2. TECHNICAL PAPERS

Background technical papers were presented and submitted in order to provide workshop participants with a basic knowledge of some of the specific topics that would need to be addressed, including the impacts of climate change on the Region, and on fisheries and aquaculture, as well as the components of the ecosystem approach which are relevant to both fisheries and aquaculture. The technical papers were submitted on the following topics:

- Climate change in the Near East and North Africa Region, by H. Kanamaru (FAO);
- Adapting to climate change: the ecosystem approach to fisheries and aquaculture in the Near East and North Africa Region. The ecosystem approach to fisheries and its links to climate change, by C. De Young (FAO), G. Bianchi (FAO), and Y. Ye (FAO);
- An ecosystem approach to aquaculture: a way to facilitate adaptation to climate change, by D. Soto (FAO) and P. White (NIVA);
- Climate change and fisheries, by M.C. Badjeck (WorldFish) and E.A. Allison (WorldFish);
- Aquaculture and climate change, by M.C.M. Beveridge (WorldFish), M.J. Phillips (WorldFish) and A.R. el-Gamal (WorldFish).

2.1 Climate change in the Near East and North Africa Region

Introduction

As the Summary for Policymakers of the Synthesis Report of the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4) concluded: "warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level". The AR4 found that the understanding of anthropogenic warming and cooling influences on climate had improved since the AR3, "leading to very high confidence that the globally averaged net effect of human activities since 1750 has been one of warming". In addition, it found that "observational evidence from all continents and most oceans shows that many natural systems are being affected by regional climate changes, particularly temperature increases".

Although the global signal of climate change is clear, regional and subregional climate change and its effects on natural and human environments are difficult to discern and have been recognized only recently owing to greater natural climate variability at regional scales, local non-climate factors and the limited spatial coverage and short time scales of many studies. The paper summarizes the state-of-the-art understanding of climate change in the RNEA from the IPCC AR4 supplemented by recent literature. The current paper also updates a paper for the FAO Conference for the Near East Region in 2008, which the author co-wrote (FAO, 2008).

Observed and projected changes in climate

Temperature
Global temperature has increased over the last 150 years at the rate of 0.74 °C/100 years. Over the last 50 years, the linear warming trend has been nearly twice the rate for the last 100 years (Figure 2.1). Continental temperature changes for Africa and Asia show a similar trend to the global trend since 1900 (black solid line in Figure 2.2). There is less confidence in temperature time series in Africa earlier in the twentieth century as observed records for that period are scarce. The blue shaded bands show the range of temperature simulated by multiple climate models using only the natural forcings due to solar activity and volcanoes without anthropogenic forcings, namely greenhouse gas (GHG) emissions due to human activities. Only when anthropogenic emissions are taken into account are climate models able to reproduce historical changes in temperature (red shaded bands).

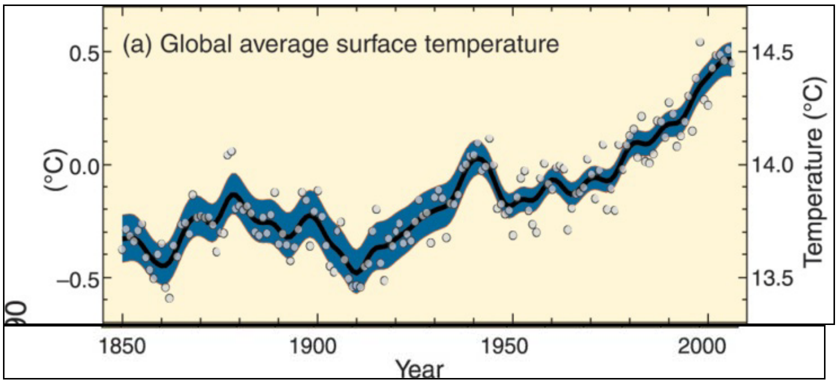

Figure 2.1 Observed changes in global average surface temperature
Source: Figure 1.1 in IPCC, 2007a.

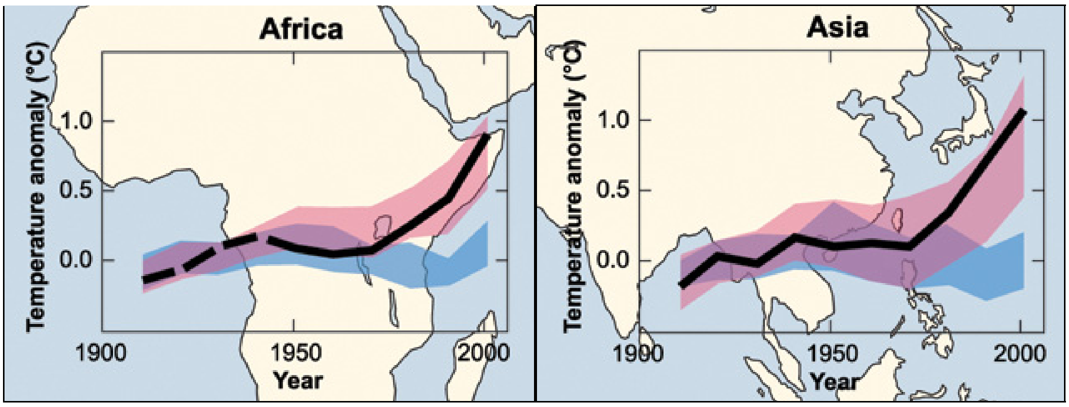

Figure 2.2 Observed continental changes in surface temperature with results simulated by climate models using either natural or both natural and anthropogenic forcings
Source: Figure 2.5 in IPCC, 2007a.

The AR4 concluded that most of the observed increase in global temperature since the mid-twentieth century was very likely due to the observed increase in anthropogenic GHG concentration in the atmosphere. Global GHG will continue to grow over the next few decades, although they will depend considerably on future climate-change mitigation policies and sustainable development practices. The likely range of globally averaged temperature increase by the end of the twenty-first century is 1.1–6.4 °C from a variety of emissions scenarios and climate models (Figure 2.3). The "best estimate" ranges from 1.8 to 4.0 °C for the same set of scenarios and models. For the next two decades, a warming of about 0.4 °C is inevitable regardless of emissions scenarios.

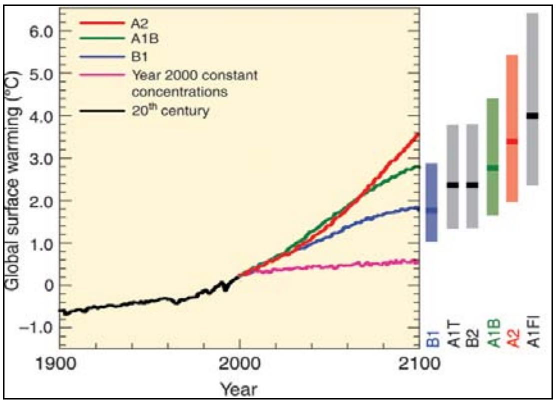

Figure 2.3 Atmosphere–Ocean General Circulation Model projections of surface warming
Note: Solid lines are multimodel global averages of surface warming (relative to 1980–1999) for the Special Report on Emissions Scenarios (SRES) A2, A1B and B1, shown as continuations of the twentieth-century simulations, and for the experiment where concentrations were held constant at year 2000 values.
Source: Figure 3.2 in IPCC, 2007a.

The RNEA encompasses three continental regions (Europe, Africa, and Asia) as defined in the IPCC reports. For the projections of temperature at subregional levels, the closest ones are Southern Europe and Mediterranean (SEM) (the southern part of which covers the coastal area of North Africa) and Sahara (SAH) (which covers the area immediately south of SEM). Annual mean temperatures in these subregions are likely to increase by more than the global mean (Figure 2.4).

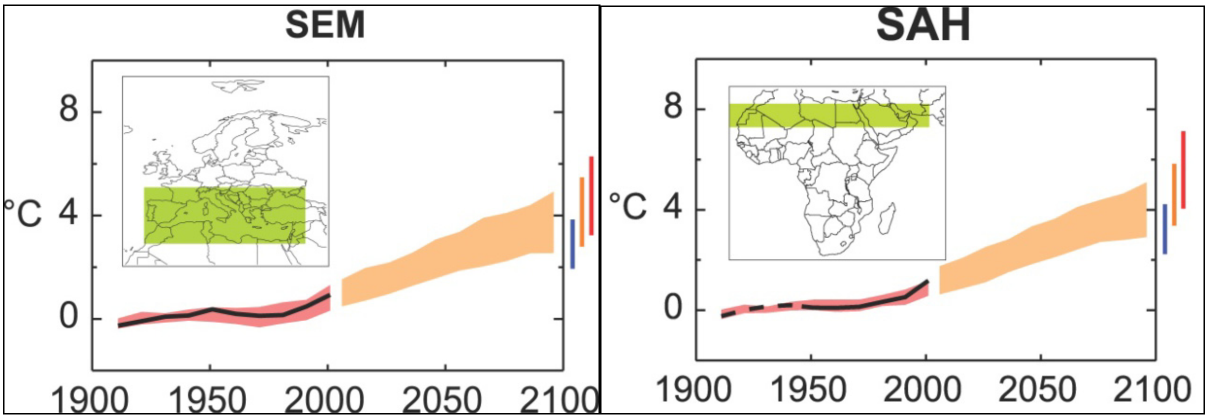

Figure 2.4 Temperature anomalies for the SEM and SAH regions for 1906–2005 (black line) and as simulated (red envelope) by multimodels incorporating known forcings; and as projected for 2001–2100 by multimodels for the A1B scenario (orange envelope)

Source: Figures 11.1 and 11.4 in IPCC, 2007b.

Figure 2.5 shows the geographical pattern of the projected warming for the A1B scenario from multiple model runs. The largest area of projected warming, above 4 °C, is found in the western Sahara while smaller values are found in coastal areas. In the RNEA, the warming is likely to be largest in summer.

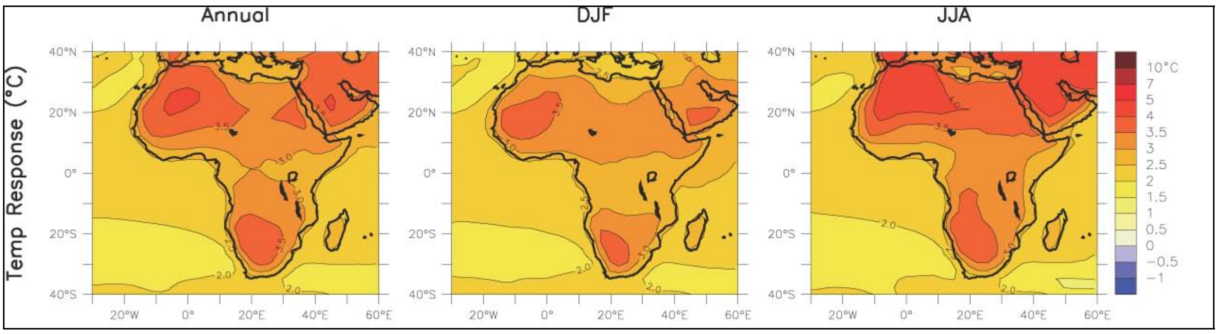

Figure 2.5 Temperature changes over Africa from the multimodel datasets, A1B simulations

Note: Annual mean, DJF and JJA temperature change 1980–1999 and 2080–2099 averaged over 21 models.

Source: Figure 11.2 in IPCC, 2007b.

Precipitation

There is an observed long-term (since 1900) decreasing trend in precipitation in the Mediterranean Basin (Figure 2.6). This general trend is supported by a number of individual studies in the region (e.g. Lebanon [Shaban, 2009]). It should be noted that interannual variability of the Mediterranean rainfall is associated with changes in atmospheric circulation patterns such as the North Atlantic Oscillation (NAO; variability of westerly wind in winter over the North Atlantic). The region experiences a drier winter during the positive phases of the NAO. For example, a more positive phase of the NAO in the 1990s brought drier conditions over the region (Knippertz, Christoph and Speth, 2003; Xoplaki *et al.*, 2004). The rest of the RNEA beyond the Mediterranean Basin is very dry and has insufficient data to establish past trends.

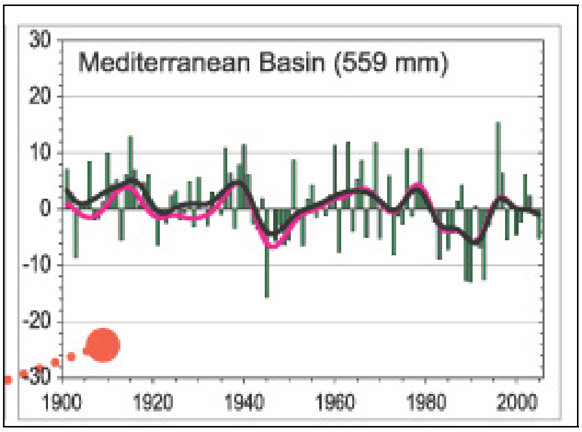

Figure 2.6 Annual precipitation for 1900–2005 (percent of mean, with the mean given at top for 1961–1990) for the Mediterranean region

Note: The Global Historical Climatology Network (GHCN) precipitation from the United States National Climatic Data Center (NCDC) was used for the annual green bars and black for decadal variations, and for comparison the Climatic Research Unit (CRU) decadal variations are in magenta.

Source: Figure 3.14 in IPCC, 2007b.

Generally speaking, increased precipitation is very likely in high latitudes, while decreases are likely in most subtropical land regions (Figure 2.7). This is in line with observed patterns in recent trends.

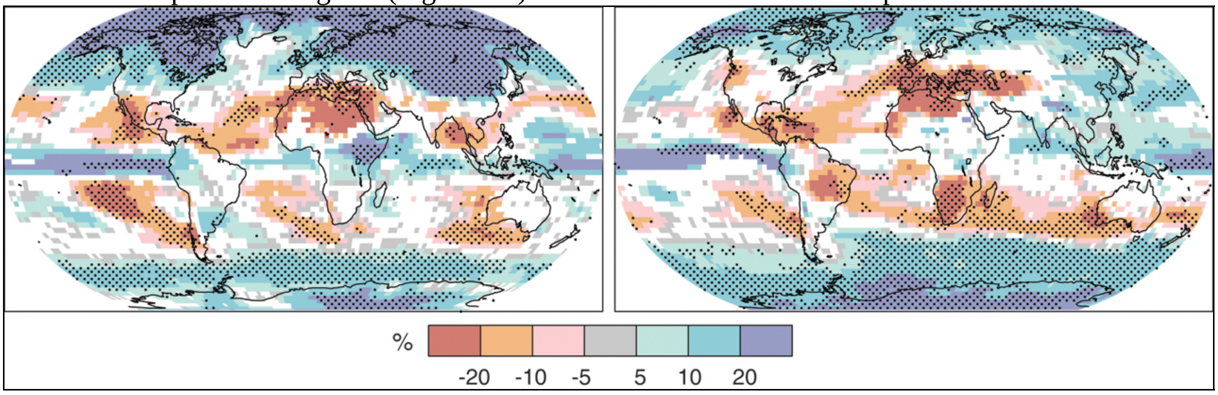

Figure 2.7 Relative changes in precipitation for the period 2090–2099, relative to 1980–1999

Note: Values are multimodel averages based on the SRES A1B scenario for December–February (left) and June–August (right). White areas are where less than 66 percent of the models agree on the sign of the change, and stippled areas are where more than 90 percent of the models agree on the sign of the change.

Source: Figure 3.3 in IPCC, 2007a.

Under future climate-change scenarios, annual precipitation is very likely to decrease in much of the RNEA. In Figure 2.8, the top panels show fractional change in precipitation between 1980–1999 and 2080–2099, averaged over 21 models. Unlike temperature projection, models often do not agree on the direction of change in precipitation. The bottom panels show the number of models out of 21 that project increases in precipitation. Models agree on projected decrease in precipitation over much of North Africa and the northern Arabian Peninsula. Projection of precipitation over the area immediately south of those areas carries large uncertainties, as the area appears as white in the bottom panels.

The likelihood of a decreased rainfall is greater as the Mediterranean coast is approached. The number of precipitation days in a year is very likely to decrease in the Mediterranean area.

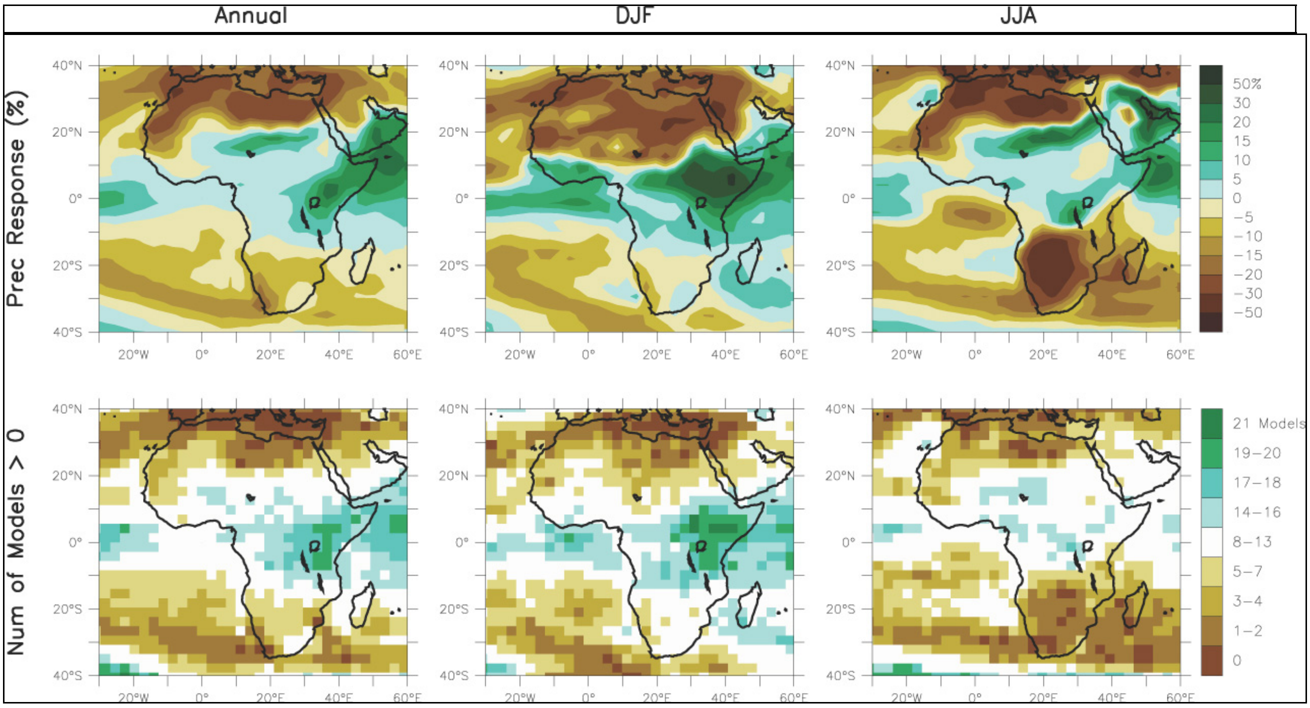

Figure 2.8 Precipitation changes over Africa from the multimodel datasets, A1B simulations
Note: Same as Figure 2.5 but for fractional change in precipitation (top row). Bottom row: number of models out of 21 that project increases in precipitation.
Source: Figure 11.2 in IPCC, 2007b.

Extreme events

Globally, at regional scale, an increase in frequency of hot extremes, heat waves, and heavy precipitation is very likely. On the other hand, there will be fewer cold days and nights. Tropical cyclone intensity is likely to increase. Figure 2.9 shows a schematic diagram of probability distribution of temperature where both mean temperature and variability increase.

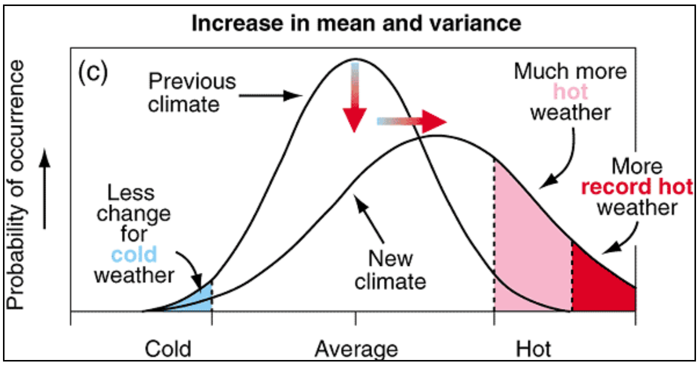

Figure 2.9 Schematic showing the effect on extreme temperatures when the mean temperature increases, for a normal temperature distribution
Source: Box TS.5, Figure 1 in IPCC, 2007b.

