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VULNERABILITY ASSESSMENT METHODOLOGIES: AN ANNOTATED BIBLIOGRAPHY FOR CLIMATE CHANGE AND THE FISHERIES AND AQUACULTURE SECTOR

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VULNERABILITY ASSESSMENT METHODOLOGIES: AN ANNOTATED BIBLIOGRAPHY FOR CLIMATE CHANGE AND THE FISHERIES AND AQUACULTURE SECTOR

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PREPARATION OF THIS DOCUMENT

This circular contains a comprehensive annotated bibliography of vulnerability methodologies specific to climate change and the fisheries and aquaculture sector. The circular was prepared between 2012 and 2013 and commissioned by FAO as a supporting background document for an international expert workshop in Namibia on climate change vulnerability methodologies, funded under the GCP/INT/253/JPN project "Fisheries management and marine conservation within a changing ecosystem context".

The annotated bibliography presents a range of the most contemporary and seminal vulnerability methodologies from over the past decade, providing a reference for workshop participants and also practitioners, policy-makers, non-governmental organizations and governmental organizations conducting vulnerability assessments. A significant degree of confusion and debate surrounds vulnerability methodologies, with a wide variety of approaches currently being used to measure vulnerability, resulting in a call from practitioners and the academic community for developing consensus on the subject. Therefore, this bibliography attempts to assist in the clarification of vulnerability methodologies specifically focused towards climate change and the fisheries and aquaculture sector, and it also includes literature from across the natural resources and social science disciplines.

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ABSTRACT

This paper presents a comprehensive annotated bibliography of the most contemporary and seminal vulnerability methodologies from over the past decade, focusing particularly on vulnerability to climate change in the fisheries and aquaculture sector. The bibliography was developed as a background paper for an international expert workshop in Namibia in 2013 on climate change vulnerability methodologies, coordinated by FAO. A significant degree of confusion and debate surrounds vulnerability assessments and the methods through which vulnerability should be measured in order to provide an accurate assessment that can feed into effective polices and strategies for adaptation and vulnerability reduction. A clear and structured approach is presented in the annotated bibliography by dividing the paper into seven main sections: reviews, frameworks, drivers of change, scale, fishery and farming ecosystem, species and vessels, and special considerations. A comprehensive range of vulnerability methodologies has been incorporated in the annotated bibliography, crossing a multitude of scales, approaches and disciplines. The paper identifies a number of important connections and links within the literature on vulnerability – developed through the use of subsections and by cross-referencing throughout the bibliography – further assisting in the clarification of vulnerability methodologies.

CONTENTS

ACKNOWLEDGEMENTS

The authors would like to thank the FAO Fisheries and Aquaculture Working Group on Climate Change, the Global Partnership for Climate, Fisheries and Aquaculture (PaCFA) and the participants of the PaCFA expert workshop on vulnerability assessments in fisheries and aquaculture for their comments and suggestions that have helped to develop this annotated bibliography.

ABBREVIATIONS AND ACRONYMS

ABNJ	areas beyond national jurisdiction
CARICOM	Caribbean Community
COBAM	Climate Change and Forests in the Congo Basin: Synergies between Adaptation and Mitigation
CRED	Climate and Regional Economics of Development
CVCA	Climate Vulnerability and Capacity Analysis
CVI	Coastal Vulnerability Index
DFID	Department for International Development
DRR	disaster risk reduction
DSS	decision-support system
EEZ	exclusive economic zone
EM-DAT	Emergency Events Database
ESI	Environmental Sensitivity Index
GCM	global circulation model
GDP	gross domestic product
GIS	geographic information system
ICZM	integrated coastal zone management
IPCC	Intergovernmental Panel on Climate Change
LVI	Livelihood Vulnerability Index
MCDA	multicriteria decision analysis
NGO	non-governmental organization
OECD	Organisation for Economic Co-operation and Development
OOA	object-oriented analysis
PAR	pressure and release (model)
PCA	principal components analysis
PLA	participatory learning for action
PVI	Physical Process Vulnerability Index
SAVI	Southern Africa Vulnerability Initiative
SLA	Sustainable Livelihoods Approach
SoVI	index of social vulnerability
SVI	Socio-economic Vulnerability Index
VPL	Vulnerability to Poverty Line
VRIP	Vulnerability–Resilience Indicator Prototype
VSD	Vulnerability Scoping Diagram

1. INTRODUCTION

Vulnerability assessments can play a vital role in the design of appropriate adaptation and mitigation policies targeted towards climate change and its impacts on marine and aquatic ecosystems, and those who depend upon these resources for their livelihoods and well-being. Assessing which particular individual, group, community, region, species or nation is vulnerable, and in what ways, enables clear and effective responses to be formulated. Vulnerability as a useful concept has been surrounded by debate in recent decades, with discussions including the ability to measure vulnerability statistically and even compare it between different groups and locations.

Extensive research and development within the field of vulnerability has occurred in the last four decades, moving from its initial formation within the natural hazards discipline (notably White and Haas [1975][1] risk and hazards approach), to encompass more social ecological systems, highlighted within Blaikie's "pressure and release" model (Blaikie *et al*., 1994[2]) and the sustainable livelihoods framework (Turner *et al*., 2003; see entry in section 3.2). The complexity entailed in encompassing and measuring various geographical, spatial, temporal and social dimensions of vulnerability has resulted in a multitude of different methodologies for measuring vulnerability, which are identified in this paper.

The purpose of this annotated bibliography is to clarify and organize vulnerability methodologies specifically targeted towards the fisheries and aquaculture sector and in the context of climate change. Owing to the relevance and multidisciplinary nature embedded in vulnerability and climate change, methodologies from a number of different disciplines such as agriculture, water resources, and natural and social sciences have been incorporated. The bibliography provides a reference point for practitioners, policy-makers and adaptation planners in constructing and implementing vulnerability assessments. The annotated bibliography was originally a background document for an FAO-led international expert workshop on climate change vulnerability methodologies, held in Namibia in April 2013. The aim of the workshop was to bring greater clarity and discussion to the field of vulnerability research, specifically in the fisheries and aquaculture sector.

[1] White, G.F. & Haas, J.E. 1975. *Assessment of Research on Natural Hazards.* MIT Press: Cambridge, MA.
[2] Blaikie, P., Cannon, T., Davis, I., & Wisner, B. 1994. *At Risk: Natural Hazards, People's Vulnerability, and Disasters.* London: Routledge.

2. METHODS

The annotated bibliography incorporates a selection of the most contemporary and seminal vulnerability literature from a combination of peer-reviewed and grey literature, providing a comprehensive view of vulnerability methodologies and highlighting contemporary debates and developments within this field. The literature was filtered by date to allow the quantity to be maintained at a manageable level and to ensure that only the most contemporary and seminal methods were included. Seminal papers were mainly identified in the vulnerability reviews, with the literature being chosen based on frequent cross-referencing with other papers, and here highlighted in the text with use of brackets after the citation.

The annotated bibliography was categorized into seven main sections: vulnerability reviews, frameworks, drivers of change, scale, fishery and farming ecosystem, species and vessels, and special considerations. A comprehensive range of vulnerability methodologies was incorporated in the annotated bibliography, crossing a multitude of scales, approaches and disciplines. The paper identified a number of important connections and links within the vulnerability literature – developed through the use of subsections and by cross-referencing throughout the bibliography – further assisting in the clarification of vulnerability methodologies. Specific questions guided the annotations and analysis throughout the bibliography, with questions varying between the initial and latter sections of the paper. The questions were developed by a need to identify common approaches used within vulnerability literature and to identify the benefits and limitations of each method. The questions provide continuity throughout the bibliography, aiding the reader to identify similarities, discrepancies and key developments of vulnerability methodologies in and between references.

A literature search was initially conducted using key words depending upon the section being researched, such as “community vulnerability assessments” for identifying literature at the community level. If this search found no results of value, then other key words were used (such as in this case “stakeholder” or “local”). Failing this approach, literature was found using cited material in related papers. The vulnerability reviews also provided an important basis for identifying seminal vulnerability literature and, therefore, the bibliography evolved as these reviews were annotated in greater detail.

Cross-referencing is used in the bibliography where specific literature is applicable to various subsections, and thus the integrated nature of vulnerability assessments can be seen. In such cases, the citation is included in the subsection with reference to the section it is annotated under, which is also the category it applies to most. The references are also listed in alphabetical order in each subsection, making it easier to find specific authors.

3. VULNERABILITY REVIEWS

This chapter presents summaries of the most comprehensive reviews of vulnerability methodologies and literature. Providing an invaluable source to draw from throughout this bibliography, the reviews present the evolution of vulnerability methodologies and highlight the key developments and references that can guide a more focused vulnerability assessment. As some of the reviews focus mainly on conceptual understanding and debate around vulnerability and others more on specific applied examples, the chapter is divided in two sections – conceptual and applied vulnerability reviews.

To guide the annotation, the following questions are applied to each review:

- What is the objective of the review?
- What approach is used to analyse and present vulnerability methodologies?
- What are the key vulnerability methodologies and gaps highlighted in the review?

3.1 Conceptual reviews

Adger, W.N. 2006. Vulnerability. *Global Environmental Change,* 16(3): 268–281.
The author reviews the existing knowledge on analytical approaches of vulnerability to environmental change, identifying the synergies and consilience between research on vulnerability, resilience and adaptation through social ecological systems. The paper outlines the antecedent vulnerability methods, specifically on entitlements and disaster research (human ecology, hazards and the "pressure and release model"). The author illustrates their relevance in current formulations of vulnerability, such as the sustainable livelihoods framework and vulnerability to poverty. A detailed account of the challenges facing vulnerability methodologies in the field of climate change is presented, highlighting three main areas of difficulty: the challenge of measurement such as the difficulty to encompass social dimensions, to create thresholds and the dilution of complex vulnerabilities when translating reality into information such as; perceptions of vulnerability, linking with measurement and environmental psychology; and issues of governance addressing equitable participation of vulnerability in decision-making. The author concludes that a theory of vulnerability must include risks, thresholds and institutional dimensions in order to accommodate the multitude of scales through which vulnerability exists.

Alwang, J., Siegel, P. & Jorgensen, S. 2001. *Vulnerability: a view from different disciplines* [online]. Social Protection Discussion Paper Series No. 0115. Social Protection Unit, Human Development Network. Washington, DC, World Bank. [Cited 07 May 2013]. http://siteresources.worldbank.org/SOCIALPROTECTION/Resources/SP-Discussion-papers/Social-Risk-Management-DP/0115.pdf

(Seminal)
This review, conducted on behalf of the Social Protection Unit of the World Bank, provides a filtered review of vulnerability literature from a multitude of disciplines, analysing the various definitions and measurements of vulnerability. The paper focuses on vulnerability at the household level, and literature is drawn from the fields of economics, sociology/anthropology, disaster management, environmental science and health/nutrition. In order to make sense of the literature, vulnerability is divided into multiple components of a risk chain – the risk, risk responses and outcome in relation to the loss of welfare. The paper identifies the commonality between disciplines in regard to risks at one end of the spectrum and underlying conditions of vulnerability at the other. The issue of measurement arises in the review, which stresses the importance of defining the "purpose", as this factor is said to shape the selection criteria used in vulnerability assessments. The authors conclude by remarking on the unlikelihood of an aggregated measurement of vulnerability, owing to the highlighted differences between disciplines and their respective methods.

Cutter, S.L, Emrich, C.T., Webb, J.J. & Morath, D. 2009. *Social vulnerability to climate variability hazards: a review of the literature* [online]. USA, Hazards and Vulnerability Research Institute and University of South Carolina. [Cited 07 May 2013]. http://adapt.oxfamamerica.org/resources/Literature_Review.pdf

(Seminal)
The authors provide one of the most recent and seminal reviews of social vulnerability to date, focused specifically on climate variability and hazards. The review, although not extensive, presents key seminal work on social vulnerability, mainly from peer-reviewed literature for the period 2000–09. The review is divided into four main sections: the conceptual models and theoretical frameworks, vulnerability assessments, measuring vulnerability and constructing indices and social vulnerability metrics and mapping. The authors provide a summary and analysis of vulnerability methods, identifying the benefits and gaps in the various assessments, noting their application and contribution to the advancement of vulnerability work. The review gives a comprehensive description of the various methods of measuring vulnerability, providing a useful point of reference from which to understand the variety of methods.

Fellmann, T. 2012. *The assessment of climate change related vulnerability in the agricultural sector: reviewing conceptual frameworks* [online]. FAO/OECD Workshop Building Resilience for Adaptation to Climate Change in the Agriculture Sector. [Cited 07 May 2013]. http://typo3.fao.org/fileadmin/templates/agphome/documents/faooecd/fellmann.pdf
The author provides a review of conceptual frameworks for vulnerability assessments in relation to climate change and in the context of an FAO/OECD report on building resilience in the agriculture sector. The paper achieves its aim of reducing the complexity of vulnerability frameworks, enabling a clear comparison of the multitude of approaches and frameworks, and identifying significant gaps. Although not a comprehensive review of the literature, an overview of the main characteristics of vulnerability assessments is provided, including the difference between adaptive capacity and coping range, alternative frameworks, temporal differences and the uncertainties/constraints of data. A brief analysis is provided for the types of vulnerability methods (indicator-, model- and stakeholder-based) identifying the benefits and limitations of each. The author elaborates on the two main differences of vulnerability approaches – outcome (end point) and contextual (starting point) – touching upon the marginalization of socio-economic approaches (contextual) in comparison with the biophysical (outcome), yet also highlighting their beneficial collaboration. The author concludes the review by providing a framework that stakeholders and policy-makers can use as a reference when undertaking vulnerability assessments, with the aim of reducing complexity and improving the communication of results and methods.

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

(Seminal)
In this seminal paper, the authors present an evolution of vulnerability assessments to climate change and a description of the approach of the Intergovernmental Panel on Climate Change (IPCC), differentiating between four stages of vulnerability assessments: climate impact assessments, first-generation assessments, second-generation assessments, and adaptation policy assessments. The paper begins with a comprehensive description of vulnerability to climate change and its various related components such as mitigation and adaptation. Three main models and frameworks of vulnerability are identified and discussed: the risk–hazard framework, the hazards of place model, and the social constructivist framework. In order to conduct an evolutional analysis of vulnerability assessments, a conceptual framework is developed to identify key concepts and their relationships, depicting this through diagrams for each stage (referred to as a "glossary" by the authors). The first stage (impact assessments) uses scenarios of future climate change to analyse anthropogenic climate impacts. The second stage, called the first-generation assessment, builds upon the impact assessment by incorporating factors that are not related to climate and the possibility of effective adaptation to diminish impacts. The next stage is the second-generation assessment, which in particular focuses upon adaptation. Lastly, the adaptation policy assessments target policy-makers and highlight key

areas for future projects, thus highlighting the shift in vulnerability assessments to incorporating suggestions on risk reduction.

O'Brien, K., Eriksen, S., Schjolden, A. & Nygaard, L. 2004. *What's in a word? Conflicting interpretations of vulnerability in climate change research* [online]. Oslo, Center for International Climate and Environmental Research. [Cited 07 May 2013]. www.cicero.uio.no/media/2682.pdf
The authors discuss two common interpretations of vulnerability in climate change literature that have caused confusion in research and policy owing to the different methods that are adopted in the two perceptions of vulnerability. The first of these is the "end point" approach, which sees vulnerability as being determined by adaptive capacity and something that resides in the future. The second view of vulnerability is as the "starting point", which shows vulnerability as already being present and determining adaptive capacity. The paper highlights the practical implications of these approaches by using an example from Norway and Mozambique. The study stresses that the differing interpretations of vulnerability that reside across the multidisciplinary scientific and policy community have significant implications for how the effects of climate change can be diagnosed and also resolved. The authors conclude that viewing vulnerability as an end point does not address the underlying causes of vulnerability but instead focuses upon the symptoms, and therefore greater insight can be found by analysing current and past contexts, by seeing vulnerability as the starting point.

* Cross-reference: section 9.8.

3.2 Applied reviews

Adger, W.N. & Kelly, P.M. 1999. Social vulnerability to climate change and the architecture of entitlements. *Mitigation and Adaptation Strategies for Global Change,* 4: 253–266.

(Seminal)
In this seminal work, the authors present a comprehensive framework for social vulnerability to climate change, placing the social and economic well-being of a community at the heart of the analysis. The importance of the availability and access to resources for individuals and groups is emphasized through the concept of entitlements. In order to bring clarity to the analysis, social vulnerability is divided into individual vulnerability (measured by social status, access to resources and income diversity) and collective vulnerability (measured by institutional and market structures of regions, nations or communities). A set of proxy indicators is developed through which vulnerability can be assessed and understood. The first indicator is poverty, for which marginalization is the proxy and reduction of entitlements, empowerment and coping strategies are some of the mechanisms for translation into vulnerability. The second is an indicator of inequality representing the function of social welfare, and the third is an indicator of institutional adaptation that is measured by decision-making, social learning and inactivity. The authors successfully applied their framework to a coastal district of northern Viet Nam, conducting field work in 11 communes (village administrative units), completing household surveys and semi-structured interviews, through which they found the political economy to be a crucial element of vulnerability. In the final section of the paper, the authors analyse whether their framework of vulnerability can be aggregated up to a global or region level, concluding that such a process is not appropriate unless it deals with the global community itself.

