAD/Pages/default.aspx

Description of the Institutional Grammar Tool:

Crawford, S.E.S. & Ostrom, E. (2005) Chapter 5: A grammar of institutions. In E. Ostrom, ed. *Understanding institutional diversity*, pp. 137–174. Princeton, USA, Princeton University Press.

Application and discussion of the Institutional Grammar Tool:

Siddiki, S., Weible, C.M, Basurto, X. & Calanni, J. 2011. Dissecting policy designs: an application of the Institutional Grammar Tool. *The Policy Studies Journal*, 39(1): 79–102. (also available online at http://fds.duke.edu/db/attachment/1498).

FOCUS GROUPS

Focus groups are an interactive form of group interviewing. Group interviewing involves interviewing a number of people at the same time, the emphasis being on questions and responses between the researcher and participants. However, focus groups rely on interaction within the group based on topics that are supplied by the researcher.

The focus group is important in providing a means of collecting data that more closely resembles daily interactive conversation and information sharing than the standard individual interview, especially in some cultures. Often, a focus group may be the best way to solicit information when, for a variety of reasons, respondents may be reluctant to participate in individual surveys. Unlike the latter or simple group interviews, focus groups encourage the respondents to react to one another, share knowledge, trade opinions and so on, all without the obligation to reach a group decision or consensus.

Source: De Young, C., Charles, A. & Hjort, A. 2008. *Human dimensions of the ecosystem approach to fisheries: an overview of context, concepts, tools and methods*. FAO Fisheries Technical Paper No. 489. Rome, FAO. 152 pp. (also available at www.fao.org/docrep/010/i0163e/i0163e00.htm).

GENDER ANALYSIS

A gender analysis weighs up and recognizes gender-differentiated identities, roles, responsibilities, value and resources. A gender analysis enables one: to gauge the extent to which the needs and priorities of women and men are reflected in development-oriented action; to organize information in order to pinpoint gaps relating to gender inequalities; and to generate gender-disaggregated information. A detailed gender analysis makes visible: the different needs, priorities, capacities, experiences, interests, and views of women and men; who has access to and/or control of resources, opportunities and power; who does what, why, and when; who is likely to benefit and/or lose from new initiatives; gender differences in social relations; the different patterns and levels of involvement that women and men have in economic, political, social, and legal structures; that women's and men's lives are not all the same and often vary depending on factors other than their sex, such as age, ethnicity, race and economic status; and assumptions based on one's own realities, sex, and gender roles.

As such, a gender analysis will map the differences socially assigned to men and women in the household, in the economy, in the political realm and within society. It is an essential part of any diagnostic work before implementing corresponding development initiatives. It is important that it be conducted at three levels: at the macrolevel (socio-economic and gender issues are introduced into the policy process, usually at the national level); at the intermediate level or mesolevel (where the focus is on the place and role of women and gender relations in institutions, structures and services that operationalize the links between macro and field levels), and at the field level or microlevel (where the focus is on individuals, households and communities).

Source: Arenas, M.C. & Lentisco, A. 2011. *Mainstreaming gender into project cycle management in the fisheries sector*. Field manual. Bangkok, FAO/Regional Office for Asia and the Pacific. 92 pp. (also available online www.fao.org/docrep/014/ba0004e/ba0004e00.pdf).

GEOGRAPHIC INFORMATION SYSTEMS

A geographic information system (GIS) is a computer system for capturing, storing, checking, integrating, manipulating, analysing and displaying data related to positions on the Earth's surface. It is a technology that can help to clarify issues that have spatial components, such as habitat loss, environmental degradation, overfishing, and population pressure, and lead to solutions by treating many spatial components simultaneously.

A GIS allows for the display of spatially related data in a way that is easily comprehensible for most people. Once maps are in digital format, it is a simple task to update them, to change them, or to merge them with other maps or new data. A GIS also allows for the easy and immediate integration of other large data sets from, for example, remote sensing, and for the presentation of a regular flow of spatially related information in a standardized format.