For the RNEA, the AR4 was not yet able to provide clear ideas on future changes in extreme rainfall events. It was found, however, that there is generally a decrease in the number of rain days. Consequently, the risk of drought in summer is likely to increase.

Table 2.1 Regional averages of temperature and precipitation projections from a set of 21 global models in the multimodel datasets for the A1B scenario

		Temperature Response (°C)						Precipitation Response (%)						Extreme Seasons (%)		
Region[a]	Season	Min	25	50	75	Max	T yrs	Min	25	50	75	Max	T yrs	Warm	Wet	Dry
SAH	DJF	2.4	2.9	3.2	3.5	5.0	15	-47	-31	-18	-12	31	>100	97		12
	MAM	2.3	3.3	3.6	3.8	5.2	10	-42	-37	-18	-10	13	>100	100	2	21
18N,20E	JJA	2.6	3.6	4.1	4.4	5.8	10	-53	-28	-4	16	74		100		
to	SON	2.8	3.4	3.7	4.3	5.4	10	-52	-15	6	23	64		100		
30N,65E	Annual	2.6	3.2	3.6	4.0	5.4	10	-44	-24	-6	3	57		100		
SEM	DJF	1.7	2.5	2.6	3.3	4.6	25	-16	-10	-6	-1	6	>100	93	3	12
	MAM	2.0	3.0	3.2	3.5	4.5	20	-24	-17	-16	-8	-2	60	98	1	31
30N,10W	JJA	2.7	3.7	4.1	5.0	6.5	15	-53	-35	-24	-14	-3	55	100	1	42
to	SON	2.3	2.8	3.3	4.0	5.2	15	-29	-15	-12	-9	-2	90	100	1	21
48N,40E	Annual	2.2	3.0	3.5	4.0	5.1	15	-27	-16	-12	-9	-4	45	100	0	46

Note: The mean temperature and precipitation responses are first averaged for each model over all available realizations of the 1980–1999 period from the Twentieth Century Climate in Coupled Models (20C3M) simulations and the 2080–2099 period of A1B.
Source: Table 11.1 in IPCC, 2007b.

Temperature and precipitation responses are summarized in Table 2.1. Shaded seasons indicate that most models agree on the projection of precipitation decrease. A decreasing trend of precipitation is clear in the Mediterranean and throughout the year and in the Sahara in winter and spring. The columns on the right indicate the fraction of years that are considered to be extremes under today's climate. By the end of the century, almost all years will be "extremely warm" in both the SEM and SAH and almost half of the years will be "extremely dry" in the SEM.

Sea-level rise

Global average sea level has risen (Figure 2.10) at a rate of 1.8 mm/year (since 1961). The rate of sea-level rise appears to have accelerated recently to 3.1 mm/year (since 1991). Increased temperature has led to thermal expansion and the melting of glaciers, ice caps and the polar ice sheets, which has resulted in sea-level rise.

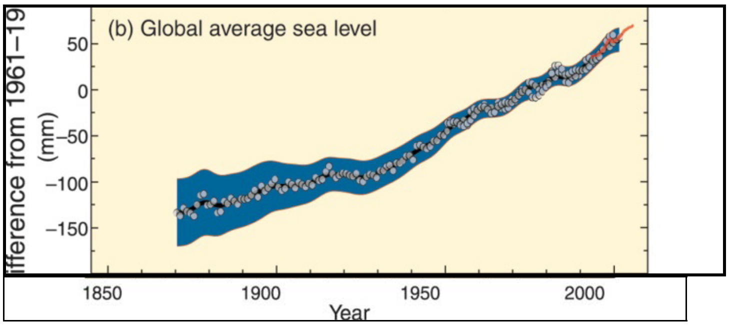

Figure 2.10 Observed changes in global average sea level from tide gauge (blue) and satellite (red) data
Source: Figure 1.1 in IPCC, 2007a.

Projected global average sea level rise by the end of this century is 20 cm or higher, but the AR4 admits that understanding of the sea-level rise mechanism is still insufficient and warns that future sea-level rise may be much higher than is estimated in Figure 2.11 (global average sea level rise for 2090–2099). The projections include a contribution from increased Greenland and Antarctic ice flow (as observed in the past ten years) but do not include uncertainties in climate–carbon cycle feedbacks nor the full effects of ice-sheet flow changes.

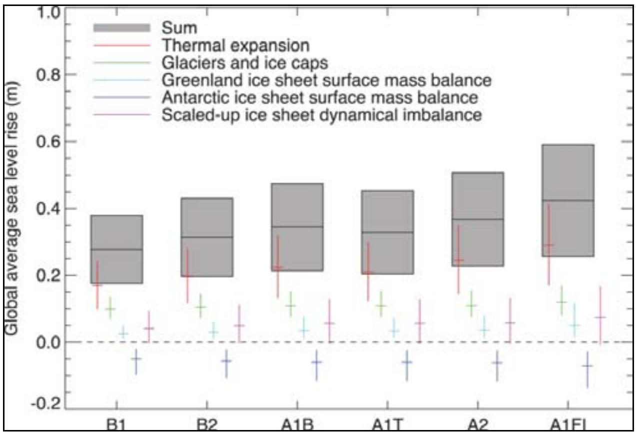

Figure 2.11 Projections and uncertainties (5–95 percent ranges) of global average sea-level rise and its components in 2090–2099 (relative to 1980–1999) for the six SRES marker scenarios
Source: Figure 10.33 in IPCC, 2007b.

The distribution of sea-level rise varies from region to region owing to ocean density and circulation changes. Figure 2.12 shows a distribution of sea-level change from 14 atmosphere–ocean coupled climate models. However, the resolution of global models is not fine enough, and local sea-level rise in the Mediterranean, Red Sea and Persian Gulf is not presented in the AR4. Although good projection of sea-level rise is not available, some parts of the region, notably the Nile Delta and the Persian Gulf coast of the Arabian Peninsula, are expected to be particularly vulnerable to flooding from rising sea levels.

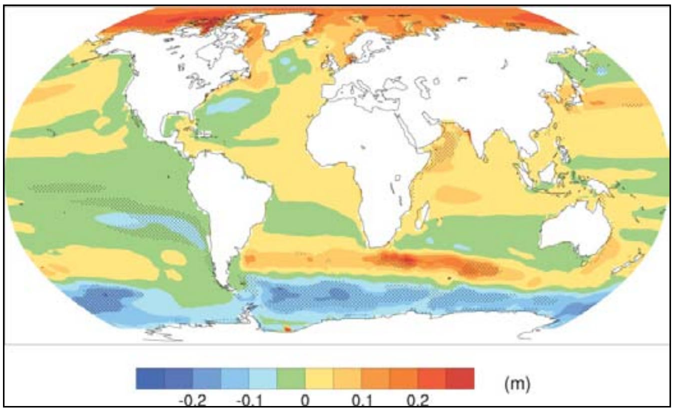

Figure 2.12 Local sea-level change due to ocean density and circulation change relative to the global average during the twenty-first century
Notes: Positive values indicate greater local sea level change than global. Change calculated as the difference between averages for 2080–2099 and 1980–1999, as an ensemble mean over 16 AOGCMs forced with the SRES A1B scenario.
Source: Figure 10.32 in IPCC, 2007b.

Not knowing exactly the extent of sea-level rise in the future, a number of individual studies looked at sensitivities of the region to varying degrees of possible sea-level rise in the region. For example, Al-Jeneid *et al.* (2008) examined a case for Bahrain and found more than 77 km^2 of land area may be inundated under a 0.5 m sea-level rise. El-Raey *et al.* (1999) assessed losses and socio-economic impacts over the Port Said Governorate in Egypt and found some industries may be seriously affected. El-Raey, Dewidar and El-Hattab (1999) and El-Raey *et al.* (1999) discuss adaptation options for Egypt.

Impacts on natural resources and food security

The annex to this paper provides a table of country-by-country overviews on impacts, vulnerability and climate-related risks compiled from national reports to the United Nations Framework Convention on Climate Change (UNFCCC) and disaster database. As is clear from the annex table, freshwater is perhaps the single most important resource for the well-being of people in the RNEA.

Freshwater

Water resources in the RNEA are already under stress from growing population, particularly rapid growth in urban areas, and economic development. Figure 2.13 shows total renewable water resources per capita in 2005. Agriculture accounts for 90 percent of the mobilized water resources, which is around 60 percent of the total renewable water resources in the region.

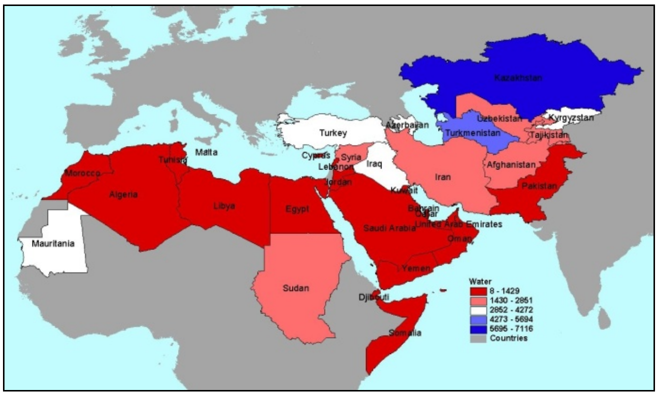

Figure 2.13 Total renewable water resources per capita in 2005, cubic metres per inhabitant per year
Source: FAO AQUASTAT (available at www.fao.org/nr/water/aquastat/main/index.stm).

Climate change is expected to exacerbate the unfavourable situation, with increased temperature and evapotranspiration, and projected decrease in precipitation over much of the Region. Projections of runoff due to changing precipitation and temperature are shown in Figure 2.14. Globally, runoff will increase by 10–40 percent by mid-century at high latitudes and in some parts of wet tropics, and decrease by 10–30 percent over some dry regions at mid-latitudes and in the dry tropics.

For the Mediterranean, more than 40 percent reduction in freshwater availability is suggested by the end of this century along the coastal areas (see also studies such as Abdulla, Eshtawi and Assaf, 2009). It is not known how freshwater availability will evolve in the rest of the RNEA, predominantly desert areas. The Nile River originates in East Africa, where increased precipitation is projected (Figure 2.14). This may have significant implications for future availability of freshwater resources for Egypt (e.g. Sene, Tate and Farquharson, 2001; Strzepek and Yates, 2000; Conway, 2005).

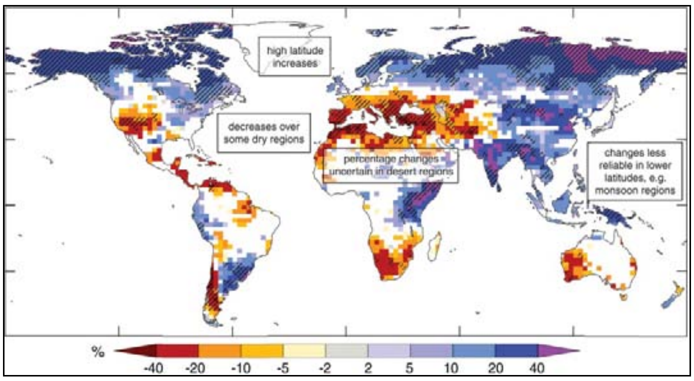

Figure 2.14 Large-scale relative changes in annual runoff (water availability, in percent) for the period 2090–2099 as compared to 1980–1999
Source: Figure 3.5 in IPCC, 2007a.

Areas affected by drought are likely to increase and a number of sectors may suffer, ranging from agriculture and water quality to human health. Many of the irrigation systems in the RNEA are under considerable environmental strain because of salinity, waterlogging or overexploitation of groundwater. Groundwater, including non-renewable fossil water, is of primary importance in most countries. A region-wide increase in irrigation demand is projected in order to maintain food production and sustain growing populations. According to four models, as presented in the AR4, groundwater recharge will decrease dramatically – by more than 70 percent – between now and 2050 along the southern rim of the Mediterranean. Additional concern for the coast areas is sea-level rise, which can compromise freshwater resources by increased risk of salinization of groundwater (e.g. Frihy, 2003).

The Near East and North Africa are particularly exposed to water shortages. An additional 155–600 million people may suffer an increase in water stress in North Africa with a 3 °C rise in temperature. Competition for water within the Region and across its borders may grow, carrying the risk of conflict.

Crop agriculture
All dimensions of food security (availability, stability, utilization and access) will be affected by climate change. Average agricultural yield will increase at high latitudes in cold areas where low temperature is a limiting factor for production. However, even the slightest increase in mean temperature will affect agriculture negatively in warm environments, decreasing average yield (e.g. Koocheki *et al*., 2006a, 2006b; Lhomme, Mougou and Mansour, 2009). Figure 2.15 demonstrates the difference in sensitivity of maize yield at low latitudes and at mid to high latitudes. Global food production may increase with an increase of up to 3 °C average temperature, but beyond this threshold, production will decrease, cereal prices will be higher and developing countries which are already dependent on imports may suffer. Smallholders in Africa and parts of Asia are particularly threatened by climate change. One study estimates up to 75 percent of people from sub-Saharan Africa will be at risk of hunger by 2080.

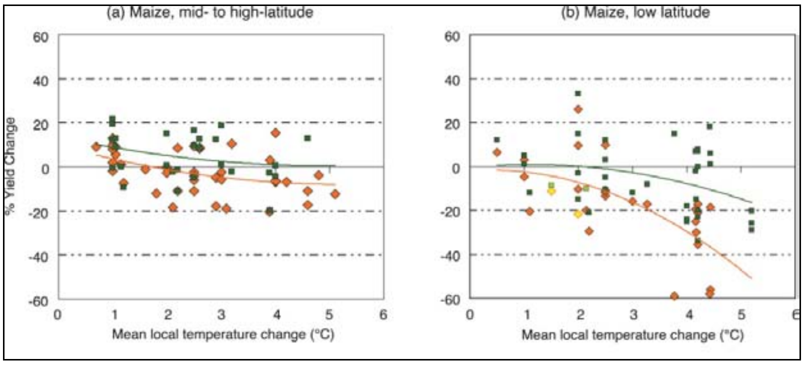

Figure 2.15 Sensitivity of maize yield to climate change
Notes: Derived from the results of 69 published studies at multiple simulation sites, against mean local temperature change used as a proxy to indicate magnitude of climate change in each study. Responses include cases without adaptation (red dots) and with adaptation (dark green dots).
Source: Figure 5.2 in IPCC, 2007c.

A recent FAO study (with the Government of Morocco and the World Bank) provides a good example of possible impact on agriculture production in the semi-arid environment. Rainfed soft wheat yield will keep decreasing towards the end of century (Figure 2.16). Yield decrease beyond 2030 is particularly pronounced. Increased concentration of carbon dioxide in the atmosphere enhances plant growth (carbon dioxide [CO_2] fertilization effect), partly compensating for the negatively affected yield due to temperature increase. However, significant yield decrease by higher temperature and less precipitation tends to outweigh positive CO_2 fertilization. There is still room for agricultural technology development in Moroccan agriculture, such as improved use of fertilizers, introduction of crop varieties better suited to new climate, and mechanization. Continued investment in agriculture research and development is key to sustainable food production as technology may well offset negative impacts of climate change on agricultural production.

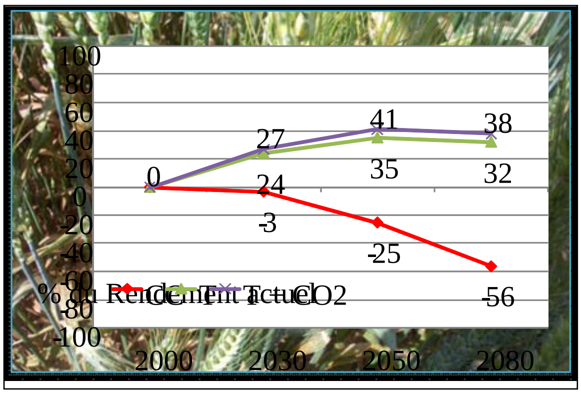

Figure 2.16 Rainfed soft wheat yield projection for the twenty-first century in the “intermediate” agro-ecological zone in Morocco
Source: Gommes *et al*., 2009.

Changes in the frequency of years with poor yields have potentially greater significance for food security than the projection of mean agricultural yields. In the Morocco study, higher interannual variability in temperature and precipitation under climate change scenarios led to a higher incidence of poor yield years (Figure 2.17).

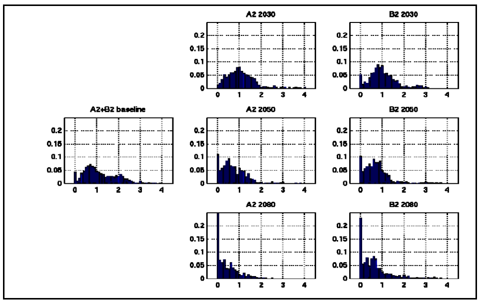

Figure 2.17 Barley projection (probability distribution) for the “intermediate” agro-ecological zone in Morocco
Source: Gommes *et al*., 2009.

In a context where land availability and land degradation are already a major concern for sustained agricultural productivity, changes in temperature, precipitation and weather events will only add to the stress on agricultural resources. Arable land is already limited in the arid and semi-arid areas that cover most of the RNEA, making agriculture potentially highly vulnerable to climate change.
Agricultural productivity in the region as a whole is likely to suffer losses because of high temperature, drought, floods and soil degradation, which, in turn, will put the food security of many countries under threat.

Livestock
Climate change in arid lands of the Region will result in less available soil moisture, exacerbating the current situation of the already degraded land. Rangelands are the dominant land type in the region, and as result of their extent, small changes in vegetation cover can significantly affect the organic carbon dynamics and storage in the ecosystem.

The livestock nomadic system spreads over a wide area with low and erratic rainfall, extending from the dry and low rainfall rangelands in the Near East and the Arabian Peninsula to the high rainfall areas (more than 1 200 mm) in southwest and southern Sudan. It is in this area that a further decline in available moisture is expected, resulting in an overall decline in productivity.

In temperate areas, temperature increases may lead to an increase in pasture production in mid-latitudes, with corresponding increases in livestock production. In general, un-housed livestock are expected to benefit from warmer winters, particularly at higher elevations, with minor improvements in feed quality in temperate high-rainfall zones possible. However, greater summer heat stress is likely to occur with negative effects on animals.

Livestock pest and disease distribution and their transmission patterns will be altered, with epidemics being almost certain.

Forests
In the Region, the majority of forest products are used for subsistence and in support of small-scale, household-based enterprises that provide income and employment for rural people, especially women. Despite their importance for local economies and livelihoods, forest products in the region remain largely neglected in the policy and decision-making processes of natural resource management.

A depletion of soil moisture may cause the productivity of major species to decline, increase fire risk and change the patterns of the Region's main pests and diseases. Modification of the habitat will subsequently induce changes in the wildlife population.

Fisheries
The region has a vast coastal area and several rivers with good potential for fishing. The region has become a net exporter in the fisheries sector, but its global share of trade is marginal, accounting for only about USD135 million in 1999. According to the IPCC, many basins already suffer from a lack of water. These basins are located, among others, in Africa, the Mediterranean region and the Near East.

It is extremely difficult to predict how climate change may affect fish stocks and the fishing industry, particularly in the context of the present stresses on fish stocks. While higher ocean temperatures may increase growth rates of some fish, the reduced nutrient supplies that result from warming may limit growth. Ocean acidification is likely to be particularly damaging.

According to the AR4, effects on macrophyte communities and the spread of warmer water species due to increased temperatures have already been observed in the Mediterranean, as have changes in populations, recruitment success, trophic interactions and migratory patterns of fish populations.