* Cross-reference: section 4.1.

Brooks, N. 2003. *Vulnerability, risk and adaptation: a conceptual framework* [online]. Working Paper 39. Tyndall Centre for Climate Change Research. [Cited 07 May 2013]. www.tyndall.ac.uk/sites/default/files/wp38.pdf

(Seminal)
The author identifies the somewhat complex terminology and confusion surrounding vulnerability assessments, and presents a conceptual framework to clarify relationships between vulnerability, adaptation and risk applicable to climate variability and change in human systems. The paper begins with an initial description of vulnerability, attempting to resolve conflict between social and biological assessments by highlighting their differences, and analysing the definition of risk in respect

of hazards and the IPCC definition of vulnerability. An examination of hazards is then given before the different conceptual timescales of vulnerability are expanded to give a platform for quantifying adaptive capacity. The author suggests a slight change in terminology, adding "adaptive likelihood" rather than capacity. The author places social vulnerability in the risk management framework by accepting the similarity of risk between the biophysical and natural hazard concepts. The measurement of risk in social vulnerability is therefore suggested to be either in terms of the mortality of humans or in factors such as educational status, coping ability or economic well-being.

Downing, T.E. & Patwardhan, A. 2005. Assessing vulnerability for climate adaptation. In: Lim, B., Spanger-Siegfried, E., Burton, I., Malone, E. & Huq, S. (eds.) ***Adaptation Policy Frameworks for Climate Change: Developing Strategies, Policies and Measures*****. Cambridge University Press, Cambridge and New York, 67-90.**

The authors present a comprehensive structure for undertaking a vulnerability assessment to assist climate change adaptation, which is part of the third technical paper of the IPCC report. Five main activities or stages for conducting a vulnerability assessment are given, all linking together to provide a conceptual framework guiding and assisting vulnerability research and assessments. The first activity is to clarify the conceptual framework and definitions of vulnerability with those conducting the assessment, reviewing previous national or regional assessments to gain greater insight into the context. The next is to identify vulnerable groups and develop a set of vulnerability indicators that feed into a vulnerability baseline for the present situation, with specific guiding questions such as who or what is vulnerable and how. The third activity is to assess the sensitivity, which shows the current vulnerability of the system and incorporates risks and disasters in the climate outcomes. The following activity is the assessment of future vulnerability, giving greater qualitative understanding of vulnerability drivers. Lastly, the fifth activity is the linking together of all the vulnerability outputs with adaptation policy, highlighting the importance of stakeholder decision-making and public awareness. In the annex of this report, the authors provide a clear presentation of previous vulnerability methodologies, frameworks and approaches useful for those conducting vulnerability assessments.

Füssel, H.M. 2007. Vulnerability: a generally applicable conceptual framework for climate change research. ***Global Environmental Change*****, 17(2): 155–167.**

The author identifies the complexity and multitude of vulnerability disciplines, approaches and frameworks, and attempts to bring clarity by presenting a generally applicable conceptual framework for vulnerability that incorporates classification of vulnerable situations and concepts based on four groupings of vulnerability factors. The four dimensions that are given as essential to describe a vulnerable situation are: the system, such as the population, geographic region or human environment; the attribution of concern, indicating the valued elements that are under threat from exposure to a hazard; the hazard; and the temporal reference, being the time or time period of interest. A method for allocating and classifying a description of a vulnerability assessment is also given, whether it is in the internal or external sphere and socio-economic and biophysical domain. The framework presented is argued to enable scholars and those involved in vulnerability assessments to see how and why vulnerability concepts differ, their diversity and their clarity to identify interpretations of vulnerability in the multitude of available assessments. A review of past conceptual frameworks at the initial stages of this paper brings relevance, depth and reference for the author's framework, assisting in the identification of gaps between the varieties of interdisciplinary vulnerability approaches.

Pearson, L.J., Nelsonc, R., Crimp, S. & Langridge, J. 2011. Interpretive review of conceptual frameworks and research models that inform Australia's agricultural vulnerability to climate change. ***Environmental Modelling & Software*****, 26(2): 113–123.**

The authors provide a unique review of the frameworks and models used in the Australian agriculture sector to assess vulnerability to climate change. Initially reviewing the various conceptual frameworks in the published literature, the authors identified the models currently being used and highlight specific gaps in need of further attention, with the use of an expert workshop of biophysical, economic and social scientists. Six criteria were used to review the vulnerability assessments: scope, scale, operational status, accessibility, validation and data availability. The review found four main

types of research approaches in Australian agriculture, the first being biophysical productivity models that identify yield production of plants and animals. The second is bioeconomic models, which focus on the economic productivity and incomes of farms to assess future changes. The next is a method for regional change planning that uses scenario assessments in various regions of agricultural industries, and, finally, there is an adaptive capacity model using the rural livelihood framework for agricultural industries. The review identifies the current vulnerability assessments in the agriculture sector as being mainly outcome-based, using predominantly biophysical models. The authors conclude by strongly suggesting a shift in Australian vulnerability assessments to more contextual frameworks, providing more emphasis on accurate estimations of crops, infrastructure and socio-economic systems.

Polsky, C., Neff, R. & Yarnal, B. 2007. Building comparable global change vulnerability assessments: the Vulnerability Scoping Diagram. *Global Environmental Change*, 17(3–4): 472–485.

The Vulnerability Scoping Diagram (VSD) developed by the authors helps to facilitate the comparison of independent vulnerability assessments and generalizations to be made, enabling a meta-analysis to guide future vulnerability research. Building from the comprehensive eight-step approach to vulnerability presented by Schröter (2005),[3] the VSD is applicable to step 5 "finding indicators for the components of vulnerability". The authors highlight the gap in being able to compare independent vulnerability assessments that may use different measurements. Research was used from the Human–Environment Regional Observatory project in the southwest and Mexico border region of the United States of America to highlight how independent research teams can apply a similar structure. Drawing upon the diagram created by the Project for Public Spaces, the VSD consists of a ring at the centre of which is the vulnerability of a given human environmental system. Vulnerability is then divided into the three main dimensions from the IPCC definition: exposure, sensitivity and adaptive capacity. The intermediate ring consists of the components of each dimension of vulnerability, such as the stressors and stressed components of exposure, responses to stresses under the adaptive capacity dimension and the first effects of stresses in sensitivity. The outer ring consists of the measurements and observable characteristics of the components, in total creating an output of indicators. In order to use the VSD, it is recommended that researchers specify five elements: hazard and associate outcomes of interest, exposure unit, dimensions, components and measures of vulnerability. The usability of the VSD to compare independent studies and make generalizations relies on multiple researchers incorporating it into their assessments, through which, over time, a meta-analysis could be conducted.

Schröter, D.C., Polsky, C. & Patt, A.G. 2005. Assessing vulnerabilities to the effects of global change: an eight step approach. *Mitigation and Adaptation Strategies for Global Change*, 10(4): 573–595.

(Seminal)

The authors present a novel guide for global change vulnerability assessments, providing a practical eight-step approach through which vulnerability studies can achieve five key criteria that the authors argue must be the objective of every vulnerability assessment: have a knowledge base, be place-based, incorporate a multitude of stressors, identify the various forms of adaptive capacity, and be prospective as well as historical. Identifying the complexity and disparity often embedded in vulnerability assessments, this method aims to provide common principles under which these core objectives can be achieved, which the authors describe as needed for preparing stakeholders to adapt to climate change. The IPCC definition and measurement of vulnerability (exposure, sensitivity and adaptive capacity) is used as a basis in the eight-step approach for achieving a successful assessment. The first three steps are suggested prior to modelling, and these are to define the study area with the stakeholders, understand the place, and hypothesize who is vulnerable and to what. The following five steps are suggested as part of the modelling process and they are: develop a causal model of vulnerability, find indicators of vulnerability, operationalize the model, project future vulnerability,

[3] Schröter, D., Polsky, C. & Patt, A.G. 2005. Assessing vulnerabilities to the effects of global change: An eight-step approach. *Mitigation and Adaptation Strategies for Global Change*, 10(4): 573-595.

and communicate vulnerability in a creative manner. To test this method, two case studies are reviewed using the eight-step approach, one of a global change assessment and the other of an impact, risk/hazard and food security approach. The authors argue the need for site-specific studies that can be spatially mapped and incorporate stakeholders in decision-making, while arguing that no universal metric exists with which to measure vulnerability.

Turner, B.L., Kasperson, R.E., Matson, P.A., McCarthy, J.J., Corell, R.W., Christense, L., Eckley, N., Kasperson, J.X., Luers, A., Martello, M.L., Polsky, C., Pulsipher, A. & Schiller, A. 2003. A framework for vulnerability analysis in sustainability science. *Proceedings of the National Academy of Sciences of the United States of America*, 100(14): 8074–8079.

(Seminal)
In their seminal paper, the authors present a vulnerability framework for assessing the coupled human–environment system, stressing the importance of this approach in the field of vulnerability research. Drawing initially from previous frameworks on vulnerability, they construct a conceptual framework as initiated by the Research and Assessment Systems for the Sustainability Program. The framework aims to present an analysis of vulnerability with greater emphasis on identifying and understanding its multiple elements and the scales present in a system, along with the inclusion of sustainability and global environmental change. Presenting their framework in the form of a comprehensive diagram, the approach is based at a specific spatial scale that links to the regional and global levels. The impacts of hazards are presented as being both located within and outside the system and place of assessment. The authors highlight the complexity of vulnerability analysis and propose a set of components that, if incorporated, will enable more effective analysis of vulnerability. These encompass elements such as identifying the complexity, nesting of scales and potential of new hazards in vulnerability assessments. They also highlight the importance for assessments to be open to quantitative and qualitative data, as well as emphasizing the coupled human–environment systems in their analysis.

4. VULNERABILITY FRAMEWORKS

This section divides vulnerability methodologies into three distinct frameworks (using Fellmann's [2012] categorization as a basis for this grouping; see entry in section 3.1) based on: indicator, model and geographic information system (GIS), and stakeholder. Assessments often use a combination of approaches when measuring vulnerability. They are categorized here under the main method used to measure vulnerability in the particular assessment.

Applied within each framework are the following questions:

- What is the objective and process of the framework?
- How does the framework measure vulnerability?

4.1 Indicator-based methodologies

Indicator-based methodologies are often used as a means of measuring vulnerability and can produce measurable outputs. However, they are not without their limitations. Schroter (2005)[4] describes some of the challenges of using indicator methodologies, such as a loss of heterogeneity, limitations with data availability and the scale at which they are used, as the complexity of vulnerability cannot easily be represented by the use of indicators. However, even given these challenges, indicators still provide one of the most dominant ways for measuring vulnerability and they continue to evolve and develop complexity, as shown in the following methodologies.

To give an indication of the variety of indices available within vulnerability methodologies, the following list is a collection of contemporary vulnerability indicators and indices that are highlighted in the following sections:

- **Livelihood Vulnerability Index (LVI):** The LVI was developed by Hahn, Riederer and Foster (2009), as detailed below, for a district-level vulnerability assessment of climate change in Mozambique. The LVI is targeted towards assisting development organizations, practitioners and policy-makers implementing vulnerability assessments.
- **Coastal Vulnerability Index (CVI):** The CVI was created by Gornitz (1990)[5] to identify risks related to sea-level rise on the east coast of the United States of America, and has subsequently been further developed (such as in McLaughlin, McKenna and Cooper, 2002[6]), and become a credible and widely used index of measuring coastal vulnerability. See section 5.1 for Duriyapong and Nakhapakorn (2011) for a description of the CVI.
- **Physical Process Vulnerability Index (PVI):** The PVI measures the physical variables of a system, for example, the coastal slope, rate of coastal erosion or the mean wave height. The PVI is often combined with other indicators to produce an overall index and can be displayed in the form of maps. See section 5.1 for Duriyapong and Nakhapakorn (2011) for a description of the PVI.
- **Socio-economic Vulnerability Index (SVI):** The SVI is a commonly used vulnerability index, identifying and combining social variables such as population density, cultural heritage and land use. It can also be combined with other vulnerability indices such as the PVI to form a composite overall vulnerability indicator. See section 5.1 for Duriyapong and Nakhapakorn (2011), and this section for Ebert, Kerle, and Stein (2008) for descriptions of the SVI.

[4] Schröter, D.C., Polsky, C. & Patt, A.G. 2005. Assessing vulnerabilities to the effects of global change: an eight step approach. *Mitigation and Adaptation Strategies for Global Change*, 10(4): 573–595.
[5] Gornitz, V. 1990. Vulnerability of the East Coast, USA to future sea level rise. *Journal of Coastal Research*, Special Issue 9: 201–-237.
[6] McLaughlin, S., McKenna, J. & Cooper, J.A.G. 2002. Socio-economic data in coastal vulnerability indices: constraints and opportunities. *Journal of Coastal Research*, Special Issue 36: 487–497.

Adger, W.N. & Kelly, P.M. 1999. Social vulnerability to climate change and the architecture of entitlements. *Mitigation and Adaptation Strategies for Global Change*, 4: 253–266.

(Seminal)
* Cross-reference: section 3.2.

Adger, W.N., Brooks, N., Bentham, G., Agnew, M. & Eriksen, S. 2004. *New indicators of vulnerability and adaptive capacity* [online]. Technical report 7. Tyndall Centre for Climate Change Research. [Cited 07 May 2013]. http://www.tyndall.ac.uk/content/new-indicators-vulnerability-and-adaptive-capacity

(Seminal)
The authors focus upon the development of new vulnerability and adaptive capacity indicators through a comprehensive analysis of vulnerability and the creation of a working database for socio-economic indicators to vulnerability from climate change. Through the use of literature reviews, practitioner meetings and discussions with key individuals, a conceptual framework was developed, from which indicators for vulnerability and adaptation were formed. The development of risk indicators was then completed with the use of the Emergency Events Database (EM-DAT), enabling a useful outcome method from which to check the validity of proxies. Predictive indicators were then developed along with proxy variables of vulnerability before the identification of indicators began. The authors found the key areas of health and social capital as being inadequately represented in previous vulnerability studies, and along with indicators of education and governance they highlighted their usefulness in assessing vulnerability to climate hazards. The project directly linked with the Tyndall Centre for Climate Change Research and fed into research on institutional influences affecting adaptation to climate change.

Allison, E.H., Perry, A.L., Badjeck, M.C., Adger, 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.
* Cross-reference: section 6.3.

Cinner, J.E., McClanahan, T.R., Graham, N.A.J., Daw, T.M., Maina, J., Stead, S.M., Wamukota, A., Brown, K. & Bodin, O. 2011. Vulnerability of coastal communities to key impacts of climate change on coral reef fisheries. *Global Environmental Change*, 22(1): 12–20.
* Cross-references: sections 7.2 and 9.2.

Cutter, S.L., Boruff, B.J. & Shirley, W.L. 2003. Social vulnerability to environmental hazards. *Social Science Quarterly*, 84(2): 242–261.

(Seminal)
In their seminal paper, the authors use the “hazards of place” model to identify and expand social vulnerability, incorporating risk and its interaction with mitigation to hazards. An index of social vulnerability (SoVI) to environmental hazards was developed with data from 1990 for the United States of America, incorporating country-level demographic and socio-economic data. In total, 42 variables were refined down to 11 and combined to create the SoVI score: personal wealth, age, density of the built environment, single sector economic dependence, ethnicity – Hispanic, housing stock and tenancy, race – African American / native American or Asian, occupation and infrastructure development. The authors highlight the benefit of using a factor analysis in their assessment as not only is it robust but it can also be replicated at various spatial scales and subsets such as coastal counties. The SoVI score was then compared with disaster declarations in the 1990s across counties, to check its value and credibility. The next step moving forward is recognized by the authors as integrating social vulnerability with biophysical risk, which is suggested to increase the validity of identifying vulnerable populations and areas, which would assist in mitigation strategies at the local, regional and national scale.

* Cross-reference: section 5.1.

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.**

This study specifically focused upon measuring social vulnerability in neighbourhoods of Honduras through an alternative method of using high-resolution images to gain proxy variables, onto which object-oriented analysis (OOA) was conducted for further definition. Along with these data, elevation and hazards were also included and, in total, 47 proxy variables were identified, including socio-economic status of households and neighbourhood characteristics. An SVI was formed using existing data from the area combined with GIS data. The study concluded that GIS data can be useful for the measurement and assessment of social vulnerability, especially when combined with further context-specific data, producing a more cost-effective study with wider coverage. Besides the benefits of this approach, the authors highlight that it is in no respect a comprehensive assessment of social vulnerability, and that integrating traditional field surveys along with GIS mapping would result in greater depth and assist disaster management in areas with scarce data.

* Cross-reference: section 4.2.2.

