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CLIMATE CHANGE VULNERABILITY IN FISHERIES AND AQUACULTURE: A SYNTHESIS OF SIX REGIONAL STUDIES

CLIMATE CHANGE VULNERABILITY IN FISHERIES AND AQUACULTURE: A SYNTHESIS OF SIX REGIONAL STUDIES

by

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PREPARATION OF THIS DOCUMENT

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The paper synthesizes regional studies on the vulnerability of fisheries and aquaculture to climate change as part of a series of outputs and activities implemented by FAO under the Japanese-funded project "Fisheries Management and Marine Conservation within a Changing Ecosystem" (GCP/INT/253/JPN).

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ABSTRACT

Global reviews of the impacts of climate change on fisheries and aquaculture systems carried out in 2009 revealed a paucity and patchiness of information concerning climate impacts on the sector. Six follow-up regional case studies were then launched by the Food and Agriculture Organization of the United Nations (FAO) in an attempt to start filling the gaps and to provide direction and initial steps in adaptation planning. Fisheries and aquaculture systems were selected across the globe to allow for diversity. The approach of the case studies followed a template allowing them to: (i) define vulnerability to climate change by understanding potential impacts on the system, the sensitivity of the system to such changes and the current adaptive capacity; (ii) identify gaps in existing knowledge in assessing the vulnerability of the system; (iii) identify potential strategies for reducing vulnerability to climate change; and (iv) provide policy guidance in reducing system vulnerability.

The objective of this publication is to consolidate, further interpret, refine and draw conclusions from the information gathered on climate change impacts, sensitivity and adaptive capacity of fish production systems in the diverse and geographically distinct social-ecological systems covered by the six case studies. Although the specificity of each case study and the complexity of vulnerability prevent a generalization of issues and the drawing of broad conclusions, the present document captures common threads from a close examination of the exposure, sensitivity and adaptive capacity of the systems considered. Information on these three characteristics of vulnerability is particularly relevant to policy-makers, development practitioners and members of the academic community concerned with the impacts of climate change on aquatic resources and the communities and economies they support. It can be used to identify areas in which interventions, policy development and/or further research are needed to better equip these systems and their stakeholders to reduce their vulnerability and enhance their adaptation to long-term climate-induced changes. It can also be used as a benchmark against which improvements in capacity may be measured or monitored over time.

Contents

ACRONYMS AND ABBREVIATIONS

AC	adaptive capacity
AI	adaptation index
AMO	Atlantic Multidecadal Oscillation
BCLME	Benguela Current Large Marine Ecosystem
CARICOM	Caribbean Community
CCA	climate change adaptation
CRFM	Caribbean Regional Fisheries Mechanism
DAI	Development Alternatives Incorporated
DEWA	Division of Early Warning and Assessment (UNEP)
DRM	disaster risk management
DWFN	distant-water fishing nation
E	exposure
EEZ	exclusive economic zone
ENSO	El Niño Southern Oscillation
FAO	Food and Agriculture Organization of the United Nations
GDP	gross domestic product
ICEM	International Centre for Environmental Management
II	impact index
IPCC	Intergovernmental Panel on Climate Change
LCB	Lake Chad Basin
MA	Millennium Ecosystem Assessment
MONRE	Ministry of Natural Resources and Environment (Viet Nam)
NAO	North Atlantic Oscillation
PaCFA	Global Partnership for Climate, Fisheries and Aquaculture
PI	potential impact
PICTs	Pacific Islands countries and territories
S	sensitivity
SI	sensitivity index
UNEP	United Nations Environment Programme
VI	vulnerability index

1. Introduction, process and objective of the synthesis

1.1 Background

Aquatic systems, both marine and freshwater, have been recognized as vital in provisioning, regulating and supporting a wide range of services[1] for humankind (MA, 2005). However, climate change is a growing threat to the continuous provision of these services (IPCC, 2007a). The implications of this global challenge to the sustainability of fisheries and aquaculture and the livelihoods and economies that depend on them have been receiving increasing attention. It is now recognized that sea-level rise, ocean acidification and changes in salinity, precipitation, groundwater and river flows, water stresses and extreme weather events are changing the productivity of aquatic habitats, modifying the distribution of both marine and freshwater fish species, and affecting the seasonality of biological and biophysical processes (Cochrane *et al.*, 2009).

The Intergovernmental Panel on Climate Change (IPCC, 2007b, p. 6) defines "vulnerability" as "the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change". Using this framework of analysis, global studies have highlighted the relative vulnerability of national economies to any potential change in their fisheries from climate change, and found that the most vulnerable tended to be least-developed countries, where the capacity to adapt may be most limited (Allison *et al.*, 2009). This finding emphasizes the fact that not only will livelihoods and national economies need to cope with immediate changes and trade-offs imposed by climate change, but they will also need to evolve in a way that allows them to develop positive adaptation mechanisms and seize the opportunities that may arise from climate change impacts in the medium to longer term.

In the last few years, much conceptual and applied work has contributed to increasing the understanding of the characteristics of "vulnerability" in fisheries and aquaculture systems, as well as in a range of other contexts (Barsley, De Young and Brugère, 2013). The IPCC definition of vulnerability – decomposed as a function of exposure, sensitivity and adaptive capacity – tends to be used as a starting point for most analyses, either in its original form or specifically tailored to fisheries and aquaculture (Figure 1). However, assessments can be divided into two broad categories: those that focus on predicting biophysical risks and hazards created by climate change and the responses of systems, usually relying on quantitative, top-down investigative methods (e.g. modelling); and those that focus on understanding the impacts of climate change on human systems, usually examining what is referred to as "contextual vulnerability" and relying on bottom-up, stakeholder-based investigative approaches (Brugère and De Young, forthcoming).

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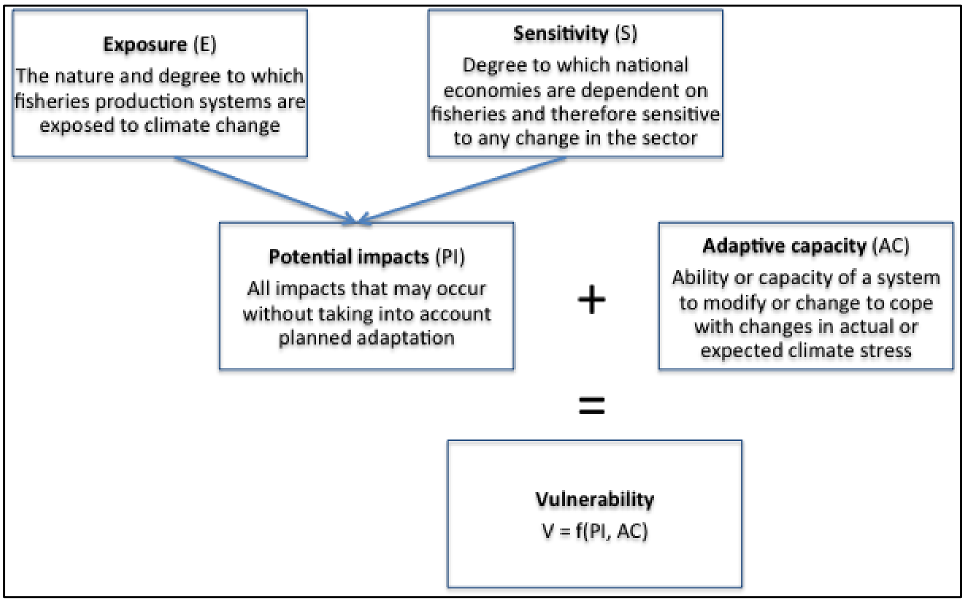
[1] Understood here as "benefits" to people, in accordance with the Millennium Ecosystem Assessment (MA) definition: the sum of products provided and functions performed by ecosystems for the benefit of humankind.

Figure 1

Example conceptual model of vulnerability applied to fisheries



Note: The term "system" can be interpreted as country, region, community, sector, social group or individual.

Source: Daw *et al.* (2009, p. 117).

1.2 FAO regional case studies

Global reviews of the impacts of climate change on fisheries and aquaculture systems carried out in 2009 (Cochrane *et al.*, 2009) revealed a paucity and patchiness of information concerning climate impacts on the sector. Six follow-up regional case studies were then launched by the Food and Agriculture Organization of the United Nations (FAO) in an attempt to start filling the gaps and to provide direction and initial steps in adaptation planning. Fisheries and aquaculture systems were selected across the globe to allow for diversity. The approach of the case studies followed a template allowing them to: (i) define vulnerability to climate change by understanding potential impacts on the system, the sensitivity of the system to such changes and the current adaptive capacity; (ii) identify gaps in existing knowledge in assessing the vulnerability of the system; (iii) identify potential strategies for reducing vulnerability to climate change; and (iv) provide policy guidance in reducing system vulnerability. However, authors were allowed flexibility in defining the system, issues and options, according to the prevailing conditions of the area or system under study. The case studies were desk-based and relied mainly on available secondary information. Each case was subsequently discussed with a range of stakeholders in six regional follow-up workshops.

1.3 Synthesis of the case studies

Materials

Preparation of this synthesis relied on the proceedings of six regional workshops on climate change vulnerability and adaptation in fisheries and aquaculture (Box 1), held in Barbados, Chad, Chile, Namibia, New Caledonia and Viet Nam in 2011 and 2012. The in-depth regional analyses prepared for each workshop – of the vulnerability of fisheries and aquaculture systems and the livelihoods and economies they support – were extensively reviewed and used as the main sources of information for this synthesis. Moreover, the analytical process that underpinned the synthesis (detailed in Section 2) was guided by the outcomes of two recent FAO workshops on climate-change vulnerability assessment for the fisheries and aquaculture sectors (De Young *et al.*, 2012a; FAO, 2013).

BOX **1**

Main sources of information for the synthesis

Lake Chad Basin
De Young, C., Sheridan, S., Davies, S. & Hjort, A. 2012a. *Climate change implications for 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*. FAO Fisheries and Aquaculture Proceedings No. 25. Rome, FAO. 84 pp. (also available at www.fao.org/docrep/017/i3037e/i3037e00.htm).

Caribbean small island developing States
McConney, P., Charlery, J., Pena, M., Phillips, T., Van Anrooy, R., Poulain, F. & Bahri, T. 2015. *Disaster risk management and climate change adaptation in the CARICOM and wider Caribbean region – formulating a strategy, action plan and programme for fisheries and aquaculture. Regional workshop 10–12 December 2012, Kingston, Jamaica*. FAO Fisheries and Aquaculture Proceedings No. 35. Rome, FAO. 136 pp.

Viet Nam, Mekong Delta
Soto, D., Phan Thi Van, P. & Fezardi, D. (forthcoming). *Climate change implications for aquaculture and fisheries communities and relevant aquatic ecosystem in Viet Nam*. *FAO Workshop 8–10 February 2012, Ho Chi Minh City, Viet Nam*. FAO Fisheries and Aquaculture Proceedings No. 38. Rome, FAO.

Benguela Current Region
De Young, C., Hjort, A., Sheridan, S. & Davies, S. 2012b. *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*. FAO Fisheries and Aquaculture Proceedings No. 27. Rome, FAO. 125 pp. (also available at www.fao.org/docrep/017/i3053e/i3053e00.htm).

Pacific Islands countries and territories
Johnson, J., Bell, J. & De Young, C. 2013. *Priority adaptations to climate change for Pacific fisheries and aquaculture: reducing risks and capitalizing on opportunities. FAO/Secretariat of the Pacific Community Workshop, 5–8 June 2012, Noumea, New Caledonia*. FAO Fisheries and Aquaculture Proceedings No. 28. Rome, FAO. 109 pp. (also available at www.fao.org/docrep/017/i3159e/i3159e00.htm).

Latin America
Soto, D. & Quiñones, R. 2013. *Cambio climático, pesca y acuicultura en América Latina: potenciales impactos y desafíos para la adaptación. Taller FAO/Centro de Investigación Oceanográfica en el Pacífico Sur Oriental (COPAS), Universidad de Concepción, 5–7 de Octubre de 2011, Concepción, Chile*. FAO Actas de Pesca y Acuicultura No. 29. Rome, FAO. 333 pp. (also available at www.fao.org/docrep/018/i3356s/i3356s00.htm).

Synthesis goal and objective
The goal of this synthesis is to raise awareness of the need for vulnerability assessment work in fisheries and aquaculture. In addition, it is hoped that it will help share what issues were raised in these case studies and what adaptation options were proposed in order to support interregional learning.

On this basis, the specific objective of this publication is to consolidate, further interpret, refine and draw conclusions from the information gathered on climate change impacts, sensitivity and adaptive capacity of fish production systems in the diverse and geographically distinct social-ecological systems covered by the six case studies. As such, the present analysis constitutes another step in the continuum of outputs generated under the project

"Fisheries Management and Marine Conservation within a Changing Ecosystem" (GCP/INT/253/JPN).

Use of the synthesis

This document should in no way replace the contents of the six case-study analyses of vulnerability, and it is recommended that readers refer back to the original case-study reports to have the full depth of information needed to devise adaptation policies and interventions. Although the specificity of each case study and the complexity of vulnerability prevent a generalization of issues and the drawing of broad conclusions, the present document captures common threads from a close examination of the exposure, sensitivity and adaptive capacity of the systems considered. Information on these three characteristics of vulnerability is particularly relevant to policy-makers, development practitioners and members of the academic community concerned with the impacts of climate change on aquatic resources and the communities and economies they support. It can be used to identify areas in which interventions, policy development and/or further research are needed to better equip these systems and their stakeholders to reduce their vulnerability and enhance their adaptation to long-term climate-induced changes. It can also be used as a benchmark against which improvements in capacity may be measured or monitored over time.

Structure of the synthesis:

The paper begins with an outline of the methodology used to review and synthesize the wealth of information contained in the six regional case studies (Section 2). A descriptive summary is provided in Section 3 of each system under study and the main threats it faces. Evaluation of the three components of vulnerability, that is, exposure, sensitivity and resilience (for ecosystems) and adaptive capacity (for human systems) is provided in Appendix 2 – and reveals the strengths and weaknesses of each system in reference to particular threats. Conclusions on the vulnerability of fisheries and aquaculture systems in the six regions, drawn from the case studies, are presented in Section 4. Section 5 presents the synthesis itself and a broader discussion of adaptation to climate change in fisheries and aquaculture, while Section 6 presents some conclusions.

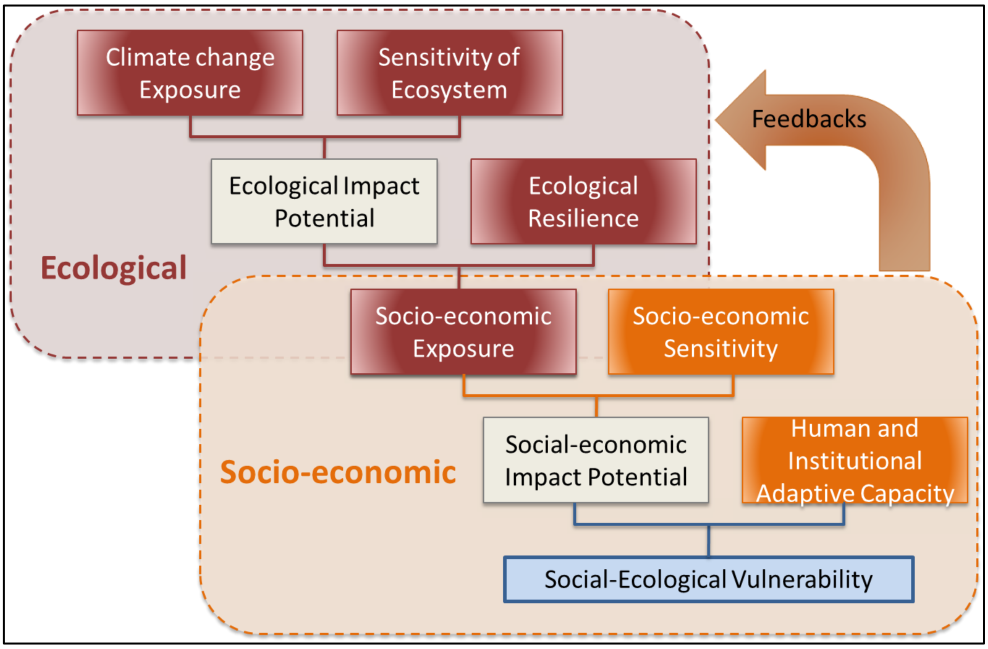
2. Approach adopted in preparing the synthesis

2.1 Methodology

FAO-commissioned case studies on the vulnerability of fisheries and aquaculture to climate change were reviewed and complemented by additional sources of information as needed. The studies took place in Lake Chad (Ovie and Belal, 2012), the Caribbean (McConney, Charlery and Pena, 2015), the Mekong Delta (De Silva, forthcoming), Benguela Current (Hampton, 2012a, 2012b), Pacific Islands countries and territories (Bell *et al.*, 2011a, 2011c; Bell *et al.*, 2013) and Latin America (González *et al.*, 2013; Quiñones *et al.*, 2013; Martínez-Ortiz and Bravo-Moreno, 2013). In order to analyse the contents of these documents as systematically as possible, a reductionist approach was applied (i.e. to "boil down" the vast quantity of information into manageable chunks), although in practice this did not preclude consideration of the connections between subcomponents, nor the wider complexity of vulnerability of the systems under study as a whole. The process followed Steps 2a, 2b and 6 of the vulnerability assessment process for fisheries and aquaculture recommended by experts (FAO, 2013), which is reproduced in Appendix 1. Thus, case study information was first summarized according to Step 2a, focusing attention on each system's key characteristics and singling out the various drivers of change to which each was subjected. Under Step 2b, the nested IPCC framework for exposure, sensitivity and resilience/adaptive capacity (Cinner *et al.*, 2013) was adopted, in order to refine and precisely pin down the causes of vulnerability, while focusing on both an ecosystem's resilience and the adaptive capacity of its linked human/institutional system (Figure 2).

Figure 2

Framework linking ecological and socio-economic vulnerability



Notes: In the ecological domain, exposure and sensitivity create impact potential. Impact potential and recovery potential together form ecological vulnerability, or exposure, in the social domain. This ecological vulnerability combined with the sensitivity of people forms the impact potential for society. Social adaptive capacity and impact potential together create social-ecological vulnerability.
Source: Cinner *et al.* (2013 – adapted from Marshall *et al.* [2010]).

The analytical process underpinning Step 6, whose questions are spelled out in Table 1, helped to answer why systems or people were vulnerable and unable to adapt – or to refine answers when these were provided only partially by the authors of the case studies – and to identify possible priorities for action.

Table 1
Questions asked to refine the vulnerability assessment of each case study

Topic	**Questions asked**
Climate exposure	To what is the system exposed? (threat *x*, assumed to be high)
Sensitivity of ecosystem	How is (threat *x*) pushing the system to threshold limits?
Ecological resilience	Is this making the system more or less adaptive? How capable is the system of dealing with these changes?
Socio-economic exposure	What are the risks that you face? (risk of *y*/exposure to *z* assumed to be high)
Sensitivity of socio-economic system	How important is that risk *y*/exposure to *z* if it occurs?
Adaptive capacity	How capable are people of dealing with that risk/exposure? How well prepared are they?

According to the information provided in the case studies, questions were attributed a high, medium or low ranking. However, exposure was assumed to be high in all cases, as it was not always possible to distinguish different levels of exposure from the information provided in the study.

2.2 Guiding thread of the synthesis: governance

Despite the fact that the case studies emphasize diversity among the different systems across the globe, and that their results are not standardized, it is proposed that "governance" be the central theme, or unifying perspective, of this synthesis.[2] Governance is understood broadly as encompassing institutions (both state and non-state) and their functioning, as well as the processes underpinning people's decision-making (e.g. collective action, power relations, networks, and individual incentives). Although it is acknowledged that another thematic perspective could have been adopted for the synthesis of the case studies, governance is prevalent throughout the discourse on climate change adaptation, and, along with institutions and institutional mechanisms, it is seen as a critical determinant of adaptation (Biesbroek *et al.*, 2013; Engle and Lemos, 2010; Adger *et al.*, 2009). It is thus suggested here that governance is a pivotal factor in the resilience and adaptive capacity of aquatic social-ecological systems in the face of climate change. This notion of the importance of governance is in line with the findings of Hughes *et al.* (2012) with regard to the role of social organization in the adaptive capacity of reef fishing communities, and of Keskitalo and Kulyasova (2009, p. 60), who have shown that, for communities of small-scale fishers, "… adaptive capacity beyond the immediate economic adaptations available to local actors is, to a considerable extent, politically determined within larger governance networks." Governance

[2] A synthesis is not a summary or a comparison. It should integrate the content of the sources on which it is based through an examination of the links between them in order to provide the reader with a unified perspective on these sources.

thus acts as the guiding thread throughout the review of the case studies and the analysis of the regional summaries, and it is then revisited and discussed in greater depth in Section 5.

3. Regional summaries

At the start of each regional analytical summary, an overview is provided of the vulnerability assessment approach adopted by the authors of the case study to evaluate vulnerability and reach their conclusions. It is important that this be made clear at the outset of every vulnerability assessment, as it conditions the perspective adopted on vulnerability and the conclusions reached (Brugère and De Young, forthcoming). Each regional analytical summary then proceeds to describe the system at stake and the adverse influences and changes pressing on it, including: climate- and non-climate-related social, institutional, economic and environmental drivers of change; human and biophysical changes and impact pathways; temporal and spatial scales of concern; identification of system thresholds and tipping points; and key stakeholders concerned with the impacts of climate change on the system. Detailed assessments of ecological resilience and human adaptive capacity, which answer the questions raised in Table 1, are provided in Appendix 2 for each case study.

3.1 Lake Chad Basin

Ovie and Belal (2012) were the main source of information for the analytical summary of the vulnerability of fisheries and aquaculture to climate change in the Lake Chad Basin (LCB).

3.1.1 Vulnerability assessment methodology

The vulnerability assessment of the LCB qualitatively describes and analyses the characteristics, threats and impact pathways of climate change on the basin's natural resources and on its social, institutional and economic systems. Potential adaptive strategies are identified. Vulnerability, in itself, is also qualitatively analysed according to the four components of the IPCC framework (exposure, sensitivity, potential impacts and adaptive capacity).

3.1.2 Description of the system at stake

The system under study is a combined human/environment system. Its administrative boundaries are the four riparian countries of the lake (Cameroon, Chad, the Niger, and Nigeria), whereas its physical boundaries are the lake watershed.