Adaptation to climate change

Looking at FAO data on actual arable land in use and irrigated areas from the mid-1990s, a rather diverse picture emerges for different countries. For example, while Algeria and Iraq probably still have potential to expand agricultural areas (Algeria has 61 percent of potentially arable land actually in use; Iraq has 75 percent), others countries such as Yemen and Saudi Arabia already utilize all their potential arable land as they have expanded into marginal lands.

Most countries have no or very limited rainfed cropping potential (Kuwait, Oman, Qatar, Saudi Arabia, United Arab Emirates and Yemen all have less than 5 000 ha). Irrigation is used extensively but may cause problems in terms of groundwater recharge. Many countries seem to be using their full rainfed and irrigation potential already.

According to FAO projections, developing countries account for 75 percent of global irrigated land and are likely to expand their irrigated area until 2030 by 0.6 percent/year, while the annual cropping intensity of irrigated land will increase from 1.27 to 1.41 crops/ha, and irrigation water-use efficiency will increase slightly. These estimates do not take into account climate change. Most of this expansion is projected to occur in already water-stressed areas, such as southern Asia, the Near East and North Africa.

In the forestry sector, there are expanses of degraded land that could be reforested if grazing is controlled. Planted forests may help to counteract negative effects of climate change on natural forests and improve local water cycles. Some countries in the region such as Kuwait, Oman, United Arab Emirates and Egypt are building solid experience in afforestation and reclamation of desert areas, using sewage water for irrigation.

In the agriculture sector, a number of adaptation measures will provide win–win opportunities for climate change adaptation and sustainable agriculture:

- improved fertilizer use – nitrous oxide released into the atmosphere is a loss and an indication of inefficient farming;
- improvements to crop water management and productivity – development of water harvesting, conservation techniques, etc., aids adaptation to rainfall variability;
- improved rice farming – higher yields are accompanied by reduced methane emissions;
- increased use of conservation agriculture – improves soil carbon storage (sink) and soil structure, and increases waterholding capacity;
- improved low-impact harvesting in forests and better soil protection;
- increased large-scale plantings of perennial crops – although limited in the region due to insufficient water availability (except in areas where irrigation is possible), there are several pine species, tamarind, citrus, almonds and several acacias that sequester carbon and protect soil and sloping lands, thereby offering an economic buffer against soil degradation and mitigating impacts;
- substitution of bioenergy and fossil fuel – although a possible option, potential adverse effects on food security and the environment should be carefully assessed before any large-scale developments are put in place.

Mitigation of climate change

Historically, the RNEA has not been a significant source of GHG emissions. In 2004, the Near East (Middle East in Figure 2.18) accounted for 3.8 percent of global GHG emissions, and Africa, 7.8 percent. However, the Near East, together with North America and Asia, has been identified as the driving force in the rise in emissions since 1972.

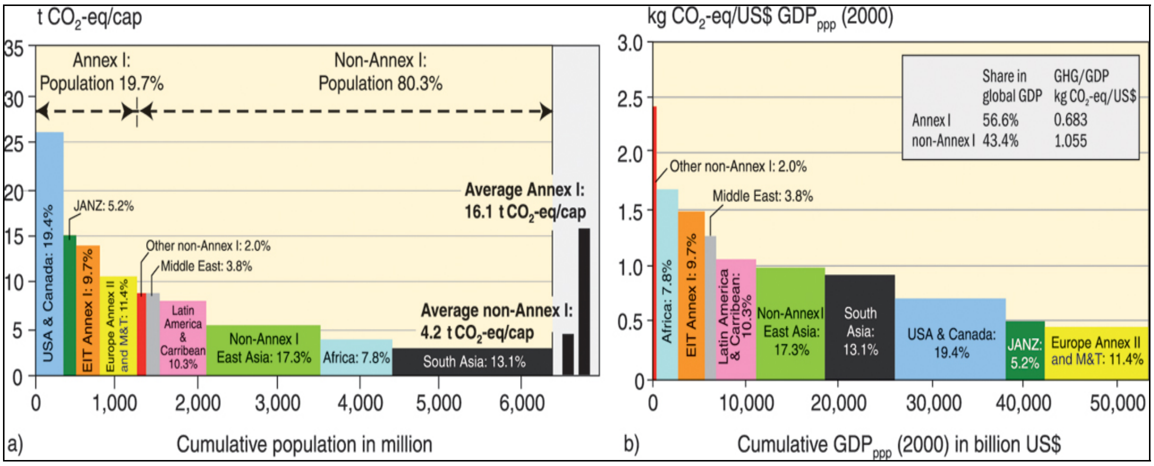

Figure 2.18 Regional distribution of GHG emissions: (a) distribution of regional per capita GHG emissions according to the population of different country groupings in 2000; (b) distribution of regional GHG emissions per USD of GDP (PPP) over the GDP of different country groupings in 2000
Source: Figure 2.2 in IPCC, 2007a.

Agriculture, forestry and fisheries sectors have multiple roles in the discussion of climate change. They are one of the first and hardest to be affected by climate change, while they account for one-third of total GHG (Figure 2.19).

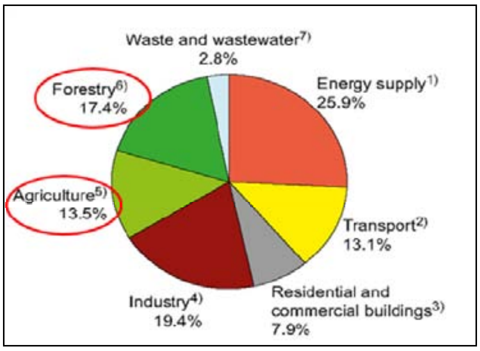

Figure 2.19 Share of different anthropogenic GHGs in total emissions in 2004 in terms of CO_2-eq
Source: Figure 2.1 in IPCC, 2007a.

This in turn suggests that agriculture has great potential to contribute to mitigating climate change by reducing emissions through avoided deforestation and forest degradation and by sequestering carbon in soils.

Conclusion

The RNEA is likely to be adversely affected by climate change in multiple sectors that directly define the well-being of the population. Several areas for action constitute opportunities for the countries in the Region. Promotion of agriculture is key in the reduction of atmospheric GHGs, through building the capacity of agricultural personnel and decision-makers. Efforts to mitigate climate change and to enhance the resilience of rural populations and their livelihoods to climate variability and climate change impacts can be considered in line with efforts to achieve higher levels of sustainability. Agricultural practices that reduce GHG emissions or sequester carbon and help farmers to adapt to climate change at the same time should be identified and promoted, contributing to sustainable development.

References

Abdulla, F., Eshtawi, T. & Assaf, H. 2009. Assessment of the impact of potential climate change on the water balance of a semi-arid watershed. *Water Resour. Manage.*, 23: 2051–2068.

Al-Jeneid, S., Bahnassy, M., Nasr, S. & El-Raey, M. 2008. Vulnerability assessment and adaptation to the impacts of sea level rise on the Kingdom of Bahrain. *Mitig. Adapt. Strat. Glob. Change*, 13: 87–104.

Conway, D. 2005. From headwater tributaries to international river: observing and adapting to climate variability and change in the Nile basin. *Global Environ. Chang.*, 15: 99–114.

El-Raey, M., Dewidar, K.R. & El-Hattab, M. 1999. Adaptation to the impacts of sea level rise in Egypt. *Mitig. Adapt. Strat. Glob. Change*, 4: 343–361.

El-Raey, M., Frihy, O., Nasr, S.M. & Dewidar, K.H. 1999. Vulnerability assessment of sea-level rise over Port Said Governorate, Egypt. *Environmental Monitoring and Assessment*, 56: 113–128.

FAO. 2009. *State of World Fisheries and Aquaculture 2008*. FAO, Rome.

FAO. 2008. *Climate change: implications for agriculture in the Near East*. Information paper for 29th FAO Regional Conference for the Near East, Cairo, Egypt. (available at ftp://ftp.fao.org/docrep/fao/meeting/012/k1470e.pdf).

Frihy, O.E. 2003. The Nile Delta – Alexandria Coast: vulnerability to sea-level rise, consequences and adaptation. *Mitig. Adapt. Strat. Glob. Change*, 8: 115–138.

Gommes, R., El Hairech, T., Rosillon, D., Balaghi, R. & Kanamaru, H. 2009. Impact of climate change on the agricultural sector – impact on crop yields. FAO, Government of Morocco, and World Bank.

Intergovernmental Panel on Climate Change (IPCC). 2007a. Climate Change 2007: Synthesis Report, Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Core writing team: R.K. Pachauri & A. Reisinger, eds. Geneva, Switzerland. 104 pp.

Intergovernmental Panel on Climate Change (IPCC). 2007b. Climate Change 2007: The Physical Science Basis, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor & H.L. Miller, eds. Cambridge, UK, and New York, USA, Cambridge University Press. 996 pp.

Intergovernmental Panel on Climate Change (IPCC). 2007c. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden & C.E. Hanson, eds. Cambridge, UK, Cambridge University Press. 976 pp.

Knippertz, P., Christoph, M. & Speth, P. 2003. Long-term precipitation variability in Morocco and the link to the large-scale circulation in recent and future climates. *Meteorol. Atmos. Phys.*, 83: 67–88.

Koocheki, A., Nasiri, M., Kamali, G.A. & Shahandeh, H. 2006a. Potential impacts of climate change on agroclimatic indicators in Iran. *Arid Land Research and Management*, 20: 245–259.

Koocheki, A., Nassiri, M., Soltani, A., Sharifi, H. & Ghorbani, R. 2006b. Effects of climate change on growth criteria and yield of sunflower and chickpea crops in Iran. *Climate Research*, 30: 247–253.

Lhomme, J.P., Mougou, R. & Mansour, M. 2009. Potential impact of climate change on durum wheat cropping in Tunisia. *Climatic Change*, 96: 549–564.

Sene, K.J., Tate, E.L. & Farquharson, F.A.K. 2001. Sensitivity studies of the impacts of climate change on White Nile flows. *Climatic Change*, 50: 177–208.

Shaban, A. 2009. Indicators and aspects of hydrological drought in Lebanon. *Water Resour. Manage.*, 23: 1875–1891.

Strzepek, K.M. & Yates, D.N. 2000. Responses and thresholds of the Egyptian economy to climate change impacts on the water resources of the Nile River. *Climatic Change*, 46: 339–356.

Xoplaki, E., Gonzalez-Rouco, J.F., Luterbacher, J. & Wanner, H. 2004. Wet season Mediterranean precipitation variability: influence of large-scale dynamics and trends. *Climate Dynamics*, 23: 63–78.

Annex – Climate change impacts and vulnerability of the countries of the Near East and North Africa Region

Vulnerable sectors and possible impacts of climate change identified in national communication reports under the UNFCCC are listed. Common climate-related disasters are identified based on the database of the Centre for Research on the Epidemiology of Disasters (www.emdat.be/database). The disasters in the database are listed according to the number of people affected. For the most recent disaster, the year of occurrence is also given. Only the most important ten recent disasters are taken into account.

Country	Vulnerable sectors and possible impacts of climate change	Common climate-related disasters
Algeria	Vulnerable to natural hazards such as floods and drought.	Floods (1969)
Bahrain	Low-lying areas of the country's islands vulnerable to sea-level rise.	None
Egypt	Reduced productivity of crops and increased water requirements. Heavily populated Nile Delta vulnerable to sea-level rise.	Floods (1994), windstorms
Iran (Islamic Republic of)	Change in length of growth period and number of freezing days. Damage from intense cyclones originating in Arabian Sea.	Drought (1999), floods
Iraq	Possible impacts on Tigris–Euphrates stream flow. Increasing irrigation demand.	Drought (1969), floods
Jordan	Increasing irrigation demand. Possible rainfall decrease adds additional stress to already scarce water resources.	Drought (1999), floods, windstorms, high temperatures
Kuwait	Low coastal areas vulnerable to sea-level rise. Storm surges affect coastal oil production.	Floods (1997)
Lebanon	Increased stresses on water resources. Shift of arable area to more arid climate zone. Negative impacts on citrus, olive, apple and sugar-beet production.	Windstorms (1992), floods
Libyan Arab Jamahiriya	Recurring droughts and dependence on rainfed agriculture. Possible desertification of Jifara Plain in northwest.	None
Mauritania	Decreased water resources. Dependence on water originating outside border. Degradation of arable land. Degradation of pasture and loss of livestock.	Drought (1980), floods
Morocco	Ouergha watershed will likely see changes in runoff.	Drought (1999), floods
Oman	Seawater intrusion into freshwater aquifers. Storm surges affect coastal oil production. Decreasing groundwater level.	Windstorms (2007)
Qatar	Increasing water stress. Storm surges affect coastal oil production.	Not available
Saudi Arabia	Water stress will increase due to warmer temperature.	Floods (2003), windstorms
Syrian Arab Republic	Possible impacts on Tigris–Euphrates stream flow. Increasing irrigation demand.	Drought (1999), floods, windstorms, landslides
Tunisia	Mediterranean coast vulnerable to sea-level rise. Increased water stress.	Floods (1979), drought
United Arab Emirates	Seawater intrusion into freshwater aquifers. Storm surges affect coastal oil production.	None
Yemen	Risk of desertification. Increasing irrigation demand.	Floods (1982), drought

2.2 Adapting to climate change: the ecosystem approach to fisheries in the Near East and North Africa Region

Introduction

The IPCC projects that atmospheric temperatures will rise by 1.8–4.0 °C globally by 2100 (IPCC, 2007). This warming will be accompanied by rising sea temperatures, changing sea levels, increasing ocean acidification, altered rainfall patterns and river flows, and higher incidence of extreme weather events (WorldFish Center, 2008).

The productivity, distribution and seasonality of fisheries, and the quality and availability of the habitats that support them, are sensitive to these climate change effects. In addition, many fishery-dependent communities are in coastal and riparian environments and highly exposed to climate change. Therefore, the impacts of climate change on fisheries are not only limited to the production sector but extended to the social and economic aspects of fisheries communities.

Many capture fisheries worldwide have declined sharply in recent decades or have already collapsed from overfishing. Climate change will compound existing pressure on fisheries. How to sustain fisheries in the face of climate change poses a great challenge to fisheries management. Due to the extensiveness, complexity and unpredictability of climate change impacts, a holistic approach must be adopted when developing coping policies and mitigation measures. The EAF (FAO, 2009) provides a framework for integrated management of fisheries, taking into account the knowledge and uncertainties in biotic, abiotic and human components of ecosystems and their interactions. The holistic nature of EAF provides the most comprehensive approach to tackling the issues of climate change impacts on fisheries.

This paper first presents a brief overview of the EAF – its background, principles and processes for application – and then provides preliminary thoughts on the role of the EAF in identifying vulnerability of fisheries to climate change and in developing policy and strategies to address climate change impacts. Much of the introductory information on the EAF has been abstracted from FAO (2009) and Bianchi, Cochrane and Vasconcelos (2009).

FAO's ecosystem approach to fisheries

Institutional foundation

The EAF emerged from the convergence of two important paradigms: conservation, and fisheries management. Conservation focuses on the protection of the natural environment; whereas, fisheries management mainly aims to harvest a resource sustainably to meet societal and economic needs. Supported by the concept of sustainable development, the EAF builds on the recognition of the interdependence between ecosystem health and human well-being. The approach is also motivated by the increased understanding of fishery–ecosystem interactions and by the poor performance of conventional fishery management approaches. The principles, concerns and policy directions contained in the provisions of the Code provide a framework for the EAF.

Hence, the concepts and principles of the EAF are not new. They are contained in a number of international instruments, agreements and conference outputs, in addition to the Code, that have been negotiated during the last few decades. The two main international roots of the EAF – as well as the Code – are the 1972 Declaration of the United Nations Conference on the Human Environment (the "Stockholm Declaration") and the United Nations Convention on the Law of the Sea (UNCLOS) adopted in 1982. In 1992, the United Nations Conference on Environment and Development (UNCED) emphasized both the importance of placing people at the centre of concerns and of the sustainable exploitation of resources. The Rio Declaration on the principles of sustainable development, and Agenda 21, which contained extensive provisions for the seas and oceans and their management, were adopted in 1992. The Convention on Biological Diversity (CBD) was also signed, elaborating the core principles of multiple-use biodiversity management and leading to the adoption in 1995 of the EA as the primary action framework under the CBD. A number of international events have followed, including the adoption of relevant United Nations General Assembly (UNGA) Resolutions (e.g. 61/105 and 61/222), which have contributed to the progressive emergence of the EAF and related paradigms.

Linked to the United Nations (UN) and international agenda are a myriad of national and regional efforts and initiatives to apply a more holistic approach to fisheries management and to safeguard ecosystems. Parallel initiatives also exist within other sectors, such as forestry and tourism; all contributing to international efforts toward sustainable development approaches and practices. In the context of oceans, examples of cross-sectoral approaches include: ecosystem-based fishery management (EBFM), implemented by, for example, the United States Pacific Fisheries Management Council; the ecosystem approach to management (EAM) undertaken by the Commission for the Conservation of Living Marine Resources of the Antarctic Region (CCLMRAR); the fisheries ecosystem management framework contained in the Australian national strategy on ecologically sustainable development (ESD); and the LME management initiatives. There are similarities in the

overarching principles and objectives of the various approaches to natural resource management, but there are also differences in their scope and emphasis.
The EAF is also closely linked to other approaches in the field of development, natural resource and spatial area management, e.g. the sustainable livelihoods approach (SLA) and integrated management (IM). These approaches are complementary to the EAF, and indeed there is a substantial overlap in terms of their underlying principles, philosophy and methods.

Principles and definition
The EAF takes its focus in fisheries management but broadens the perspective beyond seeing a fishery as simply "fish in the sea, people in boats", beyond consideration only of commercially important species, and beyond management efforts directed solely at the fish harvesting process. The EAF requires the inclusion of interactions between the core of the fishery – fish and fishers – as well as other elements of the ecosystem and the human system relevant to management. The EAF is aligned with the more general EA but is mainly bounded by the ability of fisheries management to implement the EA(F). However, this should not be seen as downplaying the fisheries sector's responsibility in collaborating in a broader multisectoral application of the EA:

- The purpose of an EAF is to plan, develop and manage fisheries in a manner that addresses the multiple needs and desires of societies, without jeopardizing the options for future generations to benefit from the full range of goods and services provided by the aquatic ecosystems.
- An ecosystem approach to fisheries (EAF) strives to balance diverse societal objectives, by taking account of the knowledge and uncertainties of biotic, abiotic and human components of ecosystems and their interactions and applying an integrated approach to fisheries within ecologically meaningful boundaries (EAF Guidelines, page 6).

Table 2.2 Moving towards an EAF – examples of the shifting focus

Conventional fisheries management	**EAF**
Stakeholders are those directly or indirectly involved in fishing activities	Stakeholders are found throughout the fishery system and in other sectors of the ecosystem
Management commonly by government fisheries authority (top-down)	Participation and comanagement with a broad spectrum of stakeholder groups
Operates through regulations and penalties for non-compliance	Compliance with regulations is encouraged through incentives
Single-species (or target-resource) management	Target and non-target species, habitat and broader ecosystem impacts
Focus on the fishery	Focus on the broader fishery system
Indicators related to fish catches and status of fish stock	Indicators related to all parts of the aquatic ecosystem and goods and services
Scientific knowledge is the only valid knowledge for decision-making	Traditional, local, and scientific knowledge systems may be used for decision-making

The EAF is not inconsistent with or a substitute for conventional fisheries management approaches but intends to improve their implementation and reinforce their ecological relevance with a view to contributing to achieving sustainable development. Accordingly, an EAF should address the following principles:

- Governance should ensure both human and ecosystem well-being and equity.
- Fisheries should be managed to limit their impact on the ecosystem to the extent possible.
- Ecological relationships between the fishery resources targeted and harvested by a fishery and those species dependent and associated with these resources should be maintained.
- Management measures should be compatible across the entire distribution of the fishery resource, i.e. in the whole area where it exists, including across jurisdictions and management plans if required.
- The precautionary approach should be applied because the knowledge on ecosystems is incomplete.

Hence, the EAF is an extension of the conventional fisheries management paradigm[2] allowing for a broader and more holistic approach to analysis and management actions. In conceptual terms, this may appear fairly clear. However, in practice, the exact shape and magnitude of this extension will vary from one situation to another as existing fisheries management systems range widely from basically free and open access to more elaborate multispecies and/or rights-based management frameworks. Table 2.2 provides some examples of the shift in focus that EAF entails.