Eriksen, S.H. & Kelly, P.M. 2006. Developing credible vulnerability indicators for climate adaptation policy assessment. ***Mitigation and Adaptation Strategies for Global Change*****, 12(4): 495–524.**

(Seminal)

The authors compare the indicators of five national-level studies on vulnerability to form elements of best practice to address the issue of developing credible indicators for measuring climate change vulnerability. The five national-level studies used in the assessment were: the vulnerability–resilience indicators by Moss *et al.* (2001);[7] the Environmental Sustainability Index from the World Economic Forum (2002);[8] dimensions of vulnerability by Downing *et al.* (1995);[9] the Index of Human Insecurity (IHI) from Longergan *et al.* (1999);[10] and the country-level risk measures by Brooks and Adger (2003).[11] The studies were then categorized by a number of indicators and countries, and their incorporation of environmental resources, economic resources, social conditions and institutional capacity. The comparison shows a wide variety of indicators were used in the studies, but with most aggregating vulnerability and presenting a static depiction of a population, which the authors argue could be improved by focusing upon the societal processes to reduce vulnerability. The study concludes that national-level indicator studies have thus far failed to encompass adequately the processes of vulnerability, and thus greater emphasis on process-based approaches is suggested. The authors make three specific recommendations to develop credible indicators: the differentiation of vulnerability at all levels: increasing the transparency of authors' assumptions and premises of vulnerability; and the importance of verifying findings.

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[7] Moss, R.H., Brenkert, A.L. & Malone, E.L. 2001. *Vulnerability to Climate Change. A Quantitative Approach*. Pacific Northwest National Laboratory, Oak Ridge, TN. http://www.pnl.gov/globalchange/pubs/vul/DOE%20VCC%20report.PDF.

[8] World Economic Forum. 2002. *Environmental Sustainability Index*. An Initiative of the Global Leaders for Tomorrow Environment Task Force, World Economic Forum, Annual Meeting 2002, World Economic Forum/CIESIN/Yale Center for Environmental Law and Policy, Geneva/New York/New Haven. http://www.ciesin.columbia.edu/indicators/ESI.

[9] Downing, T.E., Watts, M.J. & Bohle, H.G. 1995. Climate change and food insecurity: Towards a sociology and geography of vulnerability. *In* T.E. Downing (ed.). *Climate Change and World Food Security*. Berlin, Springer, pp. 183–206.

[10] Lonergan, S., Gustavson, K. & Harrower, M. 1999. Mapping human insecurity. *In* S.C. Lonergen (ed.). *Environmental Change, Adaptation, and Security*. Dordrecht, NATO/Kluwer, pp. 397–413.

[11] Brooks, N. & Adger,W.N. 2003. Country Level Risk Measures of Climate-related Natural Disasters and Implications for Adaptation to Climate Change. *Working Paper* 26. Tyndall Centre for Climate Research, Norwich, University of East Anglia.

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.

In a joint effort between Emory University (the United States of America) and CARE-Mozambique, the authors developed an LVI for estimating the climate change vulnerability of two districts of Mozambique: Mabote and Moma. The LVI combined seven components or indicators for vulnerability: livelihoods, sociodemographics, social networks, health, natural disasters and climate variability, food and water security. These data were gathered at the household level by CARE field workers, applying a random selection process and using numerous data collection methods such as surveys, interviews and focus groups. The various components of vulnerability were then weighted equally and combined into an overall LVI. An alternative approach was then formed by combining the LVI model and its seven components with the IPCC's three factors of vulnerability (exposure, sensitivity and adaptive capacity). Implemented at the district level, the authors highlight the relevance of this method for resource and adaptation planning, noting the applicability of the LVI for development organizations, practitioners and policy-makers wanting to assess vulnerability. The authors highlight the limitations and benefits of this approach, with the former being the simplification of complex reality into only seven components (reducing the variance of results) and the latter being the usefulness at district-level planning and the ability for comparing vulnerability between locations.

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

The author presents a comprehensive analysis of vulnerability indicators, clarifying their purpose and usability in respect to the policy problems they should aim to address. Initially developing a conceptual framework for vulnerability indicators, the author uses this to review a range of arguments used in vulnerability indicators such as the deductive, inductive, normative and non-substantial. Six types of problems that indicators of vulnerability should address are presented, namely, the identification of mitigation targets, vulnerable people, communities and regions, raising awareness, allocating adaptation funds, monitoring adaptation policy and conducting scientific research. The review found that only indicators identifying vulnerable people were appropriate, with those being used for the other five problems being deemed an inappropriate concept or method to use. The author argues that measuring vulnerability is impossible and that thus a change of terminology is required within the field of vulnerability research. The importance of recognizing the difference between vulnerability and harm indicators is also noted, with the latter not including future dimensions.

Luers, A.L., Lobell, D.B., Sklar, L.S., Addams, L.C. & Matson, P.A. 2003. A method for quantifying vulnerability, applied to the agricultural system of the Yaqui Valley, Mexico. *Global Environmental Change*, 13(4): 255–267.

(Seminal)

The novel framework for measuring vulnerability proposed by the authors begins by choosing an outcome variable such as agricultural yield, then identifies the appropriate stresses to this variable such as climate change and its comparative limit of damage, and finally forms variables of sensitivity to stressors and the relative exposure of the system. The methodology goes one step further in that it estimates the system's adaptive capacity to climate change, and as a result also identifies the minimum likelihood of vulnerability. The framework requires outcome variables to be identified such as income or yield, and the stressors such as drought or climate change. The framework is applied to the case of changing markets and climate causing vulnerability of wheat yields in the Yaqui Valley, Mexico. The advantage of this framework is argued to be its simplicity, it being applicable to single-dimensional and multidimensional systems and also allowing for the independent analysis of each of four variables such as sensitivity or adaptive capacity.

Moss, R.H., Brenkert, A.L. & Malone, E.L. 2001. *Vulnerability to climate change, a quantitative approach*. Richland, USA, Pacific Northwest National Laboratory.

(Seminal)
* Cross-reference: section 4.2.1.

4.2 Model- and GIS-based methodologies

Biophysical and socio-economic models are often used as a means to measure vulnerability and have a tendency to focus upon a specific driver of change or group, and apply statistical measures and mapping technologies to display vulnerability. The distinction between models and GIS-based methodologies has been made in this section in order to bring greater clarity to the types of measurement approaches. A significant number of assessments have also been cross-referenced with other sections in the bibliography, which indicates the often combined process of using models or GIS systems with other approaches in vulnerability assessments.

4.2.1 Models

Moss, R.H., Brenkert, A.L. & Malone, E.L. 2001. *Vulnerability to climate change. A quantitative approach.* Richland, USA, Pacific Northwest National Laboratory.

(Seminal)
In this seminal work, a comprehensive analysis and description for measuring vulnerability to climate change is presented. The authors developed a prototype computer model, the Vulnerability–Resilience Indicator Prototype (VRIP), which they applied to the IPCC's three different scenarios of future climate change. The VRIP incorporated factors of sensitivity and coping capacity, with the former characterized by settlement, food security, human health, ecosystems and water, and the latter by economic and environmental capacity and human resources, each of which contained 1–3 proxies. The VRIP model was put into a Monte Carlo analysis to identify dominant proxies, which showed the most relevant and important indicators of vulnerability and resilience. The proxies are then combined into a cumulative indicator of vulnerability, which if it produces a negative value means it is sensitive and if a positive value that it is resilient. Although combined into a single value, the authors highlight the multiple dimensions of the model and its ability to be decomposed into its causal factors. Guided by the three IPCC scenarios, the model was subsequently applied to 38 countries and the world, calculating current conditions with national data from 1990 and future conditions by applying regional outputs given by an integrated assessment model (MiniCAM). The application of the model used the three IPCC future scenarios of climate change: rapid growth (A1v2), local sustainability (B2h) and delayed development (A2A1). Although using country data was useful to gain an overview of vulnerability, the authors argue that more subnational studies should be applied to give more appropriate findings for policy-makers.

* Cross-reference: section 4.1.

Nelson, R., Kokic, P., Crimp, S., Meinke, H., Howden, S.M., De Voil, P. & Nidumolu, U. 2010. The vulnerability of Australian rural communities to climate variability and change: Part II—Integrating impacts with adaptive capacity. *Environmental Science & Policy*, 13(1): 18–27.
* Cross-references: sections 4.3 and 6.1.

Stanton, E.A., Cegan, J., Bueno, R. & Ackerman, F. 2012. *Estimating regions' relative vulnerability to climate damages in the CRED model* [online]. Stockholm Environment Institute. [Cited 07 May 2013]. www.sei-international.org/mediamanager/documents/Publications/Climate/SEI-WorkingPaperUS-1103-v2.pdf
The VI-CRED model is an index of vulnerability to climate change, encompassed in the Climate and Regional Economics of Development (CRED) integrated assessment model. It is highlighted from other indices for its simple and clear approach, measuring national vulnerability through three main areas: gross domestic product (GDP) and its share between agriculture and tourism (described as the sectors most sensitive to climate change), percentage of population less than 5 m above sea level, and

access to freshwater resources. The indices distribute vulnerability over nine regions of the world in the CRED model, using data from 2005. The paper includes six other indices related to adaptation and vulnerability, highlighting the significant variation between different indices. This variation is shown through a comparison with other vulnerability models such as Maplecroft and DARA, which shows significant differences in the predicted region of vulnerability between models. This variation highlights the disparity between different vulnerability models and thus the need for collective methods to guide accurate and effective adaptation. VI-CRED is said to enable the CRED model to identify where policy intervention is most required and the countries and regions most vulnerable to climate change.

* Cross-reference: section 6.4.

Thornton, P.K., Jones, P.G., Owiyo, T., Kruska, R.L., Herrero, M., Orindi, V., Bhadwal, S., Kristjanson, P., Notenbaert, A., Bekele, N. & Omolo, A. 2008. Climate change and poverty in Africa: mapping hotspots of vulnerability. *AfJARE*, 2(1): 24–44.
* Cross-reference: section 6.2.

4.2.2 GIS-based

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.
* Cross-reference: section 4.1.

Gao, J., Nickum, J.E. & Pan, Y. 2007. An assessment of flood hazard vulnerability in the Dongting lake region of China. *Lakes & Reservoirs: Research & Management*, 12(1): 27–34.
* Cross-references: section 5.1 and 7.4.

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.
The framework presented in this study uses a GIS combined with the CVI to assess the natural and socio-economic vulnerability of a coastal segment in northeast Brazil. Sixteen separate natural and socio-economic variables were identified and weighted using the Arcview 3.2 program, creating a combined CVI score used to measure the disparity between communities and regions exposed to related hazards. The process to develop the CVI included data gathering, data input and pre-processing, storage and processing and data output. Results of the assessment are displayed through three maps: natural, socio-economic and total vulnerability. The study emphasized its numerous limitations in regard to gaining enough reliable data with which to conduct the assessment, and it recommends further investigation along with ensuring that the reader accepts the assessment as a "view" of reality. The study identified four specific areas upon which most vulnerability assessments of coastal zones agree: the behaviour of the coastal zone is not homogenous; there is a need to integrate different types of information; subjective elements should not be used to define or quantify vulnerability; and the outcomes of the assessment must feed into appropriate coastal zone planning and management.

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.
* Cross-reference: section 6.4.

4.3 Stakeholder-based methodologies

Stakeholder-based vulnerability methodologies focus upon the affected individual, community or group, and they use a wide range of tools for the collection and analysis of vulnerability, such as cognitive mapping, interviews, surveys, participatory processes and experts to achieve effective and context-specific vulnerability assessments that often feed into adaptation planning. Stakeholder

assessments are closely linked with community-based vulnerability methodologies and have also been used at the regional level when identifying vulnerability of governance systems.

Daze, A., Ambrose, K. & Ehrhart, C. 2009. *Climate vulnerability and capacity analysis handbook*. First edition. CARE International.
The Climate Vulnerability and Capacity Analysis (CVCA) created by CARE International builds upon its community-based approach, with the belief that empowerment through participation and knowledge sharing can enable transformation. The CVCA uses participatory methods of analysis, aiming to link community knowledge with scientific data in order to create a mutually beneficial process for analysis and adaptation of vulnerability. The method recognizes the importance of context-specific analysis and increasing dialogue within communities, also at the regional and national levels, and it combines prior work on poverty and vulnerability with that of disaster risk reduction (DRR). The CARE handbook provides an overview of the methods and guidelines for applying the CVCA, using many tools such as participatory learning for action (PLA), along with a particular emphasis on climate change. The CVCA is structured along four sections in the community-based approach: resilient livelihoods, DRR, capacity development, and addressing underlying causes of vulnerability. These help guide the vulnerability analysis applied to the national, local government/community and household/individual level.

Devisscher, T., Bharwani, S., Tiani, A.M., Pavageau, C., Kwack, N.E. & Taylor, R. 2011. *Component 2: Adaptation in the field. Baseline assessment of current vulnerability and adaptive capacity. COBAM – Project 2011* [online]. [Cited 07 May 2013]. http://static.weadapt.org/knowledge-base/files/1002/50251311d7252cobam-vulnerability-report.pdf
This report outlines a methodology for implementing a stakeholder-based vulnerability assessment, conducted for the project Climate Change and Forests in the Congo Basin: Synergies between Adaptation and Mitigation (COBAM) in the Tri-National de la Sangha (TNS) Landscape. The assessment was targeted specifically towards identifying communities' potential to incorporate adaptation programmes based on REDD+. The assessment was divided into three stages and began with a literature review and the contacting of stakeholders to assist in the fieldwork. The second step was the fieldwork and data collection using a wide range of participatory approaches such as focus groups, observations, interviews, surveys and participatory mapping. Emphasis was placed on the social dimensions of vulnerability, with analysis based on factors such as social networks, collective action, multiple threats and differential exposure. The data collection methods were first refined before being implemented, with 40 household surveys (divided into two, one on perceptions and the other on REDD+ feasibility) conducted at 3 sites. The final stage was the delivery of the research findings in a workshop, with stakeholders assisting to verify the findings and build consensus on future directions. The vulnerability methodology incorporated a range of stakeholders through a variety of means, mainly at the community scale and social dimension.

* Cross-reference: section 6.1.

Keskitalo, E.C.H. 2008. Governance in vulnerability assessment: the role of globalising decision-making networks in determining local vulnerability and adaptive capacity. *Mitigation and Adaptation Strategies for Global Change*, 14(2): 185–201.
* Cross-reference: section 9.5.

Nelson, R., Kokic, P., Crimp, S., Meinke, H., Howden, S.M., De Voil, P. & Nidumolu, U. 2010. The vulnerability of Australian rural communities to climate variability and change: Part II—Integrating impacts with adaptive capacity. *Environmental Science & Policy*, 13(1): 18–27.
* Cross-references: sections 4.2.1 and 6.1.

Pamungkas, A., Bekessy, S. & Lane, R. (Undated). *Assessing the benefits to community vulnerability of proactive adaptations for disaster risk management background* [online]. [Cited 07 May 2013]. http://iiirr.ucalgary.ca/files/iiirr/151.pdf
* Cross-references: sections 5.1 and 6.1.

5. DRIVERS OF CHANGE

This section focuses upon the drivers of change. It encompasses climate-related hazards and non-climate-related drivers, along with specific climate change impacts on the fisheries and aquaculture sector, such as temperature changes in air and water, and ocean acidification. Methodologies for measuring multiple drivers of vulnerability are also included because of their importance and relatively limited use in vulnerability research thus far.

Applied within each driver of change are the following questions:

- What approach (approaches) has (have) been used?
- To what extent is it following or departing from existing proposed methods of assessments?
- What contextual and/or fundamental modifications were brought to improve/adapt an existing methodology?
- What are the perceived advantages or disadvantages of the method used?

5.1 Climate-related hazards and disasters

Vulnerability methodologies that focus upon climate-related hazards and disasters predominantly use biophysical assessments and combinations of indicator- and model-based methodologies. These methods identify the driver of the assessment as the particular hazard or event, with the analysis focused upon the "cause" or "exposure" of vulnerability (incorporated in the IPCC definition of vulnerability). The assessments are highlighted as being important for measuring the vulnerability to climate change as the incidences of climate-related hazards and disasters are set to increase, with events such as flooding, storms and droughts becoming more common.

Brooks, N., Adger, N. & Kelly, P.M. 2005. The determinants of vulnerability and adaptive capacity at the national level and the implications for adaptation. *Global Environmental Change,* 15(2): 151–163.
* Cross-reference: section 6.3.

Cutter, S.L., Boruff, B.J. & Shirley, W.L. 2003. Social vulnerability to environmental hazards. *Social Science Quarterly*, 84(2): 242–261.

(Seminal)
* Cross-reference: section 4.1.

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.
The authors combined the PVI and the SVI to create an overall CVI for assessing the vulnerability of the Samut Sakhon coastal zone. The PVI was formed of four variables: coastal erosion rate, coastal slope, mean tidal range and mean wave height. The SVI also contained four variables: land use, population density, roads/railways and cultural heritage. The physical and social indicators were collected using GIS and remote sensing, and ranked by their level of vulnerability with 5 being the most vulnerable and 1 the least vulnerable. An analytical hierarchy process was then applied to assess the weighting of each variable, which was decided upon through questionnaires presented to socio-economic and physical experts.

* See section 4.1 for description of SVI, CVI and PVI.

