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Synthesis of current knowledge, adaptation and mitigation options

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Chapter 21: Climate change and aquaculture: vulnerability and adaptation options

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KEY MESSAGES

- Vulnerability assessments of aquaculture to climate change show that a number of countries in both high and low latitudes are highly vulnerable.
- In general, vulnerability is directly associated with governance, from national to farm level.
- Global assessments of vulnerability must be complemented by investigations at more localized levels, where specific aquaculture practices, environmental conditions and interactions with stakeholders and communities are taken into account.
- Longer-term climate-driven trends, e.g. increases in temperature and salinity, are more readily addressed than increasing climate variability and extreme events. With regard to the former, there is time to plan and implement adaptation measures (e.g. development and adoption of strains better adapted to increasing salinity conditions) while it is more difficult to plan for surprises and short-term events, such as storm surges. Adaptation strategies must, however, encompass the short-term, which also facilitates understanding, and use inclusive, bottom-up approaches involving stakeholders.
- Vulnerability reduction depends on broader adaptation measures beyond the aquaculture sector and there is a strong need to integrate aquaculture management and adaptation into watershed and coastal zone management.
- Ultimately, it is at the farm level where vulnerability reduction efforts converge; vulnerability assessments should be as fine-grained as resources allow in order to be relevant to farmers.
- Capacity building in addressing vulnerability and improving adaptation to climate change, especially among target stakeholders, is an investment that more than pays for itself.
- Specific measures to reduce aquaculture vulnerability in accordance with the ecosystem approach to aquaculture include:
  - improved management of farms and choice of farmed species;
  - improved spatial planning of farms that takes climate-related risks into account;
  - improved environmental monitoring involving users;
  - improved local, national and international coordination of prevention and mitigation actions.

21.1 INTRODUCTION

Climate change brings about both challenges and opportunities for global food systems and those engaged in them. The challenges are principally experienced by the global poor in low latitudes while the opportunities in general are realized at higher latitudes (IMF, 2017). This applies to aquaculture as much as to any other food sector, whether it is viewed in isolation, as a livelihood component or as an element of a landscape level food production system.

21.2 MODELLING AND FORECASTING

21.2.1 Introduction to models and aquaculture vulnerability

Vulnerability of aquaculture to climate change can be equated to short- or long-term risk and a variety of indices are available to enable evaluation of the likely response of aquaculture systems and the industry to the probable effects of climate impacts (FAO, 2015). Assessment of the vulnerability of aquaculture and associated industries in the value chain, including the many dependent livelihoods, can be considered at a range of scales from single farms or small areas - typically at a high spatial resolution - to global assessments where resolution may be at the scale of countries or features such as drainage basins. Given the uncertainties about future developments and data limitations, broad scale more generalised assessments of vulnerability often aim to show relative differences between geographic areas in terms of ranked vulnerability scores rather than attempting to quantify results. In addition to providing useful tools for decision-makers, such broad vulnerability assessments (VAs) can be an objective starting point for guiding further and more detailed research in specific areas.

For aquaculture, models designed to assess vulnerability need to take into account multiple drivers including relevant aspects of the physical environment, chemical environment, infrastructure, access to goods and services and economic factors. Importantly, societal factors are also key to VA and in consequence assessments should be interactive and collaborative, involving stakeholders and end-users. Having identified factors leading to high vulnerability, responses to climate change must centre on boosting adaptive capacity and resilience, of both the communities and the ecosystems on which they depend.

Vulnerability (V) can be expressed as a function of exposure to climate change (E) and sensitivity to climate change (S), and adaptive capacity (AC), as in the following equation:

$$V = f\,(E, S) - AC \qquad \text{[equation 21.1]}$$

where better adaptive capacity can mitigate the negative effects of exposure and sensitivity. This method was implemented in the Intergovernmental Panel on Climate Change (IPCC) third assessment report (McCarthy *et al*., 2001) with similar approaches being used in a range of vulnerability studies (e.g. Allison *et al*., 2005, 2009; Metzger, Leemans and Schröter, 2005; O'Brien *et al*., 2004; Schröter, Polsky and Patt, 2005).

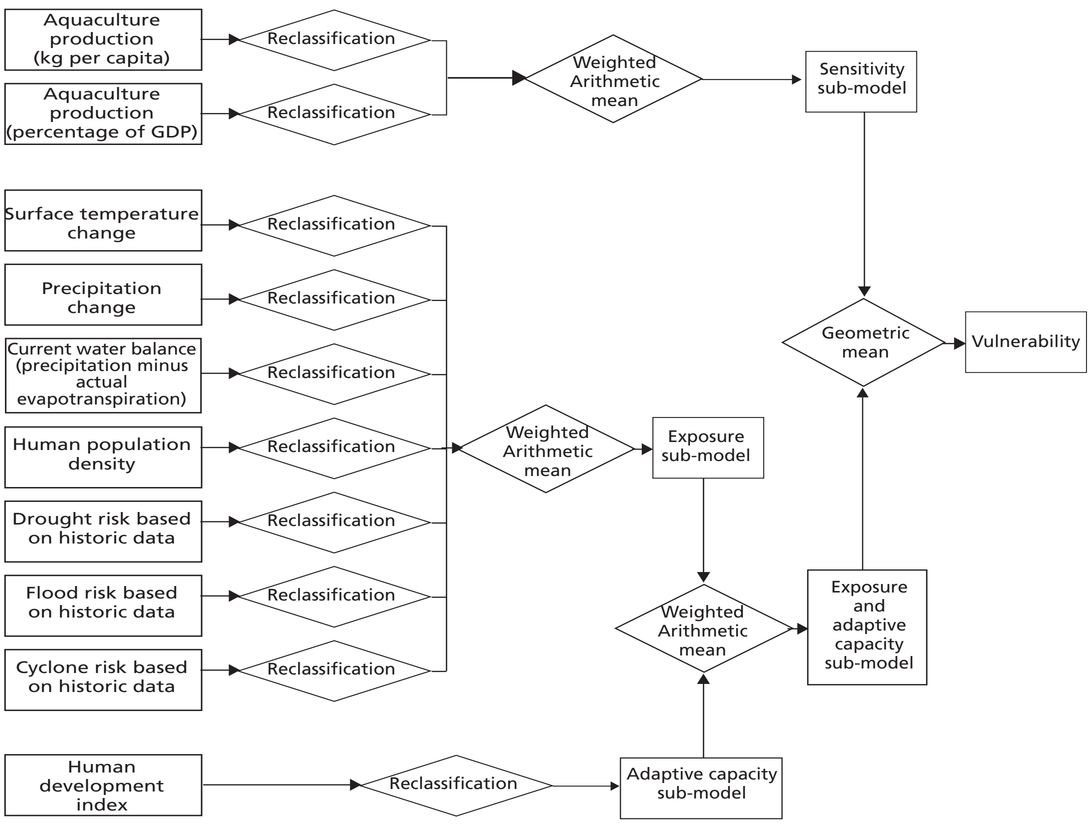
21.2.2 Modelling aquaculture vulnerability at the global scale

To date there have been few attempts to compare vulnerability between regions at the global scale in relation to the aquaculture or fisheries sectors. Allison *et al*. (2005, 2009) used a range of indicators to rank nations in terms of vulnerability of livelihoods dependent on capture fisheries to climate change. Rather than representing key variables using only simple numerical indices, and recognising that vulnerability is location specific, Handisyde *et al*. (2006) used geographic information systems (GIS) to represent and combine qualitative and quantitative data spatially for aquaculture at the global scale. In addition to allowing for visual interpretation of results and intermediate stages of the modelling process, GIS enables the combination of multiple key variables available at varied resolutions and scales while maintaining as much detail as possible.

Handisyde, Telfer and Ross (2017) developed a significantly improved hierarchical model structure to that of 2006 in which a range of indicators was pooled to represent the sensitivity, exposure and adaptive capacity components, which were then combined to indicate vulnerability. A schematic overview of the model structure and potential input variables is provided in Figure 21.1. Not all inputs are necessarily used in every scenario as choice of inputs and weightings (level of influence within the model) vary depending on the aquaculture environment (fresh, brackish or marine) being evaluated. When considering aquaculture trends and adaptive capacity, Handisyde, Telfer and Ross (2017) considered that extrapolation of future scenarios over a time period relevant to climate change would be likely to introduce considerable inaccuracies into the modelling process. The authors therefore used current indicators of adaptive capacity in association with future climate scenarios to provide the best proxy when comparing vulnerability at a broad scale.