The EAF in practice

The EAF process
The typical EAF process has been described in the EAF Guidelines produced by FAO, and the various concepts and mechanisms are pulled together here with a focus on how to operationalize an EAF. While recognizing that the paths into an EAF vary and that the process is iterative, the planning and implementation of an EAF follow Figure 2.20 and five main steps:

- initiation and preparation;
- formulation of an EAF policy and identification of issues;
- development of a management plan and operational objectives;
- implementation;
- monitoring and evaluation.

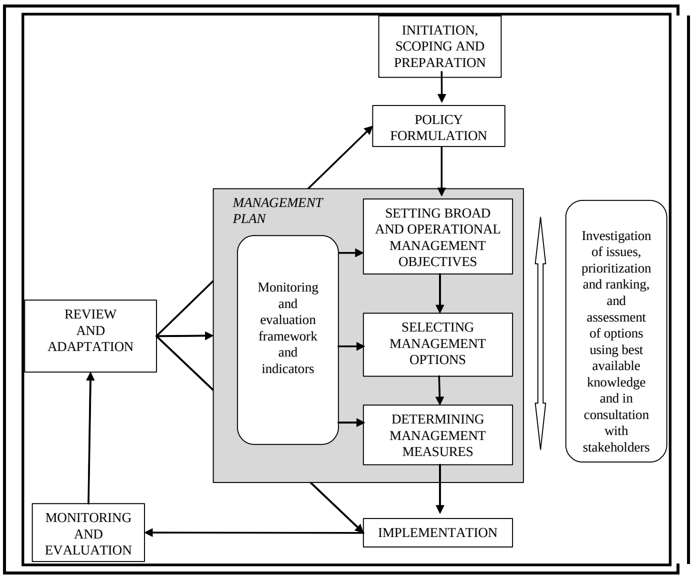

Figure 2.20 Steps in the EAF process

Initiation and preparation

Whatever the path into an EAF is, and independent of the existing fisheries management situation, the first activities of any EAF process will concern planning and preparation. The purpose of this first step is to gather initial information and to plan a participatory process consistent with the context (cultural, resources available, types of fisheries, etc.). It will also include the definition of the scope

[2] In medium- and large-scale commercial fisheries, the dominant fisheries management paradigm in recent decades has been so-called target-resource-oriented management (TROM), focusing mainly on the stock of the target species. However, many small-scale, multispecies fisheries are undertaken with little intervention beyond development support, or are based on more traditional management systems. The term “conventional fisheries management” will be used in this paper referring to the global situation, of which TROM is a part.

and scale of the EAF, and the development of a common understanding of what the current situation is and what the potential issues are.

An EAF can be initiated at a variety of levels and by different stakeholder groups. However, the responsibility for coordinating and implementing the EAF generally remains with the competent fisheries management authority. The EAF coordinators will need to establish an initial EAF process plan and ensure that the necessary basic resources for carrying out the process are available. Human resources are a key element and the EAF team should have the necessary multidisciplinary and technical capacities as well as the ability to bring about collaboration with partners and stakeholder groups. This means constructing an EAF team consisting of scientists and practitioners including, *inter alia*, sociologists, anthropologists, economists and biologists, preferably with interdisciplinary capacities. There is also a need for process-oriented skills such as facilitation, negotiation and change management. It is important to ensure that all relevant disciplines are integrated in the process, i.e. for planning and preparation, policy formulation and identification of issues, management plan development, implementation, and monitoring and evaluation. The formal integration of all EAF disciplines will reduce the cost of management and make the EAF process more effective than if they are kept separate.

There may also be a need to establish a specific mechanism for intersectoral coordination. Depending on the scope and scale of the EAF and on the composition and mandate of the EAF team, an intersectoral advisory group or committee could be needed to support and coordinate the work at a higher political and administrative level. Such a group or committee would include representatives from relevant government agencies as well as key non-governmental organizations (NGOs) and the private sector.

The identification of stakeholders – by conducting a stakeholder analysis – is a key activity at the beginning of the EAF process. This exercise will widen the group of individuals, organizations and agencies that should be consulted and involved beyond the EAF team and immediate partners. Further along the EAF process, these stakeholder groups may expand or change. Establishing rules and institutional structures for how different stakeholders engage and participate in the EAF is fundamental for its implementation.

It is also critically important to ensure that there is a common understanding among stakeholders of what the EAF means in the context of fisheries management, so that policy and management measures that are subsequently developed are informed by the underlying concepts. The EAF plan needs to have clear objectives and should define the EAF principles that it is based on. In conjunction with defining the scope and scale of the EAF, the coordinators have to be clear about what they intend to achieve and ensure that this view is shared with key stakeholders and the EAF team members. Early on in the process, this perspective should be communicated and discussed with the wider group of stakeholders and the public. It is likely that efforts and resources will have to be allocated to raising awareness and building capacity as part of the EAF communication strategy.

Initial stakeholder consultations should identify main societal goals and the interests and objectives of different groups. These should be shared, recognizing that the perceptions and aspirations of different groups may sometimes appear difficult to reconcile and require repeated facilitation and negotiations. Once it is understood that a reconciliation of views is required , objectives can be developed into a common vision for the EAF. A vision is a description of the ideal state of the fishery and its ecosystem that stakeholders aspire to, both in terms of its biological status and their socio-economic circumstances and governance arrangements, and it constitutes a basis for policy formulation.

A “scoping exercise” is another element of the initial preparatory phase. This entails a preliminary collection and consolidation of basic information on the fishery system and the related ecosystem as defined by the agreed scope and scale of the EAF. At this stage, a background document that can be expanded and elaborated on further is required; this will help the EAF team to understand the potential critical issues that the EAF should deal with. The issues and concerns identified in the consultative process should also be taken careful note of and will together with the vision form the basis for developing an EAF policy and, subsequently, a management plan.

In summary, the outputs of the EAF "initiation and preparation" step are an EAF team, a detailed process plan, a preliminary mapping of stakeholders, plans for participation and communication, a draft scoping document (i.e. a summary of the nature of the fishery system and its context) as well as an initial list of potential issues and a vision statement.

Identification of priority issues and formulation of an EAF policy

This step comprises a further elaboration of the preliminary scoping exercise and the definition of policy options and goals. However, in most cases, the move towards an EAF is incremental and is unlikely to involve wholesale scrapping of existing policies and management frameworks. Although it may be appropriate and desirable to formulate entirely new policies in some cases, it is more likely that there will be a gradual review and modification of existing policies.
The setting of goals requires input from all relevant stakeholder groups and is informed by an analysis of the information collected on the fishery system, its policy, institutional and legal frameworks and socio-economic context. The issues identified in the preparatory phase and the vision statement provide the general framework for the policy formulation. The process for identifying goals will vary depending on the scale of the EAF (e.g. LME versus local level) and may require several iterations to ensure that the goals identified do in fact represent stakeholders' priorities. There will also be a need for continual reference to the EAF principles to ensure conformity. It should be recognized that the setting of priorities will also be influenced by other factors, such as the macroeconomic policies of the country, the particular focus of the current political regime or commitments that have been made in terms of international agreements or conventions.

Typical policy level goals could include statements relating to fishery rights and access (management and use rights), priorities given to different fishery subsectors or the role the fisheries sector should play, for example, economically or for creating employment opportunities – locally or in the region – and, of course, outline biological and ecological goals with regard to desired states of fishery resources or ecosystems. At times, the existing legal framework may not support the policy change that the EAF entails. In such cases, EAF coordinators have to investigate the possibilities of revising relevant legislation.

The output of the policy formulation process will be a policy document. This document should be made available to all stakeholders and the public in general in order to ensure transparency. It should also be remembered that policies are not static instruments but need to be reviewed regularly, incorporating relevant developments and experiences gained.

Development of an EAF management plan and its objectives

The EAF management plan provides a mechanism to support the implementation of desired policy directions. Thus, while the policy level is strategic in nature, a management plan is at the practical level of specifying the objectives and actions needed to achieve the broad goals of a fishery or an associated ecosystem which, in turn, provide the inputs into the subsequent operational aspects of implementation. The development of the management plan is a key step in the EAF process and will include the setting of management objectives, selecting management options and determining management measures (see Figure 2.20). The management plan should also contain indicators and performance measures and outline monitoring, assessment and review processes.

An EAF management plan is designed along similar lines to a management plan that might be developed within a government department, NGO or private business in order to meet policy goals. The essential idea is also similar to that of a conventional fisheries management plan, but the suite of fisheries management tools proposed in an EAF management plan should be explicitly linked to the principles and practice of the EAF.

Generally, the stakeholder analysis carried out as part of the initial preparations would need to be refined at this stage. It is also advisable to identify a few individuals who could represent the interests of larger stakeholder groups, and who would interact with the EAF managers on an ongoing basis. Special attention should be given to ways of identifying and involving poor and marginalized groups and individuals who may not respond to mainstream announcements of opportunities for public involvement. Including poor and food-insecure fishers and fish workers in the management processes is likely to improve the potential for pro-poor content of the EAF and address potential inequitable distributional effects. There may be a need to provide capacity building and training to ensure that all stakeholder groups have equal opportunities to participate in the EAF.

Management-level objectives are more narrowly expressed than policy goals and are generally defined at two levels: broad management objectives, and operational objectives. The broad objectives state the intended outcomes of the EAF management and constitute the link between the policy goals and what a specific EAF management is trying to achieve. The operational objectives are more specific and have direct and practical meaning for the fishery system that is being managed. They should be measurable and linked to specific time periods.

The real challenge is not simply to list all objectives but to prioritize them in order to reflect the reality of limited resources and the fact that some objectives will be considered more important than others. In order to do so, there is a need to further investigate and prioritize the underlying issues and concerns. This may involve simply providing a consolidated list of all issues raised and grouping them under common headings, with a brief description of all the issues based on currently available information. However, more often, investigations should involve follow-up discussions with stakeholder groups. In order for stakeholders to make informed judgements regarding priority issues and which of the available options might best serve societal needs and goals, information about their potential impact (e.g. effectiveness and distribution) and other consequences (e.g. costs/benefits and political implications) needs to be gathered and made available. There are various methods that can be used to assist in this process and the approaches for assessing costs and benefits and associated risks, as described in De Young, Charles and Hjort (2008), are useful tools in this respect.

To achieve the objectives, choices have to be made regarding the specific EAF management tools to be used. These measures can include technical measures (e.g. gear regulations), spatial and temporal controls (e.g. marine protected areas [MPAs] and closed seasons), and input (effort) and output (catch quota) controls as well as incentives and other mechanisms. In deciding which measures and instruments to use, the impacts and effectiveness of the different options need to be assessed and analyses of costs and benefits is a key approach here. For example, suppose that a policy decision has been made to adopt a participatory comanagement approach in a particular fishery. While there are clear benefits to this approach, there are also likely to be cost implications in terms of time and expense. Decisions may have to be made in the context of the management plan to determine a specific form of participatory comanagement that achieves a desired balance among these costs and benefits. Depending on the specific context, some options being considered for a management plan may turn out to have excessively large cost implications whatever the potential benefits (e.g. implementing a multispecies quota system, as a means to deal with bycatches and species interactions, may be financially infeasible in many circumstances), while other options might be seen as "win–win" options (e.g. using a suitably inexpensive device to reduce unwanted bycatch while simultaneously reducing fishing costs).

The distributional implications of a management option are additional key factors to consider. In some cases (e.g. the establishment of certain MPAs), the aggregate benefits may clearly outweigh the costs, but the distributional impacts of the measure may be a critical issue, i.e. inequities in impacts across stakeholders, with some benefiting greatly while others incur a disproportionate fraction of the costs.

As it is likely that there will be divergent stakeholder interests, it is inevitable that hard choices will have to be made, and key issues that often arise are: (i) Who ultimately determines which objectives and management options are the preferred ones?; and (ii) What are the criteria that ultimately inform such choices? In order to arrive at an effective management plan, compromises often have to be made. In fact, it is likely that there is no optimal route satisfying everybody's wishes, but "second best" – for everyone – management options may be the solution. In order to arrive at acceptable compromises, extensive negotiations may be required, combined with facilitation methodologies, e.g. scenario exercises and analyses of risks and uncertainties. If consensus cannot be reached, the decision-makers may need to call in a skilled negotiator or they may decide to make the final choices without further reference to the participatory process. However, care should be taken not to ignore any minimum requirement defined by stakeholder groups when settling for a "second-best" management option.

In addition to specifying management measures, it is fundamental that the management plan includes the necessary institutional details for implementing the EAF processes that have been chosen. It also has to be ensured that the preferred management options are supported by the existing legal framework. For example, if a policy decision were made to involve stakeholders in management, then the management plan would need to clarify the degree of such comanagement, the roles and responsibilities of the participants and guidance for the institutional structure and functioning. The legal framework needs to allow for delegation of management authority to comanagement groups. If not, it will be difficult to implement the management plan until a legislative revision has taken place.

Implementation

The management plan specifies choices of management options and management measures that are considered suitable to achieve the objectives set at the beginning of the process – objectives for management that build on broader policy goals and indeed overall societal goals. Once the various choices have been made, there remains the challenge of implementation.

While in conventional fisheries management practices, implementation may have been carried out by the government fisheries agency alone, EAF management generally involves a broader institutional setup including collaboration with parties outside the fisheries sector. Even within the fisheries sector, the stakeholder groups are likely to be more numerous and diverse, and this reality may require a review of the institutional structure. Owing to the broadening of the management scope, support from higher levels within the national administration and political arena – and from other partners, e.g. NGOs and private sector – for coordination and provision of the resources necessary for implementation will be desirable. A need for capacity building and training of staff should be expected in order to ensure a thorough understanding of the EAF concept.

As with the other steps discussed in the EAF process, the implementation details will be situation-specific, but successful EAF implementation is likely to depend on:

- political commitment;
- appropriate legal and institutional frameworks that enable practical implementation;
- capacity and skills, both with regard to human resources and equipment;
- cooperation across relevant sectors and departments;
- ongoing stakeholder support;
- appropriate funding, especially when substantial new processes and systems need to be established.

In practice, some of the tasks to be performed by the EAF managers and other staff may be similar to those carried out previously where a conventional fisheries management plan had been in place. When developing a detailed EAF task implementation plan, a careful review should be carried out considering what needs to change, what additional tasks need to be undertaken and what no longer needs to be done. Difficult choices may be needed, particularly in an environment of limited resources. The roles and responsibilities, as well as the resources needed for undertaking each task and activity, should be clearly identified. Operational plans for each partner or group, e.g. research group, compliance group, and information management unit, should be put in place. Procedures and systems need to be updated according to the new EAF management and implementation plan.

Similarly, the monitoring, control and surveillance (MCS) functions need to be reviewed and changed as required. These will depend on the scope of the EAF and the management measures that are used, as is also the case under conventional fisheries management practices. However, the EAF will address a wider scope of ecosystem elements and may also use a wider range of management measures. Observer schemes (e.g. for bycatch and discard monitoring), vessel monitoring systems (VMSs; e.g. for control of closed areas and MPAs) and means for patrol and enforcement are examples of possible MCS components.

Communication and transparency are key aspects of EAF operational implementation. Information on the development of the fishery and its EAF management system has to be made available and communicated to all directly concerned. Although the fishing industry and fishers will have been involved in the participatory process of establishing the EAF management plan, there will still be a need for meetings and information sharing with all relevant parties.

Monitoring and evaluation

An EAF requires a suitably integrated and interdisciplinary approach to monitoring and evaluation, and a system for review and adaptation needs to be built into the process. Depending on the particular situation and local conditions, the monitoring and evaluation package will vary from one EAF to another. There are a number of different approaches that can be used, including participatory methods and performance indicators. Indicators and reference points are commonly at the core of a monitoring system and should be defined within an overall framework that will allow for adaptive management.

While monitoring and evaluation are essential aspects of any fisheries management system, there are particular challenges in EAF management, owing to the increased scale and scope involved. In other words, it becomes necessary to monitor not only the narrow aspects of a specific fish stock and the fishers exploiting it, but also the state of the aquatic ecosystem, interactions with and impacts on other uses of that ecosystem, and relevant human dimensions, including the dynamics of fishers, fishing communities, and the surrounding socio-economic environment. Furthermore, both the scope and the criteria for evaluation must be broadened to allow for the reality that additional objectives, both ecosystem-oriented and multiuse related, are being pursued.

There are many different criteria and types of indicators that may be of interest within an EAF framework. The policy document and management plan should specify indicators and reference points for all goals and objectives. These will hence range from reflecting broader sustainability issues at the policy level, e.g. social, economic and institutional targets derived from the Millennium Development Goals (MDGs), to more basic measures of fish catches and exports, fishery employment and revenues, and fishing community welfare, as well as attributes such as ecosystem health and community resilience. It is also desirable to include performance monitoring in the management plan, including process-based indicators for assessing the quality of implementation. The outcome-based indicators should be related to the impact of the fishery, so that its value is altered if the fishery impact changes.

Indicators should deliver meaningful information on results, achievements and performance. They need to be based on data and the means for collecting information, and the cost implications should be taken into consideration when designing the monitoring system. If a large number of indicators are suggested, reflecting the priorities of different stakeholder groups, these need to be assessed and a selection made as to which are the most pertinent ones. Particularly in data-poor situations, the number of indicators should be restricted to a few effective ones based on defined criteria.

Monitoring and review should take place at regular intervals to systematically compare the current situation and what has been achieved to date, with the reference points defined for each indicator. An EAF would typically include both continuous monitoring, short- and long-term review and evaluation cycles. The monitoring and review/evaluation processes should include mechanisms for reassessing and redefining policy goals and management objectives and measures as required in accordance with the adaptive management approach.

The EAF and climate change

Potential impacts of climate change on fisheries

Climate change has a strong impact on fisheries and aquaculture, with significant food security consequences for certain human populations. Such impacts have already been observed in many circumstances and include:

- In marine waters, climate processes and extreme weather events will increase in frequency and intensity – the most well known of these is the El Niño phenomenon in the South Pacific.
- The ongoing warming of the world's oceans is likely to continue, but with geographical differences and some decadal variability. Warming is more intense in surface waters but is not exclusive to these, with the Atlantic showing particularly clear signs of deep warming.
- Changes in fish distributions in response to climate variations have already been observed, generally involving pole-ward expansions of warmer-water species and pole-ward contractions of colder-water species.
- Shifts in ocean salinity are occurring, with near-surface waters in the more evaporative regions of most of the world's oceans increasing in salinity, while marine areas in high latitudes are showing decreasing salinity owing to greater precipitation, higher runoff, melting ice and other atmospheric processes.
- The oceans are becoming more acidic, with probable negative consequences for many coral reef and calcium-bearing organisms.

However, the consequences and extent of the impacts of climate change are difficult to predict or quantify. To maintain the long-term sustainability of fisheries, there is a strong need to develop an effective and flexible fisheries management system in an ecosystem context and to adopt a precautionary approach.

Using the EAF to identify key climate change issues

A key step in the EAF process described above includes the identification of issues (and their prioritization) that need to be addressed by management. To assist in this process, FAO has adopted the ESD issues identification trees that help to identify the specific issues to be managed in the EAF process, including all direct and indirect impacts of the fishery on the broader system. Included in this step is the identification of any non-fisheries issues (those that are external to the fisheries management system) that are affecting, or could in the future affect, the performance of the system and its management.

Figure 2.21 presents generic trees that may be used as starting points for issue identification for a particular fishery or operating unit (OU). To aid in identifying issues in line with the EAF, a three-branched tree is usually proposed: 1. ecological well-being; 2. human well-being; and 3. ability to achieve. The third branch comprises all governance[3] aspects and all extra-fisheries aspects. Climate change naturally finds itself as an issue here as well as impacts on the system from other aquatic and coastal resource users, impacts of changes in prices, and other social, political and economic aspects affecting the fisheries but outside the direct mandate of fisheries management.

[3] Governance is interpreted as the formal and informal arrangements, institutions and mores that determine how resources or an environment are utilized; how problems and opportunities are evaluated and analysed, what behaviour is deemed acceptable or forbidden, and what rules and sanctions are applied to affect the pattern of resource and environmental use (Juda, 1999).