Gao, J., Nickum, J.E. & Pan, Y. 2007. An assessment of flood hazard vulnerability in the Dongting lake region of China. *Lakes & Reservoirs: Research & Management,* 12(1): 27–34.
This vulnerability assessment was the first completed in China for flood prevention, as a result of the Yangtze River floods in 1998, and jointly agreed to be conducted by the United Nations Environment Programme, the United Nations Centre for Human Settlements and the State Environmental Protection Administration of China. Targeting flood prevention and mitigation strategies, the assessment of vulnerability uses GIS through remote sensing, land-use databases and numerous other models to create detailed maps for policy-makers and public awareness. The method also uses applied

analytical hierarchy in order to weight indicators and normalize data into a scale, with 1 = low vulnerability and 10 = high vulnerability. Categories of components that generate flood disasters are used and include the disaster environment, disaster drivers and disaster bearers. Identifying 20 counties or districts within the region, the method uses an index to measure precipitation (in millimetres), population density (measured in persons per square kilometre) and GDP. Finally, the impact to flood bearers is measured by the weighting of their relative importance for six categories: human life, buildings, agriculture, fishery, the economy and the environment. This vulnerability assessment incorporates additional emphasis on social, environmental and economic factors of flooding and it has resulted in regional mitigation measures such as creating flood-impact zones.

* Cross-reference: section 4.2.2.

Pamungkas, A., Bekessy, S. & Lane, R. (Undated). *Assessing the benefits to community vulnerability of proactive adaptations for disaster risk management background* [online]. [Cited 07 May 2013]. http://iiirr.ucalgary.ca/files/iiirr/151.pdf

* Cross-references: sections 4.3 and 6.1.

5.2 Non-climate-related hazards and disasters

This section outlines methodologies for the measurement of vulnerability to hazards and disasters that are not directly the result of the climate, for example, large oil spills or the HIV/AIDS pandemic. The literature in this section highlights the fact that similar methods for vulnerability measurement are used in non-climate assessments, and are often used in the identification of risk and subsequent adaptation or mitigation planning.

Castanedo, S., Juanes, J.A., Medina, R., Puente, A., Fernandez, F., Olabarrieta, M. & Pombo, C. 2009. Oil spill vulnerability assessment integrating physical, biological and socio-economic aspects: application to the Cantabrian coast (Bay of Biscay, Spain). *Journal of Environmental Management*, 91(1): 149–159.

This comprehensive methodology measures the vulnerability of oil spills for coastal environments that is applicable on a global scale and specifically uses the *Prestige* oil spill on the Cantabrian coast of northern Spain as an example. An oil spill vulnerability index was developed, incorporating physical, biological and socio-economic characteristics, through the use of three scenarios (worst-case, average and survey-based), along with an Environmental Sensitivity Index (ESI) vulnerability score. The findings of this study show that by using the worst-case index, an excessively conservative ranking is developed, which hinders risk management in coastal oil spills. The physical dimension identifies the coastal impact and its ability to self-clean, using indices of wave exposure and shoreline slope as measurements. The biological dimension measures the ecological impact, focusing upon estuaries, beaches and coastal rocky zones, identifying the state of conservation (structural and functional status), singularity value (value of conservation) and resilience factor (power of community). The economic index identifies the socio-economic costs from oil spills, completing a cost valuation from income loss for each segment and cleaning costs. Finally, an integrated vulnerability index was developed using a Delphi survey, incorporating stakeholder participation of those in relevant socio-economic sectors of the coast. This process is seen as the most beneficial index, as it promotes public participation in implementing integrated coastal zone management (ICZM). Results from this vulnerability study are displayed through coastal maps, enabling policy-makers and planners to identify vulnerability from oil spills clearly and to appropriate take action.

Tsasis, P. & Nirupama, N. 2008. Vulnerability and risk perception in the management of HIV/AIDS: public priorities in a global pandemic. *Risk Management and Healthcare Policy*, 1: 7–14.

The authors use the pressure and release (PAR) model to assess the vulnerability of populations to HIV/AIDS and the process of its development, which they term a slow-onset disaster. Three stages associated with the building up of pressure are identified in the model: the root causes, the dynamic pressure and the unsafe conditions. Another three factors indicate the vulnerability to risk: the resilience of a population, the health of a population (affected by their livelihoods and social

structures) and the degree of preparedness of a population (determined by their values and beliefs). The authors of the study emphasize the often indirect social dimensions associated with the vulnerability of a population to HIV/AIDS. It is suggested that the PAR model be used as a checklist through which to identify the existing factors of vulnerability; this can then indicate the HIV/AIDS disaster phase that the region is in. The model can assist in mitigation, as by selecting and addressing the root causes of vulnerability, the overall risk of HIV/AIDS can be reduced.

5.3 Temperature change (air or water)

Research found no temperature-change-based vulnerability methodologies. However, temperature change is discussed in many of the methodologies on vulnerability to climate change, it being the key driver of sea-level rise, ocean acidification and other climatic changes.

5.4 Ocean acidification

This section discusses vulnerability assessments focused upon ocean acidification, which is identified in these studies as predominantly affecting coral reef fisheries and causing significant vulnerability to food systems and livelihoods. The methodologies range from local to national-based assessments, incorporating indicator frameworks and species or ecological systems that may be vulnerable to ocean acidification.

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.

The vulnerability methodology developed by the authors identifies a scale through which to measure nations' vulnerability to ocean acidification through their reduction in mollusc harvests. Nations are grouped as either net importers or exporters and subsequently allocated points depending on a set of criteria, which provide the crux of the methodology. The conditions and questions for scoring vulnerability are as follows (and highlighted in brackets are the vulnerability dimensions applied from the IPCC definition): whether molluscs contributed more than 1 percent of citizens protein (sensitivity); whether they provide more than 0.001 percent of GDP (sensitivity); whether the increase in production by 2050 has to be more than 100 percent (adaptive capacity); and whether the country does not have aquaculture mollusc farming (adaptive capacity). Points are also awarded on a scale basis depending on nation average adaptabilities (adaptive capacity). The overall indicator for vulnerability is termed the "hardship indicator" whereby those with the highest points are most vulnerable to problems caused by ocean acidification. This methodology applies the common vulnerability factors of exposure, sensitivity and adaptive capacity, enabling policy-makers to target appropriate responses.

* See section 4.1 for description of hardship indicators. Cross-reference: section 9.2.

Huelsenbeck, M. 2012. Ocean-based food security threatened in a high CO_2 world: a ranking of nations' vulnerability to climate change and ocean acidification [online]. Washington, DC, Oceana. [Cited 07 May 2013]. http://oceana.org/sites/default/files/reports/Ocean-Based_Food_Security_Threatened_in_a_High_CO2_World.pdf

* Cross-references: sections 6.3 and 9.2.

5.5 Multiple drivers

This section outlines the vulnerability methodologies that simultaneously measure vulnerability to a multitude of drivers and stressors, such as climate change and globalization. They highlight the importance of begin able to assess multiple drivers of vulnerability, as the reality is that vulnerability is complex and often not driven by a single factor.

O'Brien, K., Quinlan, T. & Ziervogel, G. 2009. Vulnerability interventions in the context of multiple stressors: lessons from the Southern Africa Vulnerability Initiative (SAVI). ***Environmental Science and Policy,*** **12(1): 23–32.**

The Southern Africa Vulnerability Initiative (SAVI) framework was developed to assess development planning and understand the multifaceted nature of vulnerability. It draws upon previous vulnerability research on multiple stressors, namely, the seminal work of O'Brien and Leichenko (2000[12] and 2008[13]) and their double exposure framework. SAVI identifies issues by focusing upon a single stressor of vulnerability, which although easier to quantify, arguably misses the dynamic context in which vulnerability exists and may result in interventions having unintended negative consequences. Therefore, the framework aims to identify the interactions between stressors of vulnerability, and uses three case studies to do this: rural livelihoods in Zambia and South Africa; trade in Durban (South Africa); and HIV/AIDS in a conservation agency of KwaZulu-Natal Province (South Africa). The studies in turn show the interacting stressors of vulnerability, its hidden nature and the linked contexts of stressors. The authors highlight that a significant gap exists in the practical application of scientific literature on multiple stressors in southern Africa. The success of vulnerability assessments and interventions is therefore said to come from changing the underlying causes of vulnerability, through incorporating a multiple stressor approach.

* Cross-reference: section 9.4.

O'Brien, K., Leichenko, R., Kelkar, U., Venema, H., Aandahl, G., Tompkins, H., Javed, A., Bhadwal, S., Barg, S., Nygaard, L. & West, J. 2004. Mapping vulnerability to multiple stressors: climate change and globalization in India. ***Global Environmental Change,*** **14(4): 303–313.**

(Seminal).

* Cross-references: sections 6.2 and 9.4.

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

[13] Leichenko, R.M. & O'Brien, K. 2008. *Environmental change and globalization: double exposures*. New York, USA, Oxford University Press.

6. SCALE

This chapter provides vulnerability methodologies applied at varying scales, such as the community, subnational, national, regional and international. Over the years, vulnerability research has focused very little upon the national and regional levels, although a variety of methods and findings have depicted vulnerability for different policy and adaptation options, contexts and time scales. This chapter outlines some of the vulnerability methodologies used at the various scales, along with the limitations, benefits, differences and commonalities within and between scales.

Applied within each scale are the following questions:

- What approach (approaches) has (have) been used?
- To what extent is it following or departing from existing proposed methods of assessments?
- What contextual and/or fundamental modifications were brought to improve/adapt an existing methodology?
- What are the perceived advantages or disadvantages of the method used?

6.1 Community

Community-based vulnerability assessments have mainly used stakeholder-based methodologies for conducting analysis of vulnerability, with a wide range of research tools such as participatory rural appraisals, focus groups, Delphi methods, questionnaires and surveys being used to capture qualitative and quantitative data. A variety of authors argue the need to conduct vulnerability assessments at the community level in order to capture the required richness of data to assess vulnerability, taking into account local variations and perceptions on vulnerability. Assessments at the community level can often be aggregated to identify vulnerability at the larger scales. The outcomes of community-based assessments are also commonly fed into local programmes or policies of adaptation, with stakeholders often being consulted regarding the findings of the assessment.

Devisscher, T., Bharwani, S., Tiani, A.M., Pavageau, C., Kwack, N.E. & Taylor, R. 2011. ***Component 2: Adaptation in the field. Baseline assessment of current vulnerability and adaptive capacity. COBAM – Project 2011*** **[online]. [Cited 07 May 2013]. http://static.weadapt.org/knowledge-base/files/1002/50251311d7252cobam-vulnerability-report.pdf**
* Cross-reference: section 4.3.

Mills, D., Béné, C., Ovie, S., Tafida, A., Sinaba, F., Kodio, A., Russell, A., Andrew, N., Morand, P. & Lemoalle, J. 2011. Vulnerability in African small-scale fishing communities. ***Journal of International Development,*** **23: 308–313.**
* Cross-references: sections 7.4 and 9.6.

Nelson, R., Kokic, P., Crimp, S., Meinke, H., Howden, S.M., De Voil, P. & Nidumolu, U. 2010. The vulnerability of Australian rural communities to climate variability and change: Part II—Integrating impacts with adaptive capacity. ***Environmental Science & Policy*****, 13(1): 18–27.**
This paper presents part two of a study that explored and argued a disconnection between vulnerability assessments and policy implementation, combining hazard and impact modelling with a more holistic measurement of adaptive capacity in order to identify the vulnerability of Australian rural communities to climate change. This methodology combines a bioeconomic model of exposure and sensitivity, using indicators of historical rainfall, pasture growth and farm income data over a ten-year period. A vulnerability index was subsequently built from the work of Nelson *et al.* (2005),[14] who applied a rural livelihoods analysis framework in the context of Australian broadacre agriculture. The rural livelihoods analysis enabled the measurement of communities' adaptive capacity, providing an overall weighting for specific variables of the five capitals (social, financial, natural, human and physical) and incorporating data from farm surveys. The study categorized farming communities into three broad types, to enable greater comparison: those reliant on extensive sheep grazing; those in the

[14] Nelson, R., Kokic, P., Elliston, L. & King, J. 2005. Structural adjustment: a vulnerability index for Australian broadacre agriculture. *Australian Commodities* 12 (1): 171–179.

wheat–sheep zone; and the coastal and peri-urban farming communities. The study concludes that the vulnerability of rural Australian communities is a result of environmental, economic and social factors, and proposes that this integrated assessment of vulnerability can be of greater benefit for policy-makers.

* Cross-references: sections 4.2.1 and 4.3.

Pamungkas, A., Bekessy, S. & Lane, R. (Undated). *Assessing the benefits to community vulnerability of proactive adaptations for disaster risk management background* [online]. [Cited 07 May 2013]. http://iiirr.ucalgary.ca/files/iiirr/151.pdf

The authors apply a dynamic system model to assess the vulnerability of a community in East Java Province, Indonesia, that faces high levels of exposure to flooding. The model incorporates a set of 29 indicators to measure community vulnerability, such as number of victims, damage losses and time to recovery. These indicators were selected using a Delphi method, which aims to incorporate different stakeholders, but avoids face-to-face meetings and uses methods such as judgement-based analysis and telephone interviews. The method thus assists in more-effective policy outcomes, and highlights the importance of perception of vulnerability in assessments. Two scenarios were formed in regard to adaptation: current adaptations and integrated adaptations. Along with these two scenarios, seven submodels were created for the different processes that add to community vulnerability: flood, victims, housing, responses, income expenditure and savings. Rankings for each scenario to community vulnerability can enable more-efficient decision-making in disaster risk management. An important element of the dynamic system model is the incorporation of resilience and adaptation, resulting in an assessment that can focus upon a community's vulnerability, but in terms of its proactive adaptations for disaster risk management.

* Cross-references: sections 4.3 and 5.1.

Schwarz, A.-M., Béné, C., Bennett, G., Boso, D., Hilly, Z., Paul, C., Posala, R., Sibiti, S. & Andrew, N. 2011. Vulnerability and resilience of remote rural communities to shocks and global changes: empirical analysis from Solomon Islands. *Global Environmental Change*, 21(3): 1128–1140.

The authors present a methodology for assessing the vulnerability of remote communities to a changing climate in Solomon Islands, specifically focusing upon the vulnerability of individuals, households and communities and their perception of resilience. Assessing three coastal communities with a high dependence on fishing, the study incorporated livelihood vulnerability assessments and focused on social dimensions of vulnerability such as community cohesion, leadership and collective action. An integrated assessment map was used to identifying multiple dimensions of the system to assist the research, along with 67 household questionnaires identifying demographics, livelihoods strategies and perception of governance. A resilience analysis was also conducted, along with a multivariate probate approach to identify relationships between respondents' answers. The authors highlight the fact that communities are not homogenous and that therefore research on vulnerability requires detailed analysis and questioning. The study incorporated and highlighted past and future problems, noting population growth on the islands as a key issue.

6.2 Subnational

This section incorporates vulnerability methodologies that include analysis at a subnational scale, providing an important assessment for national and regional governmental organizations. Three papers are cited in this section, which highlights a gap in the bibliography research of subnational-level vulnerability assessments.

O'Brien, K., Leichenko, R., Kelkar, U., Venema, H., Aandahl, G., Tompkins, H., Javed, A., Bhadwal, S., Barg, S., Nygaard, L. & West, J. 2004. Mapping vulnerability to multiple stressors: climate change and globalization in India. *Global Environmental Change*, 14(4): 303–313.

* Cross-references: sections 5.5 and 9.4.

Ovie, S.I. & Emma, B. 2012. Identification and reduction of climate change vulnerability in the fisheries of the Lake Chad Basin. *In* C. De Young, S. Sheridan, S. Davies & A. Hjort. *Climate change implications for the fishing communities in the Lake Chad Basin. What have we learned and what can we do better? FAO/Lake Chad Basin Commission Workshop, 18–20 November 2011, N'Djamena, Chad,* pp. 23–84. FAO Fisheries and Aquaculture Proceedings No. 25. Rome, FAO. 2012. 84 pp. (also available at www.fao.org/docrep/017/i3037e/i3037e.pdf).
This report was prepared as part of a subnational workshop on climate change implications for fishing communities in the Lake Chad Basin, hosted by the Lake Chad Basin Commission in 2011, implemented by the FAO. The report is a desk-based review, focusing initially on the physical, social and economic boundaries of the Lake Chad Basin, before identifying the future impacts of climate change on livelihoods and natural resources in the area. The study analyses the system's vulnerability, using the definition of vulnerability as the "susceptibility of individuals or groups to harm as a result of climate change", and adopting the IPCC framework for measuring vulnerability. The report identifies a number of potential factors of vulnerability to the fisheries sector such as increased temperatures, reduced river flow causing habitat change and loss, and reduced precipitation. Policy recommendations for reducing vulnerability to climate change in the subregion are then suggested.

* Cross-reference: section 7.4.