Source: de Graaf, G., Marttin, F.J.B., Aguilar–Manjarrez, J. & Jenness, J. 2003. *Geographic information systems in fisheries management and planning. Technical manual*. FAO Fisheries Technical Paper No. 449. Rome, FAO. 162 pp. (also available at www.fao.org/docrep/006/y4816e/y4816e00.HTM).

In the context of disasters, vulnerability mapping can allow for improved communication about risks and what is threatened. It allows for better visual presentations and understanding of the risks and vulnerabilities so that decision-makers can see where resources are needed for protection of these areas. The vulnerability maps will allow them to decide on measures to prevent or reduce loss of life, injury and environmental consequences before a disaster occurs.

Source: Edwards, J., Gustafsson, M. & Näslund-Landenmark, B. 2007. *Handbook for vulnerability mapping* [online]. EU Asia Pro Eco project, Swedish Rescue Services Agency. (available at www.unep.fr/shared/publications/pdf/ANNEXES/3.2.4%20Risk%20assessment%20and%20vulnerability%20maps/Handbook%20for%20Vulnerability%20Mapping.pdf).

MULTICRITERIA DECISION ANALYSIS

Multicriteria decision analysis (MCDA) is an umbrella term to describe a collection of formal modelling approaches that seek to take explicit account of multiple criteria in helping individuals or groups explore decisions that matter. It seeks to take explicit account of multiple, conflicting criteria, it helps to structure management problems, it provides a model that can serve as a focus for discussion, and it offers a process that leads to rational, justifiable and explainable decisions.

In the context of fisheries and other natural resources where data are seldom complete, known or fully understood, MCDA can conveniently deal with mixed sets of data, thus accommodating knowledge gaps and filling them with qualitative data, expert opinions or experiential knowledge. It is also structured to enable a collaborative planning and decision-making environment. This participatory environment accommodates the involvement and participation of multiple experts and stakeholders in assessments, but needs to be complemented with more flexible modelling paradigms in order to overcome the inherent rigidity of some of the traditional MCDA algorithms.

Source: Belton, S. & Stewart, T.S. 2002. *Multiple criteria decision analysis. An integrated approach*. Massachusetts, USA, Kluwer Academic Publishers.

Example of an application to natural resource management:

Mendoza, G.A. & Martins, H. 2006. Multi–criteria decision analysis in natural resource management: a critical review of methods and new modeling paradigms. *Forest Ecology and Management*, 230: 1–22. (also available at http://cmq.esalq.usp.br/~lcer/LCF5734/ED4_Texto_08.pdf).

RAPID RURAL APPRAISAL / PARTICIPATORY RURAL APPRAISAL

A rapid rural appraisal (RRA) emphasizes the importance of learning rapidly directly from people. An RRA involves tapping local knowledge and gaining information and insight from local people using a range of interactive tools and methods.

A participatory rural appraisal (PRA) involves field workers learning with local people with the aim of facilitating local capacity to analyse, plan, resolve conflicts, take action and monitor and evaluate according to a local agenda.

An RRA is regarded as a set of guidelines and tools that can be used in many different ways and many different circumstances, and without necessarily attempting to change political and social structures. A PRA is the specific use of RRA approaches and tools to encourage participation in decision-making and planning by people who are usually excluded from these processes. An RRA is a useful technique for data gathering and problem identification, whereas a PRA is more appropriate to programme design and planning. The distinction is not merely one of proper sequencing. If not used correctly, a PRA can generate false expectations of what the programme will provide or what local people can achieve. This can cause problems in the relationship between the community members and the programme staff, which can threaten success. Both approaches are carried out by multidisciplinary teams, and they differ from conventional information gathering approaches in that field workers work with and learn directly from local people. The methods involve a minimum of outsider interference or involvement.

Source: De Young, C., Charles, A. & Hjort, A. 2008. *Human dimensions of the ecosystem approach to fisheries: an overview of context, concepts, tools and methods*. FAO Fisheries Technical Paper No. 489. Rome, FAO. 152 pp. (also available at www.fao.org/docrep/010/i0163e/i0163e00.htm).