Using the identification of biophysical changes due to climate change expected for the fishery/OU (e.g. changes to water surface temperature, pH levels, and sea level, extreme events), their impacts on the three branches can be identified in a systematic manner. The example shown in Figure 2.21 shows how biotic and abiotic changes identified are, for example, translated into impacts on the species under investigation (Branch 1). Impacts under Branch 2 could include issues regarding safety at sea or along the coasts, impacts on the profit structure of fisheries, and loss or no longer appropriate placement of infrastructure[4]. Impacts under Branch 3 could include increasing demands on the government to deal with fish and human migration issues and changes in the costs of fuel.

How these branches are filled in depends on the context at hand, but the process would allow for a systematic identification of issues and a means to prioritize management responses in the short and long terms. Having the broadened monitoring system that an EAF would imply would also help to monitor changes in the aquatic ecosystems, whether they are leading indicators that help predict likely future changes or indicators that identify current changes to the system. As noted below, FAO is developing a suite of indicators useful for monitoring changes affecting fisheries systems.

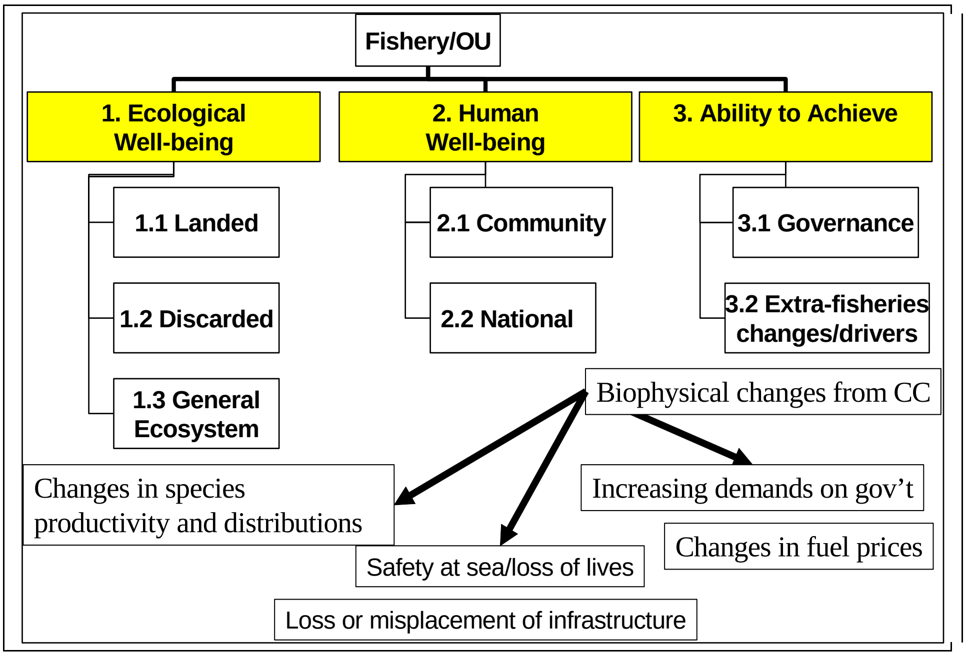

Figure 2.21 Using the EAF issue identification process to identify climate change impacts

Using the EAF to address climate change

Mitigation (increased sequestration and decreased emissions)

Fisheries activities make a minor but still significant contribution to GHG emissions during production operations and the transport, processing and storage of fish and fish products. The primary mitigation route for the sector lies in its energy consumption, through fuel and raw material use and through the responsible management of distribution, packaging and other supply chain components. Fuel efficiency for the sector as a whole can be improved by EAF management – current overcapacity and excess effort lead to lower catches per unit effort and, therefore, lower fuel efficiency. The EAF would reinforce the sector's move to environmentally friendly and fuel-efficient fishing and to eliminating subsidies that promote overfishing and excess fishing capacity. The EAF lends itself as the approach to attain these mitigation goals by directly promoting improved governance, innovative technologies and more responsible practices that generate increased and sustainable benefits from

[4] An example of such is occurring in Namibia, where, owing to shifts in population distributions, processing plants are now finding themselves 100 nautical miles displaced *vis-à-vis* the stocks, having obvious impacts on their profitability.

fisheries. In addition, the EAF will help to eliminate any negative impacts the sector may have on the role of aquatic systems as natural carbon sinks.

Adaptation
To build resilience to the effects of climate change and to derive sustainable benefits, fisheries and aquaculture managers, as a top priority, need to adopt and adhere to best practices such as those described in the Code and the EAF. Progress in this direction would be an important contribution to maintaining biodiversity, preserving the resilience of human and aquatic systems to change, and improving capacity to anticipate and adapt to inevitable climate-induced changes in aquatic ecosystems and the related fisheries production systems. Some direct potential benefits of implementing the EAF include:

- creating a resilient ecosystem, human and governance communities and decreasing vulnerability to change through decreasing the impacts to the sector, decreasing the communities' sensitivities to change and increasing the sector's adaptive capacity;
- supporting intersectoral collaboration (e.g. integrating fisheries into national adaptation and disaster risk management [DRM] strategies and supporting integrated resource management);
- improving general awareness of climate change within and outside the sector;
- promoting context-specific and community-based adaptation strategies;
- avoiding "mal-adaptation" (e.g. overly rigid fishing access regimes that inhibit fisher migrations);
- allowing for quick adaptation to change;
- promoting natural barriers and defences rather than hard barriers that would affect the ecosystem.

Mitigation and adaptation – understanding synergies and trade-offs
As discussed above, there are many possibilities for mutually reinforcing synergies, and benefits exist among mitigation and adaptation actions within the sector and the sector's own development goals. In addition, the sector may benefit from synergies stemming from outside the sector, such as the inclusion of mangroves in the programme of the United Nations Collaborative Initiative on Reducing Emissions from Deforestation and Forest Degradation in Developing Countries (UN-REDD)[5] that should promote their conservation and provide positive spin-off benefits for fisheries, safeguarding the aquatic environment and its resources against adverse impacts of mitigation strategies and measures from other sectors.

There can be negative trade-offs between adaptation and mitigation. As noted in FAO (2008a), adaptation measures in one sector may negatively affect livelihoods in other sectors. For example, river fisheries can be negatively affected from adaptations in other livelihood sectors upstream. In particular, irrigation's additional water needs can reduce flows and affect seasonal spawning and fish productivity. Mitigation measures, such as fertilization of the oceans, can have unintended effects on marine ecosystem structure and functions.

The EAF and EA in general could reduce risks from these trade-offs by promoting diverse and flexible livelihood and food production strategies, flexible and adaptable institutions, food-security risk reduction initiatives and planned food-security adaptation to climate change (FAO, 2008a).

FAO in action

In addition to a series of Technical Guidelines (FAO, 1997, 2003, 2008a and 2008b) and Technical Papers (De Young, Charles and Hjort, 2008; Garcia *et al*., 2003; Plagányi, 2007), FAO's Department of Fisheries and Aquaculture is also in the process of developing a set of practical approaches and

[5] See www.undp.org/mdtf/un-redd/overview.shtml

methods in support of EAF implementation. It is expected that a first Web-based "EAF toolbox" will be made available and, furthermore, a detailed review of indicators useful for monitoring ecological, socio-economic and governance issues under an EAF will be completed and made available to the general public. In the meantime, some process methodologies and information management tools are included in De Young, Charles and Hjort (2008).

In response to FAO's Member Countries' requests for assistance in applying the EA, several trust fund projects are being implemented in FAO with the purpose of addressing the EAF through concerted efforts aimed at simultaneously achieving progress in several if not most of the relevant aspects of the EAF in selected locations or ecosystems. These projects are described briefly in the annex to this paper.

Regarding climate change activities, FAO's Department of Fisheries and Aquaculture has formed an internal Working Group on Climate Change and has helped form the Global Partnership Climate, Fisheries and Aquaculture (PaCFA)[6], comprising 20 international organizations and borne from a mutual desire to draw together potentially fragmented and redundant climate change activities through a multiagency global programme of coordinated actions and the pressing need to raise the profile of fisheries and aquaculture in the UNFCCC negotiating process[7]. Strategic and programme frameworks are being developed both within FAO's Department of Fisheries and Aquaculture and the PaCFA.

FAO's Department of Fisheries and Aquaculture has recently published an overview of current scientific knowledge regarding climate change implications for fisheries and aquaculture (Cochrane *et al*., 2009) and will focus its near-term activities on:

- identifying fish production systems most likely to be impacted by future climate change;
- developing the baseline information and definition of indicators to monitor changes in aquatic ecosystem productivity and human well-being with respect to climate change;
- developing documentation on adaptive frameworks, mechanisms and best practices as well as Technical Guidelines on adaptive strategies in fisheries and aquaculture;
- creating awareness and outreach and developing capacity building;
- producing ongoing reviews of best available knowledge at various scales and regions;
- integrating climate change adaptation and disaster risk reduction planning to increase resilience in fishing communities;
- identifying emissions and mitigation potentials from fisheries and aquaculture and promoting their implementation.

---

[6] See www.climatefish.org/index_en.htm
[7] See, for example, ftp://ftp.fao.org/FI/brochure/climate_change/policy_brief.pdf

References

Bianchi, G., Cochrane, K., & Vasconcelos, M. 2009. Implementing the ecosystem approach to fisheries. *In* Anon. *Fisheries, sustainability and development*, pp. 225–240. Royal Swedish Academy of Agriculture and Forestry. 478 pp.

Cochrane, K., De Young, C., Soto, D. & Bahri, T., eds. 2009. *Climate change implications for fisheries and aquaculture: overview of current scientific knowledge*. FAO Fisheries and Aquaculture Technical Paper No. 530. Rome, FAO. 212 pp.

De Young, C., Charles, A. & Hjort, A. 2008. Human dimensions of the ecosystem approach to fisheries: an overview of context, concepts, tools and methods. FAO Fisheries Technical Paper No. 489. Rome, FAO. 152 pp.

FAO. 1997. *Fisheries management*. FAO Technical Guidelines for Responsible Fisheries No. 4. Rome. 82 pp.

FAO. 2003. *Fisheries management 2. The ecosystem approach to fisheries*. FAO Technical Guidelines for Responsible Fisheries No. 4, Suppl. 2. Rome. 112 pp.

FAO. 2008a. Climate change adaptation and mitigation in the food and agriculture sector: technical background document from the expert consultation held on 5 to 7 March 2008. Rome. (available at www.fao.org/foodclimate/expert/em1/outputs-em1/en/).

FAO. 2008b. Fisheries management. 2. The ecosystem approach to fisheries. 2.1. Best practices in ecosystem modelling for informing an ecosystem approach to fisheries. FAO Technical Guidelines for Responsible Fisheries No. 4, Suppl. 2, Add. 1. Rome. 78 pp.

FAO. 2009. Fisheries management. 2. The ecosystem approach to fisheries. 2.2 Human dimensions of the ecosystem approach to fisheries. FAO Technical Guidelines for Responsible Fisheries No. 4, Suppl. 2, Add. 2. Rome. 87 pp.

Garcia, S.M., Zerbi, A., Aliaume, C., Do Chi, T. & Lasserre, G. 2003. *The ecosystem approach to fisheries. Issues, terminology, principles, institutional foundations, implementation and outlook*. FAO Fisheries Technical Paper No. 443. Rome, FAO. 71 pp.

Intergovernmental Panel on Climate Change (IPCC). 2007. Summary for policymakers. *In* M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden & C.E. Hanson, eds. *Climate change 2007: Impacts, adaptation and vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, pp. 7–22. Cambridge, UK, Cambridge University Press.

Juda, L. 1999. Considerations in the development of a functional approach to the governance of large marine ecosystems. *Ocean Dev. Int. Law*, 30: 89–125.

Plagányi, É. 2007. *Models for an ecosystem approach to fisheries*. FAO Fisheries Technical Paper No. 477. Rome, FAO. 108 pp.

WorldFish Center. 2008. *Small-scale capture fisheries: A global overview with emphasis on developing countries*. Preliminary report of the Big Numbers Project. Penang, Malaysia, FAO, PROFISH, World Bank and WorldFish Center. 63 pp.

Annex – FAO EAF projects

The project "Ecosystem Approaches for Fisheries Management in the Benguela Current Large Marine Ecosystem", a cooperation between FAO, the Benguela Current Large Marine Ecosystem (BCLME) programme and fisheries agencies of Angola, Namibia and South Africa, examined the feasibility of implementing the EAF in the Benguela region. This project pursued a structured and participatory approach based on the FAO Guidelines, to identify and prioritize the gaps in the existing approaches and consider potential management actions to address them.

"Scientific Basis for Ecosystem-based Management in the Lesser Antilles including Interactions with Marine Mammals and Other Top Predators" was another project that provided technical assistance to fisheries institutions of selected countries in the Lesser Antilles to develop information tools, including ecosystem modelling and geographic information systems (GISs), collect standard fisheries data, to improve management of their pelagic resources and fisheries in accordance with the EAF. This project was funded by the Government of Japan, that currently is also funding another project providing extended capacity building for the EAF to selected countries mainly through smaller-scale pilot studies and workshops examining the needs and priorities for EAF, and is also supporting ongoing investigations on ecosystem indicators and modelling approaches and the production of an abridged version of the Technical Guidelines on the EAF, aimed at a more general audience.

Another project is being implemented with core funding from the Government of Norway and in partnership with various Global Environment Facility (GEF)–LME regional projects, to strengthen the knowledge base for implementing EAF in developing countries. With an initial focus in the African region, this project will promote capacity building, standardized data collection and monitoring of marine fisheries and related ecosystems, while supporting policy development and management practices consistent with EAF principles.

Several complementary subregional projects that implicitly address the various biological and socio-economical aspects of EAF in the Mediterranean region are also being implemented with funding from the Governments of Greece, Italy, Spain and the EU and in cooperation with the General Fisheries Commission for the Mediterranean (GFCM).

The EAF is an underlying feature of projects funded by the GEF in the Bay of Bengal, Canary Current ecosystem and the Mediterranean Sea, in which FAO is playing a leading role.

The above projects have allowed the introduction of principles and methodologies for the application of the EA in a number of countries and regions, mainly through workshops at the national and regional levels.

2.3 An ecosystem approach to aquaculture: a way to facilitate adaptation to climate change

Introduction

As aquaculture growth worldwide involves the expansion of cultivated areas, a higher density of aquaculture installations and of farmed individuals, greater use of feed resources produced outside of the immediate area, increased use of freshwater, etc., many negative effects have been identified when the sector grows unregulated or under insufficient regulation and poor management.

On the other hand, aquaculture is increasingly affected by external forcing factors or drivers. These include population growth and development especially including other users of aquatic habitats and coastal ecosystems as well as global trade and climate change. All these forcing factors affect the interactions of aquaculture and the ecosystem at all geographical scales, and with a temporal dimension, adding to uncertainty.

Climate change is foreseen as a major driver for all food production sectors, including aquaculture. The main elements of climate change that could potentially affect aquaculture production – such as sea-level and temperature rise, water stress, changes in rain patterns, extreme climatic events and increasing spread of diseases and transboundary pests – require firm and clear adaptation policies and management measures. However, aquaculture can also offer an important alternative and adaptation opportunity when other sectors are more affected. For example, aquaculture, and particularly cage farming systems (non-consumptive water use) and mariculture, are much less dependent on freshwater compared with land-based food production. This is a relevant issue for countries where freshwater is a limiting factor that will be exacerbated by climate change, as seems to be the case for most countries in the Near East and North Africa. The annex to this paper offers a synthesis of potential threats and benefits or opportunities.

Aquaculture also offers opportunities for the reduction and mitigation of GHG production and sequestration of carbon through good aquaculture production practices, such as use of freshwater effluents for irrigation of rice fields and orchards and replanting of mangrove buffers for coastal protection of ponds bordering the sea and a nutrient sink for marine and brackish water effluents.

FAO has recently been working on the formulation of an EAA framework, following the pathway taken by fisheries (Garcia *et al*., 2003), although a systems perspective has been an implicit consideration in aquaculture (FAO, 2007) because, as a farming process, it must take into consideration in explicit ways the inputs, resource use and outputs, including human resources.

"An Ecosystem Approach to Aquaculture (EAA) is a strategy for the integration of the activity within the wider ecosystem such that it promotes sustainable development, equity, and resilience of interlinked social-ecological systems" (Soto, Aguilar-Manjarrez and Hishamunda, 2008).

The EAA facilitates the adoption of the Code (FAO, 1995) and also responds to the development principles stated in the formulation of the EAF. It has three main objectives within a hierarchical tree framework:

i. ensuring human well-being;
ii. ensuring ecological well-being;
iii. facilitating the achievement of both, i.e. effective governance of the sector/areas where aquaculture occurs and has potential for development.

Two prime goals of the EAA are: (i) to contribute to a "truly" sustainable aquaculture sector (environmentally, economically, socially) considering external forcing factors such as climate change; and (ii) to change the attitude to and perception of the aquaculture sector by the public (in the broadest possible sense).

Key principles

The EAA can be regarded as "the" strategy to ensure that aquaculture contributes positively to sustainable development and should be guided by three main principles, which are also interlinked:

Principle 1
Aquaculture development and management should take account of the full range of ecosystem functions and services, and should not threaten the sustained delivery of these to society.

Developing aquaculture in the context of ecosystem functions and services is a challenge that involves defining ecosystem boundaries (at least operationally), estimating some assimilative capacity and production carrying capacity, and adapting farming accordingly. This should be done for ecosystem services to be preserved or guaranteed. It is important to consider that carrying capacity could change due to climate change. For example, increased temperatures may enhance eutrophication and thereby diminish the previously estimated carrying capacities.

Principle 2
Aquaculture should improve human well-being and equity for all relevant stakeholders.

This principle seeks to ensure that aquaculture provides equal opportunities for development and that its benefits are properly shared, and that it is not detrimental for any groups of society, especially the poorest. It promotes both food security and safety as key components of well-being.

Principle 3
Aquaculture should be developed in the context of other sectors, policies and goals.

This principle recognizes the interactions between aquaculture and the larger system, in particular, the influence of the surrounding natural and social environment on aquaculture practices and results. This principle also acknowledges the opportunity of coupling aquaculture activities with other producing sectors in order to promote materials and energy recycling and better use of resources in general.

Principle 3 is a call for the development of multisectoral or integrated planning and management systems. This is required to account for policies and goals in other sectors as well as to provide a framework and consistent cross-sectoral standards for the delivery of management and development initiatives to meet Principles 1 and 2. This principle is also very relevant under climate change scenarios as adaptation for aquaculture cannot take place in isolation – a watershed perspective is fundamental.

Planning and implementation process

The steps to implement an EAA are depicted in Figure 2.22. To implement an EAA, there must be an aquaculture policy in place; this consists of a broad vision for the sector, reflecting its directions, priorities and development goals at various levels including provincial, national, regional and international. The process starts with the agreement or acceptance of a high-level policy goal. The agreed policy could state something like: "Aquaculture should promote sustainable development, equity, and resilience of interlinked social-ecological systems".

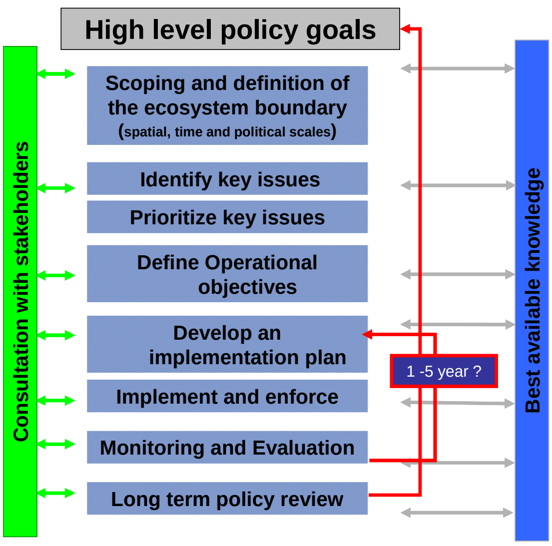

Figure 2.22 The EAA planning and implementation process
Source: Modified from AFPIC, 2009.