Thornton, P.K., Jones, P.G., Owiyo, T., Kruska, R.L., Herrero, M., Orindi, V., Bhadwal, S., Kristjanson, P., Notenbaert, A., Bekele, N. & Omolo, A. 2008. Climate change and poverty in Africa: mapping hotspots of vulnerability. *AfJARE*, 2(1): 24–44.
The authors present a methodology applied at the subnational level to assess the vulnerability to climate change of agricultural systems throughout sub-Saharan Africa, enabling identification of adaptation strategies. The methodology draws from the work completed by the Department for International Development (DFID) to map vulnerability in sub-Saharan Africa and enable more precise resource allocation. The methodology focuses upon biophysical and social vulnerability, initially identifying hotspots for climate hazards by downscaling global circulation models (GCMs) and using the length of growing periods as proxy indicators for agricultural impacts. Models such as WorldCLIM and MarkSim are used to compress the data into 18 km grid squares, along with classifications such as the FAO farming system, which uses a livelihoods approach. Current vulnerability is then measured using components of the sustainable livelihoods framework, applied on a country-by-system basis and using a principal components analysis (PCA) to compress indicators. Finally, the study maps vulnerability to climate change at the subnational level, using the various models and weather systems such as GCMs. Specific limitations highlighted in the study are: the exclusion of extreme events from the analysis, the lack of wider-ranging vulnerability indicators, and the exclusion of coastal ecosystems, fisheries and aquaculture systems.

* Cross-reference: section 4.2.1.

6.3 National

Measuring vulnerability at the national level is recognized for its importance in guiding policy and decision-making, which often occurs at this scale, with the assumption that if vulnerable countries can be identified then comparisons between countries can also be made. However, the literature highlights the difficulties of conducting a national-level vulnerability assessment, with challenges often arising when trying to develop and compare indices of vulnerability between different countries that may have varying social, economic and biophysical contexts. The methodologies identified here commonly apply an indicator-based approach, often selecting and measuring a set of indices within a country to a given variable of exposure such as climate change and a particular sector such as fisheries. In comparing between national-level vulnerability assessments, various studies have ranked vulnerable nations differently, which highlights the variation that results from a mixture of combined indicators.

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.

(Seminal)
In this seminal work, the authors present the first national-level vulnerability assessment of climate change impacts to the fisheries sector, using an indicator-based approach to compare 132 countries. Recognizing the need for national-level vulnerability assessments, in view of the scale at which policies and decision-making occur, a global picture of vulnerability is attempted. The methodology used exposure, sensitivity and adaptive capacity indicators to measure the vulnerability of national economies. The exposure indicator identified the physical impact of climate variability through the measurement of air temperature projections for 2050. Sensitivity was measured as the dependence of nations upon economic and social returns from fisheries, indicated by the production in landings, fisheries employment, export income and dietary protein. Adaptive capacity was then accounted for by the nation's ability to offset climate impacts, using a climate analysis indicator tool that incorporated four human development indices of life expectancy, education, governance and size of the economy. The overall vulnerability score was weighted 25 percent each for exposure and sensitivity, and 50 percent for adaptive capacity, owing to the unknown value of each component. The study found the most vulnerable economies to be Malawi, Guinea, Senegal and Uganda in central and western Africa, Peru and Colombia in northwest South America, and Bangladesh, Cambodia, Pakistan and Yemen in tropical Asia. Limitations and suggestions surrounding the measurement of vulnerability were also highlighted in the study, such as the exclusion of 60 countries owing to a lack of data, which is suggested to highlight problems surrounding vulnerability methods, as those most likely to be vulnerable are excluded from the study. The authors suggest and recommend that in the assessment of exposure it would be beneficial to use more context-specific biomes such as for freshwater and coastal areas, for example, sea surface temperature gives a greater accuracy for high seas than land surface temperature would.

* Cross-reference: section 4.1.

Brooks, N., Adger, N. & Kelly, P.M. 2005. The determinants of vulnerability and adaptive capacity at the national level and the implications for adaptation. *Global Environmental Change,* 15(2): 151–163.
This study presents a novel approach to measuring vulnerability at the national level. It uses empirical analysis to develop indicators of vulnerability, specifically focusing upon mortality (consisting of readily available data) from climate-related hazards and disasters over a decadal timescale. Using data from EM-DAT, mortality as a percentage of population was measured together with proxies for risk for each country. Eleven indicators (grouped as health status, governance and education) were finally selected to measure national vulnerability, displaying a correlation with mortality and climate disasters. The proxy categories used within the study were: the economy, health and nutrition, education, infrastructure, governance, geography and demography, agriculture, ecology and technology. Indicators were then verified through expert judgement using focus groups and weightings assigned accordingly. Each indicator was then given a score of 1–5, with 1 equal to low vulnerability and 5 to high vulnerability. The study identified countries in sub-Saharan Africa as the most vulnerable, along with those countries that have recently experienced conflict. Generic indicators of vulnerability such as poverty and elements of governance were compared at the national level and were used as a basis on which to build more specific indicators. Although noting the advantages of national-level vulnerability assessment, the authors also highlight the importance of local, subnational and regional vulnerability assessments.

* Cross-reference: section 5.1.

Handisyde, N.T., Ross, L.G., Badjeck, M.-C. & Allison, E.H. 2006. ***The effects of climate change on world aquaculture: a global perspective*** **[online]. Department for International Development (DFID), UK. [Cited 07 May 2013]. www.ecasa.org.uk/Documents/Handisydeetal_000.pdf**
* Cross-reference: section 7.6.

Huelsenbeck, M. 2012. ***Ocean-based food security threatened in a high CO_2 world: a ranking of nations' vulnerability to climate change and ocean acidification*** **[online]. Washington, DC, Oceana. [Cited 07 May 2013]. http://oceana.org/sites/default/files/reports/Ocean-Based_Food_Security_Threatened_in_a_High_CO2_World.pdf**
This short study ranks nations vulnerability to food insecurity from the separate and joint effects of climate change and ocean acidification. The method adopted for assessing vulnerability was to measure the exposure, dependence and adaptive capacity of each nation to climate change and ocean acidification. The indicators of exposure to climate change was the predicted percentage of loss in fisheries' catch potential in exclusive economic zones (EEZs) by 2055, and for ocean acidification the indicator was for acidification based on the amount of aragonite saturation in EEZs by 2050. Climate change indicators for dependence were the fish and seafood consumed as a percentage of available protein, with indicators for ocean acidification being the coral reef fisheries as a proportion of national population and mollusc consumption as a percentage of available protein. Finally, the indicators for adaptive capacity for both climate change and ocean acidification were GDP per capita, population growth rate for 2012–2050 and the percentage of the population undernourished. The categories for exposure, dependence and adaptive capacity all had an equal weighting and were combined to form an overall vulnerability estimate. The study highlighted the most vulnerable nations to food insecurity as Maldives (as a result of climate change), the Cook Islands (as a result of ocean acidification) and the Comoros (combined together).

* Cross-references: sections 5.4 and 9.2.

Hughes, S., Yau, A., Max, L., Petrovic, N., Davenport, F., Marshall, M., McClanahan, T.R., Allison, E.H. & Cinner, J. 2012. A framework to assess national level vulnerability from the perspective of food security: the case of coral reef fisheries. ***Environmental Science & Policy,*** **23: 95–108.**
* Cross-reference: section 9.2.

6.4 Regional

Vulnerability methodologies included in this section focus upon the regional level, where policy decisions are often made, along with useful comparisons of predicted vulnerability with other regions. Coastal regions are at the centre of the analysis in these methodologies, and the studies highlight the need in regional assessments to divide areas into measureable components, often using various mapping systems such as GIS.

Bell, J., Johnson, J., Ganachaud, A., Gehrke, P., Hobday, A., Hoegh-Guldberg, O., Borgne, R., Lehodey, P., Lough, J., Pickering, T., Pratchett, M., Sikivou, M & Waycott, M. 2013. Vulnerability of fisheries and aquaculture to climate change in Pacific Island countries and territories. ***In*** **J. Johnson, J. Bell & C. De Young, C.** ***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,*** **pp. 25–109. FAO Fisheries and Aquaculture Proceedings No. 28. Rome, FAO. 93 pp. (also available at www.fao.org/docrep/017/i3159e/i3159e.pdf).**
The authors present a comprehensive vulnerability assessment of Pacific fisheries and aquaculture to climate change, which fed into a number of workshops including a regional workshop hosted by the Secretariat of the Pacific Community, implemented by FAO in 2012. The study is composed of five main sections: examining climate impact to atmosphere and the ocean on coastal and freshwater fish habitats and levels; identifying the sensitivity and adaptive capacity of these resources and the economies and communities dependent upon them; policy and adaptation strategies; gaps in the existing knowledge to enhance the assessment of vulnerability; and the investments needed to

implement adaptation strategies. The study assesses vulnerability through the IPCC definition and framework, measuring exposure, sensitivity and adaptive capacity. Data for surface climate and the ocean were extracted from the multimodel data set used for the IPCC's Fourth Assessment Report, the Coupled Model Intercomparsion Project Phase 3. The vulnerability of coastal, oceanic and freshwater fisheries and aquaculture was measured by combining the direct and indirect exposure of habitats and stocks, along with factors of exposure in economies and communities.

Hampton, I. 2012. Vulnerability to climate change of the Benguela Current Large Marine Ecosystem and the human livelihoods dependent on it. ***In*** **C. De Young, A. Hjort, S. Sheridan & S. Davies.** ***Climate change implications for fisheries of the Benguela current region – making the best of change. FAO/Benguela Current Commission Workshop, 1–3 November 2011, Windhoek, Namibia,*** **pp. 25–77. FAO Fisheries and Aquaculture Proceedings No. 27. Rome, FAO. 125 pp. (also available at www.fao.org/docrep/017/i3053e/i3053e.pdf).**
This report is one of the first assessments of climate change vulnerability in the Benguela Current Large Marine Ecosystem, commissioned by FAO and supported by the Benguela Current Commission as part of a regional workshop in Namibia in 2011. The assessment used the IPCC method for measuring vulnerability, analysing the sensitivity, impact (exposure) and adaptability of the Benguela region to climate change, specifically the fisheries and aquaculture sectors. A vulnerability index was formed by creating a score for each of three variables, which were then all multiplied to give the overall vulnerability score. The assessment focused upon the regional vulnerability of the Benguela region by combining the analysis of each country in the current area: Angola, Namibia and South Africa. The vulnerability assessment avoided comparison betweens the three countries in view of the differences in the importance and scale of the fisheries sector in each country. The research highlighted the most vulnerable fisheries, such as the artisanal and semi-industrial fisheries in Angola, the rock lobster fishery and small-scale line fishing in South Africa. The report concludes by providing a range of suggestions for adaptation, specifically for the reduced abundance and availability of fish stock.

McConney, P., Charlery, J. & Pena, M. (forthcoming). Climate change adaptation and disaster risk management in fisheries and aquaculture in the CARICOM region: Assessment study. ***In*** **FAO.** ***Regional Workshop on the Formulation of a Strategy, Action Plan and Programme Proposal on Disaster Risk Management, Climate Change Adaptation in Fisheries and Aquaculture in the CARICOM and Wider Caribbean Region, 10–12 December 2012, Kingston, Jamaica*****. FAO Fisheries and Aquaculture Proceedings.**
This report is part of an FAO and Caribbean Regional Fisheries Mechanism initiative on "Climate change adaptation and disaster risk management in fisheries and aquaculture in the Caribbean Community (CARICOM) region". The paper assesses the vulnerability to disasters and climate change in the CARICOM countries, using the IPCC framework for measuring vulnerability, assessing the impacts, sensitivity and adaptive capacity of the system. The paper identifies a number of gaps in the current knowledge for assessing vulnerability and provides suggestions for reducing vulnerability, giving policy guidance for a range of stakeholders such as non-governmental organizations (NGOs), universities, and governmental agencies. The CARICOM region faces a variety of hazards such as increased temperatures, drought, flooding, landslides, storms and hurricanes, sea-level rise and ocean acidification. The report identifies the exposure and sensitivity of each of these hazards and their potential impacts, such as increased temperature having a high impact on coastal fisheries as a result of the high sensitivity in coral reefs. The regional assessment took into account the differences in sensitivity, exposure and impact between the wide variety of ecosystems contained in the Caribbean region.

Quinones, R.A., Salgado, H., Montecinos, A., Dresdner, J. & Venegas, M. (forthcoming). Evaluación de potenciales impactos y reducción de la vulnerabilidad de la pesca al cambio climático: el caso de las pesquerías principales de la zona centro-sur de Chile. ***In*** **FAO.** ***Cambio climático, pesca y acuicultura en América Latina (LA): potenciales impactos y desafíos para la adaptación. Informe del Taller de Expertos, 5–7 de Octubre de 2011, Concepción, Chile*****. FAO Actas de Pesca y Acuicultura No 29.**

This paper was commissioned by FAO and it assesses the vulnerability of fisheries to climate change in the south-central area of Chile, focusing upon the impacts, sensitivity and resilience of the system. The paper also recommends various strategies for adaptation and aims to provide information to develop policy guidelines targeted at fisheries adaption to climate change. The assessment targeted the most important fisheries in respect of their socio-economic value in central-southern Chile and provides one of the most descriptive assessments of socio-economic vulnerability in the region. The authors began the assessment by reviewing climatic models and databases to predict the future impacts of climate change, before applying the IPCC framework of measuring vulnerability, incorporating exposure, sensitivity and adaptive capacity. Five specific factors of sensitivity in the region were found to be: the intensity and temporal dynamics of upwelling events, spatiotemporal dynamics of mesoscale physical structures, sea temperature, dynamics of oxygen minimum zone on the continental shelf, and the freshwater input by rivers.

Sena S. De Silva. 2012. Identification and reduction of climate change vulnerability in fisheries and aquaculture in Mekong Delta, Vietnam. *In* FAO. (forthcoming). Climate change - implications for aquaculture and fisheries communities and relevant aquatic ecosystems in Vietnam, 8 - 10 February 2012, Ho Chi Minh City, Vietnam. FAO Fisheries and Aquaculture Proceedings.
In this report commissioned by FAO, the author attempts to evaluate the vulnerability of the fisheries and aquaculture sectors in the Mekong Delta, providing guidance for policy-makers through strategies to reduce climate change vulnerability.

Stanton, E.A., Cegan, J., Bueno, R. & Ackerman, F. 2012. *Estimating regions' relative vulnerability to climate damages in the CRED model* [online]. Stockholm Environment Institute. [Cited 07 May 2013]. www.sei-international.org/mediamanager/documents/Publications/Climate/SEI-WorkingPaperUS-1103-v2.pdf
* Cross-reference: section 4.2.1.

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.
Presented in this paper is a regional vulnerability assessment methodology (RVA), one specifically developed to measure coastal vulnerability to climate change and enable greater adaptation planning. Through the use of biogeographical and socio-economic vulnerability indicators, the methodology produces regional and local vulnerability hotspots, enabling the identification and prioritization of specific areas of vulnerability. The authors 2012 apply this methodology to the coastal area of the north Adriatic Sea (Italy), showing how the assessment may be applied in land-use planning and coastal zoning. The regional vulnerability assessment is based on a multicriteria decision analysis (MCDA), engaging with stakeholders and experts to assist aggregate quantitative and qualitative indicators. The method begins with the definition of the vulnerability matrix, including factors of susceptibility, pathway (exposure) and value, which are subsequently normalized through a system of aggregation, weighting scores and linguistic evaluation. GIS vulnerability maps are then developed along with the use of Hot Spot Analysis (Getis-Ord Gi*) scores identifying clusters of high vulnerability, strengthening the knowledge transfer to decision-makers.

* Cross-reference: section 4.2.2.

Torresan, S., Critto, A., Dalla Valle, M., Harvey, N. & Marcomini, A. 2008. Assessing coastal vulnerability to climate change: comparing segmentation at global and regional scales. *Sustainability Science,* 3(1): 45–65.
The authors identify a gap within vulnerability literature and research for coastal assessments at the regional level, and subsequently propose a set of regional indicators and implement a comparative analysis between the global and regional scales. Two sets of indicators were used for the regional and global levels, respectively, each containing the same factors such as: topography and slope, density of coastal population and number of inhabitants, geomorphological characteristics and distribution of

wetlands and vegetation cover. The variables draw upon those in the DIVA model that is used at the global scale, which indicates the benefits and costs of various adaptation strategies. The study was conducted along the Veneto coastal zone of northern Italy, under the Euro-Mediterranean Center for Climate Change, whose aim is to develop better GIS decision-support systems (DSS) for coastal zones. The study showed a significant difference between the division of coastal segments using GIS, with the regional scale divided into 140 segments (1 km each) and the global scale just 4 segments (66 km each). The study concludes that regional vulnerability assessments contain a far greater level of detail and relevance for coastal policy-makers and that they manage to incorporate the complexities of the coastal system. International Vulnerability assessments conducted at the international scale often adopt a large range of indicators, data sets and statistical models that are aggregated into larger generic indices of vulnerability. Represented by this single study of European vulnerability to climate change, a variety of mapping systems have been used to indicate vulnerable regions, which could assist international policy-makers in adaptation planning in Europe. Although often criticized for being too generic and lacking the statistical depth that is commonly found at the community level, international methodologies are often combined with smaller assessments to provide a clearer indication of vulnerability.