FIGURE 21.1

Schematic representation of model used by Handisyde, Telfer and Ross (2017). Primary variables (leftmost column) were standardised to a continuous 0-1 scale with higher numbers representing greater vulnerability, greater exposure, greater sensitivity or lower adaptive capacity. This results in a continuous series as opposed to the assignment of a number of distinct classes (see Handisyde, Telfer and Ross, 2017, for further details)



Sensitivity

In the model developed by Handisyde, Telfer and Ross (2017) sensitivity is represented at a national scale and indicates the importance of aquaculture to people within a country and thus how sensitive their livelihoods may be to climate impacts on the aquaculture sector. Two metrics are used; aquaculture production quantity (kilograms per capita) and aquaculture production as a percentage of gross domestic product (GDP), in both cases excluding aquatic plants. The quantity of aquaculture products per capita represents the physical size of the aquaculture sector within a country assuming that, generally, nations with a high per capita production of aquaculture products are likely to have a greater percentage of their population whose livelihoods' are either directly or indirectly linked to aquaculture production. Consideration of the value of aquaculture production as a percentage of GDP gives an indication of its importance to the economy, which is dependent on the scale of aquaculture production within a country in terms of physical quantity, the relative value of the aquaculture products and the size of the national economy. In richer countries it is likely that not only will aquaculture make a smaller contribution to overall wealth but also people are more likely to have economic alternatives and thus be more able to adapt to potential impacts and change.

Exposure

Exposure to climate change in the model is viewed as the relative extent of change in climate drivers between locations rather than attempting to quantify changes. Future changes in annual mean temperature and precipitation are considered while water balance (precipitation minus actual evaporation) is used as a proxy for current water availability. The inclusion of population density assumes that higher population densities may exacerbate the potential impacts of climate change through mechanisms such as increased requirements for resources including water (Murray, Bostock and Fletcher, 2014), and greater environmental pressure, e.g. through increased pollution.

The frequency of past climate extremes in the form of cyclones, drought and flood events is used as a proxy for future risk on the assumption that any increases in the intensity or frequency of these extremes are likely to be particularly significant in areas where they are already common (Handisyde *et al*., 2006; Islam and Sado, 2000). The global mean warming used for the model was 2 °C, derived from multiple global circulation models and based on a year 1990 base point. Data from an increasingly large number of climate models are now available and when operating at the global scale, the combined results from an ensemble of climate models typically show greater skill in reproducing the spatial details of climate when compared to a single model. The authors considered that multiple warming scenarios were not relevant to this assessment as the aim was to show relative differences between global areas, rather than quantify vulnerability in relation to a given amount of warming.

Adaptive capacity

Adaptive capacity was based on the United Nations Human Development Index (HDI) (Malik, 2013), which is a globally complete and consistent data set based on the combination of health (life expectancy at birth), education (a combination of mean years of schooling and expected years of schooling) and living standards (gross national income per capita). The components of the HDI are transformed to a 0–1 scale before being combined as a geometric mean. Gall (2007) undertook an evaluation of global indices in relation to social vulnerability and, while generally critical of many indices, concluded that the HDI outperforms the others examined despite being based upon a smaller number of variables.

21.2.3 Forecasting aquaculture vulnerability at the global scale

Handisyde, Telfer and Ross (2017) show images of the model assessments of overall vulnerability as well as sensitivity, exposure and adaptability separately for each culture environment (Figure 21.2a, b, c). The greatest variability is seen between countries as a result of the more strongly weighted sensitivity and adaptive capacity components where data are available at the national level. Variability within countries results from the exposure component and provides a useful indication of where the effects of changing climate may be most extreme. Handisyde, Telfer and Ross (2017) also showed combinations of exposure and adaptive capacity giving an indication of vulnerability that is independent of the scale of a region's aquaculture production. While those results are not shown here, examination of the exposure and adaptive capacity components in isolation is useful when considering all countries involved in aquaculture, regardless of current extent, and is potentially valuable when considering nations where aquaculture production is currently low but where an indication of vulnerability is needed. It is also possible that where aquaculture is less significant countries may be less able, or prepared, to invest in adapting to impacts on production.

The vulnerability of freshwater aquaculture is greatest in Asia, with its large aquaculture sector. Viet Nam is the most vulnerable country followed by Bangladesh, The Lao People's Democratic Republic and China (Figure 21.2a). Within the Americas, Belize, Honduras, Costa Rica and Ecuador appear most vulnerable. Uganda is indicated as the most vulnerable country in Africa followed by Nigeria and Egypt. It is worth noting that while African countries are ranked quite low in the overall VA because of relatively low current levels of aquaculture production, many also have low levels of adaptive capacity.

For brackish water production, Viet Nam, again, has high vulnerability scores, as does Ecuador. Egypt with its aquaculture production within the Nile delta and Thailand with its significant brackish water production of crustaceans also feature strongly (Figure 21.2b). When considering adaptive capacity alone in relation to countries currently engaged in brackish water aquaculture at any level, Senegal, Ivory Coast, Tanzania and Madagascar score highly (indicating low adaptive capacity) in Africa, as do India, Bangladesh, Cambodia and Papua New Guinea within Asia.

The highest vulnerability in relation to marine aquaculture was recorded for Norway and Chile, perhaps unsurprising because of the large relative size of their respective industries (Figure 21.2c). Interestingly, in terms of per capita aquaculture production and contribution to GDP, the Faroe Islands is significantly above Norway and Chile but could not be included in the assessment because of lack of data. Within Asia, China is most vulnerable in terms of mariculture production, followed by Viet Nam and the Philippines. In Africa, Madagascar is most vulnerable, while in the Americas, Peru emerges most strongly after Chile. Mozambique, Madagascar, Senegal and Papua New Guinea all emerge as countries involved in mariculture but with low adaptive capacity (Figure 21.2c).

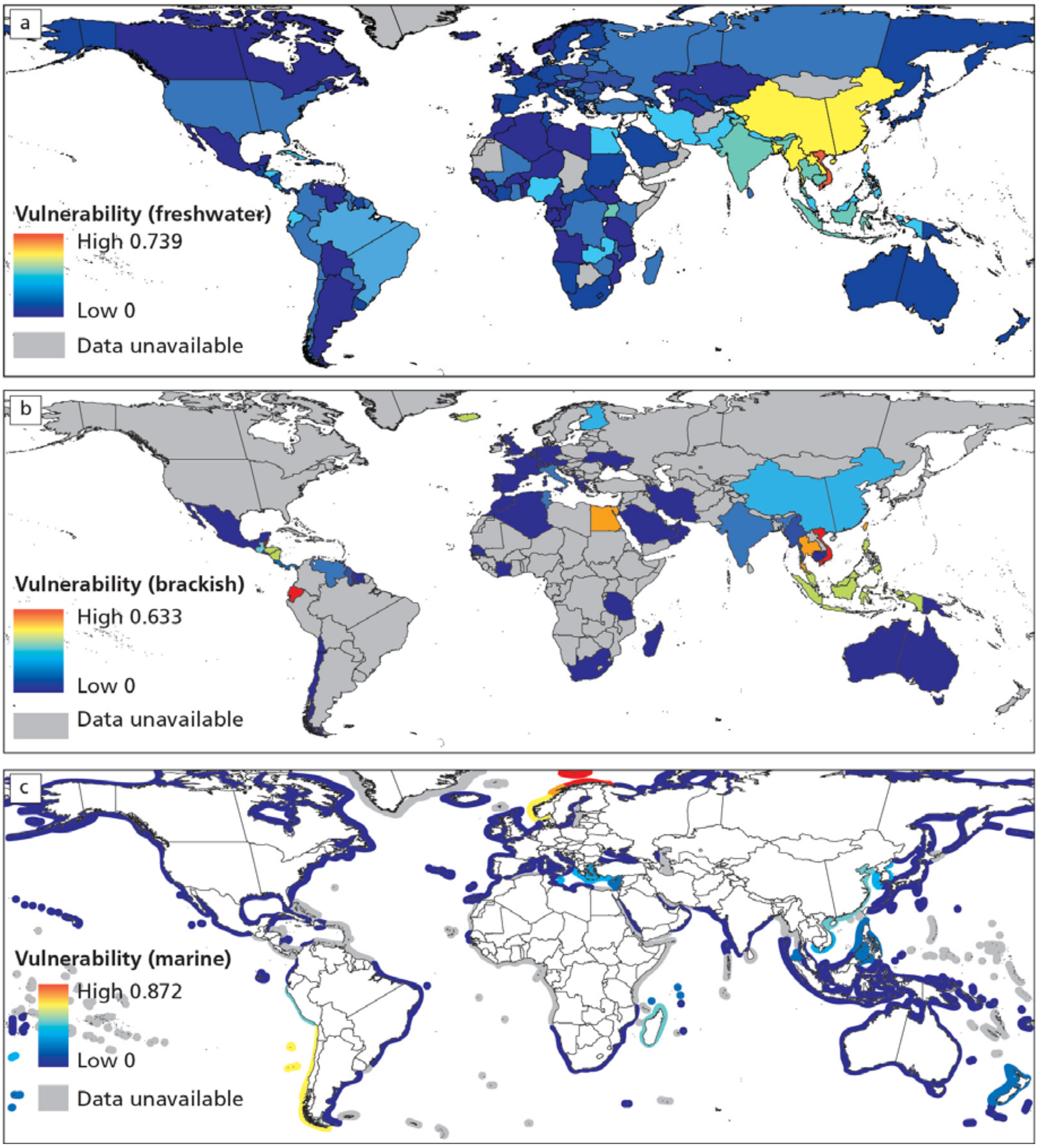
Table 21.1 shows the averaged scores for the 20 most vulnerable countries for each culture environment along with their sensitivity, exposure and adaptive capacity drivers. The values are relative rather than absolute and no direct comparison of values can be made between different culture environments because of the varied data used in the respective models. However, a high ranking of countries for more than one environment is significant. Due to their substantial aquaculture industries, a number of Asian countries, Viet Nam, The Lao People's Democratic Republic, Bangladesh and to a lesser extent China, were considered most vulnerable to impacts on freshwater aquaculture production. Viet Nam along with Ecuador was also ranked as highly vulnerable in terms of brackish water production. Norwegian and Chilean mariculture were indicated as most vulnerable to climate change influenced by the extremely high per capita levels of production and despite both being well developed countries. Other locations with high mariculture vulnerability include China, Viet Nam, the Philippines, Thailand, Greece and Madagascar. Viet Nam is notable in achieving high vulnerability scores across all three culture environments.