Current fish catches from the lake itself amount to 100 000 tonnes per year (they have halved since the mid-1970s), worth USD60 million per year. Two hundred thousand people are involved directly in fishing, and 10 million are supported by the entire sector.

3.1.3 Adverse influences and changes

Major drivers of change in the system

Although covering several ecological zones, ethnic groups and four economies, the LCB can be considered a relatively homogeneous system, environmentally as well as economically, unlike some other systems (e.g. the Benguela Current, see Section 3.4). The following dominant social, economic and environmental influences affect the LCB as a whole:

Social and institutional
• weakness of the Lake Chad Basin Commission in implementing its mandate;
• population growth.
Economic
• high poverty.
Environmental
Directly related to climate change:
• recurring droughts;
• considerable variation in rainfall from year to year.

Temperature (leading to evaporation) and rainfall (leading to drought) are the two main climate-related influences on the system as a whole. The geographical location of the LCB gives it a hot, dry climate, with an average annual temperature of 26 °C. Rainfall has a large influence on the hydrology and agroecology of the lake and the entire basin, including basins of the rivers feeding into the lake. Rainfall has decreased in absolute terms and become more variable: there was a 35-percent decrease in period means in rainfall on open water surface between pre-1970s and 1971–1990, and an overall 50 percent decrease in inflows to the lake between these two periods (Oyande, 1997, and UNEP/DEWA, 2003, cited in Odada, Oyebande and Oguntola, 2006). The 1950s were the wettest years in the basin, but rainfall has since remained below the mean (Zilefac, 2010). Evaporation is very high: 2 300 mm/year, as reported in Odada, Oyebande and Oguntola (2006). However, no historical data for evapotranspiration rates are available (Zilefac, 2010), so it is not possible to establish whether evaporation trends have been worsening or not.
Not directly related to climate change:
• dam construction on major effluent rivers;
• unsustainable exploitation of fish and other living resources;
• pollution;
• irrigation demand.

Although drought appears today as the dominant climate-specific driver of change in the LBC, it is exacerbated by equally strong anthropological drivers (water abstraction and dam construction). Note, however, that variations in lake size seem to be within the norm compared with those observed in the past (Butzer, 1983).

Changes and impact pathways
The size of Lake Chad shrank by about 90 percent in the period 1963–2001, from 25 000 km^2 to about 1 400 km^2 (Zilefac, 2010).[3]

Human changes (direct):
• reduced income for nearshore fishers;
• increased migration of fishers;
• increased health impediments (e.g. cholera, meningitis);
• increased farming activities;
• reduced number of head of cattle.
Biophysical changes (direct):
• increased salinity;
• increased flood occurrence;
• modification of lacustrine hydrology, ecology (proliferation of hydrophytes) and chemistry (e.g. low dissolved oxygen);
• decline in composition, diversity and production of fisheries (catch and recruitment);

[3] However, this figure may be disputed owing to the difficulty of estimating areas under aquatic vegetation. Lemoalle *et al.* (2012) estimate the area of "small" Lake Chad to vary from 2 000 to 14 000 km^2.

- slower groundwater recharge, overall increase in water scarcity.

Temporal scale
Long-term historical and prehistorical time scales should be considered, so as to reconstruct the palaeoecological evolution of the lake and its response to past climatic variations – although no information in this regard could be found to complement Ovie and Belal (2012).

Spatial scale of concern
The system appears vulnerable to climate change at multiple scales: at the local scale, through the impact of declining catches on local fishing communities; at regional (i.e. with several countries involved) and ecological scales (i.e. when an entire ecosystem/basin such as the lake is affected), through changes in water flows and balances in the basin; and at the national scale (i.e. within particular countries).

Identification of thresholds / tipping points for the system
Although the regression of the lake is likely to continue, it is difficult to establish what minimum area and minimal inflows are needed to maintain the ecosystem services currently provided by the lake, and beyond which the lake system will be transformed "beyond recognition" (for example, support a completely different set of biological diversity). Palaeoenvironmental records show that the lake has completely dried about once every century (since 1450), the most recent occurrence being in 1900. However, information is scant on how the system recovered or transformed after such episodes.

Key stakeholders concerned with the impacts of climate change on the system
- primary producers: fishers (nearshore, migrant and offshore), farmers, livestock herders and raisers;
- those involved in ancillary activities associated with fishing, farming and herding/livestock-raising: women, fish traders;
- consumers: both locally and in urban centres;
- authorities: the Lake Chad Basin Commission, irrigation departments and fisheries management authorities (traditional and formal).

3.2 Caribbean

McConney, Charlery and Pena (2015) were the main source of information for the analytical summary of the vulnerability of fisheries and aquaculture to climate change in Caribbean small island developing States.

3.2.1 Vulnerability assessment methodology
Although the four dimensions of the IPCC framework underline analysis, the two entry points through which vulnerability of fisheries and aquaculture in the Caribbean is assessed are climate change adaptation and disaster risk management. The assessment process combines a number of frameworks to shed light on different aspects of vulnerability. Thus, a strong focus is on understanding the human dimension of vulnerability through a livelihoods framework adapted to disaster risk management (Baas *et al.*, 2008). In considering adaptive capacity throughout the fisheries value chain, the assessment used the framework provided by the ecosystem approach to fisheries and its human dimensions (De Young, Charles and Hjort, 2008). The process included a review of available evidence from IPCC projection models scaled down for the Caribbean. Using the Mahon (2002) framework for assessment of the impacts of climate change on the fisheries of Caribbean Community (CARICOM) countries, linkages were made between biophysical impacts of climate change and policies for sustainable fisheries and food security. Stakeholders were identified through a simple network analysis. Their views on vulnerability to changes and hazards, capacity issues and priority strategic actions for adaptation and resilience were collected through a series of consultations. Consequently, overall assessment of vulnerability was qualitative, reflected these views, and

naturally focused more on what was needed for future adaptation than on characteristics of the current vulnerability of the region.

3.2.2 Description of the system at stake

The assessment covers 17 members of the Caribbean Regional Fisheries Mechanism (CRFM) that are full CARICOM member States: Antigua and Barbuda, the Bahamas, Barbados, Belize, Dominica, Grenada, Guyana, Jamaica, Montserrat, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Suriname and Trinidad and Tobago), plus two associate members: Anguilla and Turks and Caicos Islands. These are relatively small economies, largely dependent on marine fisheries. Marine small-scale fisheries for demersal and pelagic species found inshore and offshore are dominant, although some larger-scale fisheries are also encountered (e.g. shrimp trawling). Marine aquaculture is underdeveloped, but small-scale brackish-water aquaculture systems (shrimp farms) and freshwater pond systems are found more widely.

The ecosystems that were focused on comprise: marine fisheries (reef, including finfish, lobster and conch), pelagic (both large and small fishes) and continental shelf (shrimp and groundfish); and inland fisheries and aquaculture (marine, including intensive cage or tank culture, and freshwater, such as ponds, tanks and integrated systems).

3.2.3 Adverse influences and changes

Major drivers of change in the system

Main drivers are hydrometeorological and geological:

Social and institutional	
•	many ongoing adaptation and capacity-building activities, but few of these focus on fisheries and aquaculture.
Economic	
•	none identified.
Environmental	
1. Directly related to climate change/meteorological phenomena:	
•	moderate increase in air surface temperature in the past 50 years, but in line with global increases;
•	seasonal variations in sea surface temperature throughout the year; projected increase to 2080;
•	no significant trend regarding rainfall patterns, but projected decrease in wet-season rainfall (May–October);
•	sea-level rise trends uncertain, although projected to be in line with the global average;
•	ocean acidification trends uncertain, although in line with global projected increases;
•	increase in occurrence of hurricanes (rainfall peaks = hurricane activity), though intensity fairly constant;
•	ENSO, NAO and AMO[4] seasonal influences; short-term variability likely to continue.
2. Disaster-related:	
•	landslides;
•	volcanic eruptions;
•	earthquakes;

[4] El Niño Southern Oscillation, North Atlantic Oscillation and Atlantic Multidecadal Oscillation.

•	tsunamis.

Changes and impact pathways
Negative changes and impacts of climate change, disasters in marine fisheries, inland fisheries and aquaculture[5] systems, and impacts on livelihoods of the Caribbean include:

Potential biophysical changes (direct):	
•	coral-reef bleaching, fish kills, alteration of mangroves and estuarine fish life cycles;
•	pond escapees;
•	modified water flows and coastal habitats;
•	changes in plankton composition.
Potential human changes (direct):	
•	damage to fishing and aquaculture community infrastructures, including roads, harbours, farms and houses;
•	unsafe fishing conditions and loss of life at sea;
•	conflicts over fishable areas and resources.

However, positive impacts are also potentially anticipated in terms of an increase in offshore productivity and creation of new spawning and nursery habitats.

Temporal scale
Historical trends are available for the last 50 years. Local projections using IPCC models scaled down for the Caribbean are available to 2080, although with great uncertainty.

Spatial scale of concern
The scales concerned are: national (administrative boundaries of concerned countries); regional (covering a range of fisheries overlapping with national boundaries); and ecological (specific ecosystems likely to fall within national boundaries, e.g. reefs, coastal fringes).

Identification of thresholds / tipping points for the system
The uncertainty of future projections makes it difficult to identify thresholds for the system as a whole with confidence. Past evolution of the region would suggest that it is still within a reasonable range of a tipping point, although the compounded threats of sea-level rise, increase in sea surface and air temperatures, increase in intense tropical cycle activity and short-term rainfall variability are likely to erode its resilience. Moreover, the specificity of the individual components of the system as a whole (marine fisheries, inland fisheries and aquaculture) warrants a more in-depth analysis of the impacts of climate- and disaster-related drivers on each subsystem.[6]

Key stakeholders concerned with the impacts of climate change on the system
- regional stakeholders (e.g. CARICOM heads of government);
- national governments and ministries;
- private sector (e.g. large corporations, small businesses, financial institutions);
- non-governmental, community-based and fishers organizations;

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[5] Note, however, that marine aquaculture is not well developed in the Caribbean and that the potential impacts considered in the report are general and not necessarily specific to the region. Consequently, marine aquaculture has not been included in the subsequent analysis of resilience and adaptation in this region. Freshwater aquaculture and brackish-water aquaculture are, however, fully considered here.
[6] However, this information may not be readily obtainable from the available documentation.

- international development community (e.g. FAO, the United Nations Environment Programme, World Bank);
- other regional/international entities (e.g. the United Nations Framework Convention on Climate Change, Caribbean Disaster Emergency Management Agency).

3.3 Mekong Delta

De Silva (forthcoming) was the main source of information for the analytical summary of the vulnerability of fisheries and aquaculture to climate change in the Mekong Delta.

3.3.1 Vulnerability assessment methodology

The Mekong Delta assessment did not explicitly consider the four components of the IPCC framework. After identifying the two dominant drivers of change in the delta (sea-level rise and flooding), it relied on available downscaled IPCC change scenarios and the published literature to identify impacts of these two drivers on Mekong Delta fisheries, aquaculture and agriculture. Robustness was to a large extent hampered by lack of information on the impacts of climate change on inland freshwater fisheries. The assessment was a qualitative, detailed narrative incorporating elements of sensitivity and adaptive capacity of the systems considered. In its overall evaluation of vulnerability, it also incorporated perceptions of the effects of, and risks associated with, climate change.

3.3.2 Description of the system at stake

The system assessed is a combined human/environment system. Although relatively homogeneous in terms of environmental characteristics (a deltaic, typically unstable ecosystem), provinces within the system display a degree of variety in relation to fishery and aquaculture activities.

The administrative boundaries of the system are those of southern Viet Nam (only one country is involved in the analysis). The physical boundaries comprise the Mekong River Delta (49 520 km^2, of which 94 percent is within Vietnamese borders).

The delta accounts for about half the food volume produced in Viet Nam (17.5 million tonnes in 2000), 55 percent of national fish and fruit production, and 61 percent of the food export value (2003 figures). It is densely populated (400 people/km^2), home to 17.4 million people (2004 census). Some 55-60 kg of fish are consumed per capita per year.

The delta supports a large floodplain fishery, with yields ranging from 190 000 tonnes (low end) to 761 000 tonnes (high end) per year. Almost all fisheries are artisanal, and aquaculture (mainly catfish and *Penaeus monodon*) covers 19 percent of the land area of the delta.

The Mekong River supports a very diverse fishery. Water flow is highly seasonal, being 12 times higher in the wet season (December–April) than in the dry season (May–November).

3.3.3 Adverse influences and changes

Major drivers of change in the system

Social and institutional	
•	population growth and increased urbanization in Lower Mekong cities (Grumbine, Dore and Xu, 2012);
•	across the wider Mekong region, a move away from subsistence farming towards plantation agriculture (ibid.).
Economic	
•	international demand for catfish (Halls and Johns, 2013);
•	rising demand for energy (hydropower generation to fuel economic development) (Grumbine, Dore and Xu, 2012);

•	increasing investment and trade in the region (ibid.).
Environmental	
Directly related to climate change:	
•	sea-level rise (main threat) and consequent saline water intrusion[7] (17 cm by 2030, 33 cm by 2050);
•	increased flooding and water availability in the dry season (no change in wet season) (Halls and Johns, 2013);
•	changes in monsoonal weather patterns: increased precipitation;
•	increase in temperature by 1 °C by 2050 and by 1.5 °C by 2070 (ibid.);
•	increased frequency of typhoons (ibid.).
Not directly related to climate change (anthropogenic):	
•	increased upstream damming and reduced river flows through damming (major factor) (Keskinen *et al.*, 2010);
•	increased use of pesticides and environmental pollution;
•	construction of infrastructure (flood-control structures, roads, irrigation canals, etc., modifying natural water flow) (ibid.);
•	aquaculture development (habitat loss);
•	reduction of spawning and nursery grounds in floodplain areas;
•	land use (Rowcroft, 2008).

Changes and impact pathways
The chain of causality (impact pathways) in the Mekong Basin is long and complex. Population growth, shifting cultivation and road-building – oft-cited main causes for land-use change (deforestation) – cannot be singled out from other drivers of change.

Although overall catches in the Mekong Delta have remained static (at about 750 000 tonnes per year), the percentage of these catches of the national total has declined markedly since 2000 (from 49 to 40 percent in 2008). At the household level, a split trend appears: the quantity of wild fish caught in flood-prone areas of the delta declined by almost 40 percent from 2000 to 2006, but household consumption of caught fish has remained stable.[8]

Human changes (direct impacts):	
•	reduction in income and nutrition (decrease in quantities of wild fish caught);
•	reduced fish and crustacean production (acid sulphate soils);
•	increased development of aquaculture, in particular catfish, driven by international demand (Halls and Johns, 2013);
•	increased conflict and competition for water;
•	loss of productive land and decrease in food production outputs, primarily rice (projected);
•	displacement of people (projected);
•	move away from adaptation to increased control of the delta's water regime through ambitious engineering projects (Keskinen *et al.*, 2010).
Biophysical changes (direct impacts):	
•	acid sulphate soils;
•	reduced recruitment of wild fish populations.

[7] Thuan (2011) estimated that sea-level rise could submerge 19–38 percent of Viet Nam's Mekong Delta, which currently produces 25 percent of the country's gross domestic product (GDP).
[8] However, the causes of this observation are difficult to determine.

A graphic summary of the main impact pathways identified is available in Halls and Johns (2013).[9]

Temporal scale

No information is available on past changes and adaptation in the Mekong Delta, except for salinization (an increase has been reported over the 1973–1997 period).

Mid-term projections are available through to the mid-2030s, long-term projections to 2090, although their reliability and applicability to the delta itself are uncertain.

The Government of Viet Nam has accepted the MONRE (2009) medium sea-level-rise scenario, based on greenhouse-gas emission scenarios for the diverse decades of the twenty-first century (IPCC, 2007c). This scenario projects the sea level rising by 30 cm by 2050 and by 75 cm by 2100.

Spatial scale of concern

The Mekong Delta is the scale of overall concern, although more data are available for the larger Lower Mekong (which includes the lower parts of the watershed, the river and the delta itself). The system can, however, be divided into four subsystems ("system scales") of equal importance based on the economic role of the productive activities supported: capture/wild fisheries, catfish aquaculture, shrimp aquaculture and rice culture. The system appears more vulnerable to climate change in coastal and inland areas within an approximately 50 km fringe from the sea. Zooming further in, the system suggests that, in these areas, the catfish farming system (a true freshwater species) has the lowest adaptive range to salinity increases and is likely to be the most directly affected by sea-level rise and overall reduced water flows from the Mekong River.

Identification of thresholds / tipping points for the system (systems)

Specific thresholds identified in the literature concern the delta and the catfish and shrimp farming sectors:

Delta. Nutrient concentrations are expected to remain below threshold values owing to the diluting effect of increasing dry season flows (Halls and Johns, 2013).

Shrimp. These systems are already operating at the limit (high intensity, constant dodging of environmental threats [disease, pollution, water quality, etc.] and aggressive management practices), and climate change "may well push them over the edge" (ICEM and DAI, 2013, p. 140).

Catfish. The "containing" of catfish farming, as well as a good understanding of its functioning, permit identification of possible thresholds:

Physical threshold. A 30 km limit inland from the coast, where the first catfish farms are located, may constitute a (physical) threshold beyond which sea-level rise (predicted at 50 cm in the next two decades) and salinity intrusion will have considerable impacts on current aquaculture production and on the revenues generated from catfish. If the cultivation of fish species cannot be adapted to higher salinities, a salinity of 20 parts per thousand could be considered a tipping point for the system, beyond which the production systems, landscape and economy (both local and national) may be changed beyond recognition.

Production threshold. Food standards imposed by importing countries constitute a threshold that, if trespassed (i.e. fish no longer meeting those standards), will imply a complete review and change of production activities to minimize the impacts of

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[9] The figure could not be reproduced here due to software compatibility issues. See http://cmsdevelopment.sustainablefish.org.s3.amazonaws.com/2013/01/22/Pangasius%20Mekong%20Delta-4b2036ad.pdf, page 71.

external pollution sources on harvested fish (Halls and Johns, 2013).

Key stakeholders concerned with the impacts of climate change on the system

- Mekong River Commission;
- Government of Viet Nam (at national and provincial levels), irrigation authorities, hydropower investors;
- fishing households;
- shrimp-farming households, including integrated rice/shrimp farmers;
- catfish farmers;
- rice farmers.

3.4 Benguela Current

Hampton (2012a, 2012b) was the source of information for the analytical summary of the vulnerability of fisheries and aquaculture to climate change in the Benguela Current Large Marine Ecosystem (BCLME) and the communities it supports.

3.4.1 Vulnerability assessment methodology

Assessment broadly followed the IPCC vulnerability framework, defining:

- "sensitivity" as the degree to which the resource is likely to be affected by the indicated change;
- "impact" as the importance of the resource to humans in terms of commercial value, employment, food security and societal values;
- "adaptability" as the degree to which industries and people dependent on the resource can adapt to changes in resource abundance and/or availability.

However, it departs from the framework in its estimation of vulnerability: a vulnerability index (VI) was produced for each major fishery in the three countries of the BCLME. The VI combined: an index of the sensitivity (SI) of the system and its commercially exploited resources to environmental and biophysical changes; an impact index (II) of the likely economic and social implications of such changes; and an index of the capacity of the fishery and the communities it supports to adapt (AI) to these socio-economic impacts, according to:

$$VI = SI \times II \times AI$$

where:

- SI ranges from 1 (mild) to 3 (severe), based on the magnitude of environmental effects on the resource and likelihood of occurrence;
- II is rated 0, 0.5 or 1, based on commercial value + employment + food security + societal importance;
- AI ranges from 1 (highly adaptable) to 4 (almost totally unable to adapt).

3.4.2 Description of the system at stake

The system under study is a combined, large human/environment system. It is not a homogeneous system in many respects:

- The northern regime of the BCLME has tropical features, while the southern regime consists of a colder, nutrient-rich upwelling.
- The three countries bordering the BCLME are at different levels of economic development: in general terms, coastal poverty increases as one moves northwards from South Africa, through Namibia, to Angola.
- The fisheries supported by the BCLME are very diverse:

  Angola. Dominant artisanal fishery for small pelagic fish (sardinella, horse mackerel, sardine) and many other species (e.g. deep-sea red crab).

Namibia. Predominantly industrial purse-seine fishery for sardine; bottom and midwater trawl fishery for hake and adult horse mackerel (demersal); line fisheries for large pelagic fish; and trap fisheries (crabs).

South Africa (BCLME region). Trawl, midwater trawl and long-line fishery for hake, adult horse mackerel and other demersal species; purse seine fishery (sardine, anchovy, round herring); offshore fishery for large pelagic fish (tuna, swordfish, etc.); commercial, recreational and artisanal/subsistence line fisheries; and a rock lobster fishery (traps, hoop nets, diving).

- Fisheries make significantly different contributions to the national economies and food security of the three countries (Table 2).

Table 2

Summary characteristics of the contribution of fisheries to the national economies and food security of Angola, Namibia and South Africa

	Angola	Namibia	South Africa
Industrial and semi-industrial fishery			
Production/year Income Employment	170 000 tonnes 3.5% of GDP 12 000 people	300 000 tonnes 8% of GDP 14 000 people	615 000 tonnes 0.1% of GDP 28 000 people
Artisanal fishery			
Production/year Income Employment	100 000 tonnes + N/A 140 000 people	Almost no artisanal fishing along the coast	Negligible Negligible 100 000 people[1]
Food security Fish consumption	90% of industrial landings consumed domestically 15.7–17.3 kg per capita per year	95% of marine landings exported 14 kg per capita per year[2]	 6.9 kg per capita per year

[1] Estimate, including informal fisheries.

[2] A large portion is freshwater fish.

3.4.3 Adverse influences and changes

Major drivers of change in the system (Benguela Current and fishers)

Social and institutional
• HIV/AIDS epidemics (although minor compared with other drivers).
Economic
• overfishing (the most important of **all** drivers).[10]
Environmental
Directly related to climate change:
• widespread warming of sea surface water at both boundaries in recent decades and cooling inshore on west and south coasts of South Africa in same period;
• increasing frequency of intrusions of warm, low-salinity and low-oxygen water from north (e.g. Benguela Niños) are the most important perturbations in Northern Benguela ecosystem;
• general decline in oxygen concentration in the last 30 years (although this may be symptomatic of Southern Benguela);
• confirmed (and projected) trend of long-term warming at both extremes of the system, and cooling inshore on west and south coasts of South Africa (increased upwelling);
• increased leakage of Agulhas Current water into South Atlantic;

[10] Overfishing is also listed under non-climate-change-related environmental drivers.