Metzger, M.J. & Schröter, D. 2006. Towards a spatially explicit and quantitative vulnerability assessment of environmental change in Europe. *Regional Environmental Change*, 6(4): 201–216.
This study presents a methodology for assessing the vulnerability of ecosystem services to climate change and land-use change throughout Europe, which was initially developed as a component of the Advanced Terrestrial Ecosystem Analysis and Modelling project. The vulnerability assessment presents comparable findings of climate change impacts on Europe's natural resources, which can be a valuable tool for policy-makers and management. GIS mapping methods were used for the vulnerability assessment and produced a set of maps depicting a variety of vulnerability levels throughout Europe, ranked by scale and sector with the use of grid cells. Owing to the size and scale of the vulnerability analysis, implementing the assessment required numerous steps, such as using global change scenarios as the input data, a generic adaptive capacity index and ecosystem services. Spatial scenarios were used to identify the factor of exposure in the study, with drivers such as socio-economic variables and land-use change for the years 2020, 2050 and 2080, using a baseline year of 1990. Indicators were then combined to give a vulnerability map, which was then verified for its relevance by various stakeholders and scientific disciplines. In order to apply their methodology, the authors use a case study from the carbon storage sector, with climate protection as the indicator of ecosystem services.

7. FISHERY AND FARMING ECOSYSTEMS

This section focuses upon vulnerability methodologies in relation to the question: "What is vulnerable?" It breaks the fisheries and farming ecosystem down into seven sections: coastal, coral-reef-based fisheries, inland river, inland lake, areas beyond national jurisdiction (ABNJ), aquaculture and recreational fishing.

Applied within each fisheries ecosystem methodology are the following questions:

- What approach (approaches) has (have) been used?
- To what extent is it following or departing from existing proposed methods of assessments?
- What contextual and/or fundamental modifications were brought to improve/adapt an existing methodology?
- What are the perceived advantages or disadvantages of the method used?

7.1 Coastal

The coastal vulnerability methodologies presented in this section mainly incorporate model-based assessments at the regional or community level, and commonly include the measurement of a CVI, which combines the multiple dimensions of vulnerability that are associated with complex coastal areas where biophysical and social dimensions combine. The complex nature of coastal areas is highlighted in the quantity of cross-references in this section with various model- or indicator-based methods.

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.
* See section 4.1 for description of CVI. Cross-reference: section 5.1.

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.
The study assessed the coastal vulnerability to sea-level rise along the Udupi coast of Karnataka, India. A CVI was used within the assessment and measured vulnerability not only in terms of sea-level rise but also the loss of land from coastal erosion. Modelling software such as ERDAS and GIS was used in the assessment, the outcome of which formed various inundation maps. Six variables were used in the assessment, encompassing geological and physical indicators: geomorphology, shoreline change rate, mean significant wave height, mean tide range, coastal slope and sea-level rise. The variables were then ranked for 38 stations along the study site, from which the CVI was calculated. The authors highlight the usefulness of the vulnerability assessment for informing a better ICZM plan. The benefit of using such approaches as remote sensing is described as being more economically efficient and able to span a wide area that may often be inaccessible in a short time frame.

* See section 4.1 for description of CVI, and section 4.2.1 for model-based vulnerability methodologies.

Ramieri, E., Hartley, A., Barbanti, A., Duarte Santos, F., Laihonen, P., Marinova, N. & Santinin, M. 2011. *Methods for assessing coastal vulnerability to climate change*. Background Paper. European Topic Center on Climate Change Impacts, Vulnerability and Adaptation. European Environment Agency.
This paper provides a comprehensive review of the various vulnerability methodologies for assessing the coastal impacts of climate change, and aims to develop useful information for the European Union (Membership Organization) and regional coastal areas. Three categories of assessment methods are described in the paper: index-based, GIS-based systems and dynamic computer models. This brief annotation expands upon the methods described in this paper in view of their relevance, benefits and limitations.

Indices:

- Coastal Vulnerability Index (CVI), which is the most widely adopted, being used at a variety of scales and providing a simple method for measuring vulnerability of sea-level rise. Measurements of the driving processes of vulnerability are formed using a numerical ranking for coastline segments, with the model being further adapted and incorporated into other index methods. The main limitation of this method is the lack of socio-economic measurements such as infrastructure damage or number of people affected.
- Composite Vulnerability Index, developed by Szlafstein and Sterr (2007)[15] combining variables of natural and socio-economic vulnerability to hazards, using GIS mapping to display the findings.
- Multi Scale CVI, developed by McLaughlin and Cooper (2010)[16], which integrates the impact of coastal erosion, using indices of coastal characteristic, coastal forcing and socio-economic to calculate a final vulnerability index.

* See section 4.1 for description of vulnerability indices.

Dynamic computer models:

- BTELSS – A model to predict environmental impacts on wetland habitats at the regional and local scale, which was developed for the Louisiana coast in the United States of America and measured vulnerability over a 30-year period. It includes a variety of elements such as hydrodynamics, vegetation growth, risk from infrastructure and water-borne particle transport. The main limitations are the high cost and expertise needed to implement the model.
- SLAMM (Sea Level Affecting Marshes Model) – Mainly used at the local and regional scale, this model simulates the changes in wetlands and shorelines as a result of sea-level rise. The model contains detailed information on the vulnerability of coastal habitats, including species, beaches, mangroves and tidal wetlands, although is limited on the socio-economic dimension.
- DIVA – A model for coastal vulnerability assessments applied at the regional, national and global scale. It includes socio-economic and biophysical impacts of sea-level rise.

*See section 4.2.1 for model-based vulnerability methodologies.

GIS-based decision-support systems:

- DESYCO is a coastal impact assessment model applied at the regional scale, incorporating a variety of stressors such as climate change, and socio-economic and resource pressure from water and soil. Three categories of vulnerability indicators are used: susceptibility factors (who or what affected), value factors (socio-economic and environmental values) and pathway factors (physical dimensions). Combined with a GIS, this system enables clear vulnerability mapping. However, it has limitations in its variety of data sources and scales.
- DITTY-DSS is a method that incorporates biogeochemical, hydrodynamic, socio-economic and ecological models. It also uses an MCDA to rank and indicators.

* See section 4.2.2 for GIS-based vulnerability methodologies.

7.2 Coral-reef-based capture fisheries

This section focuses upon coral-reef-based vulnerability methodologies, and it highlights the complex dynamics embedded in measuring vulnerability in this system, with elements of food security, ocean acidification and species dynamics present throughout. Combinations of indicator-based, socio-economic and biophysical models have been used in these assessments to measure vulnerability, which was mainly assessed at the community or national level.

[15] 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.

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

Cinner, J.E., McClanahan, T.R., Graham, N.A.J., Daw, T.M., Maina, J., Stead, S.M., Wamukota, A., Brown, K. & Bodin, O. 2011. Vulnerability of coastal communities to key impacts of climate change on coral reef fisheries. *Global Environmental Change*, 22(1): 12–20.
The authors provide a comprehensive and novel vulnerability analysis, following a specific impact pathway focused upon social vulnerability in the context of coral bleaching. The study identifies the temporal and spatial vulnerability of fishery returns to coral bleaching (in five Western Indian Ocean countries) through research conducted within 29 coastal communities. The study applies the three recognized dimensions of vulnerability from the IPCC (exposure, sensitivity and adaptive capacity), rigorously selecting indicators and methods from previous seminal work and developing a holistic approach through combining their own novel measure of sensitivity. A coral susceptibility model is used to create an exposure map, along with the identified dependence of fisheries and occupation to measure sensitivity. Adaptive capacity is measured from eight indicators using informant interviews and surveys, combined into a single metric agreed upon by experts. The authors find important variability between and within countries and recommend specific temporal and spatial policy actions to reduce vulnerability at a specific location. The authors compare their findings to the seminal work of Allison *et al.* (2009; see entry in section 6.3), and find similarities at the national level, arguing also that the methodology can be applied to other threats and social-ecological systems.

* Cross-references: sections 4.1 and 9.2.

Lokrantz, J., Nystrom, M., Norstrom, A.V., Folke, C. & Cinner, J.E. 2010. Impacts of artisanal fishing on key functional groups and the potential vulnerability of coral reefs. *Environmental Conservation*, 36(4): 327–337.
* Cross-references: sections 8.2 and 9.6.

Marshall, N.A., Marshall, P.A., Tamelander, J., Obura, D., Malleret-King, D. & Cinner, J.E. 2009. *A framework for social adaptation to climate change; sustaining tropical coastal communities and industries*. Gland, Switzerland, IUCN. 36 pp. (also available at http://data.iucn.org/dbtw-wpd/edocs/2010-022.pdf).
This vulnerability study is targeted towards coral-reef and marine ecosystem managers, academics and practitioners concerned with building greater resilience to climate change. The paper adopts the IPCC definition and methodology for vulnerability assessments, incorporating exposure, sensitivity and adaptive capacity dimensions. The framework is used to assess the vulnerability of social systems that are connected with coral reefs to climate change, highlighting communities' dependence upon natural resources. The study works through each dimension of vulnerability, giving an assessment of each in general terms for the coral reef, such as the exposure function highlighting the exposure of coral bleaching and the varying levels of impact that this can cause. Providing the basis for further assessment and resilience planning, this short study highlights the commonly adopted IPCC method and its applicability to measure coral-reef vulnerability to climate change in the social system.

7.3 Inland River

This section identifies inland river vulnerability methodologies. There may be further scope for vulnerability assessments at this scale as research only identified one specific assessment from Bangladesh conducted at the household level.

Brouwer, R., Akter, S., Brander, L. & Haque, E. 2007. Socioeconomic vulnerability and adaptation to environmental risk: a case study of climate change and flooding in Bangladesh. *Risk Analysis*, 27(2): 313–326.
The authors conducted a comprehensive vulnerability assessment alongside the Meghna River in Bangladesh, identifying the connection between poverty, vulnerability and environmental risk, and using a novel approach for assessing adaptive coping strategies. Conducted at a household and community level, the study focused upon the socio-economic factors of vulnerability, using local college teachers to survey more than 700 residents in the river's floodplain and 50 semi-structured interviews with key informants at the community level. Thirty-two villages were selected as a result of their distance from the river and a stratified sampling method was used, with every fifth house on

the main road being interviewed. Drawing upon Adger and Kelly (1999),[17] the authors used indicators of risk exposure such as the community's distance from the river, flooding depth at the household level, and economic damage of flooding to the individual. Blackwood and Lynch (1994)[18] indicators of poverty were applied in the study: annual household income in relation to the Bangladesh Bureau of Statistics' estimation of the official poverty value, household access and ownership of natural resources, land for crop production and the distribution of income at the community level. To test the validity of their results, a follow-up survey was conducted six months after the first assessment. The study highlighted the assumption that the inhabitants closer to the river were poorer and more vulnerable to flooding. However, the authors argued that the connection between poverty and the cost from damage was not as straightforward, with the poor being affected in relative terms but not in absolute terms, such as wealthier inhabitants were.

* Cross-reference: section 9.3.

7.4 Inland lake

This section includes vulnerability methodologies for inland lake assessments, and identifies the complex livelihoods and relationships between inhabitants and the natural resources of the lake and basin. Literature is cross-referenced with sections such as small-scale fisheries that contain communities who predominantly live and depend upon such ecosystems.

Béné, C. & Russell, A.J. 2007. *Diagnostic study of the Volta Basin fisheries: Part 2 Livelihoods and poverty analysis, current trends and projections*. Report commissioned by the Focal Basin Project – Volta. Cairo, WorldFish Center Regional Offices for Africa and West Asia. 66 pp.
This assessment was completed as part of the Basin Focal Project for the Volta Lake, which conducted a detailed analysis of the causes of current and future poverty, and of socio-economic factors of fishing communities surrounding the lake and basin. The study in general applied a livelihoods analysis to identify households' livelihoods, distinguishing between the varieties of communities living along the shoreline. The poverty–exclusion–vulnerability framework developed by Allison, Horemans and Béné (2006)[19] was applied to the case of Lake Volta to identify the poverty, exclusion and vulnerability in fishing households and communities. Vulnerability of households was measured using the IPCC definition of vulnerability, measuring the impact of exposure to a certain event and the sensitivity and adaptive capacity to respond. Encompassed within the poverty–exclusion–vulnerability framework are sections of analysis relating to vulnerability, such as food insecurity, land degradation, lack of economic opportunities, disease prevalence and diminishing common-pool resources. In this example, vulnerability was measured alongside poverty and exclusion, resulting in overlaps between the three dimensions, so ensuring a wider and more detailed analysis.

Gao, J., Nickum, J.E. & Pan, Y. 2007. An assessment of flood hazard vulnerability in the Dongting lake region of China. *Lakes & Reservoirs: Research & Management*, 12(1): 27–34.
* Cross-references: sections 5.1 and 4.2.2.

Mills, D., Béné, C., Ovie, S., Tafida, A., Sinaba, F., Kodio, A., Russell, A., Andrew, N., Morand, P. & Lemoalle, J. 2011. Vulnerability in African small-scale fishing communities. *Journal of International Development*, 23: 308–313.
* Cross-references: sections 6.1 and 9.6.

[17] Adger, W.N. & Kelly, P.M. 1999. Social vulnerability to climate change and the architecture of entitlements. *Mitigation and Adaptation Strategies for Global Change*, 4: 253–266.
[18] Blackwood, D.L. & Lynch, R.G. 1994. The measurement of inequality and poverty: a policy maker's guide to the literature. *World Development*, 22(4): 567–578.
[19] Allison, E.A., Horemans, B. & Béné, C. 2006. Vulnerability reduction and social inclusion: strategies for reducing poverty among small-scale fisherfolk. Paper prepared for the Wetlands, Water and Livelihoods Workshops. St Lucia, South Africa, Wetland International.

Ovie, S.I. & Emma, B. 2012. Identification and reduction of climate change vulnerability in the fisheries of the Lake Chad Basin. *In* C. De Young, S. Sheridan, S. Davies & A. Hjort. *Climate change implications for the fishing communities in the Lake Chad Basin. What have we learned and what can we do better? FAO/Lake Chad Basin Commission Workshop, 18–20 November 2011, N'Djamena, Chad,* pp. 23–84. FAO Fisheries and Aquaculture Proceedings No. 25. Rome, FAO. 2012. 84 pp. (also available at www.fao.org/docrep/017/i3037e/i3037e.pdf).
* Cross-reference: section 6.2.

7.5 Areas beyond national jurisdiction

Research found no vulnerability assessments based on ABNJ.

7.6 Aquaculture

This section contains aquaculture-based vulnerability methodologies, with marine and inland aquaculture combined under a single section owing to their appearance in each assessment. Therefore, the methodologies below represent a mixture of specific and general measurements and methods for assessing vulnerability within aquaculture.

Handisyde, N.T., Ross, L.G., Badjeck, M.-C. & Allison, E.H. 2006. *The effects of climate change on world aquaculture: a global perspective* [online]. Department for International Development (DFID), UK. [Cited 07 May 2013]. www.ecasa.org.uk/Documents/Handisydeetal_000.pdf
The authors provide a model for measuring the vulnerability of aquaculture at a national level, combining individual submodels for sensitivity, exposure and adaptive capacity to climate change. The submodels in themselves provide an indication of the impacts of climate change, with each containing numerous components such as undernourishment in the sensitivity submodel and annual mean temperature in the exposure submodel. The submodels and their indicators are merged through a number of combinations to produce various vulnerability outcomes, using a multicriteria evaluation and converted into raster images (an image using small cells in a grid, each with numerical values) and an IDRISI spatial model. The model initially provides a general vulnerability output and then combines different elements of the submodels to focus on vulnerability to food security, economic importance of aquaculture, adaptive capacity, on vulnerability of freshwater aquaculture to flooding and drought, and of brackish-water aquaculture and mariculture to cyclones. The model contains a number of limitations such as data availability and quality, and thus the authors recognize this as a basis upon which further accuracy can be developed. The study also applies this methodology to the case of aquaculture in Bangladesh, presenting a specific national-level vulnerability assessment for aquaculture.

* Cross-reference: section 6.3.

Pickering, T.D., Ponia, B., Hair, C.A., Southgate, P.C., Poloczanska, E.S., Patrona, L.D., Teitelbaum, A., Mohan, C.V., Phillips, M.J., Bell, J.D. & Silva, S.D. 2011. Vulnerability of aquaculture in the tropical Pacific to climate change. *In* J.D. Bell, J.E. Johnson & A.J. Hobday, eds. *Vulnerability of tropical pacific fisheries and aquaculture to climate change*, pp. 647–731. Noumea, New Caledonia, Secretariat of the Pacific Community. (also available at http://cdn.spc.int/climate-change/fisheries/assessment/chapters/11-Chapter11.pdf).
The editors of this publication produced a comprehensive vulnerability assessment of tropical Pacific fisheries and aquaculture to climate change. Chapter 11 by Pickering *et al.* provides a specific vulnerability assessment for the whole aquaculture sector. A vulnerability framework proposed at the beginning of the overall study was applied to the case of aquaculture. It used the IPCC definition and framework of vulnerability – that of measuring exposure, sensitivity, potential impact and adaptive capacity in relation to livelihoods and food security. They also applied the same scenarios used by the IPCC in its study, using B1 (low emissions) and A2 (high emissions) for the years 2035 and 2100. The assessment is split into farming methods and species encompassed in aquaculture. Species contained in the study were: tilapia and carp, milkfish, pearls, shrimp, seaweed, marine ornamentals, sea cucumbers, marine fish, freshwater prawns and trochus. The exposure and sensitivity factors described under each species were that of temperature, rainfall, sea-level rise, ocean acidification,

cyclones and habitat alteration. The findings of the vulnerability assessment are displayed in such a way as to be beneficial to those who wish to identify the vulnerability of a specific species as well as that of a farming system.