Scoping: definition of system boundaries and the relevant stakeholders within
There is a need to define the ecosystem boundaries in space and time when attempting to implement the EAA. The definition of the relevant ecosystem boundaries is a necessary prerequisite exercise including the decision on whether the planning and implementation of the strategy will cover the whole aquaculture sector of a country/region, or (more typically) address an aquaculture system or

aquaculture area in a country/subregion. The definition of the ecosystem boundaries is also needed to identify the relevant stakeholders and to address the different issues (Soto, Aguilar-Manjarrez and Hishamunda, 2008).

Relevant scales

Geographical scales

Farm

The individual farm is easy to locate and identify, and local effects are often easy to assess. However, in cage aquaculture, especially in open ecosystems such as open seas, it may be challenging to establish the boundary of potential effects. Most management practices are developed for this scale and most top-down regulation measures worldwide apply at this scale. Moreover, BMPs are implemented at this level and can be assessed here.

Although it may seem less relevant or meaningful to talk about alteration of ecosystem services at this scale, individual large intensive farms often alter local/site ecosystem functions.

Farmed species escapees and diseases originate and can be prevented/controlled at the farm scale although their effects usually occur at the next spatial scale – the watershed.

Impacts on water and sediment quality and on biodiversity can be dealt with at the farm level, at the “farm group” level, or at a higher level corresponding to some identifiable waterbody, watershed or “agro-ecosystem”.

Most top-down regulations and controls, such as environmental impact assessment (EIA), are designed for this scale although in most cases it only applies to large farms (see FAO, 2009). However, they can be adapted to cover the increasing problem from the clustering of small-scale farms as seen in Asia, where the cumulative impact from many small-scale farms can create significant impacts on the environment.

Stakeholders at this scale are usually farm owners, workers, family members, local inhabitants. Many climate-change adaptation measures can be, and are already undertaken by the farmer at the farm level, such as increasing the height of dykes to combat increasing river heights, sea levels and tidal fluctuation.

The watershed/aquaculture zone, geographic region

This is the geographical scale that includes a cluster of farms that share a common waterbody and need coordinated management. This is the scale where most efforts are needed and where the EAA can be most effective in ensuring the sustainable development of the sector.

While the environmental and social impacts of a single farm could be marginal, more attention needs to be paid to ecosystem effects of collectives or clusters of farms and their aggregate, potentially cumulative contribution at the watershed/zone scale, for example the development of eutrophication as a consequence of excessive nutrient outputs.

Escape of alien species or alien genotypes takes place at the farm level. However, the establishment of alien species and genes and relevant impacts on biodiversity occur through whole watersheds. Similarly, disease outbreaks take place first at the farm level but often need control, management and mitigation at the watershed scale. Even more important, adaptation to climate change must in most cases take place at the watershed level, for example to face the spread of a disease or to establish a monitoring programme of water quality (e.g. temperature and salinity) and coastal protection from increasing tidal surge.

Stakeholders and relevant institutions include: clusters of farms/farmers, watershed management bodies, agriculture associations (agriculture, industry and other interacting sectors as well as aquaculture), local communities and local authorities, servicing entities (transport, local dealers, etc.), research and training institutions, etc. The scale at which these entities operate will depend on the nature of the issues.

Regional/global scale

This scale refers to the global industry for certain commodity products (e.g. salmon, shrimp, catfish) and also to global issues such as production, trade of fishmeal and fish oil for feeds, trade of aquaculture products, certification, technological advances, research and education of global relevance etc. Of particular importance is the supply of fishmeal and fish oil in some areas of the world that are feed ingredients for fish and shrimp production in other areas. This means that resources and energy are moving between different regions of the world with unexpected consequences. The sustainability of these resources is particularly important for the long-term sustainability of aquaculture at a global level and the availability of fishmeal can be very sensitive to climate change and, therefore, make global aquaculture very sensitive.

Global issues can be better tackled by organizations such as FAO, World Organization For Animal Health (OIE) or World Trade Organization (WTO) seeking action and coordination between governments. Local and regional issues are typically best addressed at some level corresponding to an identifiable aquatic system or agro-ecosystem, although a compromise may have to be struck depending on the nature and scale of existing or potential management systems and associated institutions.

Regional fishery bodies (e.g. the GFCM and RECOFI) are very relevant at both watershed aquaculture zone and at regional and global scales.

Temporal scales

Because aquaculture is affected by external forcing factors or drivers such as climate change, it is necessary to apply a precautionary approach owing to unknown ecosystem threshold or resilience, including the human components. Therefore, time scales are relevant in strategy and planning.

Identification and prioritization of issues

The identification of issues should be constrained to the system boundary and also to the ability of addressing the issue. The different issues related to aquaculture activities have been discussed at length in numerous publications (FAO, 1997, 2006, 2007, 2009; Soto, Aguilar-Manjarrez and Hishamunda, 2008). However, it is, as always, relevant to define a clear methodology for the identification and clarification of these together with relevant stakeholders.

For the purpose of the present paper, we focus more on issues/impacts of aquaculture on the ecosystem that are exacerbated by climate change and issues/impacts of climate change on aquaculture.

Issues related to aquaculture effects on the ecosystem

Because aquaculture as a production process requires land, water and specific inputs to produce expected outputs (together with unwanted outputs), issues affecting ecological and social well-being can be associated with the main parts of the process, as shown in Figure 2.23. Usually, direct impacts are of greater concern; nevertheless, indirect impacts can also be relevant. For example, looking under Inputs and into the "Feeds" box in Figure 2.23, the use of trash fish and/or small pelagics to feed tuna could have a negative impact on the small pelagic stocks (Figure 2.24). However, many small-scale artisanal fishers live on these fisheries and benefit from the price paid for tuna feed, and so there is a positive livelihood effect when they do not have other choices (Figure 2.25). Other indirect negative effects could be on wild predator species that live on these pelagic species (e.g. in a nutrient-deficient ecosystem such as the Mediterranean Sea).

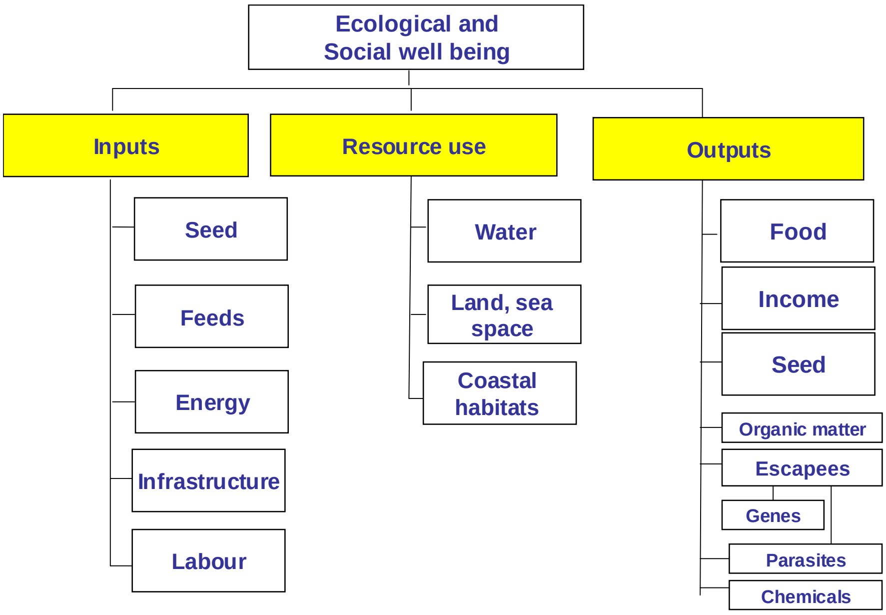

Figure 2.23 Main issues relating to aquaculture impacts on the ecosystem

Types of issues

It is also important to distinguish clearly different types of issues when examining the boxes in Figure 2.22 as there may be ecological, social and "ability to achieve" issues. The latter are related to governance and institutional factors, and most often these are the root cause of the ecological and social issues. Other external forcing factors such as climate change should also be considered under "ability to achieve", also catastrophic events, international market crashes, etc. In the example mentioned above, the feeding of small pelagics to tuna farms encompasses ecological, social and "ability to achieve" issues as already described.

Indeed, a relevant external forcing factor on the aquaculture sector is climate change (De Silva and Soto, 2009), although time scales are not clear. Using the same example described above, climate change could have a strong impact on small pelagic stocks, thereby exacerbating the human harvest effect, to feed tuna in the farms. Therefore, the EAA must consider such events within agreed time scales, particularly at the watershed/waterbody scale (e.g. the Red Sea, the Mediterranean Sea).

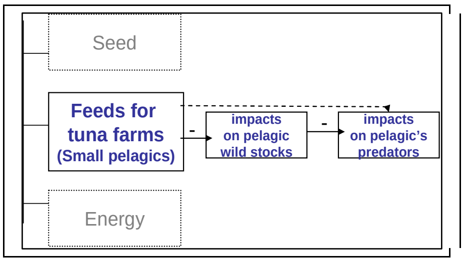

Figure 2.24 Ecological issues relating to aquaculture feed

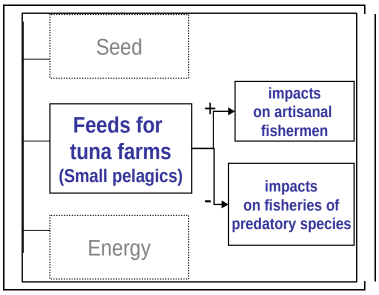

Figure 2.25 Social issues relating to aquaculture feed

Identification process requiring background documentation and knowledge
Proper identification of issues requires: (i) involving the relevant stakeholders for the selected system (within the defined boundaries in the scoping process); (ii) adequate background information available to all these relevant stakeholders; and (iii) a facilitation process including a “neutral facilitator”.

Issues related to inputs
Aquaculture has a number of inputs as part of the farming process (Figure 2.26). Climatic changes negatively affecting these inputs will have an effect on aquaculture productivity and on the communities dependent on aquaculture as a livelihood. Such is the case of freshwater.

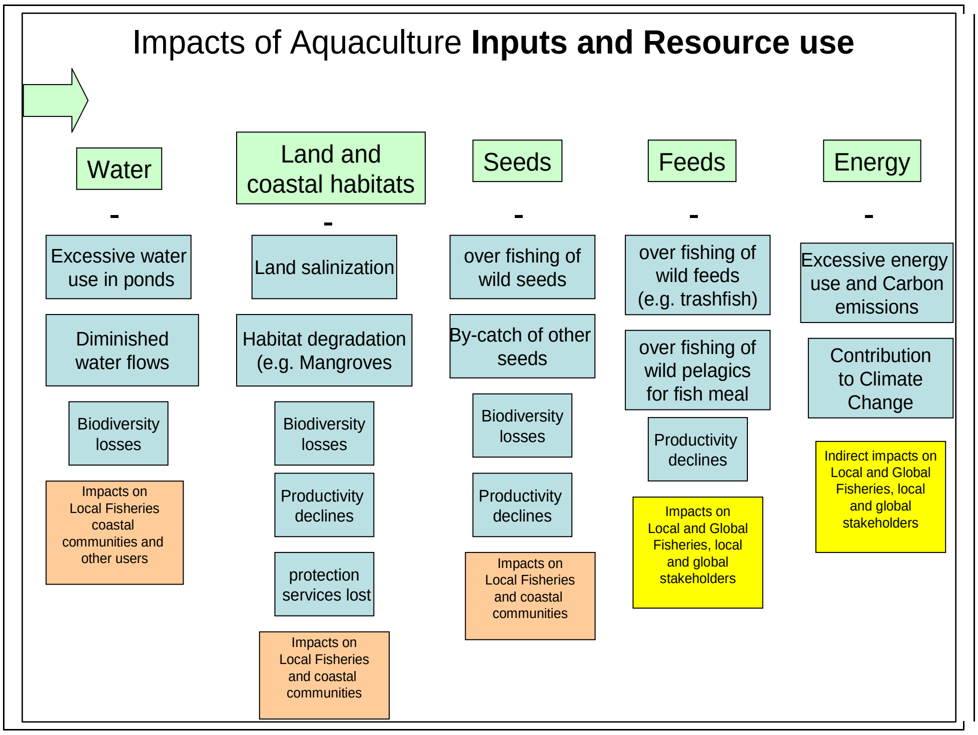

Figure 2.26 Impacts of aquaculture inputs and resource use

Freshwater
The water requirement for various aqua-ecosystems ranges from 0.1 to 0.2 m^3/kg of fish production for recycling systems through 2.0–6.0 m^3/kg for intensive fish ponds up to 500–900 kg/m^3 for flow-through systems, although raceways associated with springs or streams only “borrow” the water as the water flows through the culture facility so quickly. Pond aquaculture is a water-intensive practice because large amounts of water are needed to fill the pond and maintain the water level throughout grow-out because of losses from evaporation and seepage.

Pumping of water from boreholes is increasingly common for both agriculture and aquaculture, and consequent lowering of the water table has become a significant issue. Pumping of freshwater from boreholes near the sea may in addition cause saline intrusion underground. The deliberate introduction of seawater to inland areas also occurs in some countries where shrimp culture has been extended inland. Climate change is affecting freshwater availability, putting more pressure on the resource.

Seeds
Capture-based aquaculture is reliant on the capture of fry, juveniles or broodstock. Examples include the collection of wild milkfish fry and elvers (eel fry). The collection of juvenile tuna for fattening, or the collection of wild broodstocks for *Penaeus monodon* culture, if undertaken on a wide-scale basis, can affect the natural populations.

Climate change is predicted to have impacts on ocean productivity, fish migration and recruitment. This together with continued habitat deterioration, overfishing, etc. will affect the availability of seeds from the wild. Therefore, increased efforts should be made to increase the production of seeds in hatcheries. Other adaptation advantages could include research and genetic selection of seeds better adapted to new environmental conditions.

Feeds
Most modern forms of aquaculture are dependent upon the input of compound feed, with fishmeal or fish oil as a significant ingredient. There are concerns for the unknown biogeochemical consequences of global net transport for elements such as nitrogen, phosphorus and carbon, mostly from the southern hemisphere to the northern hemisphere, partly driven by aquaculture. Other relevant concerns are those related to the global environmental costs or “footprints” of aquaculture in terms of energy, water usage, and carbon production.

The use of fishmeal and fish oil makes the largest CO_2 footprint in aquaculture owing to the energy requirements of pelagic fisheries. On the other hand, the culture of fish higher in a trophic food web, that is carnivorous fish, require a higher proportion of fishmeal while herbivorous fish, such as carps and tilapia, have greater yields with lower or no fishmeal inputs.

The culture of filter feeder species (e.g. mussels and clams) and extractive species (seaweeds) not only offer food and development opportunities but they also have a very low or zero CO_2 footprint, provide other services such as extraction of excess nutrients in coastal zones, and absorb carbon (in the case of seaweeds). Such aquaculture forms could eventually gain access to “carbon credits” such as is the case with some land forestry and certain forms of agriculture – possibilities under current discussions under climate change mitigation.

Issues related to outputs

Food supply
Food is the most relevant socio-economic output of the aquaculture process. Aquaculture contributes towards the nutritional needs of a wide cross-section of human populations. Fish is the only affordable source of animal protein available to the poor in some parts of the world. Small-scale aquaculture generates food for the producer’s household and in the immediate community, and thus contributes to social resilience. Aquaculture is an increasingly important source of high-quality animal protein for direct human consumption and, where production is geared towards national urban and international markets, local people earn incomes sufficient to purchase foods produced elsewhere.

Food production through aquaculture can offer adaptation options under some climate change stresses such as freshwater scarcity. For example; cage farming in reservoirs and lakes offers an opportunity to produce protein with very reduced freshwater use (only through feeds).On the other hand, mariculture can offer solutions for coastal agriculture communities affected by droughts or by sea-level rise and salinization of coastal areas.

Seeds and juveniles for stock enhancement
The aquaculture production of seeds and larvae for the establishment of new/additional fish resource for fisheries and livelihoods is an important positive output of the process. Hatchery-produced larvae can also contribute to the conservation and improvement of endangered species. Restocking to enhance fisheries or to recover endangered stocks can provide important opportunities also under climate change threats

Excessive nutrients and chemicals
Water effluent from aquaculture that uses feed has increased nutrient levels. This can affect water quality and the downstream use of that water.

Because of the production process, there are unwanted outputs such as excess nutrients, escapees and chemicals. This can lead to some loss of biodiversity or affect ecosystem[8] services. The resulting loss of biodiversity is a sacrifice that most developing economies are quite willing to make so long as this does not undermine the delivery of the valued services themselves in the medium and long terms. However, there is increasing appreciation that changes to current practices are required as some of these services are being compromised (instability in production; pollution; flooding; erosion; dwindling or poor quality water supplies).

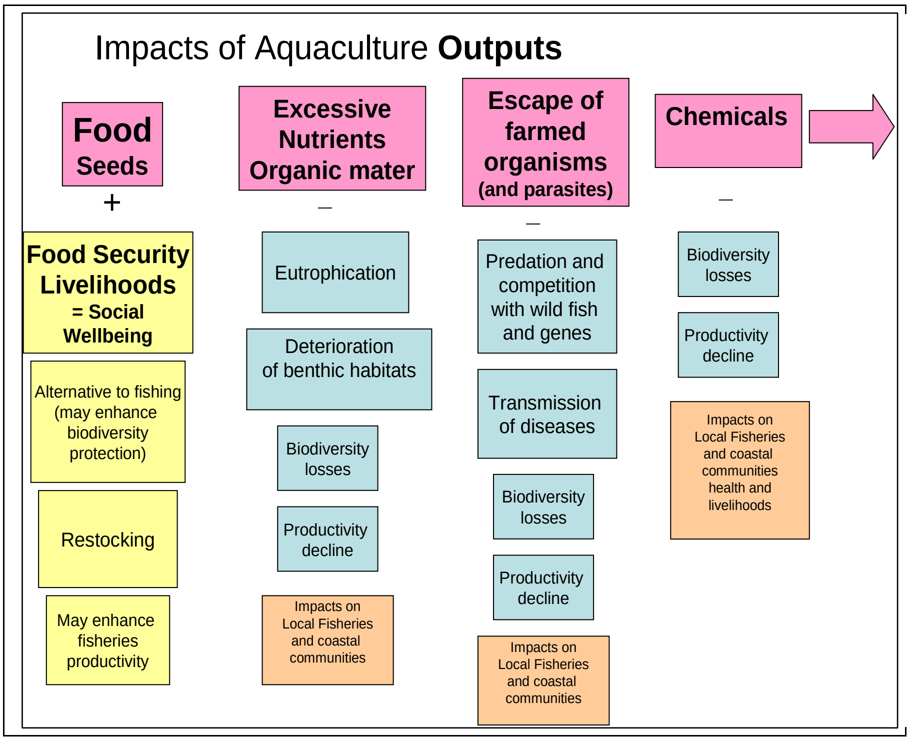

Figure 2.27 Impacts of aquaculture outputs

Biodiversity presents a dilemma. Extensive systems promote relatively higher biodiversity but require a large area to generate a tonne of fish. In contrast, more intensive systems are characterized by low biodiversity but require little space, leaving more aside as natural habitat and "green infrastructure".

The local (farm) impacts of excess nutrients on sediments and, therefore, on biodiversity and ecosystem services from fed aquaculture or accumulation of particulate organic matter from filter feeders are well known and are being addressed in many ways. Often, however, the considerations of ecosystem carrying capacity to support nutrient inputs are not taken into consideration.

Prioritization of issues

A large number of issues related to aquaculture impacts or impacts of external drivers on the sector can be identified but their importance varies greatly. Prioritization of issues will also help to define operational objectives and to define the plan within the strategy (Figure 2.28). Both the identification of issues and prioritization must be fully participatory – including relevant stakeholders. In this way, decisions and further actions have ownership and can be better implemented.

[8] An ecosystem is defined by the Convention on Biological Diversity (CBD) as "a dynamic complex of plant, animal, and microorganism communities and the nonliving environment interacting as a functional unit" (CBD, 2004).