For further information:

Jackson, B. & Ingles, A. 1998. *Participatory techniques for community forestry: a field manual*. Nepal–Australia Community Forestry Project. Technical Note 5/95. Canberra, ANUTECH Pty Ltd. (also available at http://data.iucn.org/dbtw–wpd/edocs/FR–IS–004.pdf).

Pomeroy, R.S. & Rivera–Guieb, R. 2005. *Fishery co–management: a practical handbook*. Ottawa, CABI Publishing/International Development Research Centre. 288 pp. (also available at www.idrc.ca/EN/Resources/Publications/Pages/IDRCBookDetails.aspx?PublicationID=185).

RICARDIAN MODELLING

Ricardian modelling is a way to model the impacts of climate change on incomes and prices using Ricardian economic theories (comparative advantage, rent, etc.). The traditional Ricardian model (Mendelsohn, Nordhaus and Shaw, 1994) captures adaptation in its measurement of impacts of global warming on agriculture based on choices (e.g. farmers' choices).

For more information: Mendelsohn, R., Nordhaus, W.D. & Shaw, D. 1994. The impact of global warming on agriculture: a Ricardian analysis. *The American Economic Review*, 84(4): 753–771. (also available at www.jstor.org/stable/2118029).

SOCIAL MAPPING

Social mapping is a visualization technique closely related to stakeholder analysis and cognitive mapping. It allows stakeholders to draw maps illustrating their interrelationships and their relationships to natural resources or other features of a particular location.

The importance of social mapping, as with many other visualization tools, lies in the ability to elicit information from stakeholders in a format that is easily understood and shared. This can serve as the basis for fruitful discussions and decision-making.

Source: De Young, C., Charles, A. & Hjort, A. 2008. *Human dimensions of the ecosystem approach to fisheries: an overview of context, concepts, tools and methods*. FAO Fisheries Technical Paper No. 489. Rome, FAO. 152 pp. (also available at www.fao.org/docrep/010/i0163e/i0163e00.htm).

STAKEHOLDER ANALYSIS

Stakeholder analysis helps to determine systematically who needs to be a partner in the management arrangement, and whose interests are too remote to make this necessary. In doing this, it also examines power, conflict, relative incentives and other relationships.

The importance of stakeholder analysis lies mainly in its ability to ensure that the many actors in a vulnerability assessment are properly identified and characterized in terms of their interests in the particular circumstance and some of their interactions that relate especially to power. Without stakeholder analysis being done at the start of the policy and planning cycles, it is likely that critical actors will be omitted from the processes and that this will lead eventually to problems with the implementation of the assessment, its results, and follow-up actions. It is an important analytical tool that also helps to promote transparency.

Source: De Young, C., Charles, A. & Hjort, A. 2008. *Human dimensions of the ecosystem approach to fisheries: an overview of context, concepts, tools and methods*. FAO Fisheries Technical Paper No. 489. Rome, FAO. 152 pp. (also available at www.fao.org/docrep/010/i0163e/i0163e00.htm).

APPENDIX 3

Assessment methodologies used in vulnerability studies in fisheries, aquaculture and other sectors

Tables A3.1 and A3.2 have been compiled using information gathered in the annotated bibliography by Barsley, De Young and Brugère (2013). The reader is encouraged to refer to that publication for further contextual details on the vulnerability assessments carried out.

A3.1 collates studies of vulnerability specifically applied in the context of fisheries, aquaculture and inland and coastal aquatic resources, and Table A3.2 does so for those in the context of other sectors. In both tables, studies are organized according to the dominant vulnerability assessment methodology used.