Handisyde, Telfer and Ross (2017) improved on the only previous global evaluation of vulnerability of aquaculture-related livelihoods to climate change (Handisyde *et al*., 2006), notable advancements being the application of a more sophisticated set of climate change projections in the form of a multi-model ensemble of data and improvements in data processing by using a geometric rather than arithmetic mean to reduce the likelihood of countries with very small aquaculture sectors (low sensitivity) being considered as highly vulnerable in situations where metrics for exposure and adaptive capacity scored highly. In addition, the impacts of exposure and adaptive capacity could be considered in isolation to give insights into vulnerability, irrespective of the size of the national aquaculture industry.

Global assessment of vulnerability provides a highly valuable indication of where aquaculture-related climate change effects may occur and where further research would be valuable. Clearly, global studies should be complemented by investigation at a more localized level where specific aquaculture practices and environmental conditions can be considered, as well as taking into account specific interactions with stakeholders and communities. While locally focused studies may identify potential negative impacts, they are also better able to evaluate positive benefits arising from changing climate on specific aquaculture practices, thus guiding future development and adaptation within the sector.

FIGURE 21.2

Relative vulnerability† of aquaculture to climate change at global level††; a) in freshwater, b) in brackish water, c) in the marine environment (shown as a 50 km buffer zone from coasts). From Handisyde, Telfer and Ross (2017)



† The colour range indicates vulnerability relative to other areas within the same culture environment and is not intended to be a quantitative means of comparing vulnerability between culture environments.

†† In some cases no data is available on aquaculture production, at any scale, in FAO FishStatJ (2013) statistics.

TABLE 21.1

Average vulnerability values (V) highest to lowest), sensitivity (S), exposure (E) and adaptive capacity (A) for the 20 most vulnerable countries in relation to the freshwater, brackish and marine environments. (see equation 21.1)

Freshwater[1]					Brackishwater[2]					Marine[3]				
	V	S	E	A		V	S	E	A		V	S	E	A
Vietnam**	0.690	0.999	0.395	0.519	Ecuador	0.558	0.950	0.277	0.355	Norway	0.307	0.809	0.357	0.000
Lao People's Democratic Republic	0.561	0.583	0.358	0.633	Vietnam**	0.557	0.664	0.368	0.519	Chile	0.273	0.486	0.045	0.209
Bangladesh*	0.544	0.498	0.436	0.676	Belize*	0.524	0.758	0.312	0.389	China**	0.160	0.068	0.347	0.393
Myanmar	0.514	0.462	0.318	0.702	Egypt	0.483	0.528	0.426	0.450	Madagascar	0.156	0.044	0.194	0.725
China**	0.504	0.616	0.452	0.393	Taiwan*	0.460	0.267	0.383	1.000	Vietnam**	0.123	0.036	0.232	0.519
Taiwan*	0.404	0.207	0.363	1.000	Thailand**	0.457	0.536	0.356	0.407	Malta	0.112	0.077	0.152	0.166
Uganda	0.342	0.181	0.408	0.767	Nicaragua	0.358	0.278	0.293	0.547	Peru	0.111	0.045	0.152	0.329
Cambodia	0.334	0.201	0.406	0.633	Philippines**	0.332	0.258	0.360	0.462	Philippines**	0.096	0.023	0.283	0.462
Thailand**	0.322	0.254	0.409	0.407	Honduras*	0.325	0.236	0.349	0.496	Greece	0.095	0.058	0.179	0.146
India	0.293	0.153	0.455	0.616	Indonesia*	0.308	0.236	0.209	0.501	Korea, Republic of	0.095	0.052	0.378	0.071
Indonesia*	0.268	0.172	0.250	0.501	Iceland*	0.265	0.554	0.232	0.075	Seychelles	0.090	0.042	0.118	0.229
Belize*	0.253	0.172	0.343	0.389	Malaysia*	0.241	0.223	0.211	0.286	New Zealand	0.085	0.119	0.073	0.055
Honduras*	0.241	0.125	0.403	0.496	Guatemala	0.222	0.100	0.337	0.575	Thailand**	0.077	0.019	0.148	0.407
Philippines**	0.239	0.134	0.351	0.462	Bangladesh*	0.207	0.075	0.379	0.676	Croatia	0.069	0.021	0.222	0.230
Costa Rica*	0.224	0.173	0.308	0.280	Panama	0.171	0.116	0.222	0.269	Japan	0.069	0.028	0.379	0.066
Nepal	0.213	0.071	0.416	0.756	Finland	0.142	0.107	0.373	0.097	Cyprus	0.068	0.026	0.201	0.164
Malaysia*	0.213	0.164	0.264	0.286	Costa Rica*	0.125	0.058	0.250	0.280	Turkey	0.066	0.014	0.216	0.358
Republic of Moldova	0.206	0.088	0.545	0.453	China**	0.111	0.032	0.391	0.393	Iceland*	0.064	0.026	0.317	0.075
Nigeria	0.199	0.062	0.438	0.743	Guam	0.109	0.015	0.449	1.000	Canada	0.063	0.022	0.396	0.068
Iran	0.195	0.095	0.542	0.327	Brunei Darussalam	0.103	0.064	0.186	0.154	Mozambique	0.061	0.005	0.165	0.965

[1] For freshwater, gridded vulnerability values are averaged over the entire land area of each country.
[2] For brackish water, vulnerability values are averaged over land area within 50 km inland of the coast.
[3] For mariculture, vulnerability values are averaged over each country's coastal waters for an area extending 50 km offshore.
** = countries appearing in the most vulnerable 20 for all three culture environments.
* = countries appearing in the most vulnerable 20 for two of the three culture environments.

21.3 VULNERABILITY ASSESSMENTS IN PRACTICE: SELECTED CASE STUDIES AT NATIONAL, LOCAL AND WATERSHED LEVELS

21.3.1 Introduction

Quantitative or semi-quantitative VAs are as yet rare for food systems *let alone* aquaculture. The sector is often assessed together with fisheries or agriculture and in coastal or watershed-based studies. Nonetheless, an increasing number of studies describe various elements of vulnerability of some aquaculture species and systems that should contribute to more formal assessments. Kais and Islam (2017) describe the main climate-related threats to shrimp farming in Bangladesh and some approaches to reduce exposure of farming systems and reduce sensitivity. Doubleday *et al*. (2013) describe an aquaculture exposure assessment carried out in Southeast Australia based on experts' views of risks from climate change biophysical hazards and Pimolrat *et al*. (2013) describe climate change risks of tilapia farms in Thailand at different altitudes. Both studies focus on exposure and analyse elements to reduce risks but do not delve into social and economic dependency or the consequences of the risks to communities. Soliman (2017) describes the threats to aquaculture in Egypt, underscoring the impact of climate change on freshwater availability as one of the major risks for the sector. Lydia *et al*. (2017) describe stakeholder perceptions of climate change risks to aquaculture in Nigeria and Egypt, supporting Soliman's findings. Studies in China address a number of the vulnerability components. For example, Li *et al*. (2016) constructed a province-level dataset to estimate the profitability and productivity of Chinese aquaculture under climate change. They noted that aquaculture production "has heterogeneous responses to climate change".