•	increased weather events and flooding.
Not directly related to climate change (and/or anthropogenic):	
•	overfishing (most important of **all** drivers).

Note, however, that many of these stresses are not new and are known to have occurred in the past, which suggests that the "system as a whole is probably highly resilient" (Hampton, 2012a, p. 37), although the adaptability and resilience of the Southern Benguela may be more pronounced than that of the Northern Benguela.

Changes and impact pathways

Biophysical changes (direct impacts) common to the current:	
•	10–100-fold increase in copepod abundance in the last 40 years (in both Southern and Northern Benguela), accompanied by substantial changes in size composition;[11]
•	overall less-productive regime, with large variations in abundance (with peaks and sudden drops) of pelagic species between Northern and Southern Benguela, including an abrupt decline in catches of sardinella (since 1999) and horse mackerel (since 1997) in Northern Benguela (Angola);
•	complete shift in anchovy and sardine biomass from west to east in Southern Benguela from 1985 to 2005, **but now reversing** (not a regime shift caused by climate change, but rather due to fishing pressure);
•	eastward shifts in West Coast rock lobster catches from 1968 to 2005;
•	changes in top predator abundance (i.e. decrease in penguin and gannet populations, increase in seal numbers);
•	interannual variations in "chlorophyll *a*" concentration, but no obvious trend that could be associated with climate changes in the region.
Human changes (direct impacts):	
•	longer periods spent at sea, with an increase in safety issues;
•	damages to coastal infrastructures, houses, fishing boats and equipment;
•	availability of fish and other resources (e.g. water) to processing industries;
•	reduction in income and nutrition, increased hardship (decrease in quantities of wild fish caught).

Temporal scale

Changes in the Benguela ecosystem have been documented since the 1950s, and these historical records have been used to understand the functioning and evolution of the system as a whole. However, projections are deemed uncertain and unreliable owing to shortages of ocean, land surface and atmospheric data. Similarly, fish recruitment predictors have so far proved unable to adequately inform future fisheries management. Owing to these limitations, the temporal scale of the assessment is relatively limited, and bears more heavily on the understanding of past accounts.

Spatial scale of concern

The spatial scale of concern is the Benguela Current itself, defined as that part of the southeast Atlantic lying between 14°S and 37°S, east of the 0° meridian. The northern boundary of the upwelling region coincides with the Angola Benguela Frontal Zone , where

[11] However, it is unclear whether this is driven by environmental conditions ("bottom up") or by predation ("top down").

the warm Angola Current meets the cool Benguela regime. The southern boundary is considered to be the Agulhas retroflection area (between 36°S and 37°S).

The special administrative/political boundaries of the system offshore lie at the 200-nautical mile exclusive economic zone (EEZ) off the coasts of Angola, Namibia and South Africa. Inshore and on land, the system encompasses the coastal fringe where most coastal fishing communities are located.

Identification of thresholds / tipping points for the system (systems)

Regime shifts. Changes in the Southern Benguela ecosystem since the beginning of the 1950s have not been as drastic as those that occurred in the Northern Benguela in the 1970s and 1980s. Nonetheless, two long-term changes that qualify as regime shifts have been identified. The first occurred in the late 1950s, when horse mackerel was replaced by sardine in the pelagic fishery. This change was attributed to fishing, with some environmental influence (possibly a period of increased upwelling). The second shift occurred in the late 1990s and early 2000s, when sardine and anchovy biomasses were simultaneously high, and the populations and spawning areas of both species were concentrated on the south rather than the west coast. This second change has been primarily attributed to environmental changes on the Agulhas Bank.

Tipping points. Overall, it is thought that it was overfishing, rather than environmental factors, that led the small pelagic system (Namibia), the West Coast rock lobster in the Northern and Southern Benguela and many line-fish species throughout the region to reach a tipping point and collapse in the 1970s and 1980s. These systems have since shown no sign of recovery, despite the subsequent reduction in fishing pressure.

Key stakeholders concerned with the impacts of climate change on the system

- industrial fishers (including industrial mariculture, companies and workforce);
- small-scale fishers;
- government, including ministries of fisheries, scientists, etc.;
- recreational fishers;
- the Benguela Current Commission.

3.5 Pacific Islands countries and territories

For the analytical summary of the vulnerability of fisheries and aquaculture to climate change in Pacific Islands countries and territories (PICTs), information from Johnson, Bell and De Young (2013) was complemented by information from Bell *et al.* (2011a, 2011b, 2011c).

3.5.1 Vulnerability assessment methodology

Vulnerability assessments of the tuna fishery, coastal fisheries and aquaculture relied on the integration of: (i) IPCC Fourth Assessment Report projections[12] of impact to 2035 and 2100 on natural resources, economies, food security and livelihoods; and (ii) characterization of the vulnerabilities of fish habitats and stocks, and the economic and social benefits of fisheries and aquaculture as a function of their exposure, sensitivity and adaptive capacity to climate change drivers. Figure 3 shows the overall approach used for each subsystem. However, to estimate vulnerability quantitatively, the usual calculations (using addition) of the IPCC vulnerability definition were altered (using multiplication):

- **Potential Impact = Exposure × Sensitivity** (PI = E × S). This permitted recognition of the importance of the contribution of fisheries (i.e. tuna) to the economies of some PICTs in terms of gross domestic product (GDP) and government revenue, and to

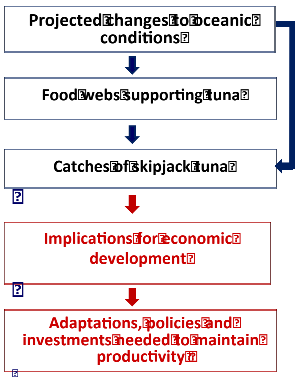
[12] Low (B1) and high (A2) emission scenarios (IPCC, 2007c).

suppress high scores that would have occurred for PICTs where catches of tuna are projected to increase substantially, but where they currently contribute little to the economy. PI values were standardized and normalized to range from 0 to 1, with higher values representing greater potential impact.

- **Vulnerability = Potential Impact × Adaptive Capacity** (V = PI × AC). Adaptive capacity was calculated from four indices: health, education, governance and the size of the economy. However, the AC index was inverted (1 – AC) where the impacts of climate change were expected to be negative (decrease in fishery). Thus, PICTs with the greatest adaptive capacity had reduced vulnerability to lower catches of tuna where the tuna fishery was projected to decrease.

Figure 3

Approach used to assess vulnerability to climate change of fisheries and aquaculture systems in PICTs



Source: J. Bell and E. Allison (2013), presentation made at the Global Partnership for Climate, Fisheries and Aquaculture (PaCFA) Expert Workshop on Assessing Climate Change Vulnerability in Fisheries and Aquaculture, Windhoek, Namibia, 8–10 April 2013 (FAO, 2013).

3.5.2 Description of the system at stake

Despite some unifying characteristics – such as similar climate and environment (the tropical Pacific and the Pacific Ocean), relative remoteness and relatively small size (although not necessarily economy) – it is difficult to consider PICTs, taken together, as a homogeneous system. Three dominant aquatic ecological subsystems can be found in PICTs: the tuna fishery, coastal fisheries and the aquaculture sector, each with different economic and ecological characteristics, and a different role in the livelihoods they support (Table 3).

Table 3

Summary characteristics of the contribution of the tuna fishery, coastal fisheries and the aquaculture sector to the national economies, livelihoods and food security of PICTs

	Tuna fishery	Coastal fisheries	Aquaculture
Characteristics			
Main species	Skipjack tuna	Demersal fish (60%), Nearshore pelagic (32%), Invertebrates (8%)	Black pearls, shrimp
Type of activity	Industrial, national and distant-water fleets	Artisanal, small-scale	Small-scale, entrepreneurial

Contribution to national economies			
Production/year	2.5 million tonnes (2009)	45 000 tonnes (2007), incl. 24 000 tonnes from freshwater and estuarine fisheries	Shrimp: 1 850 tonnes (2007)
Value	USD4.2 billion (2009)	USD165 million (2007)	USD210 million (2007)[3]
GDP	From 1.5% (Papua New Guinea) to 21% (Marshall Islands)[1]	Worth USD272 million across the region. From 0% (Guam) to 16.6% (Kiribati)[2]	< 1%
Employment	From 1% to 3% of workforce, 12 000 on vessels, > 20% of paid jobs in American Samoa (canneries)	N/A	17 323 (2007, 2009, 2010)
Contribution to food security and livelihoods			
Use of catch	Exports	Subsistence, local markets	International trade (pearls) and regional markets
Fish consumption	N/A	From 50 kg (rural areas) to 60–145 kg (coastal areas)[4]	N/A
Role in livelihoods	Paid employment (vessels and canneries)	Complementary source of income[5] and food	Self-employment

Notes: N/A = not available.
[1] From fishing operations only, excluding post-harvest activities. Also excludes income from foreign access fees paid by distant-water fishing nations.
2 Represents a contribution of USD105 million to the combined GDP of PICTs in 2007.
3 Includes USD173 million (pearls), USD29 million (shrimp) and USD8 million (other).
4 May include tuna. However, the majority of the fish consumed (52–91% in 14 PICTS) is caught off coral reefs and other coastal habitats.
5 Some 47% of households derive either their first or second source of income from fishing.

3.5.3 Adverse influences and changes

Major drivers of change in the tropical Pacific (current and projected)

Social and institutional
• population growth;
• urbanization and international labour migration;
• political instability;
• shifts in culture, educational attainment and lifestyle aspirations.
Economic
• technological innovation (e.g. substitution of labour by technology);
• markets and trade;
• fuel costs;
• patterns of foreign aid.
Environmental
Directly related to climate change:
• increase in tropical Pacific air, sea surface and ocean temperatures;

• more rainfall, although unevenly distributed across the tropical Pacific;
• increase in decadal variation (with implications for rainfall) of the position of the South Pacific Convergence Zone, although no long-term variations in the position have been observed;
• strengthening of the South Pacific gyre (current);
• decrease in nutrient supply;
• decline in dissolved oxygen;
• increase in ocean acidification;
• acceleration of sea-level rise;
• alteration of three of the five ecological provinces of the tropical Pacific (i.e. area reduction of the Pacific Equatorial Divergence, area increase of the Western Pacific Warm Pool and expansion of the North Pacific tropical gyre and South Pacific subtropical gyre towards the poles and to the west).
No changes are anticipated in the frequency of tropical cyclones (decline even possible), ENSO events (projected frequency and intensity patterns uncertain) and wave height. Thus, these three features should not be considered major drivers of change (although they may act as amplifiers).
Not directly related to climate change:
• habitat degradation.

Changes and impact pathways

Biophysical changes (direct impacts) common to the aquatic resources of the tropical Pacific:
• changes in the location of tuna spawning grounds eastward or to higher latitudes, and shifts in the distribution of prey for juvenile and adult tuna to the east. Eventual shift of the distribution of skipjack tuna eastwards and to higher latitudes;
• reduced diversity and abundance of coastal demersal fish and invertebrates;
• decline in coral reef, mangrove and seagrass habitats;
• expansion of the distribution of freshwater fish and invertebrates, and changes in growth rates (positive for some species, negative for others, depending on sensitivity).
Human changes (direct impacts):
• long-term decrease in tuna catches in the western Pacific, but increase (> 40 percent) in the eastern Pacific;
• long-term decrease in coastal demersal fish catches (–20 percent by 2050, from –20 to –50 percent by 2100). Note, however, that this decline will be in part compensated by the shift in distribution of nearshore pelagic fish (i.e. tuna);
• long-term increase in freshwater fisheries production;
• increased production of commodities farmed for food security (tilapia, carp and milkfish);
• decreased efficiency of aquaculture production activities (in particular seaward, livelihood-supporting activities).

Temporal scale

Projections are made to the near term (2035) and long term (2100) based on global climate models for low and high emission scenarios.[13] Projected changes are relative to averaged values for 1980–1999. Where data permit, observed changes are relative to the period 1950–1960. For the purpose of the present synthesis, however, information about exposure, sensitivity and resilience/adaptation is presented in the tables of Appendix 2, Section A2.5, without reference to a particular time scale.[14]

Spatial scale of concern
Assessment covered the full range of oceanic, coastal and freshwater fisheries and aquaculture activities that occur in PICTs, spanning the area from 130°E to 130°W, and from 25°N to 25°S (more than 27 million km^2). The local scale is also concerned, in particular when it regards livelihoods based on coastal fisheries and coastal and freshwater aquaculture systems.

Identification of thresholds / tipping points for the system (systems)
None could be identified in the documents analysed.

Key stakeholders concerned with the impacts of climate change on the system

- governments (income generation);
- tuna fishers;
- coastal, artisanal fishers;
- aquaculture producers;
- local populations/communities.

3.6 Latin America

Three sources of information were used in the analytical summaries for Latin America: González *et al.* (2013) and Quiñones *et al.* (2013) for the vulnerability assessments of the Chilean aquaculture and capture-fisheries sectors, respectively; and Martínez-Ortiz and Bravo-Moreno (2013) for the vulnerability assessment of the fisheries and aquaculture sectors of the Gulf of Fonseca in Central America.

3.6.1 Vulnerability assessment methodology

Aquaculture (Chile). González *et al.* (2013) used the methodology proposed by Allison *et al.* (2009) for a global study of the vulnerability to climate change of fisheries-based economies. They used a quantitative approach to calculate indices of exposure (E) based on IPCC scenarios, sensitivity (S) based on value of production, export income and employment, and adaptation capacity (AC) based on life expectancy, education, governance and GDP. Vulnerability (V) was calculated according to formula [1]. Weights applied were those of Allison *et al.* (2009).

$$V = \frac{1}{3}E + \frac{1}{3}S + \frac{1}{3}(1 - AC) \quad [1]$$

Capture fisheries (Chile). Quiñones *et al.* (2013) applied empirical models (projections) developed by Cheung *et al.* (2008) and Cheung, Lam and Pauly (2008) to fisheries to evaluate future catch levels – accompanied by a qualitative, historical approach to evaluating adaptive capacity (jack mackerel crisis case study). No assessment of vulnerability as such was proposed.

[13] All projections for surface climate and the ocean in this case study are derived from the Coupled Model Intercomparison Project Phase 3 (CMIP3) multimodel data set used for the IPCC Fourth Assessment Report.
[14] The reader is encouraged to refer to the original references for further information.

Gulf of Fonseca fisheries and aquaculture. Martínez-Ortiz and Bravo-Moreno (2013) used the IPCC projections for Central America and Mexico (IPCC, 2001), relying on scenarios A2 and B2 for emission projections, in addition to two local studies on climate projections for Central America carried out in 2006 and 2007.[15] The analysis of E, S and AC of the various components of the social-ecological system studied is qualitative. No assessment of vulnerability as such was proposed.

3.6.2 Description of the system at stake

Three dominant aquatic ecological subsystems can be found in Latin America: marine capture fisheries, aquaculture – itself subdivided into large- and small-scale operations – and freshwater capture fisheries, each playing a particular role in national economies and rural livelihoods (

Table 4).

In Chile, the two systems at stake are capture fisheries and coastal aquaculture. Ninety percent of aquaculture production comes from the austral part of coastal Chile, whereas 45 percent of all captures come from the central-south zone.

Table 4

Summary characteristics of the contribution of aquaculture and fisheries to the national economies and livelihoods in Chile and in countries of the Gulf of Fonseca

Chile	**Large-scale commercial aquaculture**	**Small-scale artisanal aquaculture**	**Capture fisheries (60% small-scale, 40% industrial)**
Characteristics			
Main species Area (ha)	Molluscs, finfish (salmon), seaweed (gracilaria) 33 052	Mussels, seaweed (gracilaria) 3 525	Anchovy, sardine, jack mackerel, hake[1]
Contribution to national economies			
Production/year and value	870 000 tonnes (2008)		4.65 million tonnes, worth USD3 931 million (2010) Centre-south zone of Chile = 45% of Chile's landings (2010)
GDP	1.3%		
Export quantities Export value	1.36 million tonnes (2009, fisheries and aquaculture) USD4 100 million (2009, fisheries and aquaculture)		

[15] *Escenarios del cambio climático para Costa Rica*, 2006 (no full reference available), and *Sintesis regional del "Proyecto Fomento de las Capacidades II para la Adaptación al Cambio Climático en México"* (Central America and Cuba, Water Center for the Humid Tropics of Latin America and the Caribbean [CATHALAC], 2008) (no fuller reference available).

Contribution to food security and livelihoods			
Use of catch	Exports	Subsistence, local markets	Fishmeal (70–85%), canned and frozen products for consumption
Fish consumption	4.9 kg/capita/year		

Gulf of Fonseca	**Industrial fisheries**	**Small-scale artisanal fisheries**	**Aquaculture**
Characteristics			
Main species	Tuna (ES), shrimp (ES, N), langoustine (ES)	Shrimp (ES, H, N), snapper (ES), snook (ES), corvine (ES), mackerel (ES)	Shrimp (ES, H, N), tilapia (ES, H, N), freshwater shrimp (macrobrachium) (ES), carp (ES)
Area	N/A	8 000 km^2 (ES) 162 km coast (H) 1 710 km coast (N)	4 000 ha (ES) 10 330 ha (N)[3] 18 500 ha (shrimp) (H)[4]
Contribution to national economies			
Production/year Value	103 361 tonnes (2006) (H: 47%, ES: 34%, N: 19%) USD1 076 million (2006) (H: 59%, ES: 17%, N: 24%)		
GDP contribution	USD33 862 million (2006) (H+N+ES) H: 6.4%, ES: 1%, N: 4.8% (average = 3.2%)		
Export value	Total of USD380.5 million (of which H = 57%)		
Employment	25 317 (H) (2002)	12 400 (H)[2] (2002)	27 750, mostly shrimp (H) (2002)
Contribution to food security and livelihoods			
Use of catch	Exports	Domestic markets, supply of PL to the aquaculture sector (ES, H, N)	Marine products: exports, freshwater products: national markets (ES). Exports of shrimp and tilapia (H)
Fish consumption	Between 1.8 and 6.4 kg/capita/year[5]		

Note: ES: El Salvador. In this country, industrial fisheries represent 50% of the total fishery. H: Honduras. N: Nicaragua.

[1] By decreasing order of importance. Sardine and anchovy are caught by small-scale fishers; jack mackerel and hake by industrial fleets.

[2] Small-scale fishers in Honduras include collectors of wild shrimp post-larvae (PL) for the aquaculture industry.

[3] 60% semi-intensive (enterprises), 40% extensive (cooperatives).

[4] Only 12 500 ha are under cultivation.

[5] Mostly from artisanal/small-scale operations.

3.6.3 Adverse influences and changes

Major drivers of change in Latin America (current and projected)

Social and institutional
• Chile: none reported;
• El Salvador: history of conflicts (social conflict in the 1980s, conflict between industrial and artisanal shrimp fishers in the 1990s); migration of small fishers to the United States of America.
Economic
• international economic downturn since 2007;
• competition from other aquaculture producing countries of the region (e.g. Peru);
• overfishing, reduction in landings;
• increased use of coastal areas for construction and port facilities;
• increased maritime traffic;
• privatization and deregulation (Nicaragua).
Environmental

Directly related to climate change:
• increase in sea surface temperature (+0.5 °C by decade along the Chilean coast, from +2 to +4 °C for the Gulf of Fonseca to 2080);
• increase in air temperature (+1.2 °C by 2050 in Central America);
• increase in winds;
• decrease in rainfall (–10 percent in Gulf of Fonseca up to 2050) and in flow of rivers to sea;
• sea-level rise;
• changes in oxygen concentrations in the water column;
• increase in frequency and intensity of ENSO;
• changes in circulation of marine currents and upwelling;
• hurricanes (e.g. Mitch, 1998), especially in the Gulf of Fonseca;
• seasonal inundations (for areas 1–10 m above sea level) and droughts.
Not directly related to climate change:
• overfishing;
• earthquakes (e.g. 2001), tsunamis, especially in the Gulf of Fonseca;
• pollution and environmental degradation, mangrove loss;
• volcanic eruptions and seisms (earth tremors);
• public concerns related to the sustainability of some aquacultural practices;
• competition for natural resources from other activities such as extension of the intensive, unsustainable and inequitable culture of sugar cane and cattle-raising (with negative impacts in terms of conflict, degradation of the social and cultural fabric of communities and of the environment).

Changes and impact pathways

Human changes (direct impacts):
• increased conflict over freshwater (Chile).
Biophysical changes (direct impacts):
• increases in mortality (hypoxia and anoxia);
• increased negative interference with production systems (e.g. increase in microalgae);
• reduced freshwater availability.

Temporal scale

The Chilean aquaculture vulnerability assessment considers three temporal scales for analyses: short-term (2011–2030), medium-term (2046–2065) and long-term (end of the twenty-first century). Its projections are based on the A2 and B2 IPCC scenarios (IPCC, 2001). The Chilean fisheries vulnerability assessment, based on the Cheung *et al.* (2008) and Cheung, Lam and Pauly (2008) models, makes capture projections to 2055 under various scenarios of climate change (IPCC A1B and stabilization of emissions at the 2000 level).

The Gulf of Fonseca vulnerability assessment considers projections to 2050 and 2100 (A2 and B2 IPCC scenarios).

Spatial scale of concern:

Capture fisheries and aquaculture are considered in two distinct areas of Latin America:

- Chile, with a maritime zone that extends from 18°21'03"S to about 60°00'00"S. Capture fisheries considered here are part of the Humboldt Current running off the centre-south

zone of Chile (approximately 35°–38°S), while aquaculture systems considered are located along the country's entire coast.
- Gulf of Fonseca, an area of 8 245 km, including an aquatic area of 2 015 km^2 and a coast of 409 km. It is bordered by three countries (El Salvador, Honduras and Nicaragua) and is located between 13°10'N and 87°40'W.

Identification of thresholds / tipping points for the system (systems)

Regarding Chilean aquaculture systems, no thresholds were identified nor was progression towards thresholds mentioned by González *et al.* (2013). In contrast, Quiñones *et al.* (2013) clearly indicate that the stocks of jack mackerel, hake and anchovy are at high risk of reaching a tipping point that could lead to their demise. No looming tipping point was reported in Martínez-Ortiz and Bravo-Moreno (2013), although the increased incidence of conflict in some parts of the Gulf of Fonseca could push the system to a threshold.

Key stakeholders concerned with the impacts of climate change on the system

- national authorities or governments in charge of fisheries and aquaculture;
- industrial aquaculture operators (Chile);
- small-scale aquaculture operators (Chile);
- industrial fishers (Chile);
- small-scale/artisanal fishers (Chile);
- post-harvest processors (Chile);
- women (in processing industries in Chile).