TABLE A3.1
Classification of the literature according to the nature of vulnerability assessment methodologies used in the context of fisheries and aquaculture

Methodologies	Quantitative (Implicit reference to outcome vulnerability, biophysical systems/CC)	Integrative	Qualitative (Implicit reference to contextual vulnerability, human systems)
Top-down (Implicit reference to outcome vulnerability, biophysical systems/CC)	Stanton *et al*., 2012 [model, indic] Duriyapong & Nakhapakorn, 2011 [indic, map] Gao *et al*., 2007 [indic, map] Cooley *et al*., 2012 [indic] Huelsenbeck & Vorpahl, 2012 [indic] Torresan *et al*., 2008 [indic, map] Dwarrakish *et al*., 2009 [indic, model, map] Marshall *et al*., 2009 [indic] Lokrantz *et al*., 2010 [indic] Handisyde *et al*., 2006 [model] Pickering *et al*., 2011 [model] Bezvijen *et al*., 2011 [indic] Hutchings *et al*., undated [indic]	Allison *et al*., 2009 [indic]	
Integrative/mixed	Castanedo *et al*., 2009 [indic, stakeh] Torresan *et al*., 2012 [indic, map] Cinner *et al*., 2012 [indic, stakeh] Hughes *et al*., 2012 [indic] [1]	Szlafsztein & Sterr, 2007 [map]	Brouwer *et al*., 2007 [stakeh, indic] Moreno & Becken, 2009 [stakeh, model] [2]
Bottom-up (Implicit reference to contextual vulnerability, human systems)		Schwarz *et al*., 2011 [stakeh]	Mills *et al*., 2009 [stakeh] Hellebrant *et al*., 2009 [stakeh]

Notes:
CC = climate change.
The dominant methodology is indicated in [...].
Indic = indicator-based methodology,
Map = mapping-based methodology,
Model = modelling-based methodology,
Stakeh = stakeholder-based methodology.

[1]: Predominantly quantitative methodology but including stakeholders as providers of quantitative information and/or views for refining the assessment.
[2]: Predominantly qualitative methodology but relying on quantitative data (for example, through surveys) to complement the assessment.

Shaded areas denote an incompatibility in approaches.

All references except Hellebrandt, Hellebrandt and Abdallah (2009) are included in the annotated bibliography by Barsley, De Young and Brugère (2013).

TABLE A3.2
Classification of the literature according to the nature of vulnerability assessment methodologies used in other sectors than fisheries and aquaculture

Methodologies	Quantitative (Implicit reference to outcome vulnerability, biophysical systems)	Integrative	Qualitative (Implicit reference to contextual vulnerability, human systems)
Top-down (Implicit reference to outcome vulnerability, biophysical systems)	Moss *et al*., 2001 [model, indic] – *general* Stanton *et al*., 2012 [model, indic] – *general, climate* Thornton & Owiyo, 2008 [model, livelihoods] – *agricultural systems* Tsasis & Nirupana, 2008 [model] – *HIV/AIDS* Pamungkas *et al*. undated [model] – *flooding* Brooks *et al*., 2005 [indic] – *general, climate* Metzger & Schroter, 2006 [indic, map] – *natural resources*	None reported	
Integrative/mixed	Ericksen, 2008 [indic?] – *food insecurity* Chaudhuri *et al*., 2002 [indic] – *poverty* Ligon & Schechter, 2003 [indic] – *poverty* Pritchett, 1999 [indic] – *poverty*	Daze *et al*., 2009 [map] – *general, adaptation* Dougill *et al*., 2010 [model] – *pastoral systems, climate change* Nelson *et al*., 2010 [model, livelihoods] – *rural communities, agricultural systems* O'Brien *et al*., 2004 [indic, map] – *climate change, globalization*	Lovendal, C., 2004 [livelihoods] – *food insecurity* Keskitalo, 2008 [stakeh] – *natural resources, livestock*
Bottom-up (Implicit reference to contextual vulnerability, human systems)		Lovendal & Knowles, 2005 [stakeh?] – *food insecurity*	Devisscher *et al*., 2011 [stakeh] –*forestry*

Notes:
The dominant methodology is indicated in […].
Indic = indicator-based methodology,
Map = mapping-based methodology (usually involving GIS),
Model = modelling-based methodology,
Stakeh = stakeholder-based methodology,
Livelihoods = livelihood-based methodology.

Shaded areas denote an incompatibility in approaches.
The field (fields) of application are indicated in italics.

All references except Dougill, Frase and Reed (2010) are included in the annotated bibliography by Barsley, De Young and Brugère (2013).