The climate change VAs reviewed here are of different geographical areas and scopes, in different agro-ecological environments, and of different targets with different livelihood resources. They aim to provide an overview of the range of purposes, stakeholder engagement strategies, assessment frameworks, methodologies and tools, and results and lessons. The assessments include a country's aquaculture sector, a national aquaculture commodity industry, i.e. salmon in Chile, fisheries and inland aquaculture in the Lower Mekong Basin (although only aquaculture is discussed here), and a mix of livelihood resources that includes fishing, aquaculture, crop and livestock farming and non-agriculture options in four coastal districts in South Sulawesi, Indonesia.

21.3.2 National assessments

a. Aquaculture sector of Chile

González *et al*. (2013) assessed the vulnerability of Chile's aquaculture sector in 2012, covering all the geographical sites and the main aquaculture resources, following the methodology of Allison *et al*. (2009). They used national climate change forecasts embodied in a model developed in 2006. It provided a good coarse-grained framework to estimate exposure in the coastal marine environment over shorter time scales (2011–2030; 2046–2065 and 2066–2100) under the IPCC scenario A2[1]. There was some confidence in the forecasts that ocean temperatures will increase, but perhaps the most relevant factor, particularly with regard to the main aquaculture areas, is the projected decrease in precipitation that results in less freshwater flowing into fjords and inner seas. The authors concluded that salmon and scallop farming were more vulnerable than other systems but that in general Chilean aquaculture had a low vulnerability to climate change. This result was strongly influenced by the high values used for indicators of adaptation capacity, such as governance. Unfortunately, the assessment

[1] See http://www.ipcc.ch/ipccreports/sres/emission/index.php?idp=94.

was rapidly shown to be misguided by the El Niño-related massive harmful algal blooms (HABs) in 2015 and 2016, because a number of critical governance tools, including monitoring, early warning, preventive measures and mitigation measures were not sufficiently in place to be effective (FAO, 2017a). Another problem is that the models used for forecasting were low resolution and did not allow for finer, local-level assessments of exposure. Finally, the models predicted trends in the mid- and long-term i.e. 20, 30 and 50 years, and they do not yet incorporate surprise changes or synergistic effects of overlapping phenomena such as a climatic trend and a short-term cyclical event such as El Niño.

b. Aquaculture and fisheries in shared marine waters

Martinez-Ortiz and Bravo-Moreno (2013) used the IPCC model adapted from Allison *et al.* (2009) to produce an initial assessment of vulnerability to climate change in fisheries and aquaculture in three countries, El Salvador, Honduras and Nicaragua, which share the waters of the Gulf of Fonseca in Central America.

For exposure they considered a number of regional forecasts under both the A2 and B2 IPCC scenarios. Both (especially the former) indicated an increase in temperature and a decrease in precipitation, although the latter was less clear. Hurricanes, big storms, flooding and drought were considered as the main direct threats in this study. The overlap of climatic variability, such as El Niño-Southern Oscillation (ENSO), and climatic trends was seen as a very relevant threat. For example, El Niño causes significant temperature increases that have damaged farmed tilapia production as a result of extreme heat and hypoxia. Increases in temperature were projected to be less damaging to shrimp farming (*Penaeus vannamei*). However, La Niña events might have greater impacts because of lower temperatures and salinities. Therefore, climate change could affect species and production systems differently. Indeed, the increase in precipitation is seen as a potentially more damaging factor, especially for shrimp farming, which would also have negative social consequences. Sensitivity was estimated as direct and indirect employment by fisheries and aquaculture and its contribution to the national GDP. For adaptation capacity, counties were considered as the ground level adaptation units and the authors used a combined indicator of the HDI and an index of "decentralization", which attempted to evaluate the capacity of local counties to take action on their own. The lack of national and regional coordination was seen as a constraint to reducing vulnerability of fisheries and aquaculture to climate change. The authors also emphasized the lack of information that prevented a more precise forecast of impacts on different farming systems at local scales.

21.3.3 Local assessments

a. Salmon aquaculture in Chile

Chile is the second largest producer of farmed salmon globally, with an annual production of over 700 thousand tonnes and an export value around USD 4 billion, making it the country's second largest export product after copper. Salmon farming has created a whole economy through direct and indirect employment in the south, where cities and some coastal communities are strongly dependent on the sector. Catastrophic red tides in 2015 and 2016 had a very strong impact on the industry, also affecting mussel farming and coastal fisheries (FAO, 2017a). Losses in production, employment and local livelihoods revealed the vulnerability of the industry to climatic variability and change. To address this, Soto *et al.* (forthcoming)[2] elaborated a climate change vulnerability matrix for the salmon farming sector. It is a participatory, simple,

[2] *Programa Mesoregional Salmon Sustentable Report,* CORFO, Chile.

flexible and dynamic tool open to all users, facilitating the identification of key points to reduce vulnerability.

VAs were performed for the most representative salmon farming counties, the smallest political and governance decision-making units in the country, so the risks can be linked to the local decision-making process while improving stakeholder understanding and involvement. The analysis considered climate change related impacts over the next 20 years to provide a realistic framework for local stakeholders' discussions and understanding. The estimation of VA components, considering the weighting of the different factors and indicators, was done with the active participation of the major stakeholders.

Exposure was estimated through a qualitative risk assessment of the main climate change-related threats on the production volume, adapted from the methodological approach used for a VA of Australian aquaculture (Doubleday *et al*., 2013). Threats considered included sea temperature, salinity, dissolved oxygen (DO), HABs, extreme weather events, ocean acidification and climate change related diseases. The assessment also considered several farm management aspects that could influence the magnitude of impacts (e.g. fish stress, stocking densities and eutrophication). Climatic drivers were estimated with an updated version of the PRECIS model that addresses Chile's climatic variability through the twenty-first century[3]. Forecasts indicate that Northern Patagonia (41–45 °S), where salmon farming takes place, will undergo an increase in temperature, especially during the summer period, within the next 50 years but most importantly, a forecast decrease in precipitation will result in less freshwater entering fjords and channels. Temperature increases are expected to be less pronounced in the southern part of Patagonia (from 45 °S to the southern tip of Chile). As in the case of the Gulf of Fonseca, described earlier, the overlap of climatic variability, such as ENSO events, and climatic trends such as reduction of precipitation, was seen as increasing the potential impacts. As Doubleday *et al*. (2013) highlighted, a qualitative screening-level assessment is an extremely valuable approach to guide the selection and prioritization of those elements that could reduce exposure. It helps to identify important information and research gaps and informs the development of cost-effective solutions. The participation of stakeholders is especially important in determining the most relevant risks.

Sensitivity to climate change was estimated by considering direct and indirect employment in salmon farming and by the contribution of the salmon farming taxes to the national budget. Other elements that could be considered under sensitivity were deemed to be better handled under adaptive capacity, for example, alternative livelihoods.

Adaptive capacity was estimated by considering the presence and quality of a number of conditions and services including education, infrastructure, insurance, health care, environmental monitoring and early warning, application of risk-based aquaculture spatial planning and management, alternative livelihoods, institutional coordination capacity, and adoption of better practices.

The assessment showed that the final vulnerability values for the different counties were not as important as the participatory process to identify the different components. The use of simple graphic models that facilitated understanding of the relationships between the forcing factors is an especially useful approach. In addition, it was concluded that having access to open source forecast models, such as PRECIS, for the different regions in the farming areas (even if they are low resolution) and the existence of national and local scientific capacity and knowledge are great assets for adaptation capacity. The most common weak point identified was the lack of coordination of the sector at county and national levels.