4. Vulnerability and adaptation in fisheries and aquaculture: conclusions of the case studies

4.1 Who/what is vulnerable to what? A summary of case study vulnerability conclusions

This section summarizes the conclusions reached by the authors of the case studies on overall vulnerability to climate change (unless specified otherwise) of the fisheries and aquaculture systems investigated.

The main threat to **Lake Chad** and the people living in its basin is drought. Ovie and Belal (2012, p. 64) conclude: “The location of the Lake Chad Basin in the Sahel means that it is highly vulnerable to the climatic perturbations in the region and climatic events have greatly influenced ecology, natural resources, and thus livelihoods,” and “the adverse socio-economic implications on riparian communities who are dependent on the basin’s natural resources for their livelihoods and well-being are obvious.” However, the capacity to tackle and manage climate-related threats is hampered by poverty, weak political and economic stability, poor institutional capacity, inadequate information and a limited knowledge base (Smith *et al*., 2003; Neiland, Madakan and Béné, 2005).

Key climate-related drivers in the **Caribbean** are a decrease in wet-season rainfall, increased temperatures, sea-level rise and an increase in tropical cyclone activity. Devoid of a concluding statement on the vulnerability of the area, the assessment (McConney, Charlery and Pena, 2015) leaves the general impression that aquaculture may be in a better position than fisheries to cope with the rapid rate of change and the compounded effects of multiple drivers of vulnerability (both climate- and non-climate-related, e.g. disasters). Aquaculture systems of the region seem to exhibit more flexibility and a wider adaptive capacity. They may also be more amenable to human interventions to assist in their adaptation. A main recommendation emanating from the stakeholders involved in the study was that analyses should not be split by hazard or sector, but rather treated in a comprehensive and integrated manner – under the umbrella of institutional and governance analyses – to “pull” and increase the effective use of resources.

De Silva (forthcoming) recognizes that the **Mekong Delta** is “significantly vulnerable” to sea-level rise (with associated changes in salinity) and flooding. Fisheries and aquaculture activities of the delta are “likely to be impacted, albeit to varying degrees” by these two particular facets of climate change (ibid). Another vulnerability analysis confirmed that “aquaculture would be more vulnerable to climate change scenarios than capture fisheries” – climate change affecting intensive and extensive production systems equally (ICEM and DAI, 2013, p. 140). However, De Silva (forthcoming) concludes that adaptive strategies for the sector are deemed feasible owing to a higher understanding of climate change impacts, and would probably be “pragmatic” and “cost-effective”.

According to Hampton (2012a, 2012b), the most important driver of change in the **Benguela Current** region is overfishing, not the climate. The most vulnerable fisheries are those with large human populations in communities heavily dependent on a diet of fish, with almost no ability to adapt, such as the artisanal and semi-industrial fisheries in Angola, and the rock lobster and small-scale line fisheries in South Africa. Other fisheries were deemed less or not vulnerable (i.e. Namibia’s and South Africa’s hake fisheries respectively). Large, highly organized and capital-intensive industries were found to be generally most adaptable to variations in catches.

In the **Pacific**, key drivers of change are climate-induced variations in the tropical Pacific air, sea surface and ocean temperatures, and projected increases in rainfall. Bell *et al.* (2011b, 2011c) conclude that, overall, PICTs are in a better position than other nations to cope with the implications of climate change for fisheries and aquaculture, and present good potential to adapt over the longer term and to seize the benefits brought about by changes in prevalent fisheries and aquaculture systems. The resulting impacts on fisheries and aquaculture, such as the move of tuna from west to east and the improved environmental conditions for the development of pond aquaculture, are likely to benefit those PICTs with a greater economic dependence on tuna, as well as constituting the source needed for fish protein supply.

In **Latin America**, a range of drivers of change is affecting fisheries and aquaculture. In Chile, these include overfishing of capture fisheries, and sea temperature changes and sea-level rise for aquaculture. Conversely, the Gulf of Fonseca seems to be more exposed to conflicts and extreme weather events (e.g. hurricanes), although variations in temperature, rainfall, sea-level rise, etc. are also likely to affect fish production systems and coastal ecosystems. González *et al.* (2013) conclude that the vulnerability to climate change of different types of Chilean aquaculture systems and operations is low overall. Although Quiñones *et al.* (2013) provide no conclusion regarding the general vulnerability status of the Chilean capture fisheries social-ecological system, the relatively high human adaptive capacity found in the region suggests a medium level of vulnerability for this sector. A similar conclusion on the vulnerability of fisheries and aquaculture to climate change in the Gulf of Fonseca is suggested.

These findings – complemented where necessary by a broad overview of the contents of the ecological-resilience and human-adaptive-capacity assessment tables in Appendix 2 – are summarized in Table 5 for biophysical systems and in Table 6 for key stakeholders of the case studies. The purpose of the tables is to provide quick snapshot answers to the question of the vulnerability of "what or whom" to "what". Empty cells signify lower vulnerability of a particular system to a particular threat, essentially owing to the fact that "enough" ecosystem resilience or human adaptive capacity is there to compensate for potential impacts. However, such an exercise is simplistic and involves a large part of subjectivity and generalization. Readers should thus refer to the details of the case studies themselves and of the tables in Appendix 2 for further information on the specific determinants of vulnerability in each case.

Table 5

Summary of the vulnerability of fisheries and aquaculture systems

To what → **Vulnerability** ↓ ***Of what***	**Overfishing**	**Drought**	**Variations in rainfall**	**Sea-level rise**	**Variations in sea surface temperature**	**Variations in currents**	**Acidification**	**Extreme weather events**	**Flooding**	**Changes in land use, damming**	**Volcanic eruptions, landslides, tsunamis**
Lake Chad fisheries and farming		□	X								
Caribbean fisheries			X	X	X		X	X			X
Caribbean aquaculture							X	X	X		X
Mekong fisheries				X						X	
Mekong aquaculture									X	X	
Mekong rice				X					X	X	
Benguela fisheries	X					X					
Pacific fisheries					X		X				
Pacific aquaculture											
Pacific coastal habitats					X		X				
Latin America fisheries	X				X			X			
Latin America aquaculture							X	X		X	

Table 6

Summary of the vulnerability of key fisheries and aquaculture stakeholders

To what → **Vulnerability** ↓ *Of whom*	Conflicts	Decrease in production and income	Institutional incoherencies, poor planning, overlapping jurisdictions	Safety at sea, general health issues	Infrastructure damage	Displacement	Decline in cultural heritage	Dependence on global markets and international pressures	Discrimination in access to inputs and decision-making
Transboundary commissions	X		X						
Small-scale fishers		X		X		X		X	
Industrial fishers		X						X	
Aquaculture operators (all sizes)	X				X			X	X[1]
National governments, fisheries and aquaculture authorities		X	X					X	
Other groups (migrants, women, …)	X	X		X					X
Land farmers and coastal users		X							
Fish processors and employees					X				X

[1] Of small aquaculture operators to feed and broodstock input discrimination.

4.2 Common issues

Although not all case study authors were conclusive about the vulnerability status of the fisheries, aquaculture and related human systems they had studied, Table 5 highlight the wide range of vulnerabilities affecting natural and human fishery and aquaculture systems around the world, as well as those factors to which some systems are more vulnerable. For example, conflict occurrence, lower incomes following climate change impacts, and the pressing influences of globalized markets on demand for aquatic products are cases in point for people and countries depending on fisheries and aquaculture. This is discussed further in Section 5.

Other general issues run through all the case studies:

- In areas where vulnerability to climate change is heightened, increased exposure to climate change variables and impacts is likely to exacerbate current inequalities in the societies concerned, further penalizing disadvantaged groups such as migrant fishers (e.g. Lake Chad) or women (e.g. employees of the processing industry of Chile).
- As could be expected, it is the limited access to essential facilities (e.g. health, education, road and communications infrastructures) that increases the vulnerability of small-scale fishers and aquaculture operators – alone or coupled with the threat of a decrease in production (catches, harvests, either for sale or direct consumption).
- Limited access to information and communications technologies is a recurrent hindrance to adapting fishing and harvesting practices and to seizing market opportunities.
- Transboundary issues, arising from the difficult sharing of aquatic resources in a number of systems and weakness of the institutions in charge of their management, are vastly complicated by the additional hurdle of climate change and the collective action it requires.

In terms of knowledge on which to base vulnerability assessments, review of the case studies also highlighted that:

- There is a general lack of scientific understanding of biophysical processes underpinning aquatic, and in particular freshwater, systems.
- Lack of palaeoecological records (with the exception of the Lake Chad Basin) precludes understanding of the past evolution of a system to predict more accurately its future sensitivity to events of a similar nature, its potential for recovery and likely adaptation pathways.
- Despite the large advances in climate modelling provided by the Fourth Assessment Report of the IPCC (2007c), data limitations remain – in particular in relation to the downscaling of IPCC models to the case study areas and systems concerned.

Overall, are fisheries and aquaculture stakeholders affected differently by climate change?

- Transboundary institutions: No. Weak governance impeding the implementation of adaptive strategies runs across the board.
- Ministries and governments: Yes. Those with better governance seem to be both coping with and planning better for the consequences of climate change for the economy and the people they are responsible for, and thus more able to handle another threat.
- Large-scale industrial fishers: Yes. They have very different capacities around the world and are operating at different levels of intensity and economic margins, making some more able than others to absorb the effects of climate change.
- Small-scale artisanal fishers: Yes and no. Depending on the context (including environmental and cultural), they have different access to opportunities for diversification. However, all are constrained by limited access to basic facilities and to participation in decision-making.

- Aquaculture operators: Yes. Largely owing to a wide-ranging intensity of operations (and slimmer margins for intensive, export-oriented production systems) and to the fact that the impacts of climate change on aquaculture operations range from positive to negative.

4.3 Recommendations for adaptation

Interested readers should refer to the case studies for detailed information on the adaptation strategies proposed by their authors. These tend to be not only context-specific, but also wide-ranging – encompassing management, economic, capacity-building and governance measures at all levels. Table 7 highlights the remit of the different propositions for adaptation that have been made for fisheries and/or aquaculture, and where they have been recommended. As postulated at the outset of the synthesis, governance takes a prominent place among the proposed avenues for reducing vulnerability to climate change in fisheries and aquaculture. The generation of new knowledge and information about the impacts of climate change on aquatic ecosystems is also fundamental. Without a better understanding of the functioning of ecosystems and of the uncertainty inherent in current climate models, "win–win" adaptation strategies are likely to be more difficult to design. Such gaps were indeed repeatedly underscored as hampering targeted adaptation efforts. The immediate need to finance and develop action plans was also reiterated in a number of case studies, as was the need to capitalize on aquaculture development activities. The majority of case studies also recognized that improved management of fisheries and aquaculture operations was undeniably linked to a reduction in their vulnerability to climate change.

Table 7

Summary of proposed strategies for adaptation to climate change in fisheries and aquaculture

	Lake Chad Basin	Caribbean	Mekong Delta	Benguela Current	Pacific	Latin America
GOVERNANCE						
Stronger partnerships, incl. outside fi+aq		X				
Development of legislation		X		X	X	
Improved governance in fi+aq[1]	X	X	X	X	X	X
INFORMATION AND KNOWLEDGE						
Dissemination of climate change and adaptation information	X	X				X
Creation of knowledge on adaptation and vulnerability		X	X	X	X	X
CAPACITY BUILDING						
Building of capacity, from schools to ministries		X			X	X
ENVIRONMENT						
Improved management	X (fi)		X (aq)	X (fi)		X (fi)
Habitat conservation					X	X
INVESTMENT AND ECONOMY						
Investment in climate-proof infrastructures		X				
Development and financing of action plans	X			X	X	X
Economic incentives, e.g. insurance			X			
Optimization of employment opportunities in aquaculture, diversification	X				X	
OTHER						
Increase in preparedness and inclusion of DRM in	X	X				X

CCA strategies						
Promotion of aquaculture development in national or international climate change strategies	X	X			X	X

Note: Fi+aq: fisheries and aquaculture; DRM: disaster risk management; CCA: climate change adaptation.

[1] Examples: integration of fisheries with other sectors at the policy level (Caribbean); work with technical agencies and community groups to enable priority adaptations (Pacific); cross-institutional collaboration (Latin America); strengthening of transboundary commissions (e.g. Benguela Current Commission, Lake Chad Basin Commission); holistic approach to climate-change policy development; and organization of fish farmers (Mekong Delta).

4.4 Process lessons from the case studies

The investigation processes adopted by the authors of the case studies varied, some adopting a mostly qualitative approach to the evaluation of vulnerability (Lake Chad, Caribbean, Mekong Delta, Latin America [Gulf of Fonseca]), some a quantitative one (Benguela Current, Pacific, Latin America [Chile]). However, all adopted – often implicitly – a risk/hazard perspective in their analysis. This implied that the focus was on the hazard, exposure and sensitivity, a particular sector and a regional scale[16] (Eakin and Luers, 2006). Some case studies broadened their analytical remit to encompass elements of the "political economy" perspective on the vulnerability of fisheries and aquaculture systems (i.e. through consideration of people and their capacity to adapt in particular places). However, in most cases, the overall analysis led to a focus on vulnerability outcomes, i.e. the linear result of projected climate change impacts on a specific unit (O'Brien *et al.*, 2007), and not so much on the contextual factors behind this vulnerability. Adaptation options were suggested in the case studies, but the focus on vulnerability outcomes instead of on "contextual vulnerability"[17] limited bottom-up assessment of their feasibility or likelihood to happen,[18] to a large extent, and, consequently, the formulation of sound adaptation recommendations. This suggests that the choice of a vulnerability assessment methodology that incorporates elements of both outcome and contextual vulnerability perspectives is likely to lead to a more-thorough understanding of vulnerability and of the scope for adaptation that exists within systems.

The consultative process in the Caribbean engaging a wide range of stakeholders stands out in this regard: those consulted made recommendations about the overall direction that climate change adaptation and disaster risk management should take, which, albeit quite generic, were clear and to some extent already rooted in ground realities. Similarly, the workshops organized by FAO to consult regional experts and stakeholders on the challenges of climate change for fisheries and aquaculture in their regions allowed refinement of the direction for follow-up and coordinated actions towards adaptation.

What this suggests is that, while vulnerability assessments may remain confined to desk and linear causal studies and still be relevant, realistic adaptation strategies need to emerge out of an analysis of contextual factors affecting vulnerability and adaptation, and a deeper engagement and consultation with stakeholders – not only those at the heart of the vulnerability assessment itself (e.g. fishers, national fisheries authorities), but also those indirectly connected to it (e.g. service providers, other ministries). These process considerations regarding vulnerability assessments should be kept in mind by those wanting to launch similar assessments in their own countries.

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[16] Either within a country or between countries.

[17] "Contextual vulnerability" is a state or condition of being moderated by existing inequalities in resource distribution and access, the control individuals exert over choices and opportunities and historical patterns of social domination and marginalization (Eakin and Luers, 2006). See Brugère and De Young (forthcoming) for further information on the categories of vulnerability assessment methodologies and the conceptual perspectives underpinning them.

[18] Such an assessment was then explicitly attempted in the compilation of the ecosystem-resilience and human-adaptive-capacity tables provided in Appendix 2.

5. Vulnerability in fisheries and aquaculture: synthesis and further discussion on adaptation

The six case study assessments have shown the variety of vulnerabilities of fisheries and aquaculture systems to climate change. No generalization is possible: while aquaculture systems (understood broadly as encompassing the people, livelihoods and economies that depend on them) appear less vulnerable in some cases than capture fisheries systems (understood in the same way), the opposite is true in other cases. This suggests that the oft-heard statement that "aquaculture will fill the gap for declining capture fisheries" may not hold true in all instances. Climate change needs to be taken seriously into account in foresight studies on the contribution of aquaculture to food security and economic development, and in the planning of its development.

Governance was proposed as the guiding theme for review and analysis of the case studies. Because of its influence on adaptation in terms of efficiency and equity, it has indeed emerged as an overarching and conditioning factor of great importance in the vulnerability of fisheries and aquaculture systems around the world.

Although, on one hand, characterization of the level of vulnerability to climate change of a fisheries-based social-ecological system is an important first step, especially if local actions are to be taken, simply describing a system's vulnerability status may yield only limited insights for regional or global policy-making. All the fisheries and aquaculture systems analysed here are vulnerable to something. While some comparison of subsystem components may be possible within the same system, it is virtually impossible to say, for example, if one system is more vulnerable than another without considerations of place, time and assessment methodology (Füssel, 2007). Yet this is problematic for policy and adaptation interventions, as the characterization of "particularly vulnerable" countries or areas has important implications in terms of prioritization of funding and investment for adaptation (Klein, 2009). To take the relevance of vulnerability assessments a step further than description and pave the way for action, it may be more useful to consider the **determinants** of resilience and adaptation, because these are the factors that will enable systems to "make it through" the threats and impacts of climate, and other, changes.

In this regard, the complementary analysis of the scope of ecosystem resilience and of the capacity for human adaptation, presented in the right-hand side column of the case study tables in Appendix 2, allows explicit consideration – and evaluation as far as possible – of two determinants of vulnerability that can be acted on. Answering the questions raised in Table 1, based on the Cinner *et al.* (2013) nested IPCC framework, proved very useful in doing this – something vulnerability practitioners might wish to consider adding to their assessments.

5.1 Determinants of resilience (for ecosystems)

The inner characteristics of ecosystems and the biological characteristics of the organisms composing them, as well as the anthropogenic interventions that can positively support them, are determinants of ecosystem resilience. Are the ecosystems considered in the case studies showing signs of resilience in the face of climate change? What attributes can be capitalized on to increase the resilience of the ecosystems concerned? The ecosystem resilience tables in Appendix 2 suggest, once again, a mixed picture. The Lake Chad Basin, Caribbean islands and Benguela Current seem to display few signs of resilience. Rather, they seem to be subject to continuous erosion of their assets, despite the shallow morphology of Lake Chad, a history of coping with water variations, and the possibilities of: exploiting or emphasizing new habitat niches (created by flooding, sea-level rise, coastal hurricane protection/reconstruction); building climate-proofed aquaculture facilities; and farming tolerant species in the Caribbean. Overfished stocks in the Benguela region – and with very few assets/potentials to capitalize on (with much uncertainty) – do not bode well for the resilience of this ecosystem. On the other hand, the Mekong Delta and Latin American systems do display some signs of resilience, for example, the opening of habitat and production opportunities for aquaculture and the quickly evolving morphology of the Mekong Delta (although the overall evolution trajectory is unknown). In Latin America, fish stocks seem to be withstanding environmental changes and fishing pressure (sardines), and production niches for aquaculture could be exploited through the use of new technologies. Finally, the movement of tuna stocks, the demonstrated adaptation and biological manoeuvring margins of plankton, seagrass, mangrove and freshwater species, as well as the potential for exploiting ecological niches for aquaculture, are all signs that Pacific ecosystems – with the exception of coral reefs – appear or are expected to be displaying signs of resilience to the effects of climate change.

Despite some key positive ecosystem characteristics, numerous weaknesses do, and will, threaten and erode further each ecosystem's resilience, as the Appendix 2 tables suggest. Moreover, this snapshot should not be considered definitive. Ecosystems evolve constantly and what is not examined here is the likely trajectory of this evolution: undesirable resilience? complete transformation?

5.2 Determinants of adaptation (for human systems)

Here, more than anywhere, the governance issue is prominent. What makes people and institutions adapt in the six geographical areas covered by the case studies? What influence does governance (encompassing markets and the role of governments) exert on the process of adaptation and on its outcomes?[19]

First, the case studies revealed that adaptation tended to be: mostly spontaneous, as in the Lake Chad Basin and Mekong Delta; planned, as in the Caribbean (especially given the link with disaster risk management) and Latin America; or a mix of both, as in the Pacific and the Benguela Current. This distinction does not presume a particular level of "success" in adaptation, but starts to point towards the nature of the factors behind "reactive" or "proactive adaptation.

Markets are a major determinant of adaptation for fisheries and aquaculture stakeholders throughout the case studies, but their role is particularly influential when other forms of governance are either weak or lacking. When they effectively connect supply and demand and allow access to inputs and support services (e.g. insurance and information), they open up opportunities and enable adaptation. In the Pacific, markets play a very important role, especially in trade of highly valued commodities such as tuna and pearls. In the Mekong Delta, producers are dependent on foreign demand and exports, while at the same time under pressure to meet standards and unable to access needed services such as insurance products. When markets are inexistent, or highly dysfunctional, and do not provide access to demand, inputs and services (as well as basic facilities), chances of adaptation are immediately curtailed (e.g. the Lake Chad Basin).

However, market forces on their own are unlikely to lead to effective adaptation (Stern, 2008). Governments, through public policies (Tompkins *et al.*, 2010), and civil society institutions, through the organization and harnessing of collective action (Agrawal and Perrin, 2009), also play a fundamental role in shaping and planning adaptation opportunities. Governments appear to have assumed a coordinating and managerial role in the Pacific, a planning role in Latin America, and an investing role in the Caribbean. However, fulfilling

[19] The intent here is not to provide an exhaustive review of all the determinants of adaptation to climate change. Only those commonly emanating from the case studies – or inadequately covered by these and warranting further attention in future assessments – are highlighted.

these roles is not easy. The transboundary nature of the natural resource base on which some of the studied fisheries and aquaculture systems depend is a main challenge to "good" governance of adaptation. This was the case, for example, with the Lake Chad Basin, the Mekong Delta, the Benguela Current, and the Gulf of Fonseca (Latin America). Yet it is also in these very places that the role of government was found to be weaker, either letting market forces dictate adaptation – although often for other motivations than climate adaptation (e.g. to maintain profits, as in the Mekong Delta aquaculture production systems) – or leaving indigenous practices and traditional management systems to fill the void. In the Lake Chad Basin, these have provided the flexibility needed to enable opportunistic seizing of favourable environmental variations created by lake-level fluctuations. However, their ongoing erosion is likely to imperil fishers', farmers' and their communities' chances of adaptation – and simple survival.