* Cross-reference: section 8.1.

7.7 Recreational

This section identifies vulnerability methodologies targeted at the recreational sector such as coastal tourism, which will undoubtedly be affected by exposure to climate change and other hazards. Recreational sectors are often complex and involve a wide range of stakeholders, locations, climates, various activities, and they are often dependent upon the environment surrounding them. This example uses scenario-based vulnerability methodologies and incorporates seminal conceptual research from the vulnerability literature, highlighting an important cross-over between conceptual and applied methodologies.

Moreno, A. & Becken, S. 2009. A climate change vulnerability assessment methodology for coastal tourism. *Journal of Sustainable Tourism*, 17(4): 473–488.

The authors identified a significant gap in the available methodologies and tools for assessing the vulnerability of coastal tourism in regard to climate change and, therefore, they developed a five-step vulnerability methodology for coastal tourism. The methodology builds upon and includes elements of contemporary vulnerability studies such as the eight-step approach for vulnerability assessments by Schröter *et al.* (2005)[20] and Polsky's (2007) vulnerability scoping diagram (VSD).[21] The authors develop a five-step framework based on the three factors of vulnerability: exposure, sensitivity and adaptive capacity. The five steps are to identify the system analysis, activity and hazards subsystem (climate), vulnerability assessments for different subsystems at risk, integrating destination and scenario analysis, and the effective communication of results. The five steps are predominantly sequential but can be circular. The study applies the framework to tourism in Fiji, specifically using Polsky's VSD to assess the vulnerability of tourism to beach cyclones and coral bleaching on snorkelling. The methodology encompasses strong stakeholder and expert input in qualitative and quantitative forms.

[20] Schröter, D., Polsky, C. & Patt, A.G. 2005. Assessing vulnerabilities to the effects of global change: An eight-step approach. *Mitigation and Adaptation Strategies for Global Change*, 10(4): 573-595.

[21] Polsky, C., Neff, R. & Yarnal, B. 2007. Building comparable global change vulnerability assessments: The vulnerability scoping diagram. *Global Environmental Change*, 17(3-4): 472-485.

8. SPECIES AND VESSEL SEGMENT

Encompassed within the fisheries and aquaculture sector is a diverse mixture of production systems, including various types of vessels and species, each with a different sensitivity to climate change vulnerability.

Applied within each species and vessel methodology are the following questions:

- What approach (approaches) has (have) been used?
- To what extent is it following or departing from existing proposed methods of assessments?
- What contextual and/or fundamental modifications were brought to improve/adapt an existing methodology?
- What are the perceived advantages or disadvantages of the method used?

8.1 Species

This section gives an indication of the types of vulnerability methods used when assessing the vulnerability of species. Owing to the vast number of species, this list does not aim to provide a comprehensive account, but outlines the main methods used when assessing species vulnerability.

Bezuijen, M.R., Morgan, C. & Mather, R.J. 2011. *A rapid vulnerability assessment of coastal habitats and selected species to climate risks in Chanthaburi and Trat (Thailand), Koh Kong and Kampot (Cambodia), and Kien Giang, Ben Tre, Soc Trang and Can Gio (Vietnam)*. Gland, Switzerland, IUCN. (also available at http://cmsdata.iucn.org/downloads/rapidassessmentspecies_mark_charlie_robert15_dec2011.pdf).

This vulnerability methodology applies the trial studies of the authors and Meynell (2011)[22] conducted in the Mekong River to develop a vulnerability assessment for coastal habitats and selected species. The authors used the framework of Williams *et al.* (2008)[23] to develop a method for focusing on the exposure, sensitivity (measured by population size, life history traits and geographic range) and adaptive capacity of species, giving each a ranking of low, medium and high that is combined into an overall vulnerability rank. Meynell (2011) then used this method to assess the vulnerability of wetland habitats. Limitations of the studies were that certain species such as invertebrates and flora were not included, and, therefore, only those of social or economic importance were included. The size of the species selection was also too small to be used as a basis for species conservation. Thirteen rapid vulnerability assessments were completed for the study, focusing upon eight coastal habitats, ten vertebrate species and three avian assemblages, with commercial marine species also reviewed. The study also analysed protected areas and their role in species and habitat vulnerability. Williams *et al*. (2008) note that biogeographic connectivity is required for species adaption to climate change, giving them adequate time and enough habitat. These factors are said to depend on the ability of species to shift to higher latitudes and elevations and on the direction of habitat corridors to escape increasing temperature.

[22] Meynell, P.J. 2011. *Case study guidance. Basin-wide climate change impact and vulnerability assessment for wetlands of the Lower Mekong Basin for adaptation planning.* Prepared for MRC. Viet Nam, ICEM.

[23] Williams, S.E., Shoo, L.P., Isaac, J.L., Hoffmann, A.A. & Langham, G. 2008. Towards an integrated framework for assessing the vulnerability of species to climate change. *PLoS Biol*, 6(12): e325 [online]. [Cited 07 May 2013]. doi:10.1371/journal.pbio.0060325

Hutchings, P., Ahyong, S., Byrne, M., Przeslawski, R. & Worheide, G. Chapter 11: Vulnerability of benthic invertebrates of the Great Barrier Reef to climate change. *In* J.E. Johnson & P.A. Marshall, eds. *Climate change and the Great Barrier Reef: a vulnerability assessment,* pp. 309–356. Townsville, Australia, Great Barrier Reef Marine Park Authority and Australian Greenhouse Office. (also available at http://www.gbrmpa.gov.au/__data/assets/pdf_file/0014/5441/gbrmpa-climate-change-and-the-great-barrier-reef-2007-title-page.pdf).
The publication presents a comprehensive study of vulnerability to climate change in the Great Barrier Reef, in which a number of chapters highlight and discuss the vulnerability of species such as mammals or, as in the case of Hutchings *et al*., benthic invertebrates (located at inter-reef bottom habitats and on the reef). The study applies the IPCC vulnerability definition and framework throughout, identifying exposure, sensitivity, impacts and adaptive capacity of benthic invertebrates to climate change. The factors of exposure used in the assessment are: ocean circulation, water temperature, physical disturbance (storms), ocean acidification, light spectra and sea-level rise. The same indicators are also used for the analysis of sensitivity, with those of rainfall and river flood plumes also included.

Pickering, T.D., Ponia, B., Hair, C.A., Southgate, P.C., Poloczanska, E.S., Patrona, L.D., Teitelbaum, A., Mohan, C.V., Phillips, M.J., Bell, J.D. & Silva, S.D. 2011. Vulnerability of aquaculture in the tropical Pacific to climate change. *In* J.D. Bell, J.E. Johnson & A.J. Hobday, eds. *Vulnerability of tropical pacific fisheries and aquaculture to climate change,* pp. 647–731. Noumea, New Caledonia, Secretariat of the Pacific Community. (also available at http://cdn.spc.int/climate-change/fisheries/assessment/chapters/11-Chapter11.pdf).
* Cross-reference: section 7.6.

8.2 Vessels

This aim of this section was to identify vulnerability methodologies for particular vessel types. However, the research identified only one specific assessment applied in relation to artisanal fishing, identifying a potential gap and future possibility for vulnerability research.

Lokrantz, J., Nystrom, M., Norstrom, A.V., Folke, C. & Cinner, J.E. 2010. Impacts of artisanal fishing on key functional groups and the potential vulnerability of coral reefs. *Environmental Conservation*, 36(4): 327–337.
In this biophysical vulnerability assessment, the authors present a comprehensive analysis of the impact that artisanal fishing has upon three groups of herbivores and the vulnerability of five coral reefs off Zanzibar, the United Republic of Tanzania. The study focuses specifically upon the herbivore species as a result of its important role within the coral reef ecosystems for controlling competition from benthic macro algae. The reefs being studied were all of a similar nature, located just off small islands and at depths of 10 m from the surface of the water to the bottom. The benthic population was divided into ten categories: live coral, turf algae, dead coral, macroalgae, soft coral, coralline algae, coral limorpharians, sediment, sand and other. Through the use of transects at 3–8 m deep located next to the coral reef, the abundance, richness and size of the herbivorous species were analysed. Fishing pressure was measured using household surveys at ten landing sites near the reefs. The surveys depicted the average number of fishing days a week and the distance to the shore from the reefs, which enabled the assessment of fishing pressure and comparison between study sites and type of fishing gear. Using a Spearman's rank correlation coefficient, the relationship between the ecological indicators and artisanal fishing pressure gave an indication of the vulnerability of coral reefs. One of the main limitations of the study was said to be that of time, but after household interviews this was found to be of only little significance.

* Cross-references: sections 7.2 and 9.6.

9. SPECIAL CONSIDERATIONS

This chapter encompasses vulnerability methodologies that may not fall specifically within any of the categories covered in earlier chapters but are still important for assessment. It includes an extensive list of special considerations owing to the complexity and multiple factors to consider and assess when conducting vulnerability assessments. It encompasses nine subsections of vulnerability methodologies based on gender, marginalized groups, food security, poverty, globalization, governance and management, small-scale fisheries and aquaculture, post-harvest loss and trade.

Applied within each special consideration methodology are the following questions:

- What approach (approaches) has (have) been used?
- To what extent is it following or departing from existing proposed methods of assessments?
- What contextual and/or fundamental modifications were brought to improve/adapt an existing methodology?
- What are the perceived advantages or disadvantages of the method used?

9.1 Gender

Research found that an increasing number of vulnerability assessments are incorporating gender and encouraging a wider adoption and mainstreaming of gender-based studies in the field of climate change and vulnerability. Women are predominantly found to have a higher degree of vulnerability to climate change, a situation that is argued by many to be a result of the socio-economic structures that cause gender inequality in a large number of countries. The following studies indicate a range of methods for measuring gender-based vulnerability, highlighting also the importance of measuring male as well as female vulnerability.

Neumayer, E. & Plümper, T. 2007. The gendered nature of natural disasters: the impact of catastrophic events on the gender gap in life expectancy, 1981–2002. *Annals of the Association of American Geographers*, 97(3): 551–566.

The authors assess the vulnerability of women to natural disasters by analysing the correlation between disasters and the gender gap in life expectancy, sampling a total of 141 countries, using data for the period 1981–2002 from EM-DAT and the International Data Base of the United States Census Bureau. The study uses vulnerability as an analytical concept, applying it to natural disasters and forming two main hypotheses to assess the bias in gender mortality. The socio-economic status of women is factored into the study using a measure of the social and economic rights of women, from Cingranelli and Richards[24] in the Human Rights Dataset. The strength of the disasters is measured in terms of the number of people killed, which is then divided by the total population of the affected country to give the magnitude of the disaster. The findings of the study indicate there is a higher mortality of women than men to natural disasters, which the authors argue is socially constructed and embedded in local socio-economic systems. The study finds that women and men have different vulnerabilities according to their social roles, which can be either voluntary or involuntary. Vulnerability is therefore argued to differ as a result of the inequalities between men's and women's exposure and sensitivity to natural hazards.

Seager, J. & Hartmann, B. 2005. *Mainstreaming gender in environmental assessment and early warning* [online]. UNEP. [Cited 07 May 2013]. www.unep.org/dewa/Portals/67/pdf/Mainstreaming_Gender.pdf

The authors use a framework for assessing vulnerability that involves five key components: the condition of a person (such as health), resilience of their livelihood, opportunities for self-protection, access to social protection and access to social capital. The study provides a list of gendered conditions that may indicate women's vulnerability to disasters, which the authors argue should be mainstreamed into environmental assessments and disaster relief planning and mitigation. The list includes conditions such as women being at greater risk of domestic and sexual violence, and having

[24] Cingranelli, D.L. & Richards, D.L. 2004. *Cingranelli and Richards Human Rights Dataset* [online]. [Cited 07 May 2013]. http://ciri.binghamton.edu/

lower incomes and more economic dependence, fewer land rights and less access to transport. The study highlights the importance of realizing that environmental disasters and changes have socially constructed impacts on gender.

Singh, A., Svensson, J. & Kalyanpur, A. 2010. The state of sex-disaggregated data for assessing the impact of climate change. *Procedia Environmental Sciences*, 1(1): 395–404.
This assessment attempts to mainstream gender into climate change vulnerability and impact assessments by incorporating a gender-sensitive approach through studying the different impacts that climate change will have on men and women. The study used data from the OECD and its report on "ranking port cities with high exposure and vulnerability to climate extremes", as it is argued to be one of the most comprehensive assessments of climate change vulnerability to date. Data for both men and women are incorporated into the study, focusing upon the disparity in social, economic and political statuses of men and women, with data drawn from the United Nations Development Programme and its Human Development Report in 2007–08. The exposure rate for each gender is measured for five categories to indicate vulnerability, including adult literacy, influence and decision-making, education, adult economic activity and income differences. The findings show a higher level of vulnerability to climate change among women compared with men, and indicate the study's limitations in regard to data gaps. It concludes by calling for a greater inclusion of gender approaches and research in climate change work.

Swarup, A., Dankelman, I., Ahluwalia, K. & Hawrylyshyn, K. 2011. *Weathering the storm: adolescent girls and climate change*. London, PlanUK. (also available at www.plan-uk.org/resources/documents/35316/).
The authors present a unique study that gave girls aged 13–18 years old in the flood- and cyclone-prone areas of Bangladesh and drought-prone areas in Ethiopia a chance to voice their thoughts on how climate change affects their daily lives, the role the play in their community and ideas surrounding approaches of adaptation. The research, conducted by Plan International in 2010, involved focus groups with more than 60 girls in the research sites of Bangladesh and Ethiopia, ensuring that girls who would not otherwise have a chance to voice their concerns and thoughts could do so. Along with the focus groups, a number of adult interviews were conducted with NGO representatives and various organizations, together with a detailed literature review of the countries' relevant documents. A number of important insights and vulnerabilities were found in the study, which the authors argue are rarely found owing to gender inequality reducing the participation of women and girls in society. However, the study also points out that it is not only women who may be vulnerable to natural hazards, providing the example that more men died in Hurricane Mitch in Central America in 1998, as result of the expectation of males to conduct high-risk rescues.

9.2 Food security

This section includes vulnerability methodologies focused upon food security, of which there are a number in regard to global environmental change, whether driven directly by food security or through other systems such as the impact on fisheries, coral reefs or agricultural production.

Cinner, J.E., McClanahan, T.R., Graham, N.A.J., Daw, T.M., Maina, J., Stead, S.M., Wamukota, A., Brown, K. & Bodin, O. 2011. Vulnerability of coastal communities to key impacts of climate change on coral reef fisheries. *Global Environmental Change*, 22(1): 12–20.
* Cross-references: sections 4.1 and 7.2.

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.
* Cross-reference: section 5.4.

Ericksen, P.J. 2008. What is the vulnerability of a food system to global environmental change? *Ecology and Society*, 13(2): 14.

The author outlines a new approach for assessing the vulnerability of food systems to global environmental change, addressing the identified gap in vulnerability methodologies of combined social-ecological systems. The framework was developed under the earth systems and science partnership and its sponsored project: Global Environmental Change and Food Systems (GECAFS). Along with using a systems approach for broad analysis of vulnerability to food security, the method also frames the outcomes of environmental change through a social-economic and political change lens in order to identify the synergies between multiple drivers causing vulnerability. To assist in the evaluation of vulnerability, the framework draws on the questions identified in Eakin and Luers (2006)[25] on resolving the complexity of combining social and ecological approaches to vulnerability. The author therefore proposes a three-step approach, the first of which is to indicate clearly the food system functions and its parts that may be vulnerable to environmental change stressors. Step two addresses the transmission of a stress caused by environmental change to a food system, before the final stage of identifying and analysing adaptive capacity. Presenting a checklist for the analysis of vulnerability to food systems, a database can be developed through which future meta-analysis can assist with early warning signs of vulnerability.

Huelsenbeck, M. 2012. *Ocean-based food security threatened in a high CO_2 world: a ranking of nations' vulnerability to climate change and ocean acidification* [online]. Washington, DC, Oceana. [Cited 07 May 2013]. http://oceana.org/sites/default/files/reports/Ocean-Based_Food_Security_Threatened_in_a_High_CO2_World.pdf

* Cross-references: sections 5.4 and 6.3.

Hughes, S., Yau, A., Max, L., Petrovic, N., Davenport, F., Marshall, M., McClanahan, T.R., Allison, E.H. & Cinner, J. 2012. A framework to assess national level vulnerability from the perspective of food security: the case of coral reef fisheries. *Environmental Science & Policy*, 23: 95–108.