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[3] http://dgf.uchile.cl/PRECIS/

The initial VA indicated that those counties that could lose freshwater inputs in the future (which will increase salinity of fjords and coastal zones, which in turn influences the growth and proliferation of parasites such as sea lice), that have higher production levels and have greater socio-economic dependency on the sector are in general more vulnerable. As to adaptation, some indicators stand out as key to increasing adaptive capacity. These include better coordination of the sector's prevention and response strategies, transparent and accessible monitoring and early warning systems (EWS), risk-based aquaculture zoning, better management including biosecurity measures, and keeping production within the carrying capacity of the ecosystem units (fjords and channels). Increasing diversification of livelihoods (beyond salmon farming) also stood out as a key element of adaptation capacity.

b. Climate vulnerability and capacity analysis of four districts located in coastal areas in South Sulawesi, Indonesia

In the past four decades floods, droughts, storms, landslides and tidal surges have caused major loss of human lives and livelihoods in Indonesia. Being an archipelago and having a coastline that is the second longest in the world, a large part of its population live near the coast. The case study described here was a component of the project "Building coastal resilience to reduce climate change impact in Thailand and Indonesia", funded by the European Commission and implemented by CARE International (Cooperative for Assistance and Relief Everywhere) that aimed to build an understanding by the local population of the impact of climate change and develop strategies for adapting to a changing environment. The Indonesian study was carried out from November 2011 to April 2012 by Rolos *et al*. (2012). The premise of this climate vulnerability and capacity analysis (CVCA) component of the two-country project was the paucity of knowledge on the impact of climate change on local livelihoods even as climate change scenarios on a global level are available. The important livelihoods in the study area were seaweed farming, coastal fisheries, pond aquaculture, farming of rice, maize and sweet potato, livestock raising, small business, masonry and driving a motorcycle taxi.

The CVCA methodology applied in this case study prioritizes local knowledge, information and data at community, household and individual levels. It incorporates climate risks and adaptation strategies and takes account of the roles of national institutions and policies in facilitating adaptation. It combines community knowledge and scientific data to improve understanding of the local impacts of climate change. In this case, because of the lack of local-scale information on climate change impacts, exacerbated by inadequate data and information on weather and climate predictions, the participatory exercises provided the opportunity to link community knowledge to scientific information on climate change. The aim of the analysis was to help local stakeholders understand the implications of climate change on livelihoods so that they could better analyse risks and plan for adaptation.

The CVCA was implemented by field facilitators recruited from villages and trained and supervised by CARE's district facilitators and the district government technical team. Data collection tools included key informant interviews of government officials from national and local government agencies, secondary data compilation from published printed and electronic sources, particularly on climate variations, local context and reported risks, and focus group discussions of which 563 were organized. Focus group discussions were used to identify the most vulnerable groups, types of livelihood resources, types and frequency of hazard occurrence in the localities, seasonal activities in the community, historical trends and seasonal changes over time, and important institutions in the community.

Quantitative data were derived from a baseline study, the main component of which was a household survey to collect demographic information of villages, socio-economic data that included descriptions of current livelihoods and potentials, climate risks, disaster preparedness measures and factors affecting resilience and adaptive behaviours. Current adaptation strategies can be a baseline for comparison with the achievements made at the end of the project.

The six participatory rural appraisal (PRA) tools used included:

- Hazard mapping to identify the important livelihood resources and the individuals and institutions that have access to and control over these, and the areas and resources at risk from climate hazards.
- Seasonal calendars to identify periods of stress, hazards, diseases, hunger, debt, vulnerability and others, which also helped identify livelihood strategies and coping mechanisms.
- Historical timelines to gain insight into past hazards, changes in their nature, intensity and behaviour. This tool made people aware of trends and changes. It also informed risk analysis, adaptation planning and investments.
- Vulnerability matrix to determine the hazards with the most severe impacts on livelihood resources and identify current coping strategies for the hazards.
- Participatory development of Venn diagrams to provide an understanding of the relative importance of the institutions in the community and indicating the engagement of different groups in local planning processes. The tool also provided an assessment of the people's access to services and the availability of local safety nets.
- Daily activity records for information on the production and family activities of men and women in a day.

The value of this study for VA practitioners is considered to be the strategic approach it employed to engage the participation of target communities. Local people participated in the process to devise an adaptation strategy and plan. The participatory methodologies and tools used served to increase awareness and understanding, based upon their own experiences and perceptions, of what makes their livelihoods vulnerable to climate change risks and why. Participants were thus made aware of the gaps between their current strategies for coping and adaptation and what is required in order to cope and adapt to future risk scenarios.

The findings showed the range of interrelated and complex threats to a community's livelihoods. The most vulnerable groups were found to be farmers and fishers who are likely to be more affected by climate variability than others, as their livelihoods are strongly related to weather conditions. Increased weather unpredictability disrupts cropping schedules of farmers while increased storminess prevents fishers from going out to fish. The major climatic hazards and impacts on the communities were identified as:

- Flooding, which has become more frequent in recent years. The impacts of this are salinity change on seaweed growing sites when pond dykes burst and discharge freshwater to the coast; loss of stock when ponds overflow or their dykes collapse; and flooded rice and corn fields, which destroy crops. Bringing a product to market becomes either impossible or costly when roads are damaged and under water.
- Tidal surges, which increase the salinity of coastal brackish water ponds because of the influx of seawater, and damage seaweed plots.
- Drought, which severely reduces freshwater supplies to Gracilaria seaweed ponds, increasing salinity and damaging or killing the seaweed. Fish in highly saline ponds become stunted. If drought occurs during the growing period of rice and corn, the crops wither or yields are reduced.
- Heavy, prolonged rainfall which adversely affects Gracilaria seaweed because the salinity of pond water is reduced and the species needs stable salinity to grow well;
- Strong winds make it difficult to go out to sea to fish, damage poorly built houses and contribute to soil erosion.

- Soil erosion from floods exacerbated by drought is another hazard. Pond dykes weakened by drought easily erode when floods occur. This is expensive and it disrupts production schedules to undertake dyke and pond bottom repair and rehabilitation. Soil erosion washes away topsoil, rendering croplands infertile.

Recommendations arising from the analysis included the need for:

- A strategy to assist communities to develop resilient livelihoods as a starting point for adaptation to climate change.
- A strategy for disaster risk reduction that emphasizes preventive activities such as coastal zone management, EWS and reliable weather forecasts based on a good national data infrastructure, and training of EWS providers and others on how to respond to warnings.
- Capacity development for government officers and local people, which is also addressed by their involvement in VAs (sharing of best practices at the local level, facilitated by a community learning centre is proposed).
- Measures to address underlying causes of vulnerability, which emphasize the crucial role of women in dealing with impacts of climate change and propose among other things that they be actively involved in the VAprocesses.
- Enabling access to basic services when a disaster occurs and while recovery is going on.
- Training and provision of opportunities in alternative occupations.

21.3.4 Watershed level assessment

The VA of capture fisheries and aquaculture (ICEM, 2013) in the Mekong river watershed was a systematic appraisal of the threats and impacts on species (in the context of fisheries) and aquaculture production systems in selected eco-regions of the lower river basin, based on projections to 2050 of weather patterns and climate conditions. Important fish species were selected as indicators of the sensitivity of hotspots for fisheries to changes in climate. For aquaculture, the focus was on species and production systems. The mainly qualitative assessment highlighted the difficulty of isolating climate change signals from other causes of vulnerability and the pitfall of trying to consider threats in isolation, or in a single farming system context.

To illustrate the climate-related hazards that influence the vulnerability of aquaculture production systems and species, the results rather than the methodology are emphasized here:

In terms of exposure, for both fisheries and aquaculture, the threats were identified as being increased temperatures, decreased water availability, decreased and increased rainfall, drought, flooding, storms and flash floods. Rising sea levels and salinity changes, which are common threats to coastal aquaculture, are not applicable to these inland study areas.

The factors that were considered to affect sensitivity were:

- The wide range of indigenous and exotic species being cultured or available for culture, which reflects the importance of biodiversity and aquaculture diversification.
- The production systems, which include extensive, semi-intensive and intensive, are still dependent on wild caught juveniles for seed and low value fish for feed. A climate change-induced scarcity of wild fish would disrupt the operation of most of the farms and thus the livelihoods of the farmers and farm workers.
- At the time of the study, production was 2 million tonnes per year and the growth in production had been exponential, dominated by Pangasius in Viet Nam's Mekong Delta. The adverse impact of climate change risks were likely to

be magnified by the large number of households dependent on aquaculture and ancillary industries for livelihoods.

- Cultured fish is important for food security in urban areas and to small-scale farmers. The Lower Mekong Basin has a population of 60 million, most of whom are small-scale farmers, and the effect of major climate change induced disruptions in fish supplies can thus be expected to have serious impacts on food security and livelihoods.