Another interesting perspective on the role of state and non-state actors in adaptation is that provided by the consideration of "modes of governance" (Bulkeley *et al.*, 2009, p. 8). Applied to the case studies, this perspective suggests that "self-governance", for example[20] – slightly reinterpreted here to encompass lower and informal and/or non-governmental levels of authority – was found in Lake Chad's relatively effective traditional fisheries-management and conflict-resolution mechanisms. In the Caribbean, where the link between climate change adaptation and disaster risk management is stronger than in other places, and to some extent in the Pacific, a "partnership" form of governance[21] was prevalent, engaging more closely with communities and non-state actors. The "regulation"[22] role of government, using command and control tools such as legislation, was underscored in the Latin America, Benguela Current and Mekong Delta case studies, although with different levels of success. However, the "enabling"[23] role of government was weak overall, and its "provision"[24] role even weaker, although in the Caribbean direct investments in climate and disaster-proof infrastructure have been made. While it is not possible to determine – without further information from and analysis of the case studies – whether one mode of governance is more effective than another in developing successful adaptation strategies, it is interesting to note the context-specificity of each prevailing mode of governance. A further investigation focused on these aspects could reveal the underlying strengths and weaknesses of each mode, as well as point towards those meriting attention in increasing adaptation and adaptive capacity.

Legislation and regulation are aspects of governance that bear a strong influence on scope for adaptation. Mentioned as existing in some parts of Latin America, unevenly developed in Benguela Current countries and not enforced in the Mekong Delta, legislation was not comprehensively addressed in the case studies. Yet Keskitalo and Kulyasova (2009) demonstrated that the adaptive capacity for coastal fishing was largely dependent on regulatory and legislative (and market) mechanisms situated beyond local communities. Thus, this particular aspect should warrant more-careful consideration in future climate-change vulnerability and adaptation assessments.

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[20] "… the capacity of local government to govern its own activities …. Self-governing relies on processes of organizational management …."
[21] When "… non-state actors work together with state actors in order to address climate change through providing information, undertaking voluntary action, and implementing projects."
[22] "… the use of traditional forms of authority such as regulation and planning law … governing by regulation through the use of enforcement and sanction …."
[23] "… the role of local government in facilitating, coordinating and encouraging action through partnership with private- and voluntary-sector agencies, and to various forms of community engagement … and governing through enabling through persuasion, argument and incentives."
[24] "… the shaping of practice through the delivery of particular forms of service and resource . governing by provision is accomplished through practical, material and infrastructural means ...."

Knowledge availability, generally (i.e. encompassing scientific and local knowledge in all its forms), is another important determinant of adaptation. Lack of knowledge and understanding, and information gaps regarding the functioning of coupled human/environment systems and climate impacts on these, were highlighted in all case studies. To various extents, they blurred the identification of the degrees of exposure and causes of sensitivity, and consequently weakened the adaptation propositions that were suggested. Although "uncertainties associated with foresight of future climate change" should not sidetrack policy-makers and practitioners in their adaptation efforts (Adger *et al.*, 2009, p. 339), they have implications, along with equality in decision-making, if resilience and adaptive capacity are to be built through governance and institutional means (Engle and Lemos, 2010).

This latter issue – equality in decision-making – touches on social justice and fairness (Paavola and Adger, 2006). The extent to which they are embedded in norms and practices underpinning the determinants of adaptation, including those discussed so far in the context of fisheries and aquaculture, will affect adaptation outcomes. Equal sharing of the responsibilities for and costs of adaptation, and fair participation in planning and decision-making on adaptation, are social-justice issues that need to be carefully considered if the "relevance and legitimacy of vulnerable actors' concerns and interests" are to be accounted for in adaptation strategies (ibid., p. 606).

5.3 Barriers to adaptation

If capacity to adapt to climate change (or the prevailing driver of change) is needed and is found to be low, as in most of the case studies, one needs to determine why in order to tackle the root causes of existing low adaptive capacity. This implies taking the findings of vulnerability assessments a step further to determine what and where the barriers to adaptation are.[25] Considering the barriers, rather than the sole "determinants" of adaptation as was done in the previous section, is part of an analytical process permitting a progressive focus on what should be done, how, where, when and with whom to increase adaptation. Not enough information was available from the case studies, and it would be beyond the scope of this document to identify these barriers. The purpose of this short section is to raise awareness of their nature and the type of questions that can be asked to pinpoint them in follow-up and/or future vulnerability and adaptation assessments.

Common barriers to adaptation typically include: threatened resources often being public-good resources; failure of collective decision-making; uncertainty in adaptation decisions; and lack of clarity over who of the public or private sector should be responsible for action (Tompkins and Adger, 2005).

In relation to governance, barriers to adaptation are usually conceived as ranging from (optimistically) errors in the design and execution of governance processes to (more pessimistically) systemic errors (Biesbroek *et al.*, 2013). Thus, interventions to overcome them range from the optimization of actors and governance processes to "giving up" because barriers are seen as unmanageable. Those adopting a realist view will see them as "temporary impasses in the complex interactions between actors about the problems and solutions" (ibid.), which can be resolved through a search for openings and dynamics in interactions among actors. Consequently, these different perceptions of barriers to climate adaptation will condition one's enquiry into their nature and into the role of governance in overcoming them.

[25] The term "barrier" here is understood differently from "limit". Barrier is defined as "… obstacles that can be overcome with concerted effort, creative management, change of thinking, prioritization, and related shifts in resources, land uses, institutions, etc." (Moser and Ekstrom, 2010, p. 22027). Limit, on the other hand, is understood as being associated with a threshold beyond which change is irreversible and, as such, absolute and objective (Adger *et al.*, 2009).

To the same extent that the methodology adopted for vulnerability assessment was found to influence its outcome, it is to be borne in mind that the effect of the analytical lens used to identify barriers will bear on the type of solution suggested to overcome them (ibid.).

Another consideration regarding barriers is whether they are arising from the actors, the system of concern (and thus closely intertwined with governance) and/or the object (i.e. here, the coupled human–environment system to be managed) (after Moser and Ekstrom, 2010). This is important, because trade-offs arising between determinants of adaptation are a barrier to it in themselves. Thus, accounting for the interrelations between development, governance and coping becomes key in those instances (Engle and Lemos, 2010).

Finally, one may ask, once barriers have been identified, how malleable are they (after Adger *et al.*, 2009)? If this point warrants further consideration in vulnerability and adaptation assessments, and in research more generally, its investigation should give ample room to context and subjective interpretation, and should never rest on the assumption that addressing or overcoming a barrier will lead to a successful adaptation outcome (Adger *et al.*, 2009; Moser and Ekstrom, 2010; Biesbroek *et al.*, 2013, 2014).

5.4 Prioritization of adaptation actions in fisheries and aquaculture

Prioritizing adaptation actions is akin to choosing which adaptation barriers to overcome first. In this regard, the framework proposed by Moser and Ekstrom (2010, p. 22030) to "help locate possible points of intervention to overcome a given barrier" could be considered and piloted on the basis of the information provided in the case studies. This framework is useful in realizing that "an actor's ability to overcome a barrier depends not just on his or her capabilities but also on the source or origin of the barrier" (ibid.) (i.e. identify who has the influence to trigger change). Each barrier to adaptation is underpinned by temporal and spatial/jurisdictional dimensions, although it is recognized that overlaps can occur (Figure 4). Different levels of control, and thus of power and capability to intervene and to progress towards effective adaptation, are attributed to the cell where the barrier is located. Different levels of "leadership, strategic thinking, resourcefulness, creativity, collaboration and effective communication" (ibid.) will be required to overcome the barriers (either through circumvention, removal or lowering), depending on their location in Figure 4.

Figure 4
Framework to identify possible interventions to overcome adaptation barriers

		Temporal	
		Contemporary	Legacy
Spatial/jurisdictional	Proximate	A	C
	Remote	B	D

Notes: Examples (from Moser and Ekstrom, 2010, p. 22030). 1. A local official may want to find scientific information on vulnerability, but cannot locate any research relevant to her community. The fact that federal agencies in years past have not provided funding to conduct such research has created a barrier that is a legacy of past science-policy decisions by remote actors (D in figure). The local official cannot easily overcome this barrier by addressing it at its source (i.e. through changes in federal research and development funding), and closer to home only with significant resources, time, and expertise (i.e. by hiring someone to do this research). 2. The

official finds that not all participants are at the table who should be and decides to extend invitations to those additional people for the next meeting. The same official may find that a local law prevents taking a certain adaptation action – a proximate legacy barrier (C in figure). Although the situation is still challenging, the official has control over initiating changes in this regulation. 3. The official may also be faced with a remote contemporary barrier, i.e. one that occurs now, but is beyond the official's direct control (B in figure). For example, a budget crisis results in an agency charged with providing technical assistance to the local process now not having sufficient staff to do so.
Source: Moser and Ekstrom (2010).

5.5 Avenues for further enquiry into vulnerability and adaptation

From the above considerations, as well as from the overall review process for the synthesis of the six case studies, several lines emerge for further enquiry into vulnerability and adaptation to climate change in fisheries and aquaculture. The suggestions that follow are intended for both practitioners (i.e. those implementing vulnerability assessments) and those carrying out research on vulnerability and adaptation:

- To help practitioners consider a number of issues that were not addressed comprehensively in the six case studies and attempt to tackle them in future assessments, bearing in mind that some fundamental knowledge may still be missing.
- To help researchers target their efforts at those lines of enquiry in which the current state of thinking and knowledge appears weak and could be reinforced, through both conceptual developments and applied research.

At this stage, one can only emphasize the need for mutual collaboration and interactions between these two groups, so as to progress more quickly towards the devising of sustainable, win–win solutions in climate change adaptation.

With a view to further understanding vulnerability and adaptation in the case study areas, as well as in other areas where such assessments may be implemented, it is worth considering:

- The past evolution and history (centuries and beyond) of ecological systems, and if possible human systems, through the use of palaeobiological and archaeological records. Understanding how coupled human–environment development trajectories were shaped in the past, and by which events, can provide insights into their possible future evolution. However, this implies enquiring from, and collaborating with, a wider range of disciplines.
- More conceptual and applied work is needed towards the identification of thresholds and tipping points for a better understanding of the "manoeuvring margin" left in ecological and human systems. Better understood, if not quantified, these will further understanding of the resilience of coupled human–environment fisheries and aquaculture systems, as well as of the type of intervention that may be required to maintain them within these limits. In this regard, aquaculture production systems, for example, where production limits are known, may constitute an easier ground for testing their application. Related issues emanating from the resilience discourse (Walker *et al.*, 2004, 2006) – of system transformation, cross-scale interactions, reorganization, learning, etc. – can also help frame and refine our understanding of the dynamics of human–environment relationships and, as such, should also be given due consideration.
- Linkages between disaster impacts, risk reduction and climate adaptation deserve more attention and are worth considering in greater depth, currently and in future case studies, following the Caribbean example. Here, distinguishing between slow- and rapid-onset changes may be useful (Cochrane *et al.*, 2009), although interactions between both should be carefully addressed: coping interventions and mechanisms can have negative impacts on long-term adaptation ("maladaptation", Barnett and O'Neil, 2010). This is particularly important for planned adaptation strategies and the

> strengthening of their planning, above all in developing nations (Berrang-Ford, Ford and Paterson, 2011).

Although the theme of vulnerability still dominates academic literature on climate change, adaptation is an up-and-coming field of enquiry (ibid.). However, conceptual frameworks for analysing barriers and dealing with them are still lacking (Biesbroek *et al.*, 2013). With the majority of studies of adaptation being case-specific and descriptive, researchers should turn their attention to the development of analytical approaches to answer the questions of "why" and "how" barriers to adaptation emerge over time and at multiple scales (ibid.).

However, measuring adaptation is a task that rivals in complexity that of measuring vulnerability, owing to the relativity and subjectivity of the measures of adaptation success and of the trade-offs involved (Adger and Barnett, 2009). As much empirical and theoretical work remains to be done in this domain, enquiries should adequately encompass justice and fairness in adaptation – an issue that was raised previously, in particular concerning how groups usually at a disadvantage (women, older people, youth) can seize adaptation opportunities. This is even more pressing given current demographic dynamics (Berrang-Ford, Ford and Paterson, 2011).

Finally, adaptive capacity does not necessarily lead to adaptation actions (Adger and Barnett, 2009). The reasons can be several, but uncertainty and long time frames are often found to paralyse decision-making. Yet some efforts are being deployed to circumvent this hurdle (Stafford-Smith *et al.*, 2011). The inherent uncertainty and complexity of fisheries and aquaculture systems make them an ideal terrain in which the approaches proposed could be piloted. Not only would this prevent the risk of maladaptation, it would also increase the confidence and accountability of decision- and policy-makers in taking action.

6. Conclusion

This technical paper has sought to refine, synthesize and discuss the findings of six case-study assessments of the vulnerability to climate change of fisheries and aquaculture. The case studies covered the Lake Chad Basin, Caribbean small island developing States, Mekong Delta, Benguela Current, Pacific Islands countries and territories, and Chile and the Gulf of Fonseca in Latin America.

Diverse components of the fisheries and aquaculture systems (human and/or environmental) are vulnerable to different climate-related threats, as well as to anthropologically driven ones (e.g. overfishing). The need for context-specificity precludes any generic statement about the vulnerability status of fisheries and aquaculture systems, and of their associated human systems. Despite this, the case studies confirmed that ecosystem resilience and human adaptive capacity were the two major determinants of vulnerability, and that governance was itself a determinant of adaptive capacity.

The various approaches to investigating and characterizing vulnerability to climate change in the case study areas yielded interesting insights, especially in terms of consolidated knowledge on "what/who" is vulnerable to "what". The strengthened understanding provided by the case studies is fundamental and, to date, new. However, it is only a first step on the way to positive adaptation outcomes, and, as it stands, insufficiently complete to be used directly in adaptation planning. To go a step further, ecosystem resilience and human adaptation should be given more in-depth consideration, because these are the factors that must be worked on to enable a system to "make it through" the threat of climate and other changes. In order to move analysis through this increasing complexity, the vulnerability analysis framework put forward by FAO (2013), and whose first steps have been piloted here in a complementary analysis of the contents of the case studies, has enabled further enquiry and progress in this direction. By explicitly considering (and evaluating) ecosystem resilience and human adaptive capacity – two key determinants of vulnerability that can be acted on – focus was placed on the reasons why systems tend to be vulnerable. In this respect, the Cinner *et al.* (2013) nested IPCC framework proved very useful in asking (and answering, as much as possible) questions related to resilience and adaptation – something vulnerability practitioners might wish to consider adding to their assessments.

More context-specific vulnerability assessments of fisheries and aquaculture are needed, in particular in areas where such studies have not been carried out. However, in areas where vulnerability information is already available, as in the six areas covered here, this information could be used, first, as a baseline, and second, as a stepping stone to move on from vulnerability characterization to decisions on adaptation actions. "Good" adaptation decisions may be perilous to make. However, considering what lies behind them appears to be a conducive strategy to ultimately understanding and addressing those barriers that can "stop, delay or divert the adaptation decision-making process" at any stage (Moser and Ekstrom, 2010, p. 22027). Documenting determinants of and barriers to adaptation, and in particular the governance and institutional issues that tend to underpin them, will aid progress towards a better understanding of vulnerability, ecosystem resilience and human adaptive capacity, and will support the design of effective, efficient, legitimate and equitable adaptation actions.

Finally, concerns about climate change impacts on fisheries and aquaculture systems, and a focus on the need for these to adapt, should not move attention away from their management. Indeed, the case studies highlighted that, in some cases, it is overfishing that is threatening the fishery, not climate change or even other environmental factors. Unless urgently addressed, this could weaken the very basis on which future adaptation will rely. Adaptation options can revolve around "no- (or low-) regrets measures" (Heltberg, Siegel and Jorgensen, 2009; Conway and Schipper, 2011). Improved fisheries and aquaculture management is one of them.

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Appendix 1

Proposed steps for a vulnerability assessment in fisheries and aquaculture

Only Steps 2a, 2b and 6 used for the synthesis are fully detailed here. Further information on all the other steps is available in FAO (2013).

Step 1: Why a vulnerability assessment? - assessment 'warm-up'

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

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

a) Important things to consider:

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

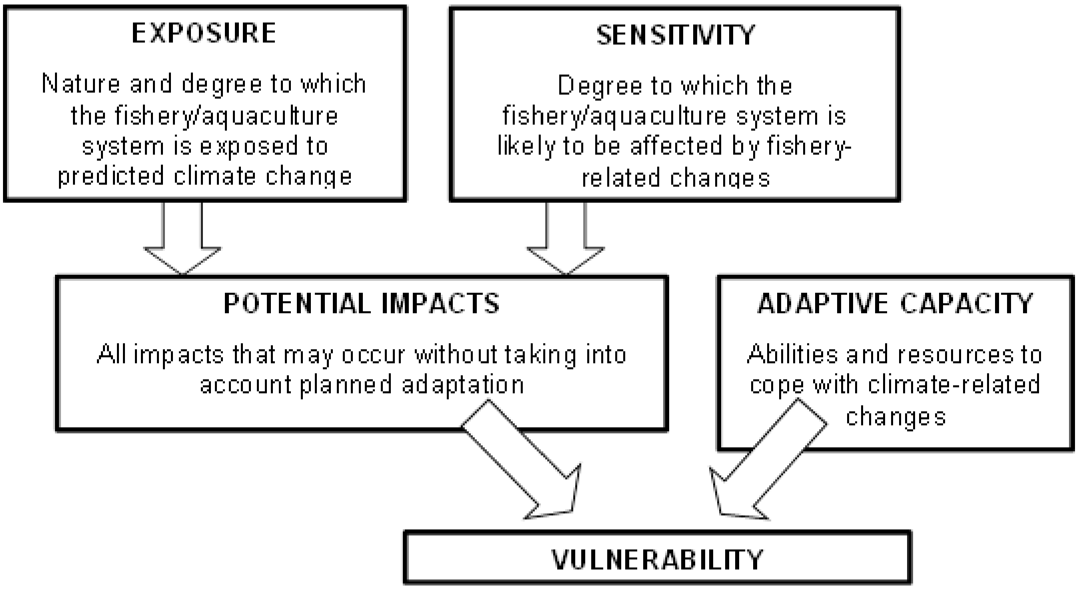
- Methods to organize information from point 2.a)

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

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

It may also be useful to organize the information according to the IPCC components of vulnerability (exposure, sensitivity, adaptive capacity – Figure A1.1) for different types of stakeholders, or scales (spatial and/or temporal).

Figure A1.1
Generic IPCC vulnerability analysis framework for fisheries and aquaculture systems



Source: Derived from IPCC (2001).

Step 3: Choosing a framework of analysis

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

Step 5: Identify how to get these data and information

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

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

The results of this step should provide refined answers to the questions Who and/or what is vulnerable to What (Step 2), as well as clearly point to the causes or reasons for vulnerability, i.e. answer Why a system or people are unable to adapt and vulnerable in such a way that recommendations and priorities for action become clear.

Step 7: Report and communicate findings

Appendix 2

Analysis of ecological resilience and human adaptive capacity in the six case study areas

A2.1 Lake Chad

Assessment of ecological resilience

Table A2.1.1
Assessment of the ecological resilience of the aquatic resources of the Lake Chad Basin
Sensitivity colour coding: red = high, orange = medium, green: low.
Ecological resilience colour coding: red = low, orange = medium, green = high.

Climate exposure (Assumed high)	Sensitivity of Ecosystem (how is it pushing the system to threshold limits?)	Ecological Resilience (is this making the system more or less adaptive? how capable is the system of dealing with these changes?)
Lake Chad watershed		
Recurring droughts	High (because of already reduced lake size, increased salinity, existing state of water scarcity in the watershed, already reduced inflows to the lake).	Probability of physical recovery: In the past: High (palaeo records).[1] MT to LT: Medium (habitat diversity supporting different fisheries, small dam construction enabling the recovery of lacustrine fish species previously decreasing due to open water shrinkage – after initial habitat damage). Ability of dry floodplains to provide enough moisture to support farming activities: Medium. Likelihood of the construction of the feed canal to the lake: Low.
Absolute decrease in rainfall from year to year High variability in rainfall	High (because of increased flood occurrence, slower groundwater recharge, modified lacustrine hydrology, ecology (proliferation of hydrophytes) and chemistry (e.g. low DO) resulting in changes in fish composition and diversity).	Ability of the ecosystem to cope with overall water reduction: In the past: High (palaeo records). MT to LT: Low (because of superimposed stress of irrigation water withdrawals). Ability of the ecosystem to cope with water variation: In the past: High (palaeo records). MT to LT: Medium (shallowness of the lake that enables re-flooding). Probability of aquatic ecosystem recovery: In the past: unknown. MT-LT: low (because of additional anthropological pressures, e.g. pollution).

[1] Contrarily to the other systems under investigation, prior palaeo investigations have taken place in the Lake Chad basin and this knowledge is reflected here in the adaptive capacity column. However, this was not possible for the other case studies.

Assessment of human adaptive capacity

Table A2.1.2
Assessment of the adaptive capacity of the Lake Chad basin stakeholders.
Sensitivity colour coding: red = high, orange = medium, green: low.
Human adaptive capacity colour coding: red = low, orange = medium, green = high.

Socio-economic exposure (what are the risks that you face) *risk of… / exposure to…*) (Assumed high)	**Sensitivity of socio-economic system (how important is that risk if it occurs?) (NB: current sensitivity)**	**Adaptive capacity (how capable are people to deal with that risk? How well prepared are they?)**
Lake Chad Basin Commission -		
Continuous inner tensions and conflicts regarding the management of the LCB Loss of credibility of the LCBC Incapacity to manage the complex and fluctuating resources of the Lake Chad basin	High (because of weak governance and limited financing).	Ability to attract funding: Uncertain. Ability to progress towards good governance: Medium. Capacity of the LCBC to play a positive role in the future adaptation of the lake and its riverine communities to climate change: Low. Disaster preparedness: Low. Potential to raise the visibility of the contribution of basin's fisheries: Uncertain. Ability of LCBC member states to include climate change in their policies: Uncertain. Ability of the LCBC to raise the status of the main fish market (Doro-Baga in Nigeria) to a regional market: Uncertain. Ability of the LCBC to cooperate with other authorities re. irrigation water management: Uncertain. Ability of the LCBC to promote free trans-boundary movement of fishers: Low (could be modelled on the ECOWAS protocol on free movement, and extended to Cameroon and Chad).
Fisheries managers (formal and informal)		
Declining catches Changes in catch composition Tightly controlled fisheries management systems (either by traditional authorities or the State)	Medium (because of diversity of management systems: traditional (informal), modern (formal) or mixed).	Ability to support evolving demands on the fisheries of the lake: Medium (erosion of traditional authorities, but informal management regimes are relatively well functioning). Ability to support conflict resolution: High. Potential to include local people/bottom-up decision-making: Uncertain. Ability to respond to climate change threats: Uncertain.