To determine the priority of issues and therefore the appropriate level of management response, the process uses risk analysis methods. A number of risk analysis tools can be used to assist this process. It is important to define the concept of hazard in aquaculture. This would be a physical agent or event having the potential to cause harm or to impair the ability to achieve our high-level objectives. These often include: a biological pathogen (pathogen risk); an escaped aquatic farmed organism (genetic risk, ecological risk, invasive alien species risk); a chemical, heavy metal or biological contaminant (food safety risk); excess organic matter (eutrophication risk); and the loss of a captive market (out of business risk, unemployment risk, etc.). Risks associated with increased water temperature, salinity and increased eutrophication potential can be climate-change-related threats. All risk assessment methods work by assessing the "risk" of not meeting the objectives (which are affected by the values/outcomes wanted – see above). A risk analysis typically seeks answers to four questions:

i. What can go wrong?
ii. How likely is it to go wrong?
iii. What would be the consequences of its going wrong?
iv. What can be done to reduce either the likelihood or the consequences of its going wrong?

Whichever risk assessment method is used, it must include appropriately detailed justifications for why the levels of risk were chosen[9]. This allows other parties who were not part of the process to be able to see the logic and assumptions behind the decisions that were made. It also helps when reviewing the issue sometime in the future – unless you know why you choose the levels, it will be hard to know if anything has changed that may require a shift in the risk levels and, therefore, management actions. This also assists in understanding the knowledge "gap" analyses/uncertainties.

Following steps in implementing the strategy

Following steps in the implementation plan of the EAA include: the establishment/definition of overall objectives and operational objectives; and the establishment of minimum requirements. These should include: (i) assess existing legal policy (high level) and institutional frameworks; (ii) create/enhance enabling legal frameworks; (iii) strengthen, modify or create new institutional arrangements; (iv) create human capacity; and (v) develop management measures with an ecosystems perspective. The operational objectives and the plan should provide a way to address the issues described in Figures 2.23–2.27.

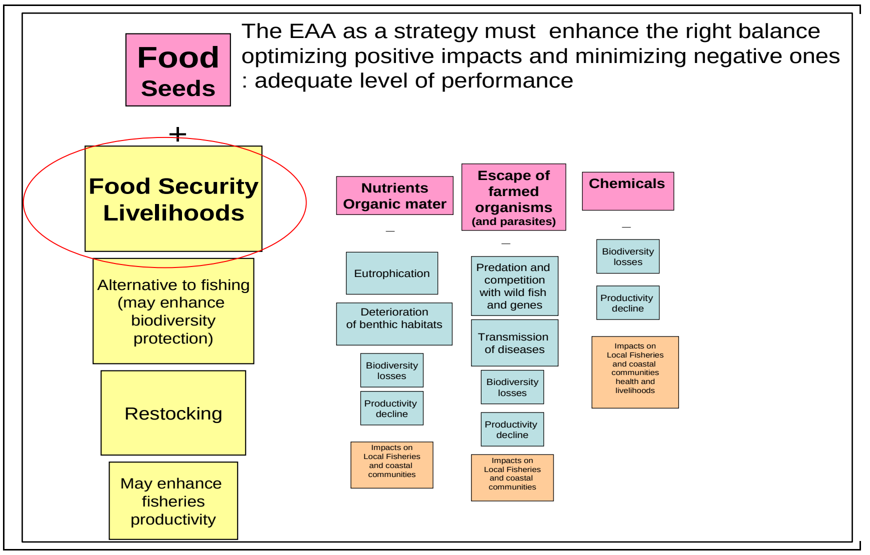

Figure 2.28 The EAA as a strategy

[9] A detailed methodology and case studies can be found in Bondad-Reantaso, Arthur and Subasinghe (2008).

Management measures that are relevant for facing climate change

Most relevant management measures at the farm scale include: (i) proper site selection and considerations of carrying capacity aspects and biosecurity in general; (ii) adoption of BMPs by individual farmers and clusters of farmers (De Silva and Soto, 2009). Practices including proper feeding and optimization of feed conversion factors can improve both climate change adaptation and mitigation aspects. Health management of farmed species and prevention of escapees are also relevant measures. Water warming and related low oxygen, eutrophication enhancement, etc. can be avoided or minimized in deeper sites with better circulation. However, there are always trade-offs with exposure to more extreme conditions. The likelihood of the spread of disease can be minimized by increasing the minimum distance between farms and by implementing tight biosecurity programmes for aquaculture clusters or zones.

However, the EAA at the watershed scale is most relevant. Here, a proper aquaculture zoning mechanism, biosecurity frameworks, risk analysis and strategic environmental assessments (FAO, 2009) that take into account the added effects of many farms are very relevant to better face potential threats such as new diseases, invasive species, and eutrophication-related problems that can be exacerbated by climate change (e.g. increased water temperature and salinity).

According to De Silva and Soto (2009), implementing proper risk communication is also very important. For aquaculture, some of the most important prevention systems must rely on critical and effective monitoring of waterbodies and aquatic organisms. A very important adaptation measure at the local level and at the waterbody/watershed scale is the implementation of effective integrated monitoring systems. Such monitoring systems should provide adequate information on physical and chemical conditions of aquatic environments, early detection of diseases and presence of pest species, including harmful algal blooms.

The integration of aquaculture with other sectors can be very important at the watershed scale. Aquaculture development affects and is affected by other human activities such as fisheries, agriculture, irrigation and industry as well as increasing urbanization, so their relative contribution to environmental degradation needs to be assessed and controlled. Interactions between food production systems could compound the effects of climate change on fisheries production systems but also offer opportunities. Aquaculture-based livelihoods could for example be promoted in the case of salinization of deltaic areas leading to loss of agricultural land.

National climate change adaptation and food security policies and programmes would need to be fully integrated with the aquaculture sector (and, if non-existent, should be drafted and enacted immediately). This will help ensure that potential climate change impacts will be integrated into broader national development (including infrastructure) planning.

Adaptations by other sectors will have impacts on aquaculture (e.g. irrigation infrastructure, dams, fertilizer use runoff), and will require carefully considered trade-offs or compromises.

Integrated aquaculture can offer relevant benefits including bioremediation, such as in the case of integrated multitrophic aquaculture (IMTA). Reducing risks is another advantage and profitable aspect of farming multiple species – a diversified product portfolio will increase the resilience of the operation, for example when facing changing prices for one of the farmed species or the accidental catastrophic destruction of a crop for example due to climate change[10]. However, some of the normative elements that are necessary to enhance this practice are not yet in place, e.g. appropriate legal frameworks.

---

[10] A recent review (Soto, 2009) provides a global perspective on the potential for integrated mariculture in coastal zones, including the Mediterranean Sea, where some of these advantages are well explored.

Aquaculture diversification and, especially, exploring new opportunities in mariculture potentially offer new adaptation options. By moving away from freshwater, both the impacts on this resource and the competition with other sectors for its use are strongly reduced. Further aquaculture movement off the coast and offshore can reduce impacts on coastal zone habitats and competition with other users (e.g. tourism), but greater exposure to rougher seas is part of the trade-off. Economic and social costs and benefits must be considered as well. A last but not least important aspect is that the implementation of the EAA must necessarily enhance and promote the culture of herbivorous/omnivorous species, especially filter feeders and extractive species. By doing this, there is a minimization of inputs external to the system.

Conclusions

The EAA emphasizes the need to integrate aquaculture with other sectors (e.g. fisheries, agriculture, urban development) that share and affect common resources (land, water, feeds, etc.) also focusing on different spatial scales: (i) the farm; (ii) the aquaculture zone, waterbody or watershed where the activity takes place; and (iii) the global scale (Soto, Aguilar-Manjarrez and Hishamunda, 2008). Perhaps the implementation of the EAA at the waterbody scale is one of the most relevant adaptations to climate change. The geographical remit of aquaculture development authorities (i.e. administrative boundaries) often does not include watershed boundaries and this is a particular challenge because climate change prevention and adaptation measures need watershed management, e.g. protecting coastal zones from landslides, siltation, discharges, or even simply providing enough water for aquaculture. On the other hand, aquaculture can provide adaptation for coastal agricultural communities that may face salinization effects because of rising sea levels.

In coastal regions, mariculture can provide an opportunity for producing animal protein when freshwater becomes scarce. Such a watershed perspective needs policy changes and integration between different sectors (e.g. agriculture–aquaculture), aside from capacity building and infrastructure requirements. Because climate change does not recognize political boundaries, adaptation policies and planning within international watersheds can be a major challenge. However, the common threat of climate change impacts can provide the opportunity for such transboundary management. For the aquaculture sector, the watershed-scale approach is also needed for an organized, cluster-type adaptation to negotiate collective insurance, to implement appropriate biosecurity measures, etc.

An EAA is being increasingly considered as a suitable strategy to ensure sustainability, including adequate planning required to take into account climate-change impacts.

References

Asia-Pacific Fishery Commission (APFIC). 2009. APFIC/FAO Regional consultative workshop "Practical implementation of the ecosystem approach to fisheries and aquaculture", 18–22 May 2009, Colombo, Sri Lanka. RAP Publication 2009/10. Bangkok, Thailand, FAO Regional Office for Asia and the Pacific. 96 pp.

Bondad-Reantaso, M.G., Arthur, J. & Subasinghe, R.P., eds. 2008. *Understanding and applying risk analysis in aquaculture*. FAO Fisheries and Aquaculture Technical Paper No. 519. Rome, FAO. 304 pp. (also available at ftp://ftp.fao.org/docrep/fao/011/i0490e/i0490e.pdf).

Convention on Biological Diversity (CBD). 2004. *The ecosystem approach*. CBD Guidelines. Montreal, Canada, Secretariat of the Convention on Biological Diversity. 50 pp. (also available at www.cbd.int/doc/publications/ea-text-en.pdf).

De Silva, S. & Soto, D. 2009. Climate change and aquaculture: potential impacts, adaptation and mitigation. *In* K. Cochrane, C. De Young, D. Soto & T. Bahri, eds. *Climate change implications for fisheries and aquaculture: overview of current scientific knowledge*, pp. 118–139. FAO Fisheries and Aquaculture Technical Paper No. 530. Rome, FAO. 212 pp.

FAO. 1995. *Code of Conduct for Responsible Fisheries*. Rome, FAO. 41 pp. (also available at ftp://ftp.fao.org/docrep/fao/005/v9878e/v9878e00.pdf).

FAO. 1997. *Aquaculture development*. FAO Technical Guidelines for Responsible Fisheries No. 5. Rome, FAO. 1997. 40 pp. (also available at ftp://ftp.fao.org/docrep/fao/003/W4493e/W4493e00.pdf).

FAO. 2006. *State of world aquaculture 2006*. FAO Fisheries Technical Paper No. 500. Rome. 134 pp.

FAO. 2007. *The State of World Fisheries and Aquaculture* 2006. Rome, FAO. 162 pp. (also available at www.fao.org/docrep/009/A0699e/A0699e00.htm).

FAO. 2009. *Environmental impact assessment and monitoring in aquaculture*. FAO Fisheries and Aquaculture Technical Paper No. 527. Rome. 648 pp. (also available at www.fao.org/docrep/012/i0970e/i0970e00.htm).

Garcia, S.M., Zerbi, A., Aliaume, C., Do Chi, T. & Lasserre, G. 2003. *The ecosystem approach to fisheries. Issues, terminology, principles, institutional foundations, implementation and outlook*. FAO Fisheries Technical Paper No. 443. Rome, FAO. 71 pp.

Soto, D., ed. 2009. *Integrated mariculture: a global review*. FAO Fisheries and Aquaculture Technical Paper No. 529. Rome, FAO. 183 pp.

Soto, D., Aguilar-Manjarrez, J., & Hishamunda, N. eds. 2008. Building an ecosystem approach to aquaculture. FAO/Universitat de les Illes Balears, Expert Workshop. 7–11 May 2007, Palma de Mallorca, Spain. FAO Fisheries and Aquaculture Proceedings No. 14. Rome, FAO. 221 pp.

Annex – Climate change related impacts on aquaculture and potential risks and opportunities/benefits

Climatic change element	Impacts on aquaculture or related function	Benefits or risks
Warming: - Long-term gradual warming - Short-term exceptional warm periods	Decreased productivity	Temperature rise above optimal range of tolerance of farmed species Higher stress
	Increased productivity	Increase in growth; improved feed conversion ratio Shorter production cycle
	Changes in wild fisheries	Availability change in wild broodstock, fry collection
	Increase in disease incidence	Increased virulence of dormant pathogens and expansion of new diseases
Sea-level rise	Intrusion of saltwater	Reduction in freshwater culture area Relocation of freshwater culture upstream Increased area for brackish-water culture
	Loss of agricultural land	Provide alternative livelihoods through aquaculture
	Coastal erosion	Coastal pond damage
Ocean circulation changes	Changes in coastal upwelling	Reduced catches from coastal fisheries Limitations on fishmeal and fish-oil supplies/price
	Changes in ocean circulation	Seedstock disruptions, less availability of trash fish
Acidification – ocean and freshwater	Impact on calcareous shell formation/deposition in marine waters	Problems with mollusc production Changes in plankton populations
	Increased incidence and level of acid rain	Problems with mollusc production Changes in plankton populations
Changes in precipitation pattern	Increased rainfall – flooding	Increased incidence of flooding Loss of stock, damage to farm facilities Changes in water quality
	Decreased rainfall – drought	Limitations for freshwater abstraction
	Changes in rainfall timing – early or late rains	Unpredictable production seasons Difficulty in pond preparation (drying)
	Changes in precipitation pattern	Change in water-retention period (inland systems reduced, coastal lagoons increased)
	Change in monsoon patterns	Unpredictable freshwater supply
Extreme weather events	Increased typhoon strength and change in location	Destruction of facilities; loss of stock; loss of business; mass escape with potential to impact on biodiversity
	Increased storm events	Damage to cages, pens and longlines Damage to coastal ponds Disruption of production
	Increased storm surge	Coastal pond damage, increased saline intrusion

2.4 Climate change and fisheries

Overview of ecological and biological impact pathways

Under IPCC scenarios, water and air temperatures in mid- to high latitudes are expected to rise, and sea-level rise combined with increased frequency and intensity of extreme events will affect coastal zones. In a recent review, Brierley and Kingsford (2009) identified some of the direct consequences of global warming on marine environments such as increasing global temperature, perturbed regional weather patterns, rising sea levels, acidifying oceans, changed nutrient loads and altered ocean circulation. These changes will unfold at different time scales but are already occurring at an alarming rate with sea levels rising by more than 15 cm in the last century and a global mean temperature rise of 0.75 ºC above pre-industrial values (Table 2.3). While marine ecosystems have experienced warm conditions in the past they have never experienced acidification conditions as high as present (Barange and Perry, 2009). Increase in atmospheric CO_2 results in more CO_2 in the ocean, increasing ocean acidity, thus reducing pH in the last 200 years (Table 2.3). These and other physical changes will affect ecological and biological processes that are critical to aquaculture productions systems.

Drivers of changes in aquaculture production systems related to climate change can be identified as: changes in sea surface temperature, changes in other oceanographic variables (wind velocity, wave action, etc.), sea-level rise, increase in extreme events and water stress. These changes will in turn create physiological (growth, development, reproduction, disease), ecological (organic and inorganic cycles, predation, ecosystem services) and operational (siting, sea cage technology etc.) changes (Table 2.4).

Water and air temperatures in mid- to high latitudes are expected to rise, with a consequent lengthening of the growing season for cultured fish and shellfish. These changes could have beneficial impacts with respect to growth rate and feed conversion efficiency. Production of shrimp farms usually increases along the Pacific coast of South America during El Niño years. The maturation, spawning, and recruitment of post-larvae and the migrations of the immature juveniles are strongly correlated with seasonal to interannual variability of oceanic temperatures off the Ecuadorian coast (Cornejo-Grunauer *et al.*, 1997). Shrimp thrive in the warm El Niño waters and grow rapidly in the brackish-water environment created by the heavy rains, which also flush out the ponds and estuaries. Wild shrimp reproduce in great numbers during El Niño periods, supplying farmers with endless quantities of the highly-prized, wild post-larvae, while during La Niña (colder waters) the opposite happens (Cornejo-Grunauer, 1998). Shrimp hatcheries have difficulty competing with the abundant wild seedstock and most temporarily close their doors (Rosenberry, 2004).

However, tropical species are often already near their lethal thermal limits, and a slight temperature change might have significant effect on their physiology. In the case of bivalves, it has been shown that tropical species live closer to their maximum habitat temperature than the temperate species (Comptona *et al.*, 2007). Tropical bivalves are thus closer to their upper lethal thermal limits than are temperate species, suggesting that temperate species are better adapted to temperature variation. It is important to note that temperature responses are species-specific, and while some species will be adversely affected, others who are better adapted to high temperature and possess a wide thermal tolerance zone, such as the catfish *Horabagrus brachysoma*, could be introduced in tropical freshwaters (Dalvia *et al*., 2009). Temperature change will thus have a direct impact on the species suitable for farming in any specified area. It will also indirectly influence other factors such as oxygen, pests, diseases and the occurrence of toxic algal blooms and paralytic shellfish toxins (2WE Associates Consulting Ltd, 2000; Moore *et al*., 2009). In Tasmania (Australia), warmer currents linked to climate variability and change are said to affect salmon in fish farms by slowing growth and increasing the presence of algae blooms and gill amoeba – a parasite on the fish that can lead to increased mortality (Paine, 2003).

Sea level rise will gradually affect marine and brackish aquaculture with saltwater intrusion, requiring the farming of high-salinity tolerant species. Increasing extremes of weather patterns and storms will be another hazard to coastal industries. Storm surges, waves, and coastal erosion are likely to have a larger effect than the rise in mean high water level (2WE Associates Consulting Ltd, 2000). Fluctuations of water level in freshwater lakes and deltas caused by changes in precipitation will also affect inland aquaculture, resulting in additional waters stress and salinity changes in certain cases. In the United States of America, droughts, which are linked to higher average temperatures, have in the past caused slower growth of catfish and increase the possibility of outbreak of diseases. In order to harvest the catfish at marketable sizes, producers had to care longer for them, which significantly increases production costs (*AgJournal*, 1999). In the eastern Hemisphere, El Niño, with its decrease in rainfall, usually has a negative effect on aquaculture production. In the Philippines, tilapia production from freshwater ponds dropped by 2.7 percent, probably owing to the prolonged drought caused by the 1997–98 El Niño. During the same period, seaweed production dropped slightly (by 0.7 percent) apparently also due to the El Niño (Yap, 1999).

Acidification can be expected to narrow the thermal tolerance for fish. Episodic hypoxaemia will manifest as reduced growth, impaired feed conversion efficiency and increased susceptibility to infectious agents (Forsythe, 2009). Impacts on calcification resulting in shell malformation will also occur. In a recent study, the exposure of edible mussels (*Mytilus edulis*) and Pacific oysters (*Crassostrea gigas*) – two important aquaculture species – to more acidic conditions for a few hours resulted in immediate diminishing of shell calcification. The linear decrease in calcification rates with increasing CO_2 suggest that, under IPCC scenarios, marine organisms might be negatively affected by lower pH (Gazeau *et al*., 2007).

Table 2.3 Time scale of changes and approximate values of changes pertinent to marine environments

	Time scale						
	Geological	Oscillatory change		Secular change			
	(Cenozoic -)	Orbital/ Milankovitch	Recent Decadal	0 to industrial revolution, 1850	Post-industrial to present	Present to 2100	2100–4000
No. years	10^6 to 10^7	10^4 to 10^5	10s	c. 2k	c. 150	c. 100	c. 2k
Temp. at end, °C cf. 1850	'Icehouse' to 'greenhouse'	Glacial-interglacial; -8 to +5 [149]	+/- 2 (detrended) [40]	Stable between -1.2 to +0.4 [32]	+0.75 [6]	+2.5 to +5.5 [136]	+10 [150]
$CO_{2[atm]}$ ppm	150 to 3500 [36]	172 to 300 [149]	+/- 1 (detrended) [40]	Stable between ~274 and 282 [149]	385 (in 2008) [42]	450 to 1000 [136]	1700 to >2000 [150]
pH	7.3 to 8.3 [36]	Varies by 0.16 [13]	Stable	Stable around 8.2 (+/- 0.3) [13]	-0.1 [13]	-0.3 to -0.5 [13]	-0.77 [57]
Sea ice coverage, %	0 to mid latitude [31]	High latitude to mid latitude	Regionally variable [118,151]	Stable, c. 7% Earth's surface [152, 153]	Antarctic stable to -25% Arctic -20% [112, 152]	-40% cf. 1999 [111]	-90% [150]
Sea level, m		-130 to 0 [154]	Stable	Stable	+0.2 [12]	+0.5 to +1.4 [12]	+100
AMO circulation	Direction reversals	-40% to +40% [37]	Variable [155]	Variable	Variable 18.7 +/- 5.6 Sv [29]	-50% [155]	3 Sv to collapse [100,150]
Suboxic volume	Highly variable	Variable	Stable	Stable	Expanding [56]	+50% [66]	+300% [150]
Species events	Range changes & extinctions	Range changes	Regime shifts	Stable	Range changes	Range changes & extinctions [156]	Mass extinctions

Source: Based on Brierley and Kingsford (2009) and references therein.