While intensive and some semi-intensive production systems have a greater risk of failure (e.g. densely packed fish are often more stressed, diseases and parasites can spread easily and if something goes wrong in one pond or farm more fish are lost) they often have greater adaptive capacity (greater capacity to invest, rebuild, relocate, secure credit, insurance, etc.) Extensive systems tend to have a lower risk of failure but also lower adaptive capacity. All three systems are vulnerable to climate change, yet intensive and semi-intensive systems are more vulnerable, as indicated in the qualitative VA described in Table 21.2, meaning that exposure can override adaptive capacity.

TABLE 21.2
Vulnerability of different farming systems

	Storms	Flash-floods	Temperature increase	Rainfall increase	Rainfall decrease	Decreased water availability	Drought	Flooding
Intensive catfish farming	H	H	H	L	M	VH	VH	VH
Semi-intensive pond polyculture of tilapia, silver barb and carps	H	H	H	M	VH	M	H	VH
Extensive pond polyculture of carps and tilapia	M	M	M	L	M	H	H	H

Vulnerability indications: VH – very high; H – high; M – medium; L – low.

21.3.5 Conclusions

The focus of the case studies presented here was assessments, based on the IPCC and derived models, of the components of vulnerability, i.e. the exposure of the subject, its sensitivity to the expected risks, and its capacity to adapt and prevent and mitigate likely impacts. Assessing each vulnerability component is as important, or even more important, than deriving a simple vulnerability value because reducing vulnerability (increasing resilience) is in fact the outcome of reducing exposure, lowering sensitivity and increasing adaptive capacity.

An assessment of vulnerability is one approach to evaluating the threats to a social ecological system and its ability to cope with those threats and there are also other frameworks for doing this. An "IPCC+ Framework" has been recommended, which acknowledges the existence and relevance of the other frameworks and builds complementary perspectives around IPCC vulnerability components (Brugere and De Young, 2015). The various models of VA could comprise the steps indicated in Table 25.4 in Chapter 25: Methods and tools for adaptation. However, in practice, most case assessments have covered only portions of the recommended steps.

Stakeholder engagement underpins the value of an assessment to beneficiaries. Handyside. Telfer and Ross (2017) suggested investigations at a more localized level, involving specific aquaculture practices and environmental conditions, could be considered. The VA cases reviewed here yield the following lessons on what this would imply for stakeholder engagement:

- It is at national and especially local levels where, in addition to being able to obtain more specific information on aquaculture practices and work on more detailed agro-ecological conditions, the social and economic circumstances and livelihood strategies of people, as well as opportunities and constraints, can be described and measured in finer detail. Data and information on sensitivity and adaptive capacity become more precise and the information more reliable and locally relevant.
- The subjects, i.e. the people in the target areas and those working at institutions providing services to them, can actively participate in the assessment process.
- The application of participatory methodologies and tools for social analysis, such as PRA, focus group discussion and risk analysis, are especially practicable.
- An inclusive bottom-up approach involving the beneficiaries of the assessment, such as recording perceptions of climate change and risks, can provide a better understanding of the climatic impacts and people's responses. Historical responses to different types of risk can be elicited to better inform the considerations of possible responses to future risk scenarios and management regimes.
- At the application stage, consultations can be carried out among primary stakeholders (policy and regulatory agencies, development agencies, civil society organizations, public-private service providers, science and technology institutions and the beneficiaries) to develop policies, strategies and action plans to increase adaptive capacities and resilience. The consultations should include determination of agency and institutional roles, capacity building and reforms.

Of the three components of a VA, exposure is the most difficult to establish, especially at the local level, because of the lack of high resolution models to understand local risks to aquaculture or aquaculture-based livelihoods. It is thus imperative to use proxies such as knowledge of past extreme events as well as methods and tools that incorporate local people's knowledge and involve their close participation. This enables a better understanding and a credible analysis of the risks that aquaculture systems and people face and to which resources and systems are exposed.

Finally, VA is not a once-off activity. Identification of groups and areas vulnerable to climate change, and updating to take account of change, must be a regular and continuous process for setting priorities and allocating resources.

21.4 ADAPTATION OPTIONS AND NEW OPPORTUNITIES

As highlighted elsewhere in this volume, climate change presents both challenges and opportunities for the sustained production of farmed aquatic food and those engaged throughout the value chain.

21.4.1 Risk-based zoning and siting

Most zoning and aquaculture site selection around the world has been undertaken on an ad hoc basis for a single farm or collection of farms without integrated or broader strategic planning. The spatial distribution of aquaculture has happened with limited attention to the impacts of climate change. However, a growing number of national and regional authorities are beginning to engage in aquaculture spatial planning processes (Aguilar-Manjarrez, Soto and Brummett, 2017; FAO, 2017a).

Adequate zoning and site selection for aquaculture through risk analysis can be an important adaptation measure to climate change. When selecting aquaculture sites, it is very important to identify the likely threats through risk assessment analysis (Cattermoul, Brown and Poulain, eds., 2014). For example, the location of marine fish cages must consider exposure to weather events, changes in currents, or to a sudden influx of freshwater, in addition to longer-term trends such as rising temperature and salinity and decreasing DO levels in order to define zones for aquaculture and decide on the location of individual farm sites. In general, moving floating fish cages farther offshore can help mitigate environmental and food safety concerns and in a few offshore sites submersible cages are being used to withstand adverse weather events. However, there are tradeoffs: moving fish farms into more exposed areas also leads to increased technological and economic challenges.

The allocation of space for inland and coastal ponds in many places around the world has been governed more by land and water access opportunities than shelter from climate change and other risks. Important climate-related risks for earthen fishponds include extreme temperatures, excessive rainfall, prolonged cloud cover, flood and drought (Pimolrat *et al*., 2013). The consideration of climate change and other risks in zoning and site selection is needed in areas both where aquaculture is beginning to develop and where aquaculture has developed and it is difficult to relocate fixed structures. Area management approaches in cases where several farms share a common water body or water source, become essential in addressing potential risks. Advances in remote sensing technology, risk communication, weather information systems and integrated monitoring systems create new opportunities to increase the effectiveness of zoning and siting strategies for aquaculture.

21.4.2 Environmental monitoring systems

Although fisheries and aquaculture are sensitive to sudden climate changes and climatic variability (as well as to long-term trends and changes) there are very few examples worldwide of integrated monitoring systems providing information and interpretation of the information that small-scale fishers and fish farmers can trust and use to make decisions. Even though information on meteorological conditions can reach fishers and fish farmers and they may have some experience interpreting this information and the potential consequences for the farm or fishing operation, simple information collected systematically over the long-term can provide a highly relevant tool for decision-making, especially when changes can produce dramatic consequences. For example, temperature changes can trigger disease in farmed aquatic products and sudden water movements or internal circulation can bring anoxic water to the surface or trigger toxic algal blooms. Changes in pH or salinity can also affect farmed fish survival, growth and production, while changes in monsoon and rain patterns can influence freshwater delivery, with sudden floods or droughts. Aquaculture farmers need to be prepared.

Early detection of HABs allows fish farmers and fishers to make timely decisions in order to minimise the damage to aquaculture and coastal fisheries. Phytoplankton monitoring networks are more common for salmon farming and for harvested or culture-based fisheries of filter feeders such as mussels and clams. Anderson (2009) reported that monitoring programmes for toxins in shellfish were being conducted in more than 50 countries. The detection of dangerous levels of HAB toxins in shellfish leads to harvesting restrictions to prevent contaminated products from entering the market. Monitoring of other variables relevant to aquaculture is much less common. Some programmes are implemented for salmon,[4] in which densities of spiny algal cells that can damage fish gills and may generate massive fish kills, rather than HAB toxins, are of interest. Adequate monitoring and early warning can facilitate mitigation strategies, such as early harvesting or relocation of fish net pens from sites of intense HABs. Even the use of simple methodologies and Secchi disk readings can facilitate early identification of a HAB and raise alarm. Other events that could be prevented or mitigated include extensive anoxic events affecting fish farming in lakes. Such events can be caused by certain winds and changes in temperature that facilitate upwelling of anoxic hypolimnetic waters. Monitoring of DO and temperature, especially the

[4] Open platform to follow phytoplankton conditions and HAB risks in salmon farming areas in Southern Chile http://mapas.intesal.cl/publico/

latter, can facilitate the identification of colder and deeper water masses that can generate such events. Another common threat is the sudden rise in water levels during extreme monsoons or heavy rain events that can damage fish and shrimp ponds. Monitoring lake and reservoir water levels may provide a simple estimate of water level rises and communication of readings through local networks can assist rapid action and prevention. The monitoring of environmental variables such as DO and water transparency can also indicate excessive nutrient output from farms that could exacerbate the effects of climate variability on farmed fish.