Near-shore fishers –		
Declining catches Changes in catch composition Reduced income Need to go further off-shore Loss in fishing culture traditions (papyrus boats replaced by plank boats, increased land-based farming) Geographical and social remoteness and isolation Extortion of illegal fishing taxes from powerful local leaders Increase in food/nutrition insecurity Forced migration Increased exposure to health impediments (e.g. cholera, meningitis, HIV/AIDS	High (because of lack sufficient resources (fishing gear), lack of access to information, lack of voice and representation in decision-making and pressures from other groups, chronic poverty, increased seasonal migration).	Ability to cope with variations in catch: Medium (switch among ecological niches for fish exploitation). Mobility to access new fishing grounds and switch between species: High (seasonal migration commonly practiced, switch in gear possible to target open water species and swamp species at different times of year). Ability to access capital/credit to purchase new gear: Low (depending on the size and formality of banking system). Ability to diversify out of fishing and switch between activities when needed: High (fishing and farming tightly linked. Recession farming as floodwater recedes, or small-scale irrigation farming with pumps). Ability to access information, facilities and markets: Low. Ability to self-organize and voice concerns: Low. Ability to secure employment out of fishing: Uncertain (depending on the size and health of the national economy). Access to health facilities: low (remoteness) Ability to access alternative protein sources: Low. Potential to adopt and develop aquaculture systems: High (recommended as one of the main adaptation strategies + supportive policy context).
Migrant fishers -		
Declining catches Changes in catch composition Reduced income Increased health impediments (e.g. cholera, meningitis, HIV-AIDS)	High (because of seasonal or permanent restrictions in fishing gear, payment of fees).	Ability to cope with variations in catch: Low (restrictions imposed by tight fisheries management). Ability to access capital/credit to purchase new gear: Low. Ability to diversify out of fishing: Unspecified. Ability to secure employment out of fishing: Unspecified. Access to health facilities: Unspecified.
Women		

Declining catches Increasing household hardship Increase in food/nutrition insecurity	High (because of lack of traditional hereditary access rights to land and fishing grounds).	Ability to engage in meaningful and viable alternative strategies: Low. Ability to access capital/credit to engage in other activities: Likely to be low (no collateral). Ability to access alternative protein sources: Low.
Off-shore artisanal fishers		
Declining catches Changes in catch composition	Low (because of higher resource endowment and can fish further offshore).	Ability to cope with variations in catch: High. Ability to access capital/credit to purchase new gear: High. Ability to diversify within fishing (investment in new gear): High.
Fish traders		
Declining catches Changes in catch composition High temperatures	High (because of high risk of spoilage).	Ability to access local and low cost preservation techniques: High.
Land farmers - risk of… / exposure to…		
Water shortages Increased health impediments (e.g. cholera, meningitis)	Medium (because of ability to access irrigation, but increasing reliance on irrigation).	Ability to access water in a timely fashion: Medium (construction of small-scale dams). Likelihood of the construction of the feed canal to the lake: Low (feasibility study commissioned in 2000, outcome unknown in 2012). Ability to store food and preserve agricultural products: High. Ability to farm all year round: High (dry-season recession farming on left-over moisture or small-scale irrigation). Access to health facilities: Low (assumed – remoteness of communities). Potential for the implementation of irrigation/water conservation strategies: Low (possible in theory but imply a lot of behavioural change). Potential to construct small-scale water storage (dams): High.
Animal herders/raisers - risk of… / exposure to…		
Water shortages Reduction in grazing lands Increased health	Medium (because of reduced number of cattle heads and increasingly reliant on caprinae).	Ability to move to new grazing lands, forage and water points: Low (reduced availability of grazing lands due to water shortages, and reduced quality and

impediments (e.g. cholera, meningitis)		quantity of forage). Ability to sell their goats/access caprinae markets: Unknown. Access to health facilities: Low (assumed because of remoteness of communities).

A2.2 Caribbean

Assessment of ecological resilience

Table A2.2.1
Assessment of the ecological resilience of the Caribbean fisheries.
Sensitivity colour coding: red = high, orange = medium, green: low.
Ecological resilience colour coding: red = low, orange = medium, green = high.

Climate exposure **(Assumed high)**	**Sensitivity of Ecosystem (how is it pushing the system to threshold limits?)**	**Ecological Resilience (is this making the system more or less adaptive? how capable is the system of dealing with these changes?)**
Marine fisheries (incl. reef, coastal and offshore fisheries and ecosystems)		
High temperatures, drought	High (because of coral bleaching, fish kills, alteration of mangrove and estuarine fish life cycles).	Ability of the subsystem to recover from disturbances: Low (very slow recovery process, in particular for corals).
Intense rainfall	High (because of sedimentation, seabed scouring).	Ability of the subsystem to recover from disturbances: Low (in particular for coastal fisheries and coral reefs).
Flooding	High (because of salinity changes, turbidity, enhanced transport of pathogens (fish kills)).	Ability of the subsystem to recover from disturbances: Low (in particular for coastal fisheries and coral reefs). Likelihood of disease occurrence/epidemics: Medium. Likelihood of increase in offshore productivity: High.
Storms and hurricanes	High (because of increased wave action, debris transport).	Ability of the subsystem to withstand hurricane and storm impacts and damage: Low (very slow recovery process for corals). Likelihood of coastal defences constituting new habitat for juvenile finfish and shellfish: High. Likelihood of receiving early warning applicable for fisheries: Low (very rapid onset).
Sea level rise	Medium (because of moderate sensitivity of coastal ecology).	Likelihood of provision of new nursery habitats: High.
Ocean acidification	High (because of weakened coral structure, unpredictable changes in plankton	Ability of the subsystem to cope with acidification: Low (especially for corals). Likelihood of international GHG emission instruments resulting in reduced

	composition, impaired calcification in several marine species).	acidification: Low.
Landslides	High (because of smothering, increased turbidity, damage to wetlands, altered water circulation).	Ability of the subsystem to recover from disturbances: Low (in particular for coastal fisheries and coral reefs).
Volcano eruptions	High (because of changed landscapes and seascapes products and functions, as in Montserrat).	Ability of the subsystem to cope with abrupt changes: Low (though this depends on the extent of the damage). Ability to implement early warning systems applicable to fisheries: Low (fisheries are not mainstreamed in CCA and DRM).
Earthquakes	High (because of changed landscapes and seascapes products and functions, as in Port Royal).	Ability of the subsystem to cope with abrupt changes: Low (depending on the extent of the damage). Ability to implement early warning systems applicable to fisheries: Low (fisheries are not mainstreamed in CCA and DRM).
Tsunamis	High (because of physical alteration to coasts and inland areas products and functions).	Ability of the subsystem to cope with abrupt changes: Low (depending on the extent of the damage). Ability to implement early warning systems applicable to fisheries: Low (fisheries are not mainstreamed in CCA and DRM).
Inland fisheries		
High temperatures, drought	High (because of risk of exceeding species' tolerance ranges, likelihood of shrinkage of fishable area, increased conflicts).	Ability of the subsystem to recover from disturbances: Low (especially in shallow water areas and seasonal water bodies).
Intense rainfall	High (because of sedimentation, riverbed scouring).	Ability of the subsystem to recover from disturbances: Medium (lower in poorly managed areas and eroding watersheds).
Flooding	Low (because this is not pushing the subsystem to its limits).	Likelihood of higher productivity in newly flooded areas: High (especially in shallower areas and seasonal water bodies). Likelihood of increased spawning areas: High (especially in shallower areas and seasonal water bodies).
Storms and hurricanes	Medium (because this is a compounding effect: storms and hurricanes may be accompanied by intense rainfall, flooding).	Likelihood of increasing overall resilience of the subsystem to other risks and threats: Low. Likelihood of receiving early warning applicable for fisheries: Low (very rapid onset).
Sea level rise	Medium (because of the relatively small impact of saline	Likelihood of complete alteration of inland habitats and fisheries: Low (except for coastal floodplains subject to marine

	intrusion).	inundation).
Landslides	High (because of physical watercourse blockage and altered drainage, destruction of critical habitat).	Potential for the subsystem to be considered alongside other watershed activities (e.g. forestry, mining, agriculture) in integrated land management: Low (not currently done, conflicts).
Volcano eruptions	High (because of changed landscapes, water flows and habitats, altered chemical composition of water bodies as a consequence of eruptions).	Ability of the subsystem to cope with abrupt changes: Medium (limited to steep slopes although likelihood of damage by ash may be more extensive).
Earthquakes	High (because of changed landscapes, water flows and habitats as a consequence of eruptions).	Ability of the subsystem to cope with abrupt changes: Medium (rare occurrence). Ability to receive enough early warning applicable to fisheries: Low.
Tsunamis	High (because of alteration to inland areas adjacent to coasts).	Likelihood of inland habitats and fisheries being altered by tsunamis: Low (except for coastal floodplains subject to marine inundation). Ability to receive enough early warning applicable to fisheries: Low.
Aquaculture systems (fresh and brackish water systems)[1]		
High temperatures, drought	Medium (because of possibility to control the growing environment, although tolerances may be exceeded in some species).	Ability of some species benefiting from higher temperature ranges: High (e.g. tilapia).
Intense rainfall	High (because of erosion of natural earth ponds and dykes).	Potential to improve construction techniques: Medium (possible though likely to be costly). Ability of the subsystem to recover without human intervention: Low (especially in shallower areas).
Flooding	High (because of pond overtopping, escape of species).	Potential to improve construction and management techniques: Medium (possible though likely to be costly). Ability of the subsystem to recover without human intervention: Low (especially in poorly drained areas).
Storms and hurricanes	Medium (because it is a compounding effect: storms and hurricanes may be accompanied by intense rainfall, flooding).	Ability of aquaculture systems to cope with this added impact: Low.

Sea level rise	Medium (because brackish species are already under cultivation and not too sensitive to saline intrusion).	Likelihood of finding species tolerant to salinity variations: High (e.g. brackish water species).
Ocean acidification	Medium (because of unpredictable changes in plankton composition and impaired calcification in several marine species, although this is only applicable to marine aquaculture).	Ability of the subsystem to cope with acidification: Low (especially for shellfish farming). Likelihood of international GHG emission instruments resulting in reduced acidification: Low.
Landslides	High (because of physical watercourse blockage and altered drainage impairing production activities).	Ability of the subsystem to recover from change and production to remain feasible: Low (especially in poorly managed areas, rivers and watersheds). Potential for the subsystem (aquaculture activities and production) to be considered alongside other watershed activities (e.g. forestry, mining, agriculture) in integrated land management: Low (not currently done, conflicts).
Volcano eruptions	High (because of changed landscapes, water flows and habitats products and functions, altered chemical composition of water bodies).	Ability of the subsystem to cope with abrupt changes: Medium (limited to steep slopes). Ability of the subsystem to find alternative sources of water: Medium.
Earthquakes	High (because of changed landscapes, water flows and habitats products and functions).	Ability of the subsystem to cope with abrupt changes: Medium (rare occurrence). Ability to receive enough early warning applicable to fisheries: Low.
Tsunamis	High (because of physical alteration caused to inland areas adjacent to coasts).	Likelihood of complete alteration of inland habitats supporting aquaculture operations: Low (except for coastal floodplains subject to marine inundation). Ability to receive enough early warning applicable to fisheries: Low.

[1] Marine systems are not explicitly considered here unless indicated, as still very underdeveloped in the Caribbean.

Assessment of human adaptive capacity

Table A2.2.2
Assessment of the adaptive capacity of the Caribbean fisheries stakeholders

Sensitivity colour coding: red = high, orange = medium, green: low.
Human adaptive capacity colour coding: red = low, orange = medium, green = high.

Socio-economic exposure **(what are the risks that you face)** ***risk of… / exposure to…)*** **(Assumed high)**	**Sensitivity of socio-economic system (how important is that risk if it occurs?)** **(NB: current sensitivity)**	**Adaptive capacity (how capable are people to deal with that risk? How well prepared are they?)**
Governments and national institutions - high level (incl. DRM/CCA authorities, Fisheries and aquaculture authorities and other ministries)		
Lack of rationalization between CCA and DRM initiatives across the region Beneficiaries consultation fatigue Declining visibility in fisheries and aquaculture in CCA and DRM plans Overlapping jurisdictions between ministries, conflicts (e.g. Ministries of Finance allocating funds to CCA and DRM) Short-term funding of donor-sponsored programmes and projects Lack of coherence among vulnerability assessment initiatives	High (because fisheries and aquaculture concerns and stakeholders (fishers, aquaculturists) might become even less accounted for in preparedness and management plans, disbursement of funds not always timely or appropriately targeted).	Potential of current processes to enable the coordination of the CARICOM response to climate change: High (done through the CCCCC). Potential convergence between CCA and DRM among agencies: High. Potential to integrate fisheries and aquaculture in CCA and DRM: Medium (through the Caribbean Community Common Fisheries Policy, though no clear trend of who should drive initiatives). Ability to coordinate action among CCA and DRM stakeholders: Medium (some ongoing but duplication of work). Ability of fisheries and aquaculture authorities to engage in CCA and DRM planning and legislation development: Low (lack of knowledge/awareness, low profile of CCA and DRM in fisheries and aquaculture development plans). Ability of fisheries and environment ministries to better coordinate and manage their initiatives (in relation to aquaculture in particular): Low. Ability of CCA and DRM agencies to communicate climate change risks to fisherfolk and aquaculturists: Low (poor communication). Potential of research and cooperation to influence CCA and DRM in fisheries and aquaculture: Medium. Ability to collect, integrate and share fisheries data, including ecosystem valuation information for better management: Medium (some initiatives ongoing, though would require more coherence). Ability to mobilize funds from alternative (non-donor) sources or use these as a complement to government-funded initiatives: Unclear. Potential to harmonize vulnerability assessment methodologies: Medium

		(some methodologies adapted to the Caribbean already available, though not systematically implemented). Potential capacity of management agencies to network and embrace "resilience" at larger, landscape scales: High (successful examples in Eastern Caribbean). Potential to promote MPAs for adaptation rather than only conservation: Unknown. Potential to create protection infrastructures (e.g. sea defences) that act as a new habitat: High (already happening in some places).
Fisherfolks and their communities		
Personal safety and loss of life at sea Variations in catch Loss of gear and equipment Damage to fishers' communities infrastructures Disruption to work patterns and income Flushing of chemicals in waterways causing health hazards	High: (because of) Low awareness of climate change and disaster risks, limited options to secure an alternative and steady income stream, independently of disasters and climate change, limited compensation provided when disaster strikes.	Ability to fish in all conditions and all year round: Medium (but important risks are taken to secure a catch and a living). Ability to access insurance schemes: Low. Access to safety at sea schemes: High. Ability to adapt fishing techniques to modified environments (e.g. fish around coastal defences): Medium (already practiced in places). Ability to receive individual compensation in case of disaster: Low (compensation only for registered employees). Ability to plan for preparedness (ex-ante planning) at the household level: Low (poverty, limited education, few alternatives that are also vulnerable (e.g. tourism), reluctance to change way of life). Ability to engage in less vulnerable/more stable income generating activities: Low (e.g. tourism). Ability to voice the needs of fishing communities in post-disaster reconstruction efforts (e.g. specific land tenure rights and traditions in the case of inland fisheries): Low (assumed from text). Ability to access suitable health care and facilities: Unknown.
Aquaculturists		
Damage to aquaculture infrastructures in disasters Loss of income Decrease in shellfish farming (acidification)	High (because of low awareness of climate change and disaster risks, low preparedness).	Willingness to engage in CCA and DRM schemes: Low (conflict of interest with agriculture-based activities, no preparedness). Willingness to diversify production to include species tolerant to a broader range of conditions: Medium (technically possible, but capital

		requirements unknown and markets and demand for new species uncertain and likely to vary with location).
Women / gender		
Prevention of mobility among activities Erosion of influence in the community and the fishing industry Growing number of poor female-headed households (post-disaster) Damage to seamoss culture operations	Medium (because of strict division of labour (e.g. Jamaica), unsystematic mainstreaming of gender in regional frameworks, marginalization of poor female-headed households. But overall influential voice of women in community planning and decisions).	Ability to maintain engagement: High. Potential for men to equally partake and benefit from CCA and DRM and reconstruction: Medium (men seem to require just as much attention as women, in the Caribbean context). Ability to receive post-disaster compensation: Unknown.
Insurance providers -		
Increased frequency of disasters and related claims	High (because of increased number of claims and higher compensation costs).	Potential to tailor insurance schemes for fisheries and aquaculture: Low.
Private providers (development of climate-proof technologies)		
Lack of incentives for technological innovations adapted to fisheries and aquaculture High prices of new technologies Economic and financial losses	High (because of limited resources of fishers/aquaculturists to purchase new equipment).	Capacity to invest in the development and promotion of technological innovation for fishers and aquaculturists: Low (too capital intensive and high-risk for micro-enterprises without the necessary back-up). Potential to target technological development funds and awards as incentives for innovation: Medium (some in place but still insufficient).
Donor community (incl. large NGOs, International organizations, etc.)		
Lack of credibility (mis-targeted, too short or fragmented interventions) Lack of visibility of fisheries and aquaculture in regional programmes	Medium (because of incomplete results and outcomes despite some progress, missing out on economies of scale).	Potential to extend the duration of interventions/programmes: Medium (one example set by CARIBSAVE and some attempts at strategic programming).
Post-harvest sector (incl. landing facilities, processing plants, etc.)		
Inadequate inclusion in CCA planning Damage to coastal infrastructures (e.g. coastal markets) Reduced space for vessel	Medium (because some areas already allocated for safe vessel landing but small-scale fishing vessels excluded from private marinas for shelter, inadequate hauling equipment available).	Capability to climate-proof facilities: Medium (some in place, though incomplete or inconsistent in many places).

haul-out for maintenance		

A2.3 Mekong delta

Assessment of ecological resilience

Table 2.3.1
Assessment of the ecological resilience of the Mekong delta
Sensitivity colour coding: red = high, orange = medium, green: low.
Ecological resilience colour coding: red = low, orange = medium, green = high.

Climate exposure **(Assumed high)**	**Sensitivity of Ecosystem (how is it pushing the system to threshold limits?)**	**Ecological Resilience (is this making the system more or less adaptive? how capable is the system of dealing with these changes?)**
Mekong delta		
Sea level rise	Medium (because increased salinity is expected to be mitigated by the expected increase in dry season flows[1]).	Ability of the Mekong River to flush salt away with increased flows: Low (trend in reduction of downstream flows). Ability of the flora and fauna of the Mekong Delta to cope with more saline conditions: Low (unlikely, although this could widen the habitat range of brackish/salt-tolerant species). Ability of lower floodplains to retain enough moisture to support farming activities: Unknown.
Increased flooding (increased flood pulse with rising average water level, increased flood duration) Dry season flooding (dam water release) Variations in monsoonal weather patterns (wetter years)	Medium (because of biodiversity and fishery productivity linked to flood pulse, disturbances to habitats and activities, compensated by reduction in dry season stress thanks to hydrological regulation (water releases from dams)).	Ability of the natural hydrological cycle to main habitats, in particular fringe habitats, and productive activities (land and water based): Medium (some production and habitat niches may be exploited).
Typhoons and storms	High (because of disturbances to habitats and activities).	Ability of the natural hydrological cycle to main habitats and productive activities (land and water based): Medium (some production and habitat niches may be exploited).
Changes in land use Upstream deforestation	High (because accompanied with increased use of pesticides, environmental pollution, modifications of natural habitats and soil chemistry).	Ability to manage and use acid sulphate soils for productive purposes: Low (bad for shrimp and rice).

	High (because of multiple drivers causing it, and because of the capacity of forests to regulate hydrological cycles).	
Dam construction and increased upstream water abstraction (for domestic, agricultural, energy, industries) Variations in sediment transport and deposition	High (because projections show sharp increases in water demand, high influence of hydroelectric dams on flows, habitats, flora and fauna). High (because this increases the risk of erosion and inundation).	Ability of the delta to withstand/adapt to artificial/man-imposed water regimes (redistribution of storage water during dry seasons): Unknown. Ability of the delta morphology to evolve: High (a very dynamic environment already, but consequences and impacts of such an evolution/transformation are difficult to predict – modelling recommended).
Capture fisheries		
Sea level rise	High (because of increased salinity moving up river).	Probability of stenohaline (truly freshwater) fish species tolerating variations in salinity: Low (unlikely). Probability of fish species moving/remaining upstream where salinity levels are lower: Medium (assumed from the text). Ability of fish species to adapt to migrate to new spawning grounds and nursery habitats: Low (in particular because of the dams). Ability of current biodiversity and catches to maintain a buffer against the effects of climate change: Uncertain.
Increased damming of the river	High (because of barriers to fish migration).	Capacity to implement fish lifts and ladders appropriate for the diversity and magnitude of the fishery: Low (assessment by Dugan *et al.* 2010).
Finfish/Pangasius aquaculture		
Sea level rise and saline water intrusion Reduced water availability Poor water quality (untreated wastewater from urban centres in the delta, irrigation return flows, pesticide runoff	Medium (because some strains exhibit some tolerance). Low (because farms rely on year-round surface water from the river). Medium (because Pangasius farms abstract untreated water in the river and canal	Potential to develop new strains of salt-tolerant catfish: High (ongoing research and trials).

from other agricultural activities)	networks of the delta, but dry season flows are expected to increase in the next 20 years (+2% to 6%), improving water quality, in particular in the dry season).	
Decrease in feed availability Dependence of smaller-scale operations on wild fish for feed	High (because prices of raw feed materials are particularly volatile and overall increasing in response to diminishing supplies, and wild fish catch are likely to decline overtime owing to a range of factors (overfishing, climate change etc.)).	Ability of finfish (snakeheads, climbing perches etc.) farming systems to increase their independence from wild/trash fish-based feed: Medium (ongoing progress towards a switch at local/farm scale, although feed provision is also threatened by climate change at a global level).
Dependence on wild caught broodstock	High (because regular partial or full replacement of broodstock is typical practice and broodstock is very sensitive to basin developments (e.g. dam barriers)).	Ability of catfish production to remain independent from wild seed: High. Ability of hatcheries to switch to hatchery-reared broodstock: Medium.
Risk of spread of an invasive rice pest species (the Golden Apple Snail) Risk of establishment and interference of exotic introduced species with wild populations	High (because of direct effect on animals and difficulty to eradicate once established).	Ability of production systems to prevent escapees (following storm/typhoon destruction of facilities): Medium. Capacity of farms to strictly control escapees: Medium (some measures exist, but risk is not null).
Shrimp aquaculture		
Acid sulphate soils Excessive flooding Prolonged drought conditions Variations in pond salinity	High (because of sensitivity of shrimps to acid conditions, growth impediments).	Ability to cope with / manage production on acid sulphate soils: Low. Ability of shrimp production to maintain its use of a range of production "niches" (e.g. integrated in rice or mangrove systems, intensive/semi-intensive etc.): High.