APPENDIX 4

Previous propositions of vulnerability assessment processes that helped develop the vulnerability assessment steps for fisheries and aquaculture

Some authors have considered the process through which assessments should be conducted. Two groups in particular have proposed a series of practical "how to" steps that could be followed to implement a vulnerability assessment, regardless of its context. They are summarized here.

(1) Schröter, Polsky and Patt (2004) proposed detailed an approach for vulnerability assessments involving **eight sequential steps**. The first three focused on the collection of quantitative and qualitative data and information, which are then used in a quantitative modelling exercise in the five remaining steps. The steps involve:

1. Defining the study area together with stakeholders, including *a priori* selecting system boundaries, time and geographic scales.
2. Getting to know the place over time, through interactions with stakeholders and secondary data and information collection.
3. Hypothesizing who is vulnerable to what, i.e. choosing a focus and formalizing investigation hypotheses that need to be explored in subsequent steps.
4. Developing a causal model of vulnerability, which is likely to comprise both qualitative and quantitative elements, and which could be used to move from causes to consequences and vice versa.
5. Finding indicators for the elements of vulnerability that are of relevance to the model developed and the place, scale and context of the system under study (these indicators should reflect exposure, sensitivity and adaptation potential).[1]
6. Operationalizing the model of vulnerability (or submodels that constitute the overall causal model of vulnerability), allowing one to weigh and combine indicators from the previous step in a measure of vulnerability.
7. Projecting future vulnerability of the system under study using scenario analysis that realistically accounts for uncertainty.

The eighth and last step is in fact common to each step. It involves communicating vulnerability creatively and refers in particular to the open dialogue that needs to be established between researchers and stakeholders to ensure the credibility and robustness of the findings of the causal model.

Finding indicators in the vulnerability scoping diagram developed by Polsky, Neff and Yarnal (2007) can assist in the completion of the fifth step of the approach proposed by Schröter, Polsky and Patt.

[1] Schröter, Polsky and Patt adopted the IPCC model. Therefore, it is logical that the indicators they recommend captured the key elements of the IPCC definition. However, this could be open depending on the definition or construct of vulnerability adopted.

(2) With the aim of increasing adaptive capacity to reduce vulnerability, Lim and Spanger-Siegfried (2004) proposed a mixed stakeholder-based and quantitative approach built around **four tasks** to assess current vulnerability:

1. Assess climate risks and potential impacts.
2. Assess socio-economic conditions.
3. Assess adaptation experience.
4. Assess vulnerability – understood as the actual identification and characterization of the sensitivity of the system under study to climate hazards and the socio-economic context, while accounting for adaptation mechanisms currently in place.[2]

Tasks 1 and 2 can be either qualitative (if they rely on stakeholder's accounts, focus groups or other qualitative technique of information elicitation), quantitative (if results from climate models and readily available indicators of socio-economic status are used), or a combination of both. Task 3 is resolutely stakeholder-oriented and qualitative in order to gather information on collective adaptation experiences. Task 4 is purely analytical as it involves a detailed synthesis of the preceding assessments to reach conclusions on who/what is vulnerable to what in the system under study. A "Task 0" would involve choosing a system (environment and people) that is considered as *a priori* threatened. The successive tasks then allow one to drill down into the system and confirm its vulnerability "status" (overall and of its parts).

[2] In relation to this, by including an analysis of adaption experiences before the actual conclusion about the vulnerability of the system under study is reached, one is able to account for the history of vulnerability and adaptation of the system, and thus for possible past maladaptation that may have contributed to increase its overall vulnerability.

This publication provides an overview of vulnerability assessment concepts and methodologies. It sheds light on the different vulnerability assessment methodologies that have been developed, and on how these are conditioned by the disciplinary traditions from which they have emerged. It also analyses how these methodologies have been applied in the context of fisheries and aquaculture, with illustrative examples of their application. A series of practical steps to assess vulnerability in the fisheries and aquaculture sector is proposed in order to support climate change specialists working with communities dependent on fisheries and aquaculture, as well as fisheries and aquaculture practitioners wishing to incorporate adaptation planning into the sector's management and development.

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