Integrated monitoring systems

Integrated monitoring systems involve continuous measuring and reporting of variables in strategic locations within a connected ecosystem so that the collected information can be integrated into a GIS or simple database. Information is periodically assessed and evaluated by a technical team that can identify early warning signals and provide feedback to users for their consideration in management decisions even at the lowest level; e.g. whether fishers will stay home or go fishing or whether a fish farmer feeds or avoids feeding fish. Decisions by fishers and fish farmers involve the knowledge and trust of risk-related information provided by those analysing the information.

Measuring variables in the field is ideally done both by technicians and experts collecting more sophisticated information and by farmers and fishers collecting simple information so that the latter are part of the monitoring system, are more aware, and can also trust the information and feedback because there is ownership of the monitoring and EWS. Obviously, because fish farmers and fishers are in the field every day, they can make observations and collect information at higher frequencies and with lower cost. Monitoring and reporting on any variable requires standardization of methodologies, indicators, etc. and training, considering the different background and knowledge of trainees, is required. Training also contributes to better understanding of threats and risks and therefore improves resilience and adaptation to climate change.

A basin-wide assessment of integrated monitoring and EWS for fisheries and aquaculture in the lower Mekong, (including Thailand, Viet Nam and Cambodia; FAO, 2017a) provides relevant information on the available systems and improvement needs, including the following key aspects:

- Environmental monitoring systems follow a risk-based approach recognising that increased risk requires increased monitoring.
- The involvement and the value of locally collected information by farmers and fishers enables them to better understand the biophysical processes and become part of the solution, e.g. rapid adaptation measures and early warning, long-term behavioural and investment changes.
- Early warning can range from large-scale life or property threatening events such as floods and storms to issues that are particularly pertinent to fisheries, fish farmers, crops and livelihoods, seasonally or over the long-term.

EWS need to be robust, reliable, timely and operate automatically where appropriate in order to avoid unnecessary delays caused by waiting for human intervention. The type of warnings such systems should provide need to be carefully considered, in addition to the time frame within which the warnings need to be communicated. Cellphones that are currently available globally are increasingly being seen as useful tools, including instant messaging, and could be a useful way to communicate with end users, although sudden public emergencies could overload mobile phone networks, so the length of the warning period is important. Warning systems need to have multiple levels of redundancy to ensure 100 percent uptime (FAO, 2017a). In addition, there are a number of global environmental monitoring systems that are increasingly being networked to provide early warnings of, for example, HABs[5].

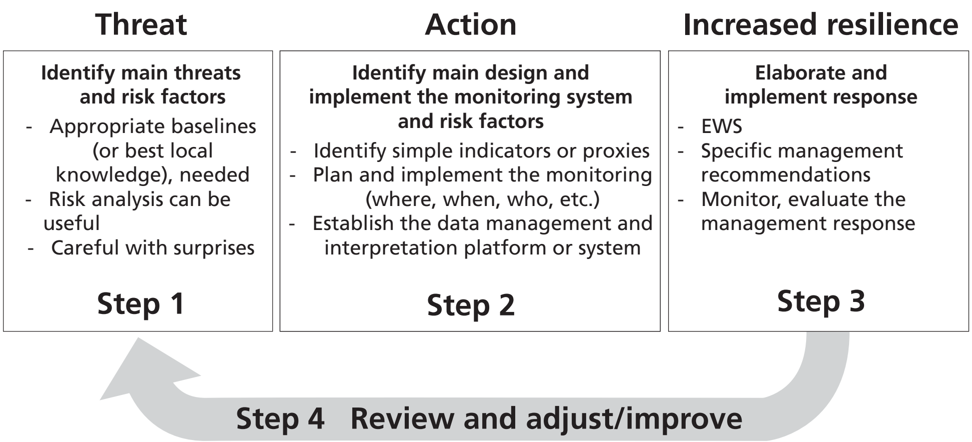
The main principles guiding the development of environmental monitoring and EWS can be summarized as follows:

- useful to farmers
- involve farmers
- cost-effective (simple, doable and useful to fish-farmers for management decisions)
- timely
- lead to and promote sustainable use of resources
- long-term
- reviewed and maintained regularly.

Key activities include training of local stakeholders on the value of the information and the monitoring and use of the feedback for decision-making. Any integrated monitoring system must also provide and enable implementation of a simple network or platform that receives and analyses information, coordinates connection with broader forecasts and monitoring systems and provides timely feedback useful to local stakeholders. This can be implemented through public-private partnerships and involving relevant research and technical institutions. A step-wise process is recommended, as shown in Figure 21.3.

Clearly, at a global level there is an increasing wealth of information being generated, but there is an urgent need to coordinate and integrate its use to benefit fishers and fish farmers and ensure the sustainability of the resources they are exploiting.

FIGURE 21.3
Schematic representation of the process and steps to implement local monitoring and early warning systems



21.4.3 Access to financial services

Credit

An issue that hangs over aquaculture is the general perception that it is a high-risk economic activity, now exacerbated by the uncertainties brought about by climate variability. The result is commonly for financial service providers to either shy away

[5] http://www.pml.ac.uk/Research/Projects/S_3_EUROHAB_Sentinel_products_for_detecting_EUtR; http://www.waterinsight.nl/info/wisp-3. Both accessed 20 February 2018.

from providing loans or insuring crops and farm assets or charge a high interest rate or premium that farmers, especially the small-scale, can ill afford.

Credit will invariably be needed to implement measures to prevent, reduce or cope with the impacts of climate change-induced risks. Capital investment is needed for relocation, infrastructure and equipment upgrade, repair or replacement required to prevent or reduce impacts of extreme weather, such as strong winds, heavy rains or floods as well as tidal surge. Adaptation increases operating costs: for example under extreme weather conditions, aeration may be needed to maintain water quality; and vitamin C, probiotics and other feed additives may be used to increase stress resilience in farmed fish. Although cost-effective, such actions may not be adopted because of poor access to affordable funds. In fed aquaculture, credit is frequently crucial to re-start operations, feed being a major portion of operational costs, and farmers who have lost their crop typically have little or no savings set aside for feed or seed. In some countries, feed dealers who supply feed on credit extend the credit line of farmers to tide them over to the next crop. There are, however, conditions attached to the harvest that are not always favourable to the farmers.

Access to affordable credit is thus crucial for effective and efficient climate change adaptation and for recovery from climate-change induced damage (Karim *et al.*, 2014). This could be effected through development of appropriate policy and through mechanisms such as micro-finance schemes and loan guarantee funds.

Insurance

Recent catastrophic natural disasters and the increasing frequency, prevalence and severity of risks driven by climate change should prompt governments to explore adaptation options in addition to disaster-relief and damage compensation. Pilot aquaculture insurance programmes provide promising examples of policy and practice to enhance national adaptation. Insuring small-scale farms, which are particularly vulnerable (and a major contributor to food security), has proved a sound investment; insurance can be included in social security policies to help farmers recover quickly from disasters and relieve the strain on government budgets. Pilot programmes in China and Viet Nam yield valuable guidance: 1) models of insurance business and innovative insurance schemes can be tailored to farmers' circumstances; 2) farmers can improve their perception of risks, leading to faster adoption of climate-smart management practices that reduce risks and make them more insurance- and credit-worthy; 3) with government support insurers have devised mutually beneficial schemes with farmer organizations that make aquaculture insurance a viable and sustainable business; and 4) government has backed political decisions with policy, institutional and financial support (FAO 2016a, 2017b).

The business viability of aquaculture insurance depends on aquaculture becoming more efficient and lower-risk. The insurance-pooled model applied to small farms can help raise production efficiencies and reduce production and market risks, leading to the following outcomes: 1) farmer adoption of good practices; 2) development of farm certification schemes; 3) strengthened producer organisations with members improving their capacity to participate in value chains; and 4) provision of credit bundled with financial products (e.g. insurance with feed credit). These can make insurance affordable to small farmers without the need for expensive subsidies. Insurance thus becomes an institutionalized risk management strategy and a cost-effective complement, if not alternative, to post-disaster relief and compensation.

21.4.4 Better management practices

Better management practices (BMPs) have been increasingly promoted to improve the environmental performance, productivity and profitability of farms. They are designed to reduce production and marketing risks and invariably enhance consumer confidence in products that are responsibly farmed and safe. BMPs have gradually incorporated provisions for food safety and social responsibility, especially in relation to farm workers and the community. Many of the practices being promoted have positive effects on mitigation and adaptation, even if climate change is not yet explicitly considered in BMPs. Climate change hazards should be incorporated into aquaculture BMPs, especially with regard to the resilience of farmed aquatic plants and animals, safety at work and farming systems.