Increased use on non-indigenous species (*L. vannamei*) Risk of emergence of new diseases, e.g. EMS in white shrimp	Low (because productions systems can be relatively easily adapted to *L. vannamei* (c.f. experiences in other Asian countries). Medium (because good management practices can help prevent and contain the disease).	Ability of shrimp (*Macrobrachium rosenbergii*) farming systems to increase their independence from wild/trash fish-based feed: Medium (ongoing progress towards a switch at local/farm scale, although feed provision is also threatened by climate change at a global level). Ability of production systems to prevent escapees (following storm/typhoon destruction of facilities): Medium.
Rice culture/farming systems		
Change in soil conditions and water quality	Medium (because salinity is a problem in lower reaches, but pesticides and industrial contaminants have not yet been detected).	Potential of farming systems to increase their efficiency in harnessing the nutrients deposited by annual floodwaters: Medium. Ability to manage production on acid sulphate soils: Low (very difficult). Potential of salt-resistant rice varieties to grow: High (research and trials are ongoing).

[1] Opinions and analyses seem to diverge regarding the effect of dam constructions on downstream dry season flows: De Silva (forthcoming) (case study report) and ICEM and DAI (2013) report a decrease, whereas Halls and Johns (2013) report an increase.

Assessment of human adaptive capacity

Table 2.3.2
Assessment of the adaptive capacity of the Mekong delta stakeholders
Sensitivity colour coding: red = high, orange = medium, green: low.
Human adaptive capacity colour coding: red = low, orange = medium, green = high.

Socio-economic exposure (what are the risks that you face) ***risk of… / exposure to…)*** **(Assumed high)**	**Sensitivity of socio-economic system (how important is that risk if it occurs?)** **(NB: current sensitivity)**	**Adaptive capacity (how capable are people to deal with that risk? How well prepared are they?)**
Mekong River Commission -		
Increased pressure for hydropower development Marginalization of the MRC by its member states from major basin development decision-making Criticisms of NGOs and CSOs for not being responsive to livelihood	High (because of weak governance and limited financing).	Ability to adequately represent the interests and water users' demands and needs of downstream countries, in particular Viet Nam (Mekong delta): Unknown. Ability of the commission to improve the capacity of riparian governments to manage and adapt the climate change: Medium (already planned by the MRC). Ability to bring various stakeholders

concerns.		together towards deliberative governance: Low (not happening at present). Ability to create trust, converging interests, strong regional identify, government institutions for successful transboundary governance: Medium (some recent developments, e.g. MRC Summit 2010, MRC-commission SEA, facilitator of discussions re. Xayaburi dam in the Lao People's Democratic Republic). Ability to raise awareness and stand up by the conclusions of the Strategic Environmental Assessment to differ the building of dams by at least a decade: Uncertain. Potential to re-discuss the terms of the 1995 Agreement on the Cooperation for the Sustainable Development of the Mekong River Basin and its Procedures and Guidelines for Action: Low (according to current state of affairs).
Fisherfolk and their communities -		
Displacement	Medium (because of hydropower development. However, it may not be felt as drastically as in the upper reaches of the basin, and may provide new opportunities for fishing).	Ability to access new reservoirs and seize new fishing opportunities: Medium. Ability to manage conflicts with existing local dwellers over access to new fishing grounds: Medium (assumed from the text).
Decrease in catches from the "white fish" group (migratory species, which constitute approx. 87% of Mekong fish spp. and 50% of the catch) and challenging of current livelihoods.	High (because of slow moving water conditions created by reservoirs (if hydropower development goes ahead)). Medium (because forecasted increases in aquaculture industry is expected to provide employment (+100,000 in 20 years), although mostly outside of the delta).	Willingness and ability of fisherfolk to secure employment outside capture fisheries (including in aquaculture, either as employee (more likely) or in their own operations (less likely)): Medium.
National authorities: Ministry of Natural Resources and Environment (including climate change), Ministry of Agriculture and Rural Development (aquaculture), Ministry of Fisheries, Irrigation authorities and hydropower investors		
Declines in food production in the Mekong delta (the most productive area of Viet Nam).	High (because of increased pressure (nationally, regionally and internationally) to integrate climate change concerns and	Ability to implement adaptation actions included in the National Target Program to Respond to Climate Change (approved in 2008): Medium. Ability to enforce national

Declines in earned revenues from rice and seafood exports. Conflicts of interests and objectives among national authorities.	adaptation in national policies and developments, as well as negative impacts on the "rice ball" Viet Nam).	environmental regulations: Low (assumed according to text). Ability of all levels of administration to adjust / climate-proof their policies: Medium (has happened for the shrimp sector in Viet Nam, and likely to happen in other sectors, but over long periods of time). Ability of authorities to systematically introduce (and enforce) risk assessment and prevention measures for prevention of escapees for ex. : Medium (lessons to be learnt from elsewhere, growing awareness of risks despite current paucity of information). Ability to consult farmers in climate change adaptation policy development: Unknown. Potential to refocus climate issues from a macro-scale to a micro-scale: Unknown. Ability of irrigation authorities and hydropower investors to demonstrate their commitment to environmental review and livelihood safeguards: Medium (some progress made but still insufficient). Willingness of the authorities to prioritize small scale, less experienced farmers, owning fewer farming units, for adaptation measures: Low (assumed as this group may not be high on their agenda). Likelihood of Vietnamese Government to prohibit the introduction of exotic species for aquaculture, and to provide adequate enforcement, controls, etc.: Low (e.g. the ban imposed by the Cambodia Fishery Administration is not enforced). Ability to withstand pressure from retailers and importers re. catfish: High (documented in De Silva and Phuong, 2011).
Finfish farmers		
Decreased production Decreasing profit margins	High (because of salinity intrusion and sensitivity of fish to saline conditions). High (because farmers are operating on very tight budgets to remain competitive, in particular if small-scale, and intensive operations are highly sensitive to market prices	Willingness of farmers to adopt new farming practices: Low (documented). Willingness of farmers to adopt salt-tolerant catfish species: High (will entail minimal disruption and no relocation, cost-effective). Potential of snakehead to be cultivated as an alternative or complement to catfish: High (although dependent on market demand). Potential of tilapia to be cultivated and

	fluctuations and production conditions (e.g. diseases)).	to cope with changing market demand: High. Ability to access adapted insurance schemes: Low. Capacity to meet certification schemes for improved management (in particular with regard to effluent discharges): Medium (because "producers at the smaller-scale end of the spectrum will be at a disadvantage in attempting to attain certification for a variety of reasons", according to Belton *et al.*, 2011: 296). Length of time before catfish production no longer meets importing countries' food safety standards: Unknown. Potential of the sector to integrate vertically while minimizing the loss of livelihoods for small and medium-scale operators: Low (doubtful both can be simultaneous). Ability of farmers to self-organize in clusters/associations: Medium (ongoing efforts). Capacity of farmers to modify production infrastructures (e.g. construct flood control embankments and deeper ponds): Medium. Capacity of farmers to invest in improved hatchery technology and management, water treatment systems (filtration, aeration): Medium.
Shrimp farmers		
Reduction in water availability Competition for water with other users Risk of crop loss due to diseases	High (because of intensive hydrological engineering of the Mekong delta).	Ability of traditional shrimp farmers to voice their needs for water: Low (water management dominated by priorities of prevention of saline water intrusion and prolonged flooding). Ability of shrimp farmers to adjust the timing of harvests in response to unexpected conditions: High (relatively simple measures, yet with a high cost if not carried out towards the end of the cycle). Ability of Better Management Practices to incorporate climate response measures (= "climate-proof BMPs"): Medium. Ability of farmers to access adapted insurance schemes: Low. Ability of farmers to access information and plan their production cycles ahead: Low. Ability of farmers to self-organize in clusters/associations: Medium (ongoing efforts). Ability of farmers to implement

		preventive measures to avoid the occurrence of diseases: Medium (voluntary codes for better management practices are in place but may not be sufficient).
Land/rice farmers		
Declining soil fertility	High (because of trapping of sediments upstream in dams (if built)).	Ability to keep adapting farming practices to changing soil conditions and fertility, without losing farming traditions that are part of the heritage of delta farmers: Medium (irrigation development may provide new opportunities to farmers).
Decline of cultural farming heritage and traditional practices	Medium (because farming practices have evolved to adapt to prevalent hydrological regimes).	Ability of farmers to keep switching among their many occupations: High (part of traditional heritage).
Declining rice yields	High (because of water pollution and other environmental factors threatening production in the delta, and because a decrease in average rice yields of just a few percent per hectare has been shown to have a dramatic impact on the Lower Mekong Basin food security and food production).	Ability of farmers to access a wider range of livelihood options, training and information: Unknown. Ability and willingness of rice farmers to switch to shrimp or euryhaline finfish culture: Medium (trend already observed, though the long term implications of such a transformation remain to be established). Ability to access adapted insurance schemes: Low (very expensive, even for land farmers). Ability of farmers to adjust their sowing and planting dates (i.e. shift calendar for planning and harvesting dates, using early maturing varieties and fertilizer) to reduce the yield gap: Medium (assumed from the text).

A2.4 Benguela Current

Assessment of ecological resilience

Because this part of the assessment focuses on the ecological vulnerability of the Benguela Current ecosystem, the subsystems considered here are the different fisheries it supports (Table 4.1). Stakeholders and national considerations are included in the assessment of the socio-economic vulnerability of the Benguela Current (Table 4.2).

Table 2.4.1

Assessment of the ecological resilience of the Benguela Current fisheries

Overall (in bold): extracted from vulnerability analysis tables of Hampton (2012a) on the basis of the scores attributed to the sensitivity and adaptability of the fisheries considered (the "adaptability" score, used here for "ecological resilience", does however include a human dimension which could not be separated from it).

Sensitivity colour coding: red = high, orange = medium, green: low.

Ecological resilience colour coding: red = low, orange = medium, green = high.

Climate exposure	Sensitivity of	Ecological Resilience (is this making

(Assumed high)	Ecosystem (how is it pushing the system to threshold limits?)	the system more or less adaptive? how capable is the system of dealing with these changes?)
***Demersal (hake) and pelagics (including small pelagic fish and horse mackerel)*[1]**		
Movement of ABF Benguela Niños ENSO events Warm water intrusions from the North	Low (because of South African hake demersal trawl fishery low sensitivity to environmental perturbations, the variety of species).	Ability of the small pelagic fishery to recover from overfishing: Low (stocks have shown no sign of recovery). Potential of fisheries to respond positively to new management measures that account of environmental factors and uncertainty in them: Medium (though difficult to ascertain).
Increase in low oxygen water on shelf and inshore Increased occurrence of Benguela Niños Increase in upwelling-favourable winds Increase in cross-shelf temperature gradient Increased influence of Agulhas Current	High (because of hake susceptibility to intrusions of low oxygen in water [effect on recruitment and force fish off the bottom], changes in sardines distribution, large-scale changes in production, distribution and species composition of phyto and zooplankton communities [used as feed by pelagic communities]). **Overall: Medium**	Ability of sardines and anchovy to maintain their spawning, survival and dispersal and movement of pre-recruits into inshore nursery areas: uncertain. **Overall: Medium**
***Crustaceans and line fishery (excluding hake longline)*[2]**		
Increase in low oxygen water inshore Increase in low oxygen water on shelf Increased influence of Agulhas Current	Medium (because of sensitivity to variability in the Southern Benguela and Agulhas-induced perturbations (mortalities)). **Overall: Medium**	Potential of depleted fisheries to respond positively to new management measures: Low (some have shown no sign of recovery since collapse). Ability of crustaceans to move further to the East: Medium (past trend could be pursued). **Overall: Medium**
***Horse mackerel fishery*[3]**		
Movement of ABF Benguela Niños ENSO events Increase in low oxygen water inshore	Medium (because of sensitive to movements of the Angola Benguela Front, but no evidence of long-term shift in distribution). **Overall: Medium**	Potential of the horse mackerel fishery stabilize: Medium (fishery at a low level since it appeared in the Namibian fishery after the sardine collapse, but no reported large changes in abundance over the past two decades). **Overall: Low**
Recreational fisheries		

Increase in low oxygen water inshore Increased influence of Agulhas Current	**Overall: Low**	Ability of recreational fisheries to withstand environmental perturbations: High. **Overall: High**

[1] Usually targeted by large-scale industrial fishers.
[2] Usually targeted by small-scale commercial fishers.
[3] Usually targeted by artisanal fishers.

Assessment of human adaptive capacity

Table 2.4.2
Assessment of the adaptive capacity of the Benguela Current fisheries stakeholders[1]
Sensitivity colour coding: red = high, orange = medium, green: low.
Human adaptive capacity colour coding: red = low, orange = medium, green = high.

Socio-economic exposure (what are the risks that you face) *risk of… / exposure to…*) **(Assumed high)**	**Sensitivity of socio-economic system (how important is that risk if it occurs?)** **(NB: current sensitivity)**	**Adaptive capacity (how capable are people to deal with that risk? How well prepared are they?)**
Industrial fishers (Namibia, South Africa), including onshore processing industries		
Overfishing Overall decline and large variations in catches	Medium (because of long-term investment). Medium (because wealthy industry but reliance on long-term investments constraining adaptation).	Willingness to abide by stricter management regimes: Medium (assumed from text). Ability to switch target species according to change in abundance and distribution: Medium (can be made without changing vessel or gear substantially, but difficult for specialized, high investment gear). Options to target unexploited or under-exploited resources: Low. Ability to fish further out: High (possible thanks to the range and endurance of vessels). Ability to implement risk management strategies to cope with bad weather due to rising sea temperatures) and declines in catches: High. Capacity to train/update the labour force skills: High.
Artisanal fishers (Angola, South Africa)		
Safety at sea risks	High (because of longer periods spent at sea, small	Capacity to change fishing techniques: low (small vessels).

Overfishing, reduced catches, economic hardship	and poorly maintained vessels). High (because of ongoing poverty and few organized social support structures).	Ability to reduce catch and dependence on fishing: Low (limited or no other sources of income, isolation). Ability to access education: Low (limited opportunities for further education). Ability to diversify income streams: Low (limited opportunities, hostile environment (e.g. desert), weight of traditions and culture). Capacity to move to new fishing grounds: Low (limited mobility). Potential to rely on community support at times of hardship: High (prevalence of culture of support in particular in Angola). Potential of small-scale fishers to gain recognition: Medium (potential to seize new allocation rights but unlikely to acquire a legal status).
Recreational fishers (South Africa, Namibia)		
Decline in catches	Low (because recreation fishers are a relatively wealthy group and do not depend on fishing for their livelihoods).	Ability to move to new fishing spots: High (availability of transport, technology).
National authorities: Ministries (and, by extension, national economies), research institutions, fisheries managers		
Decline in contribution of foreign exchange from fishing to national economies Increased expenses to protect and rebuild coastal communities' infrastructures affected by extreme weather events Criticisms for top-down, biased management plans (favouring industrial fisheries versus artisanal ones)	High (because of dependence of two national economies on fisheries and importance for food securities and livelihoods and influence of globalization and global economic downturn (exchange rates) on domestic fisheries). High (because of competition for scarce resources within national governments and remoteness (hence higher costs) of some communities).	Possibility of national management plans to maintain their reliance on good information sources and stay fine-tuned to stock situations: High. Ability to implement economic measures for mitigating effect of lower catches: uncertain. Ability to develop new legislation and compliance measures to improve fisheries management effectiveness: Medium (although a-priori uneven ability between SA, Namibia and Angola). Capacity of national and local authorities to better plan and invest in infrastructures: Medium. Ability of fisheries plans to account for the interests of artisanal fishers and fence off industrial fisheries: High (occurring in places, especially with the involvement of local communities).

		Potential of research to predict accurately environmental changes and inform responses: Medium (data limitations but ongoing efforts).
Fish processors		
Decline in fish quantities to process	Medium.	Ability of processing industries to improve processing and distribution efficiencies, and to find new market openings for different species: High. Ability of processing factories to anticipate closures, and of their workers to cope: Low.
Benguela Current Commission		
Lack of visibility on the regional and international scene.	Medium (because it is new).	Potential to implement and enforce climate-flexible management plans: High (impetus behind Benguela Current Commission, forthcoming GEF project etc.).

[1] For the sake of analytical summary, and despite the oversimplification this may entail, countries are associated with the main fisheries and categories of fishers they have.

A2.5 Pacific Islands Countries and Territories

Assessment of ecological resilience

Because this part of the assessment focuses on the ecological vulnerability of the tropical Pacific, the subsystems considered here are the different fisheries it supports. Stakeholders and national considerations are included in the assessment of the socio-economic vulnerability of the area (Table A2.5.2).

Table 2.5.1
Assessment of the ecological resilience of the aquatic resources of the tropical Pacific
Sensitivity colour coding: red = high, orange = medium, green: low.
Ecological resilience colour coding: red = low, orange = medium, green = high.

Climate exposure **(Assumed high)**	**Sensitivity of Ecosystem (how is it pushing the system to threshold limits?)**	**Ecological Resilience (is this making the system more or less adaptive? how capable is the system of dealing with these changes?)**
Tuna fishery and food webs it depends upon		
Increasing sea surface and ocean temperature Decreasing nutrient supply	*Plankton*: High (because food web organisms' metabolism and respiration increase with temperature and reduction of supply of nutrients needed for primary production). *Tuna*: High (because of impact during larval and juvenile stages).	Ability of *food web organisms* to adapt to temperature and nutrient supply variations: Medium (high for temperature, low for nutrients). Ability of *tuna* to follow its preferred temperature range and preys: High (highly mobile).

Shallowing of the Mixed Layer Depth (MLD)	*Plankton*: High (because of effect on size and biomass of phytoplankton).	Ability of *phytoplankton* to adapt to reduced nutrients and maintain food web efficiency: Low.
Upwelling	Low (for phytoplankton).	Ability of *phytoplankton* to benefit from higher iron concentrations: High.
Lower solar radiation (increased cloud cover)	*Plankton*: High (because of photo-inhibition influences on photosynthesis)	Ability of *phytoplankton* to maintain productivity under increasing cloud cover: High (primary production also determined by nutrient concentrations and potential to redistribute to appropriate depths).
Decline and westward expansion of oxygen-minimum waters in the eastern Pacific basin	*Plankton*: High. *Tuna*: Medium (because of variations in tolerance of low oxygen levels among species).	Available “manoeuvring margin” of *plankton* organisms to cope with lower oxygen without decreasing productivity and/or migrate: High. Capacity of tuna to change the ocean layers they use: High (but may have effects on distribution and catchability).
Increased ocean acidification	*Plankton*: Low (because calcareous organisms comprise only a minor part of the plankton). *Tuna*: Medium (because of tolerance to a wide range of dissolved CO2 concentrations and pH).	Potential for replacement of affected species by others, with unknown consequences on the overall food web: Unknown. Capacity of tuna to adapt to ocean acidification: Unknown.
Changes in ocean circulation (currents)	*Tuna*: High (because of influence on location of spawning grounds, larvae dispersal and prey distribution).	Capacity of *tuna* to seek out suitable conditions for spawning and productive areas: High.
Corals reefs, mangrove and seagrass habitats		
Increase in sea surface temperature Increase in air temperatures	*Corals*: High (because of thermal stress (bleaching reaction)). *Mangroves*: Medium (because of) increased mortality of younger seedlings. *Seagrass*: High (because of risk of respiratory demands exceeding photosynthesis).	Potential for a shift in *coral* species composition (heat-tolerant species): Medium (progressive dominance of heat-tolerant species with unknown consequences). Capacity of *corals* to increase *Symbiodinium* in tissues to withstand the heat: Medium (only up to +1.5°C). Potential of *mangroves* to cope with increased evapotranspiration: High re. air temperature (reduce leaf stomata apertures) but low re. SSF. Capacity of *seagrass* to colonize deeper areas: Low (constrained by high light requirements).
Changes in solar radiation (cloud cover)	*Corals*: High (because of bleaching effects of photo-synthetically	Capacity of *corals* to photo-adapt: Medium (only for a period of 5-10 days).

	active radiation and ultraviolet radiation). *Mangroves*: Medium (because of sensitiveness to increases in light, but not decreases). *Seagrass*: High (because of effect on photosynthesis and composition of seagrass communities).	Capacity of *mangroves* to adapt to higher solar radiation: Low. Capacity of *seagrass* to morphologically and physiologically adjust to short-term reduction in light: High.
Increased ocean acidification	*Corals*: High (because of inability to build skeletons in conditions of reduced aragonite saturation levels). *Mangroves*: Low *Seagrass*: Low (because already experiencing pH variations).	Capacity of *corals* to maintain a positive reef carbonate balance: Low (no evidence of adaptation to lower concentrations of carbonate ions occurring under acidification). Capacity of mangroves and seagrass to cope with acidification: High.
Increases in cyclones and storm intensity	*Corals*: High (because of physical damage). *Mangroves*: High (because of foliage damage and stability erosion). *Seagrass*: High (because of turbidity).	Capacity of *corals* to recover from breakage and rebuild: Medium (some evidence of full recovery taking 10-50 years for some species). Capacity of *mangroves* to resprout and of seedlings to recruit from adjacent areas: High. Capacity of *seagrass* to repropagate: High (though lower for species without deep rhizomes).
Increases in rainfall	*Corals*: High (because turbidity and lower salinity impedes photosynthesis and encourages algal growth). *Mangroves*: Low. *Seagrass*: Medium (because of turbidity, sedimentation, delivery of nutrients and pollutants).	Capacity of *coral* species to tolerate higher sedimentation: Medium (possible in some, not others, and at a high energy cost). Capacity of *mangrove* to regulate evapotranspiration: High. Capacity of *seagrass* to adapt to lower water quality: Low.
Sea level rise	*Corals*: Low. *Mangroves*: High (because of) implications for plant growth, respiration and survival. *Seagrass*: High (because of limits to photosynthesis and growth).	Capacity of *corals* to respond to rising sea level: Uncertain. Ability of *mangroves* to migrate landward: Medium (possible but dependent on topography, hydrology etc. and may not keep the pace with the rate of sea level rise). Likelihood of *seagrass* to migrate: Medium (unlikely deeper, but possible landward).
Changes in ocean circulation and nutrient delivery	*Corals*: High (because of reductions in connectivity and net	Capacity of *corals* to cope with increased stratification (causing reductions in net primary production) and changing availability of nutrients and current strengths: Low. Capacity of *mangroves* adapt to changes in nutrient levels: High. Ability of *seagrass* to cope with increased growth of epiphytes: Medium.