This study presents a national-level vulnerability index specific to food security by identifying those countries that are vulnerable as a result of reducing coral reef fisheries. The methodology used the commonly adopted IPCC vulnerability indicators of exposure, sensitivity and adaptive capacity, selecting and evaluating vulnerability to food insecurity in 27 countries. Countries' exposure was measured as the degree of coral reef degradation as a result of anthropogenic impacts, and was subsequently measured using a coral reef map and cumulative impact scores from 1 km^2 grids of coral reef based on 38 categories of threat. Sensitivity was measured as a country's degree of dependence on coral reef fisheries, whereby the lack of alternative sources of protein results in higher vulnerability. Finally, a country's adaptive capacity was measured by its ability to react to changes in the food system provided by coral reef fisheries, using four categories to quantify adaptive capacity: countries assets (GDP, access to sanitation and reef area), flexibility (Gini index, GDP and balance of trade), learning (adult literacy and the science in decision-making) and social organization (government effectiveness index, fisheries management and planning). Weighting each component equally, the standardization of their values formed an overall vulnerability index for each country. Finally, the study was compared with a general vulnerability assessment conducted by the World Resources Institute in its latest "Reefs at Risk" report, highlighting the studies' different outcomes. The study found that low-income countries commonly have a low adaptive capacity, whereas middle-income countries have a higher adaptive capacity yet a high sensitivity. Adaptive capacity was shown to have a significant effect on a country's vulnerability scores and, thus, the authors recommend greater emphasis on this component of the food system. The research indicated Indonesia and Liberia as those countries most vulnerable to food insecurity from coral reef depletion, and Malaysia, Sri Lanka and the Dominican Republic as the least vulnerable.

* Cross-reference: section 6.3.

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

Løvendal, C.R. & Knowles, M. 2005. *Tomorrow's hunger: a framework for analysing vulnerability to food insecurity* [online]. FAO Agricultural and Development Economics Division. ESA Working Paper No. 05-07 (05). [Cited 07 May 2013]. ftp://ftp.fao.org/docrep/fao/008/af140e/af140e00.pdf

The authors briefly present a framework for identifying the vulnerability of a food system, highlighting the importance of its dynamic and forward-looking methods for assessing the causes of food insecurity. They incorporate risk into their vulnerability framework and define food insecurity as people's tendency to slip or stay below a food-secure threshold, setting a probability higher than 50 percent as the cap at which people become insecure. The framework identifies vulnerability through a chain of cumulative events, with people's risk of food insecurity (measured by the type, level, frequency, timing and severity of shocks or trends) initially measured and subtracted from their ability to manage risk. This measurement is then added to people's present food security status, finally also incorporating food availability, access, food consumption and utilization into the vulnerability framework. The methodology highlights the importance of recognizing the instruments of risk management at a variety of levels, including the global, national, community, household and individual levels.

Løvendal, C.R., Knowles, M. & Horii, N. 2004. *Understanding vulnerability to food insecurity lessons from vulnerable livelihood profiling* [online]. FAO Agricultural and Development Economics Division. ESA Working Paper No. 04-18 (05). [Cited 07 May 2013]. ftp://ftp.fao.org/docrep/fao/007/ae220e/ae220e00.pdf

As part the work of the Food Security and Agricultural Projects Analysis Unit of FAO, a number of pilot studies (conducted in Benin, Guatemala, Viet Nam, Nepal and Afghanistan) were developed on which to apply a methodology for assessing vulnerability to food insecurity. The main methodology used to assess vulnerability was the Sustainable Livelihoods Approach (SLA), which is mainly quantitative and enables a multisector analysis to incorporate the various dimensions causing vulnerability. The overall aim of the vulnerability profiling was to assist with the development of national-level policies for addressing vulnerability. The SLA also encompassed participatory elements and thus enabled greater inclusion of stakeholders in the analysis, giving depth to the national-level assessments. To measure vulnerability in the pilot programmes, secondary data were collected prior to national or subnational workshops including stakeholders such as government institutions and international organizations. Finally, community focus group meetings were held along with in-depth semi-structured household interviews built from the Minimum Food Security Information Set. A SWOT analysis was used to identify past and future food insecurity, and vulnerable people were clustered by socio-economic or similar livelihood activities, giving a broad understanding and assessment of the vulnerable population.

9.3 Poverty

This section includes vulnerability methodologies based upon poverty, which in the identified literature occurs predominantly at the household level. The methodologies commonly use a combination of statistical equations to measure vulnerability to poverty, developing levels of poverty thresholds based upon a variety of factors such as consumption levels (used in one of the assessments below).

Brouwer, R., Akter, S., Brander, L. & Haque, E. 2007. Socioeconomic vulnerability and adaptation to environmental risk: a case study of climate change and flooding in Bangladesh. *Risk Analysis*, 27(2): 313–326.

* Cross-reference: section 7.3.

Chaudhuri, S., Jalan, J. & Suryahadi, A. 2002. *Assessing household vulnerability to poverty from cross-sectional data: a methodology and estimates from Indonesia*. Department of Economics Discussion Paper No. 0102-52. New York, USA, Columbia University.

The authors propose and apply a methodology for assessing the vulnerability of households to poverty, with the use of cross-sectional data to identify the risk that a household may fall below the poverty line or remain poor. The authors begin by outlining the difference between poverty and

vulnerability assessments, noting that the latter are predominantly forward-looking. Identifying the data limitations for conducting a comprehensive vulnerability assessment is said to require a rich level of information. However, the authors argue that a valid analysis can still be made from cross-sectional household surveys in which information regarding consumption, income and household characteristics is found. Data from a mini SUSENAS survey in 1998 from Indonesia were used as a case study on which to apply the vulnerability methodology. The findings of the study indicate that the proposed method can accurately predict those households that are vulnerable to future poverty in terms of being consumption-poor.

Ligon, E. & Schechter, L. 2003. Measuring Vulnerability. *Economic Journal*, 113(486), C95–C102.

The authors develop a vulnerability measurement that quantifies welfare loss in relation to poverty and other forms of insecurity, identifying those populations that are vulnerable. The study begins with an analysis of the term vulnerability and the authors describe its decomposition into measures of poverty, unexpected risk, idiosyncratic risk and aggregate risk. The vulnerability measurement is applied to data from Bulgaria in 1994 that were collected at monthly intervals and identified the impact of reforms in the Bulgarian economy. The methodology used to assess vulnerability to poverty was applied at the household consumption level, using expenditure on food as the key measurement. The simple vulnerability measurement developed here using various calculations and formulas is highlighted as being robust as it encompasses error from consumption expenditures.

Pritchett, L., Suryahadi, A., & Sumarto, S. 2000. Quantifying vulnerability to poverty: a proposed measure, applied to Indonesia. *Policy Research Working Paper* 2437. The World Bank.

(Seminal)

This seminal paper outlines a method for quantifying vulnerability to poverty, using a factor of probability to define vulnerability as the likelihood that a household will face a period of poverty in the close future, measured by 50-50 odds or worse. The Vulnerability to Poverty Line (VPL) is developed as a means to measure the threshold at which household expenditure drops below the poverty line, thus representing vulnerability to poverty. A headcount vulnerability rate then builds upon the VPL to quantify the percentage of vulnerable households. The assessment begins by identifying the variation in household income and forming an average number of those currently in poverty and those vulnerable to poverty. The magnitude and distribution of those vulnerable is then assessed by specific characteristics at the household level. The method is illustrated using an example from Indonesia and applying two data sets, highlighting the ability of the approach to differentiate between vulnerability within households in relation to factors such as level of education, gender, rural-urban areas and occupation of the household head. By calculating the vulnerability to poverty, the author underlines the importance of this measurement for policy-makers and social insurance programmes.

9.4 Globalization

The most comprehensive literature on vulnerability methodologies in relation to globalization was found in studies by O'Brien and co-authors and their concept of double exposure. This concept is outlined in these assessments and highlights the importance of applying a multidimensional vulnerability methodology when measuring the impact of globalization. As globalization is not a single factor driving or causing vulnerability, it is measured with a combination of other factors such as, in this case, climate change.

O'Brien, K., Quinlan, T. & Ziervogel, G. 2009. Vulnerability interventions in the context of multiple stressors: lessons from the Southern Africa Vulnerability Initiative (SAVI). *Environmental Science and Policy*, 12(1): 23–32.

* Cross-reference: section 5.5.

O'Brien, K., Leichenko, R., Kelkar, U., Venema, H., Aandahl, G., Tompkins, H., Javed, A., Bhadwal, S., Barg, S., Nygaard, L. & West, J. 2004. Mapping vulnerability to multiple stressors: climate change and globalization in India. *Global Environmental Change*, 14(4): 303–313.
This methodology draws on the seminal work of O'Brien and Leichenko (2000),[26] who developed a method of "double exposure" to assess vulnerability to multiple stressors. In this study, their framework is applied to the case of climate change and globalization in India, specifically in the agriculture sector at the subnational level. Identifying the need to examine multiple stressors of vulnerability, the methodology begins by identifying vulnerability to climate change, measuring the adaptive capacity in relation to biophysical, socio-economic and technological factors in agriculture and sensitivity under exposure through the climate sensitivity index. Next, the methodology focuses upon vulnerability to impact of economic globalization, using crop production and distance from large ports as a measure of sensitivity to international trade and thus globalization. The same indicators of adaptive capacity for climate change are used to assess globalization as trade liberalization, and combined with those of sensitivity such as low crop productivity and close proximity to ports, which result in a high measurement of vulnerability. Using the climate change vulnerability map as a base, the globalization map is then overlaid to identify areas of "double exposure" at the district level and thus areas for policy interventions. Finally, case studies are conducted at the local level in order to provide greater depth to the assessment and identify the role of institutions and local support systems that are otherwise missed in the methodology. One limitation of this methodology is the lack of precision at the district level, which to some degree is addressed by the top-down and bottom-up approaches used in the assessments.

* Cross-references: sections 5.5 and 6.2.

9.5 Governance and management

This section identifies only one vulnerability methodology applied to governance and management, highlighting a potential gap in the literature. Focused predominantly upon the transmission of decision-making, which can be reflected in communities' or individuals' access to resources, the vulnerability of governance systems is an important dimension, especially in the climate change arena, where national and global policies can often determine local outcomes.

Keskitalo, E.C.H. 2008. Governance in vulnerability assessment: the role of globalising decision-making networks in determining local vulnerability and adaptive capacity. *Mitigation and Adaptation Strategies for Global Change*, 14(2): 185–201.
The author presents an assessment of climate change adaptation within the reindeer herding, forestry and fishing community of northern Norway, Sweden and Finland, focusing upon vulnerability in the decision-making process at various levels of governance. The study begins by focusing upon the local level and analysing the impact that higher levels (such as the international scale) have upon adaptation options and, thus, the power perspective embedded within governance systems that may cause vulnerability to local or remote actors. The study outlines the effect that the international and regional levels of planning have upon local adaptations and the governance system and actors that are shaped by factors of globalization, which the author argues will form decision-making networks and redistribute resources for local communities. The methodology applied semi-structured interviews to stakeholders from appropriate sectors at the regional and local level, conducting 55 interviews between 2003 and 2005. Interviews included questions of sensitivity in relation to change (such as economic and political), adaptive capacity, descriptions of their own socio-economic situations and the factors they viewed as affecting them in regard to governance structures.

* Cross-reference: section 4.3.

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

9.6 Small-scale fisheries and aquaculture

This section encompasses a short list of vulnerability methodologies based upon small-scale fisheries and aquaculture, which are cross-referenced to other sections. As a result of their scale, assessments that are predominantly more at stakeholder and community level are applied to capture the level of detail and data that may not be represented at the national or regional scale.

Lokrantz, J., Nystrom, M., Norstrom, A.V., Folke, C. & Cinner, J.E. 2010. Impacts of artisanal fishing on key functional groups and the potential vulnerability of coral reefs. *Environmental Conservation*, 36(4): 327–337.
* Cross-references: sections 7.2 and 8.2.

Mills, D., Béné, C., Ovie, S., Tafida, A., Sinaba, F., Kodio, A., Russell, A., Andrew, N., Morand, P. & Lemoalle, J. 2011. Vulnerability in African small-scale fishing communities. *Journal of International Development,* 23: 308–313.
This brief report focuses upon two pilot studies completed in the Niger River of Mali and on the shore of Lake Kainji in Nigeria, specifically identifying the vulnerability of small fishing-dependent communities. Ninety households in Mali and 40 in Nigeria were randomly selected for analysis, with the participatory methods being used to identify the key factors of vulnerability affecting people's livelihoods. Specific demographic variables such as socio-economic background, household income, assets and livelihood strategies were included within the surveys. A ranking system was also used in the research, with stakeholders asked to rank their main vulnerabilities. The benefit of conducting the two pilot projects was in the ability for comparative analysis, which identified differences and similarities between the communities that could assist and guide policy-makers, such as the variation in vulnerability between fishers and non-fishers.

* Cross-references: sections 6.1 and 7.4.

9.7 Post-harvest loss

Research found no post-harvest vulnerability methodologies. Embedded within some post-harvest loss assessments are elements of vulnerability. With factors such as climate change causing increasing variation in agricultural and farming systems, there is the likelihood of greater vulnerability in regard to post-harvest loss. However, no specific comprehensive vulnerability methodology could be found.

9.8 Perceptions

This section incorporates vulnerability assessments with an emphasis on including perceptions of vulnerability by individuals, households and communities. The research highlights that the ways in which people perceive vulnerability can be dramatically different owing to the wide diversity of social, economic and political factors that vary between and within communities individuals and groups. The importance of understanding perceptions of vulnerability is highlighted as a crucial factor to be obtained from vulnerability assessments, and one that can be invaluable for creating effective adaptation strategies and methods of vulnerability reduction.

Dow, K., O'Connor, R.E., Yarnal, B., Carbone, G.J. & Jocoy, C.L. 2007. Why worry? Community water system managers' perceptions of climate vulnerability. *Global Environmental Change*, 17(2): 228–237.
The authors present the findings of a mail survey conducted on the community water systems managers in South Carolina and Pennsylvania's Susquehanna river basin in the United States of America, assessing managers' perceptions of vulnerability to climate change. Managers were asked to assess ten weather and climatic events and their perceived respective levels of vulnerability. Research found that the severity of droughts in the area is related to experience prior to the droughts and financial issues. The findings of the study are argued by authors to be of specific use in designing adaptation strategies owing to their importance to decision-makers and highlighted the fact that further research is needed to address future management challenges.

Krishnamurthy, P.K., Fisher, J.B. & Johnson, C. 2011. Mainstreaming local perceptions of hurricane risk into policymaking: a case study of community GIS in Mexico. *Global Environmental Change*, 21(1): 143–153.
This article presents a framework for assessing local perceptions of vulnerability to hurricane risk, through a case study conducted in El Zapotito commune in the State of Veracruz, Mexico. The authors conducted a vulnerability and capacity assessment, which constructed a participatory GIS-based model to quantify and spatially assess specific household-level vulnerabilities from information generated through interviews. A household vulnerability index was created and combined with a participatory GIS map, which provided a unique integration of local knowledge into the vulnerability assessment. This approach enables a visual representation of vulnerability, combining information on the local context, which the authors argue is essential to reducing vulnerability at the community level and providing policy-makers with more specific information. Data collected in the interviews were categorized into social, physical, economic and environmental factors that translated to four factors of risk used in the GIS maps. The method of combining modern research models with local knowledge is said to empower communities to assess and react to their perceived vulnerability and address the common gaps between government perception of vulnerability and local perceptions.

Linnekamp, F., Koedam, A. & Baud, I.S.A. 2011. Household vulnerability to climate change: examining perceptions of households of flood risks in Georgetown and Paramaribo. *Habitat International*, 35(3): 447–456.
The authors present a study of households' perceptions of vulnerability to flooding in two Caribbean cities located in low-lying coastal areas. The assessment aimed to investigate the differences in household vulnerability as a result of the various socio-economic inequalities and entitlements to resources that are present at the research sites. The research highlighted the differences in vulnerability between the research sites by categorizing the locations from low-income to high-income areas, and their respective exposure, adaptive capacity and resistance to natural hazards. A method of random selection was used to determine the surveyed households, with data collected over a three-month period. Exposure to flooding was measured using rainfall for the different locations, which was combined with the participants' interview responses. Household perception of vulnerability is argued by the authors to be an essential component in understanding the true nature of vulnerability and the methods through which people can individually and collectively build resilience.

Munji, C., Bele, M.Y., Nkwatoh, A.F., Idinoba, M.E., Somorin, O.A. & Sonwa, D.J. 2013. Vulnerability to coastal flooding and response strategies: the case of settlements in Cameroon mangrove forests. *Environmental Development*, 5(1): 54–72.
This paper investigates the vulnerability of six local settlements to flooding in the Cameroon mangrove forest zone and improves understanding of perceptions and responses to past and current coastal flooding. Data were collected through a questionnaire distributed to 200 participants along with a combination of participatory rapid rural appraisal tools, which provided important insights into local people's perception of vulnerability. The sites' coordinates and altitude were also recorded for geospatial analysis, translating them onto base topographic map from 1965, indicating coastal changes over the years. The study found a large majority of participants had been affected by flooding, which damaged households, fish stocks, water sources and their surrounding landscape.

O'Brien, K., Eriksen, S., Schjolden, A. & Nygaard, L. 2004. *What's in a word? Conflicting interpretations of vulnerability in climate change research* [online]. Oslo, Center for International Climate and Environmental Research. [Cited 07 May 2013]. www.cicero.uio.no/media/2682.pdf
* Cross-reference: section 3.1.

9.9 Trade

Research found no trade-based vulnerability methodologies. However, aspects of trade-based vulnerability are shown within section 9.2 on food security, as climate change causes disruption in food systems and, therefore, elements of vulnerability in market-based trading and livelihood security are incorporated.