The link between BMPs as well as technological innovations (which are often the cutting edge of BMPs) and the financial services, credit and insurance, is that BMPs, by reducing risks and increasing the adaptive capacity of farmers, make aquaculture more credit- and insurance-worthy. This also tends to improve productivity and profitability, which then enables farmers to invest in capital, adopt innovations and adhere to better practices that strengthen their resilience.

21.4.5 Technological innovations

The term "technological innovations" is applied here to alternative species and climate-adapted strains and aquaculture systems that reduce susceptibility to climate change, as well as to technologies that can inform risks and adaptation.

Given the pace of innovation and growth in computational power, spatial technologies have an increasingly important role to play in climate change adaptation strategies in the aquaculture sector. Recent advances in remote sensing platforms (e.g. drones and satellite constellations) are now being integrated with information and communication technologies; examples include early warning information systems (e.g. weather forecasts and early detection of HABs) and communication of risks using mobile communication devices (e.g. smartphones and tablets), cloud-based data systems and virtual reality and simulations (see also Section 21.5.3).

Stronger materials and better system designs (including mooring), coupled with the development and implementation of rigorous technical guidelines, play a role in reducing vulnerability to climate change in the marine aquaculture sub-sector of countries such as Canada, Chile, Norway and the United Kingdom. Such technologies, however, can be costly. Moving water-based aquaculture (especially cages and pens for finfish) onto land and employing recirculating aquaculture system (RAS) technologies are also being proposed as a means of reducing exposure to climatic extremes. In such systems, water quality, including temperature, DO, salinity and pH, can be controlled to meet species' needs. RAS, however, remain comparatively expensive in terms of both capital and operational costs and require high levels of technical expertise (Murray, Bostock and Fletcher, 2014). While there has been steady progress, the long-term reliability of RAS still needs to be demonstrated. Aquaponics, the production of fish and plants in an integrated system, is proposed as a means of producing food in areas where freshwater is limited (Somerville *et al.*, 2014). Aquaponics can be considered as a particular type of RAS and thus shares many of the same attributes. It is also worth pointing out that neither system is likely to be immune from extreme climate events in small island developing states or coastal areas vulnerable to such events without further development.

At the farm level, well-designed and well-built ponds or rice–fish fields can help mitigate against some of the adverse effects of climate change. Deeper ponds, for example, provide a thermal refuge and greater DO reserves for fish, while raised pond embankments can help prevent fish escapes and dyke destruction during floods and serve as water storage during droughts. A well-conceived facility can sustain multiple purposes beside aquaculture. Converting flow-through ponds and raceways into more water-efficient technologies is also desirable, as is reducing seepage through the use of pond liners.

Use of non-native aquatic germplasm, including exotic species (e.g. use of euryhaline, estuarine species or species tolerant of warmer water), has been proposed as a means of adaptation to climate change (Harvey *et al*., 2017), albeit that there are strong associated risks, as discussed in Chapter 19. While the development of strains of farmed aquatic organisms with improved salinity tolerance has long been practiced (Abu Hena, Kamal and Mair, 2005) the development of strains tolerant of higher or lower temperatures, or indeed other environmental variables impacted by climate change, is in its infancy and largely unproven, but will likely prove difficult, time consuming and costly. Transgenics are already being co-opted to deal with temperature changes[6] and CRISPR-CAS9 gene editing tools will open many important prospects. The ecological, economic and market origin pitfalls associated with diversification can be responsibly addressed by the application of the principles in Table 21.3.

TABLE 21.3.
Principles for aquaculture diversification (Harvey *et al*., 2017)

	Principle
1	Diversification demands information. Identify knowledge gaps and seek expert advice.
2	Diversification should anticipate, adapt to and mitigate the effects of climate change.
3	Diversification should be compatible with local ecosystems and not reduce aquatic biodiversity.
4	Diversification should be compatible with other responsible food producing sectors.
5	Diversification should comply with national and international laws, codes of conduct and conventions.
6	Diversification should be planned in consultation with all stakeholders and be attractive to farmers.
7	Diversification should minimize risks from pathogens and predators.
8	Diversification should be profitable in domestic and/or export markets, taking account of the risks of market shifts.

21.5 AQUACULTURE AS AN ADAPTATION OPTION

Climate change may create new opportunities to promote diversified and more resilient aquaculture-based livelihoods.

Most Pacific island countries and territories are exploring the potential of freshwater aquaculture to improve food security in the context of climate change (see for example Chapter 12). In Chile, aquaculture has long been considered an alternative for fishers and as a means to strengthen small-scale enterprises and diversify the livelihoods of fisheries-dependent coastal communities (FAO, 2017a). Aquaculture is also increasingly proposed as a solution to reduce fishing pressure on coral reefs affected by trade in live reef organisms (Pomeroy, Parks and Balboa, 2006).

Bangladesh provides several examples of the use of aquaculture as a climate change adaptation option (Karim *et al*., 2014). For instance, in the coastal region of Southwest Bangladesh, waterlogged croplands are being transformed into crop–aquaculture systems, while in a disaster-prone region of the country, aquaculture ponds were found to be important for supplying food and income during post-disaster periods. Similarly, in the northeast of Bangladesh, where rainfall can be erratic and the flooding of wetlands has affected fisheries, cage culture is being proposed as a means of producing fish during the dry season.

[6] AquaBounty has developed and is marketing a faster growing strain of Atlantic salmon, based on transgenic technologies https://www.scientificamerican.com/article/first-genetically-engineered-salmon-sold-in-canada/, accessed 20 February 2018.

In Viet Nam salt-tolerant varieties of rice and rice–fish cultivation can reduce vulnerability to sea level rise and storm surge damage (Shelton, 2014). In drought prone areas of the Near East and North Africa regions, integrated agri-aquaculture production systems are being used to promote water saving activities (Crespi and Lovatelli, 2011) while in Brazil, the introduction of cage cultured tilapia to reservoirs has provided viable alternative livelihoods and employment opportunities in areas that are vulnerable to drought and erratic rainfall (FAO, 2017a).

Climate-smart agriculture aims to sustainably increase agricultural productivity and incomes, while building resilience through adaptation to and mitigation of the impacts of climate change. It guides actions needed to transform and reorient agriculture systems to increase productivity, enhance resilience (adaptation), reduce or remove greenhouse gases (mitigation) where possible, and enhance the achievement of national food security and sustainable development goals (FAO, 2013, forthcoming). CSA differs from other approaches such as sustainable intensification of aquaculture in its explicit focus on addressing climate change and the search for maximizing synergies and trade-offs between productivity, adaptation and mitigation while ensuring accessible and nutritious food for all. This challenge has led some researchers and fish farmers to consider CSA as an alternative and innovative adaptation practice that allows increased aquaculture production while ensuring societal and environmental sustainability. For example, integrated multi-trophic aquaculture uses the farming of a combination of fish, shellfish and aquatic plants to remove particulate and dissolved wastes from fish farming and provide a self-sustaining source of food (FAO, forthcoming).

CSA principles have been applied to aquaculture to:

- improve the efficiency of natural resource use and maintain the resilience of the surrounding aquatic systems and communities that rely on them;
- the management of genetic resources to ensure that species with relevant traits for climate change adaptation and mitigation are conserved; and
- increase the uptake of RAS technologies to reduce the need for fresh, clean water while maintaining a healthy environment for fish.

To facilitate the promotion of aquaculture-based livelihoods, efforts are needed to integrate aquaculture into climate change adaptation and food security policies at national level, ensuring their incorporation into broader development planning.

21.6 CONCLUDING REMARKS

To address adaptation it is necessary to understand vulnerability and be able to identify major drivers and general exposure to climate change. It is almost always difficult to foresee what will happen in the future as a result of climate change but likely negative impacts can be reduced by reducing the sensitivity of the sector and by increasing measures to minimize exposure.

In general, aquaculture spatial planning and management following an ecosystem approach to aquaculture (FAO, 2010) could strengthen adaptation capacity, especially at local level. This requires the understanding of risks at relevant spatial and temporal scales, prioritizing those most relevant and the development and improvement of measures and management plans to address such risks through participatory approaches and using the best available information. Most important is that all measures and investments to reduce vulnerability are good for aquaculture sustainability in any future scenario. Reduction of vulnerability is unlikely to take place for aquaculture alone and the EAA can facilitate better integration of preparedness and response with other users of resources.

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