	primary productivity). *Mangroves* and *Seagrass*: Medium (because of fertilization).	
Coastal (including invertebrates and reef fisheries) and freshwater (FW) fisheries (including estuarine fisheries)		
Increased sea surface/water temperature	*Coastal*: Medium (because of tolerance to short-term temperature changes). *FW*: Medium (because of effects on larval fish growth, metabolic rates etc. although some fish may benefit).	Ability of *coastal fisheries* larvae to settle outside their normal distribution range: Medium (more difficult for reef fisheries). Capacity of *FW species* to tolerate higher temperatures: Low (especially if combined with other stressors, e.g. pollutants etc.).
Increased ocean acidification	*Coastal*: Medium (because of sensitivity beyond threshold levels to rebuild shells).	Capacity of *coastal fisheries* to adapt to ocean acidification: Low (lack of genetic variation necessary for rapid adaptation).
Changes in ocean circulation, rainfall and river flow	*Coastal*: Medium (because of reduced opportunities for larval dispersal). *FW*: Medium (because of both positive and negative effects on water quality and habitat availability).	Capacity of *coastal fish post-larvae* supply to replenish resident coastal fisheries populations: Medium (though surrounded with uncertainty). Capacity of *FW fisheries* to maintain productivity: Medium (positive in places, uncertain in others).
Increases in turbidity	*FW*: High (because of damage to the gill epithelium of fish and effect on respiration).	Capacity of *FW species* to adapt to increased turbidity: Medium (dependent on the species and prevailing environmental conditions).
Changes in dissolved oxygen	*FW*: Medium (because depends on preferred species habitats and tolerance to oxygen depletion).	Capacity of *FW species* to exploit a range of physiological and behavioural changes to adapt to low oxygen conditions: High.
Progressive habitat degradation, loss of structurally complex and diverse habitats	*Coastal* and *FW*: High (because of role of range of habitats in providing food and shelter).	Capacity of *coastal fisheries* species to deal with reduced biodiversity, increased predation and mortality risks: Medium (higher for generalist species that can switch to alternative habitats or food sources, lower for niche species). Capacity of *FW fisheries* to exploit new niches and floodplain habitats: Medium (dependent on removal of barriers to movement, maintaining vegetation in good condition).
Farmed aquatic organisms (coastal and freshwater)		
Tilapia & carp - Increase in water	High (because of indirect effect on pond	Ability of tilapia and carp to benefit from changing environmental conditions: High

temperature Increase in rainfall Sea level rise Increased intensity of cyclones	water temperature and exchange, and direct effect on growth and reproduction).	(growth rate improvements, extension of possible farming locations, possible to alter farming systems, though more easily carried out in extensive than intensive systems).
Milkfish – Increase in water temperature Increase in rainfall Sea level rise Increased intensity of cyclones Ocean acidification Habitat degradation	High (because of effect on growth and reproduction).	Ability of tilapia and carp to benefit from changing environmental conditions: High (growth rate improvements, extension of geographical range, farming seasons and pond areas – although expensive).
Pearls – Increase in sea surface temperature Increase in rainfall Ocean acidification Sea level rise Increased intensity of cyclones	High (because of susceptibility to pathogens and parasites, effects on nacre deposition and pearl quality). High (because of risk of mass mortality). High (because of effect on spat survival, shell calcification). High (because of infrastructure exposure to damage).	Flexibility and ability of pearl farming operations to manage the growing environment and control the growth cycle: High (but likely to increase operational costs).
Shrimp – Increases in water temperature Increase in rainfall Sea level rise	High (because of risk of temperature-related diseases). High (because of effect on pond drainage and shrimp growth).	Ability of shrimps to benefit from changing environmental conditions: High (higher growth rates and improved yields). Flexibility of shrimp operations to embrace new environmental conditions: High (pond design and construction, wider range of cultivable species)
Seaweed – Increase in sea surface temperature Ocean acidification Sea level rise Increase in rainfall Increased intensity of cyclones	High (because of stress-induced effect on plant growth, outbreaks of epiphytic filamentous algae and tissue necrosis). High (because of reduction in number of possible farming locations). High (because of effect on production infrastructures).	Ability of seaweed to benefit from higher levels of carbon dioxide (resulting from ocean acidification): Medium. Scope for adaptation of seaweed farming by shifting production to higher latitudes: Low.
Marine ornamentals – Increase in sea surface temperature Increase in rainfall Ocean acidification	High (because of effect on growth and survival of corals and clams).	Potential of marine ornamental production to benefit from improved water exchange and nutrient supply to oligotrophic sites: Medium. Potential to transfer operations inland in

Habitat degradation Sea level rise	 Medium (because of effect on water exchange).	controlled recirculating systems: High. Potential to develop markets for more tolerant coral species: High.
Freshwater prawns – Increases in water temperature Increase in rainfall Increased intensity of cyclones	Medium (because of effect on growth, provided temperatures remain within thermal limits and on geographical farming range).	Potential of freshwater farming systems to benefit from increased availability of freshwater, expansion of freshwater habitats: High. Scope to modify pond infrastructures to enhance adaptation: High.
Marine fish – Increase in sea surface temperature	Medium (because of operations' environment is controlled, but sensitivity of juveniles and adult growth to higher temperatures).	Ability of marine fish production systems to adapt: High (projected climate change effects can be taken into account in planning/design stages, fish can be fed more to counteract higher metabolic rates).
Sea cucumbers – Increase in air and sea surface temperature Increase in rainfall Ocean acidification Habitat degradation (seagrass)	High (because of risk of mortality).	Potential of hatchery and pond system design to control the production environment: High.
Trochus – Increase in sea surface temperature Increase in rainfall Sea level rise Increased intensity of cyclones Ocean acidification	High (because of low tolerance levels to salinity variations). High (because of effect on availability of rock pool habitats). High (because of high mortality of dislodged trochus). Unknown.	Potential of restocking programs to form breeding populations: Medium.

Assessment of human adaptive capacity

Table 2.5.2
Assessment of human adaptive capacity of the PICTs
Sensitivity colour coding: red = high, orange = medium, green: low.
Human adaptive capacity colour coding: red = low, orange = medium, green = high.

Socio-economic exposure (what are the risks that you face) ***risk of… / exposure to…)***	**Sensitivity of socio-economic system (how important is that risk if it occurs?)** **(NB: current sensitivity)**	**Adaptive capacity (how capable are people to deal with that risk? How well prepared are they?)**

(Assumed high)		
Governments		
Declines in the contribution of fisheries and aquaculture to national economies Growing gap between fish required to meet national demand and available fish from coastal fisheries.	High (because of limited options to generate wealth and jobs in other sectors). High (because of population growth and increasing demand for fish).	Capacity of PICTs governments to size the benefits of the transfer of capacity from DWFNs and increase in license fees: High. Capacity of governments to generate revenues from expected improvements in tuna catches: High. Potential to overcome constraints for the development of onshore processing facilities: Low (especially in smaller PICTs where freshwater supplies and environmental capacity are limited and freight charges high). Capacity of governments to maintain a stake in the management of highly migratory tuna stocks: High (long history of regional cooperation and establishment of the Western and Central Pacific Fisheries Commission - WCPFC). Capacity of governments to capitalize on and promote aquaculture development, including development of national legislation to encourage investment and implement global standards for aquatic animal health: Medium (commodities to drive this development remain to be identified). Capacity of governments to implement strict reductions in fishing pressure to restore the productivity of coastal stocks: Medium (job losses could be compensated by opportunities in near-shore pelagic catches). Potential to contain and manage human pressures on coral reefs (e.g. reduction of sediments from catchments): Medium (expected to limit coral loss and growth of macro-algae by 2035, doubtful after). Capacity of governments to climate-proof landing and shore-based infrastructures: Medium (possible but at high costs). Capacity of governments to address non-climate drivers before climate change impacts become limiting: Medium (involves development

		decisions and tough choices). Capacity of governments to lift social barriers (e.g. cultural norms, gender issues) to broaden communities' access to alternative livelihood strategies: Uncertain. Capacity of governments to harmonize governance, e.g. national agencies' objectives, and implement priority adaptation measures: Low (limited national capacity). Capacity of governments to effectively implement the vessel day scheme (VSD): Medium (will require some improvements in governance). Capacity of governments to develop and main an economic partnership agreement (EPA) with the EU: Medium (will require compliance with EU food safety requirements and IUU fishing regulations). Potential for strengthening the implementation of the Community-based ecosystem approach to fisheries management (CEAFM): High (already in place, comprehensive, facilitated by some existing customary marine tenure).
Tuna fishers		
Altered distribution of tuna stocks	Medium (because benefits in the east, disadvantage in the west).	Capacity of fishers to meet the costs of upgrading fleets (incl. safety at sea) and up-scaling operations to catch projected increased catches in tuna: Medium (may be very costly). Capacity to mitigate the effects of increasing fuel costs (catching and transporting fish): Medium.
Artisanal fishers (coastal)		
Declines in productivity of the demersal fish and invertebrate components of coastal fisheries	Medium (because likely to be compensate by increase in catches of near-shore pelagic fish (skipjack and yellowfin Tuna) in the east).	Capacity of artisanal fishers to transfer effort to near-shore fisheries: High (relatively easy modification of their fleets and capture methods). Capacity to seize new employment opportunities in near-shore fisheries: High.
Aquaculture producers (coastal and inland)		
Declines in efficiency of their production systems	Medium (because some species (freshwater + milkfish) are not very	Ability to seize opportunities provided by the expansion of FW aquaculture: High.

	sensitive and are actually likely to benefit, others (marine, brackish) are more sensitive to variations in production conditions and likely to suffer).	
Local populations/communities		
Shortage in fish protein supply Increased prices of fish commodities Progressive erosion of sea/fishing traditions, culture and values	High (because of dependence on fish as main protein source and fishing/seafaring activities as a way of life).	Ability to access reasonably priced fish (from aquaculture and coastal fisheries) and to satisfy households' consumption needs: Medium (shortfalls per person projected in some PICTs but climate change not expected to have a large additional effect on the availability of fish per person). Ability to seize income-earning opportunities created by additional employment in tuna (near-shore fisheries) and freshwater aquaculture: High. Capacity of communities to seize the benefits of government-promoted and spontaneous adaptations: High (tradition of community self-help).

A2.6 Latin America

Assessment of ecological resilience

Table 2.6.1
Assessment of ecological vulnerability of the aquatic resources of Chile and other selected areas of Latin America
Sensitivity colour coding: red = high, orange = medium, green: low.
Ecological resilience colour coding: red = low, orange = medium, green = high.

Climate exposure **(Assumed high)**	**Sensitivity of Ecosystem (how is it pushing the system to threshold limits?)**	**Ecological Resilience (is this making the system more or less adaptive? how capable is the system of dealing with these changes?)**
Chilean aquaculture systems [1]		
Increasing sea surface and ocean temperature Variations in dissolved oxygen levels Sea level rise	High (because of increased risk of hypoxia and anoxia (mortalities), increased growth of micro-algae). Medium (because of need for relocation of some operations, but minimal impact on	Potential to move production units to suitable areas to maintain yields: Medium (possible but costly, suboptimal, at least in the short-term). Capacity of production units to adapt their design and structures to new environmental conditions: Medium (possible but costly).

Increase in wind speed Decrease in rainfall Decline in distribution and availability of feed fisheries for fishmeal and fish oil. Ocean acidification	farmed resources per se). High (because of effect of alterations in the water column and of ocean stratification on availability of food for filter-feeders, decrease in growth rates). High (because of reliance of the salmon industry on freshwater (for smolt production) and of the invertebrate industry on good water quality (salinity and estuarine conditions)). High (because these fisheries are very sensitive to changes in winds, currents and ocean stratification). Medium (because of decreases in yield due to stress vary among cultivated species and locations [north vs south]).	Capacity of production systems to cope with interferences non-cultivated species present in the ecosystems: Medium (assumed from the text). Capacity of the salmon industry to refocus its activities on smolt production according to the availability of freshwater: High. Capacity of aquaculture systems to access alternative protein sources for feed: Medium (ongoing research and alternative sources of protein available, though likely at a cost). Potential of production systems to address the effects of acidification on flesh production: Low (difficult to control and adapt to).
Chilean capture fisheries (Jack mackerel, hake, sardine, anchovy)		
Increase in sea surface temperature Alteration of oceanic currents and upwelling Variations in oxygen concentrations Change in rainfall and river flows Increase in frequency and intensity of ENSO events Variations in lower trophic level productivity	Medium (because of different degrees of sensitivity according to the species concerned). High (because of effect on the movement and availability of feed fisheries and on life cycles and on the functioning of the ecosystem). Medium (because of some variations observed in landings according to various salinity levels). High (because of dependence on healthy food webs and ecosystems and demonstrated	Capacity of anchovy recruitment to withstand variations in sea temperature: High. Potential of sardine catches to remain stable under higher sea temperature: Low (production reported to decrease with higher temperatures). Capacity of the four main species to cope with variation in currents and oxygen levels: Unknown. Capacity of species to withstand variation in salinity: Unknown (for region Centre-South of Chile). Likelihood of all species fisheries to remain within ecological thresholds of survival: Low.

Overfishing	relationship with fish mortality). High (because stocks are already overexploited and in a critical state, and low recruitment (exception of common sardine)). High (because) stocks of anchovies are already overexploited and in a critical state, low recruitment).	Capacity of populations of Jack mackerel and hake fisheries to cope with current fishing, in addition to other pressures: Low. Capacity of sardine stocks to cope with fishing pressure: High. Capacity of populations of anchovies to respond positively to new management and to recover quickly: Uncertain (unconvincing evidence, for example: Lehuta *et al.*, 2010).
Fisheries of the Gulf of Fonseca		
El Niño-related events	High (because of both positive and negative direct impacts on ecosystem productivity).	Ability to adapt: unknown.
Change in currents	High (because of both direct positive and negative impacts on tuna and other fisheries).	Ability to adapt: unknown.
Earthquakes	High (perception that marine fauna moved away from the coast).	Ability of affected fisheries to recolonize the inshore maritime platform: Unknown (though likely to be low given that the earthquake happened over 10 years ago).
Coastal habitat modification (mangroves)	High (because of the reliance on mangroves as nursing areas).	Potential of affected fisheries to migrate to find alternative reproductive and nursery grounds: Medium (has been reported in some instances, in the context of other drivers). Potential application and enforcement of water laws: Medium.[2]
Aquaculture systems of the Gulf of Fonseca		
El Niño-related events, incl. temperature increases, decrease in dissolved oxygen, increased pH.	*Shrimp*: Medium. *Tilapia*: Medium. *Carp*: Low.	Capacity of farmed species to cope with a variation in growing environment: Medium (assumed).
Increased hurricane occurrence.	*Shrimp*: High (because of prior mangrove destruction, lack of protection of shrimp ponds and direct impact on production units due to changes in salinity).	Potential for protective *shrimp* pond designs to be constructed: Medium (possible though likely to be costly).
Droughts and inundations	*Shrimp*: High (because of importance of water quality). *Tilapia*: Medium. *Carp*: Medium.	Capacity of farmed species to cope with a variation in growing environment: Medium (assumed).

Disease epidemics	*Shrimp*: High (because of new nature of some diseases in the area, e.g. Taura syndrome).	Internal capacity of shrimp to respond to disease, in particular in closed systems: Low (after Bush *et al.*, 2010).
Mangrove ecosystems of the Gulf of Fonseca		
Increase in farmed area, including shrimp ponds	High (because of pressure from shrimp farms and sugarcane plantations on common mangrove property, lack of enforced protective legislation – Beitl, 2011 in the case of Ecuador).	Potential for habitat restoration and reforestation: Medium.[2]
Hurricanes	High (because of destructive impact of past hurricanes, e.g. Mitch).	Potential for habitat restoration and reforestation: Medium.[2]
Overexploitation of wood resources	High (because of reliance as fuel source, habitat degradation).	Potential for habitat restoration and reforestation: Medium.[2]

[1] Scallops and red seaweed (north coast of Chile), salmonids, mussels and gracilaria seaweed (southern coast of Chile).
[2] Martinez-Ortiz and Bravo-Moreno (2013) proposed a series of general adaptation measures, without specifying the likelihood or realism of their future implementation. It was therefore arbitrarily estimated that the capacity to implement these measures and their potential future implementation was "medium".

Assessment of human adaptive capacity

Table 2.6.2
Assessment of human adaptive capacity in Chile and the Gulf of Fonseca
Sensitivity colour coding: red = high, orange = medium, green: low.
Human adaptive capacity colour coding: red = low, orange = medium, green = high.
Aqua = aquaculture sector, *Capt* = capture fisheries sector.

Socio-economic exposure (what are the risks that you face) *risk of… / exposure to…*) (Assumed high)	**Sensitivity of socio-economic system (how important is that risk if it occurs?) (NB: current sensitivity)**	**Adaptive capacity (how capable are people to deal with that risk? How well prepared are they?)**
National governments (and the economies they represent), and authorities responsible for fisheries and aquaculture management		
Declines in the contribution of fisheries and aquaculture to national economies	High: (because of) importance of these fisheries and aquaculture in the national economy (Chile).	*Aqua:* Capacity of the Chilean government to amend laws and regulatory frameworks to support the relocation of farms: Medium (existing rigid frameworks that may be difficult to modify). *Aqua:* Capacity of the Chilean government to develop a plan of action for adaptation that is coherent with

		national development objectives and with the National Strategy on Climate Change: High (assumed given national circumstances and capacity). *Aqua:* Potential of national Chilean authorities to develop training programmes and financial schemes accessible to all aquaculture producers, in particular small ones: High (assumed given national circumstances and capacity). *Aqua:* Capacity of national Chilean authorities to promote the diffusion of information on climate change adaptation to all aquaculture producers, in particular small ones: High (assumed given national circumstances and capacity). *Capt:* Potential of the Convention on the Conservation and Management of High Seas Fishery Resources in the South Pacific Ocean, of which the Republic of Chile is a signatory, to promote the sustainable management of Jack mackerel: Medium (part of efforts towards management of overcapacity and sustainable harvesting). *Capt:* Ability to provide State assistance programmes targeted at small-scale fishers: High. *Capt:* Capacity of the Chilean government to implement policy, legal and management measures to protect fisheries and fishers under threat: High (lessons learnt from the past J. mackerel crisis and current change from TAC to maximum catch limit per vessel (MCLV) management).
Inter-ministerial/agency conflicts over the use of natural resources. Declines in provision of coastal ecosystem services provided by mangroves	High (because of added pressure from the agricultural sector). High (because of the protective and productive role of mangroves).[1]	Capacity of governments to implement better information and data collection systems to monitor stocks: Medium.[2] *Aqua*: Capacity of Gulf of Fonseca governments to implement conflict resolution mechanisms: unknown. Capacity of governments to replant mangroves and enforce legislation for the protection of mangrove areas: Medium.[2]
Industrial aquaculture operators (Chile)		
Global economic downturn, drop in international demand for seafood Drops in production	High (because of dependence on seafood exports). Medium (assumed).[3]	Capacity of industrial aquaculture operators to develop and implement contingency plans: High (96% of them currently have one). Capacity of industrial producers to

High prices of fishmeal and fish oil	High (assumed).	adjust the capacity of production units: unknown. Capacity to access and carry out research in alternative sources of protein: High.
Artisanal/small-scale aquaculture producers (Chile)		
Further shrinking in national demand Recurring environmental and disease problems affecting yields High prices of fishmeal and fish oil	High (because of dependence on the activity for employment). High (assumed). High (assumed).	Capacity of small producers to invest in technology developments, including fishmeal alternatives: Low (80% of producers have not introduced innovations over the last 3 years). Capacity of small aquaculture operators to develop and implement contingency plans: Low (only 33% of them possess one). Ability of small producers to access external sources of funding and ICTs: Low. Capacity of small producers to access government incentives: Low (only 6% benefit from governmental incentives). Capacity to access information and implement better management practices: Unknown. Capacity of small producers to find alternative sources of employment: Unknown.
Shrimp farmers (Gulf of Fonseca)		
Diseases Post-hurricane infrastructure damage	High (because of direct effect on yields and income). High (because of immediate destruction on ponds).	Ability of shrimp farmers to benefit from analysis labs and anticipate disease: Low (no such labs exist in El Salvador, no information provided for other countries). Capacity of farmers to improve pond management at minimal cost to reduce disease occurrence and increase yields: High (easily adjusted production conditions, e.g. decrease in stocking densities, increase in water exchanges etc.). Capacity of farmers to restart production and recover production levels: Medium (pre-Mitch hurricane production levels were recovered after approx. 3 years in Honduras). Capacity of farmers to access early warning systems (to enable early harvest for ex.): Unknown.
Fishers, both artisanal and industrial of the Gulf of Fonseca		
Overexploitation Declines in landings	High (because of dependence on this activity).	Potential to find alternative sources of employment in emerging activities (e.g. ecotourism industry): Medium. Capability of fishers to increase the

		value of their catch: Low (proposed as an adaptation measure for implementation in the context of the Gulf of Fonseca).
Processors (including manufacturers of fishmeal, canned and frozen products)		
Stagnation of exports, declining demand for fish products. Dependency of the processing sector on only four main species*.	Medium (because of possible risk of factories overcapacity, yet compensated by current high international prices)	Capacity of processors to diversify their outputs to respond to increases in demand for fish products: High (past switch from J. mackerel used for fishmeal to it being used in canneries). Potential to seize opportunities provided by high international prices, new markets for fishmeal and development of aquaculture elsewhere: High.
Employees of the processing industry (salaried)		
Changes in fishery resources Restructuration of the industry	High (because of risk of redundancies following earthquake and tsunami and crisis of Jack mackerel).	Capacity of employees of industrial fleets and fishmeal factories to bounce back in case of redundancy: High (high education levels, high incomes, relative protection). Capacity of employees of processing plants to bounce back in case of redundancy (excl. fishmeal): Low (lower education levels, unstable employment conditions).
Gender discrimination (in particular with regard to earnings)	High.	Capacity of women from the processing sector to increase their participation and seek alternative employment in other subsectors than seafood processing plants: Low (deeply engrained gender divide, likely existence of culture biased against women in other branches of the fisheries sector, e.g. as in fishmeal processing industries).

[1] MA (2005); Barbier (2012).

[2] Martinez-Ortiz and Bravo-Moreno (2013) proposed a series of general adaptation measures, without specifying the likelihood or realism of their future implementation. It was therefore arbitrarily estimated that the capacity to implement these measures and their potential future implementation was "medium".

[3] "Assumed from text" indicates that this could not be inferred from the available sources of information, and is a personal appreciation.

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