Table 2.4 Possible climate-change impacts on aquaculture

Drivers of change	Physiological impacts	Ecological impacts	Operational impacts
Sea surface temperature changes	Increase in harmful algal blooms that release toxins in the water and produce fish kills Spread of pathogens and disease Decreased dissolved oxygen Increased incidents of disease and parasites Enhanced growing seasons Lower natural winter mortality Enhanced growth rates and feed conversions (metabolic rate) Enhanced primary productivity (photosynthetic activity) to benefit shellfish production of filter-feeders	Competition, parasitism and predation from exotic and invasive species Altered local ecosystems – competitors and predators Decrease in sea-ice cover	Increased infrastructure and operation costs Increased infestation of fouling organisms, pests, nuisance species and/or predators Moratorium on products due to bans Expanded geographic distribution and range of aquatic species for culture
Change in other oceanographic variables (variations in wind velocity, currents and wave action)	Decrease flushing rate, which can affect food availability of shellfish	Change in water exchanges and waste dispersal	Accumulation of waste under pens Increased operational costs
Sea-level rise	Changes in salinity affecting growth especially brackish-water fish	Reduced ecological areas available for aquaculture	Damage to infrastructure Changes in aquaculture zoning Competition for space with ecosystems providing coastal defence services (i.e. mangroves) Increased insurance costs
Acidification	Calcification: affecting growth and development of shellfish. Affecting growth and exoskeleton of fish Change in productivity due to phytoplankton species shifts	Coral skeleton growth hindered	Changes in species
Extreme events (floods, droughts hurricanes, storms)	Changes in salinity affecting growth especially brackish-water fish		Higher operational costs, need to design cages moorings, jetties etc. that can withstand events Negative effect on pond walls & defences Increased insurance costs
Water stress (increasing evaporation rates and decreasing rainfall)	Decreased water quality leading to increased diseases	Reduced lake level Altered and reduced freshwater supplies	Costs of maintaining lake level artificially Conflict with other water users

Note: This table is not intended to be comprehensive but to give examples of potential impacts.
Sources: Modified from 2WE Associates Consulting Ltd (2000), Johannes (2004) and Milewski (2002).

The impacts of global environmental change on other production systems are also likely to affect aquaculture production systems. The fluctuation in supply of fish oil and fishmeal and its possible impact on aquaculture production is illustrative of such linkages. More than half of global aquaculture production was freshwater finfish in 2006, and finfish culture production in developed countries is mostly carnivorous species (FAO, 2007). The price and availability of fishmeal and fish oil inputs is a non-trivial issue to fish farmers practising intensive culture of carnivorous species; feed costs represent up to 60 percent of their total operating cost (Stikney, 1994). Fluctuation of fishmeal production owing to climate variability can thus have significant effects on the livelihoods of fish farmers. The case of the Peruvian anchoveta is a stark example of the possible impact of climate change on fish farmers' livelihoods. Since 1976, the combined share of Peru and Chile in world fishmeal production has averaged 34 percent (Delgado *et al*., 2003). In 1997–98, an El Niño event decreased the harvest of Peruvian anchoveta, leading to soaring prices of fishmeal.

Changes in capture fisheries can also have an impact on the aquaculture sector through changes in bycatch. In Asia, bycatch or "trash fish" is often transformed into fishmeal for the local and regional aquaculture markets. For example, in China, as much as 5 000 000 tonnes of fish were being used for fishmeal, livestock and aquaculture feed by 2001 (Grainger *et al*., 2005). In Viet Nam, local fishmeal ("fish powder" produced in a artisanal way) is mainly used to feed livestock and some freshwater fish for grow-out feed, as it is generally of poor quality; only 10 percent of the fishmeal is estimated to be locally produced (Edwards *et al*., 2004). However, future demand for fishmeal is expected to increase dramatically as aquaculture production increases and some species, such as catfish, are increasingly fed pelleted diets containing fishmeal. Overexploitation combined with changes in fish biomass induced by climate change could have repercussions for the aquaculture sector, especially for farmers who rely on low-cost fishmeal inputs.

Indirect impacts arising from adaptive strategies pursued by different sectors may also be significant and compound the effects of direct climate impacts on aquaculture production and dependent livelihoods (Badjeck *et al*., 2009a). These potential interactions make impact predictions difficult to make and more uncertain. For example, increased sea-level rise might prompt the development of coastal defence systems, which will limit the availability and suitability of culture sites. Adaptive strategies by the agriculture sector that focus upon the construction of more flood control, drainage and irrigation schemes might influence water quantity and characteristics (salinity, pH, etc.) of aquaculture systems, prompting changes in species.

Finally, the livelihoods perspective can be used to understand impacts of climate variability and change on livelihoods capitals of households and communities dependent on aquaculture. The next section presents some of the impacts of climate variability and change on the physical, financial, human and social capitals (natural capital has already been covered in this section).

Impacts on aquaculture-based livelihoods

Damage to physical capital and reduced financial capital

Any increases in the intensity and frequency of extreme climatic events, such as storms, floods and droughts will have a negative impact on aquaculture production and may result in significant infrastructure damage – mainly related to decreased farming capacity (loss of infrastructure) or decreased access to markets (damaged roads). This often translates into economic losses that small fish farmers are unable to cope with. In Indian River Lagoon, Florida (the United States of America), the Florida Department of Agriculture estimated that Hurricane Frances and Hurricane Charley (2004) caused USD8.7 million in crop losses for clam and oyster farmers, with USD7.2 million of that caused by Hurricane Frances (Bierschenk, 2004). The State of Florida's shellfish industry is primarily comprised of clam farmers. This number does not include infrastructure losses, such as buildings, docks, vessels, and nursery and hatchery facilities. In Collier County, the clam industry lost 100 percent of its food clams, according to state agricultural officials.

In Bangladesh, the 2004 floods caused damage to the aquaculture sector. Fish farms overflowed and in the Chandpur District most of the 13 000 fish farms lost part of their stock, which translated into economic losses of about USD3.5 million (Growfish, 2004a). In the village of Sobulia in Fulpur, freshwater shrimp farms on some 30 acres (about 12 ha) of land were washed away by floodwaters (Hague, 2004). The Bangladesh Small Fishermen Association estimated that fires and growing niches of 80 percent of waterbodies in 45 flood-hit districts were washed away causing significant losses to cultivators. Most fish farmers did not have the financial resources to repay some of the loans they had contracted to enter the fish-farming business and they made an appeal to the government to supply interest-free loans and supply of fish fry free of cost from government hatcheries (Growfish, 2004b).

In Latin America, although Ecuador's production of farmed shrimp increases during El Niño, strong El Niños, like the ones in 1981–82 and 1997–98, result in a net loss to the industry (Rosenberry, 2004). Roads and bridges were washed away, limiting access to processing plants, and low-lying ponds were flooded (Cornejo-Grunauer, 1998; Rosenberry, 2004). In Nicaragua, small, government-backed cooperatives occupy the backwater areas, where the flooding was the heaviest during the El Niño. An estimated USD2 million worth of shrimp escaped; overall, Nicaragua lost 25–30 percent of its 1998 crop, and the industry suffered an USD8 million loss (Rosenberry, 1999). In Honduras, about 10 percent of the total farm infrastructure was damaged by storms, primarily as erosion damage to pond dykes and flooding of farm buildings (offices, workshops, and feed/fertilizer storage buildings). In addition, a lot of equipment, vehicles, machinery and pumps were damaged or destroyed (Rosenberry, 1999).

Reduced human capital and impacts on social capital

Climate variability and change may, through increased extreme events, have an impact on employment in the aquaculture sector and result in resource-use conflicts. The 1997–98 El Niño Southern Oscillation event significantly affected employment in the aquaculture sector, with the collapse of shrimp hatcheries (approximately 300) that affected about 6 000 people (Cornejo-Grunauer, 1998).

In Thailand and Taiwan Province of China, intensive shrimp farming has led to pumping large volumes of underground water to achieve brackish-water salinity, leading to a lowering of groundwater levels and salinization of adjacent land and waterways (Braaten and Flaherty, 2001; Dierberg and Kiattisimkul, 1996; Primavera, 1998). Salinization reduces water supplies not only for agriculture but also for drinking and other domestic needs (Primavera, 1998). Under increased climate-change scenarios, which increase the frequency of droughts and floods, availability of freshwater might be a source of conflict between the aquaculture sector and other sectors (e.g. rice agriculture), or at the least become an impediment factor for the full development of aquaculture. Aquaculture can cause habitat modification by affecting such ecosystem services as coastal protection and flood control by removing mangroves (Naylor *et al*., 2000). Conversion to shrimp ponds has been the main cause of mangrove loss in the last few decades in Bangladesh and Sri Lanka, while in Viet Nam a total of 120 000 ha of mangroves was cleared for shrimp farming between 1983 and 1987 (Primavera, 1998). In the context of increased extreme events driven by climate change, there is an incentive to reclaim mangrove areas, which in the long run could lead to conflicts between aquaculture producers and other users of the coastal zone.

Climate change in the context of multiple pathways and multiple drivers

As described above, climate change will affect the aquaculture sector through indirect and direct pathways. These are illustrated in Figure 2.29, with Table 2.5 providing a specific example for Viet Nam. It is important to note the additive and multiplicative impacts of climate change on other non-climate stressors. Indeed, indirect climate effects mediated through socio-economic pathways may interact with, amplify or even overwhelm biophysical impacts on fish ecology. Non-climate drivers such as infrastructure development and population growth can have multiplicative and additive effects on the impacts of climate change.

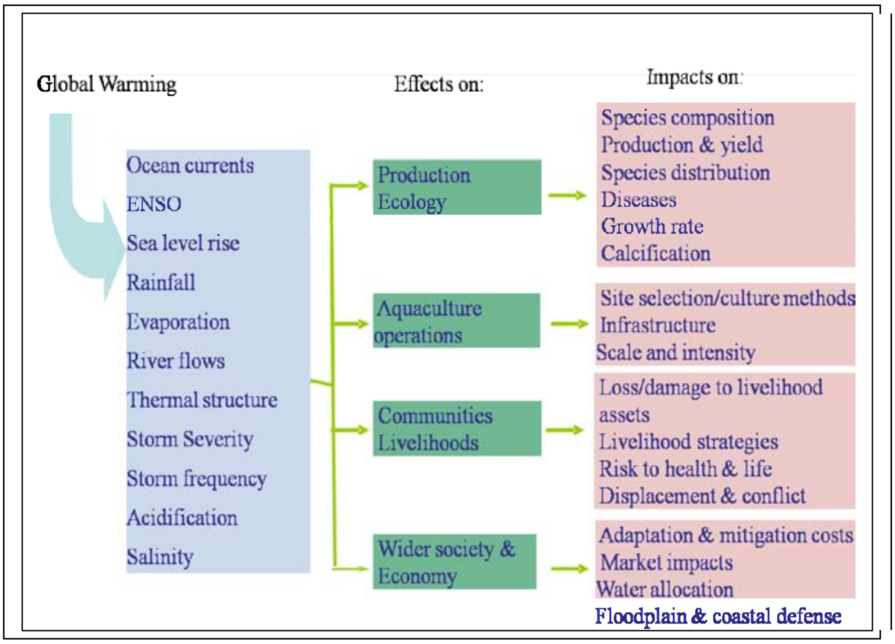

Figure 2.29 Global warming and capture fisheries: impact pathways

Note: This figure is not intended to be comprehensive but to give examples of potential impact pathways.

Source: Modified from Badjeck *et al.* (2009a).

Table 2.5 Main characteristics of aquaculture production systems in Viet Nam and implications of impacts and adaptation to climate change

Characteristics of aquaculture production systems	Impact and adaptation
There are two main aquaculture systems based on freshwater and brackish-water environments, with mariculture (in the marine environment) as a minor subsector.	The nature of climate change (CC) impacts on these environments is different; hence, the exposure of these main systems is also different.
Aquaculture production is at different levels of intensity and capitalization and involves different levels of participation, ranging from large numbers of small-scale producers to relatively small numbers of highly commercialized enterprises.	Vulnerabilities and adaptive capacities in the context of climate and other global drivers of change vary substantially with aquaculture production systems.
There is a diversity of aquatic species and production systems for freshwater and brackish-water aquaculture, fitting into different agro-ecologies, ranging from purely aquaculture activities to integrated production (e.g. within rice and mangrove areas).	Unlike single species commodities, such as rice or livestock animals, this diversity of aquaculture products and systems makes it potentially an adaptable sector as environmental conditions change due to CC.
Aquaculture, in various forms, competes with or complements other food production systems particularly in the use of water resources, in both freshwater and brackish-water environments.	Availability and management of water resources for aquaculture and other uses under CC scenarios is crucial, underscoring the observation that "…as much as CC mitigation is about energy, CC adaptation is about water" (START, 2009)[1]
Aquaculture is a dynamic and volatile sector that is subject to economic booms and busts, particularly the export-oriented commodities that are particularly susceptible to global fluctuations in demand (and hence prices) and international pressure on product quality, production standards and food safety regulations. Vietnamese producers as well as the government are highly market-responsive.	For planners, "climate is not the only change around" (START, 2009)[1]; CC is regarded as a slow variable. Other drivers, with shorter-term and more obvious impacts, are of greater concern within the 10–15 year time horizons for planning of the aquaculture sector. These include market-related drivers and impacts of upstream development, particularly hydropower development in the Mekong River Basin.

[1] www.water.tkk.fi/English/wr/research/global/material/water&cc_2009_policy_brief

Source: Badjeck *et al*., 2009b.

References

2WE Associates Consulting Ltd. 2000. *Aquaculture and climate change in Canada*. A discussion paper. Seafood sustainability in a changing climate: A participatory workshop to develop solutions for the Northeast Pacific Ocean and coastal zones. Victoria, Canada, Canadian Institute for Climate Studies, University of Victoria.

***AgJournal*.** 1999. Drought hurts catfish production.

Badjeck, M.-C., Allison, E.H., Halls, A.S. & Dulvy, N.K. 2009a. Impacts of climate variability and change on fishery-based livelihoods. *Marine Policy* (article in press).

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

Barange, M. & Perry, R.I. 2009. Physical and ecological impacts of climate change relevant to marine and inland capture fisheries and aquaculture. *In* K. Cochrane, C. De Young, D. Soto & T. Bahri, eds. *Climate change implications for fisheries and aquaculture: overview of current scientific knowledge*, pp. 7–95. FAO Fisheries Technical Paper No. 530. Rome, FAO. 212 pp.

Bierschenk, E. 2004. *Storm damages shock local shellfish industry*. Victoria, Australia, GROWfish, Gippsland Aquaculture Industry Network-GAIN.

Braaten, R. & Flaherty, M. 2001. Salt balances of inland shrimp ponds in Thailand: implications for land and water salinization. *Environmental conservation*, 28: 357–367.

Brierley, A.S. & Kingsford, M.J. 2009. Impacts of climate change on marine organisms and ecosystems. *Current biology*, 19: R602–R614.

Comptona, T.J., Rijkenberga, M.J.A., Drenta, J. & Piersmaa, T. 2007. Thermal tolerance ranges and climate variability: A comparison between bivalves from differing climates. *Journal of Experimental Marine Biology and Ecology*, 352: 200–211.

Cornejo-Grunauer, P. 1998. Variaciones climáticas: Impacto del Fenómeno de El Niño/Oscilación Sur en la Acuicultura de Ecuador. *Boletin. CENAIM*, 41: 5–7.

Cornejo-Grunauer, P., Calderón, J., Santos, J.L. & Silva, G. 1997. *Application of climate information in shrimp aquaculture: the Ecuadorian Case*. ENSO SIGNAL, IRI-OGP-NOOA.

Dalvia, R.S., Pala, A.K., Tiwarib, L.R., Dasa, T. & Baruahc, K. 2009. Thermal tolerance and oxygen consumption rates of the catfish Horabagrus brachysoma (Günther) acclimated to different temperatures. *Aquaculture*, 295: 116–119.

Delgado, C.L., Wada, N., Rosegrant, M.W., Meijer, S. & Ahmed, M. 2003. *Fish to 2020: supply and demand in changing global markets*. Washington, DC, and Penang, Malaysia, International Food Policy Research Institute and WorldFish Center.

Dierberg, F. & Kiattisimkul, W. 1996. Issues, impacts, and implications of shrimp aquaculture in Thailand. *Environmental management*, 20: 649–666.

Edwards, P., Tuan, L.A. & Allan, G.L. 2004. A survey of marine trash fish and fish meal as aquaculture feed ingredients in Vietnam. ACIAR Working Paper No. 57.

FAO. 2007. The State of World Fisheries and Aquaculture 2006. Rome. 162 pp.

Forsythe, A. 2009. New Zealand aquaculture industry. Ocean acidification: What does it mean for New Zealand? Wellington, Royal Society of New Zealand.

Gazeau, F., Quiblier, C., Jansen, J., Gattuso, J.P., Middelburg, J.B.M. & Heip, C.H.R. 2007. Impact of elevated CO_2 on shellfish calcification. *Geophysical Research Letters*, 34.

Grainger, R., Yingliang, X., Shengha, L. & Zhijie, G. 2005. *Production and utilization of trash fish in selected Chinese ports*. Paper presented at the "Regional Workshop on Low Value and 'Trash Fish' in the Asia-Pacific Region", 7–9 June 2005, Hanoi.

Growfish. 2004a. Floods: the bad news and the good news: Bangladeshi joy at fish bonanza. Gippsland Aquaculture Industry Network.

Growfish. 2004b. *Flood-hit fish farmers seek govt support*. Daily Star and Gippsland Aquaculture Industry Network.

Hague, Z. 2004. *Blow to fresh water shrimp farmers.* Daily Star and Gippsland Aquaculture Industry Network.

Moore, S.K., Mantua, N.J., Hickey, B.M. & Trainer, V.L. 2009. Recent trends in paralytic shellfish toxins in Puget Sound, relationships to climate, and capacity for prediction of toxic events. *Harmful Algae*, 8: 463–477.

Naylor, R.L., Goldburg, R.J., Primavera, J.H., Kautsky, N., Beveridge, M.C.M., Clay, J., Folke, C., Lubchenco, J., Mooney, H. & Troell, M. 2000. Effect of aquaculture on world fish supplies. *Nature*, 405: 1017–1024.

Paine, M. 2003. *Warming threat to salmon*. The Mercury and Gippsland Aquaculture Industry Network.

Primavera, J.H. 1998. Tropical shrimp farming and its sustainability. *In* S.S. De Silva, ed. *Tropical mariculture*, pp. 257–289. London, Academic Press.

Rosenberry, B. 1999. Mitch's reign: three days of rain flood shrimp farms in Honduras and Nicaragua. San Diego, USA, Shrimp News International.

Rosenberry, B. 2004. *About shrimp farming*. San Diego, USA, Shrimp News International.

Stikney, R. 1994. *Principles of aquaculture*. New York, USA, John Wiley & Sons.

Yap, W.G. 1999. *Rural aquaculture in the Philippines*. Bangkok, Thailand, FAO Regional Office for Asia and the Pacific.

2.5 Aquaculture and climate change

Introduction

The evidence that the climate of the earth is changing profoundly due to the activities of humankind is becoming increasingly stronger. The implications of climate change for humankind are still not fully understood or, indeed, universally accepted. The actions needed to mitigate climate change and to prepare society, particularly its most vulnerable members, have also not been properly considered, let alone implemented.

The present paper focuses on aquaculture, the farming of aquatic organisms. Over the past two decades, aquaculture has consistently been the fastest-growing food production sector in the world (FAO, 2009), and now accounts for half of all fish consumed. Worldwide, it generates tens of millions of jobs, directly and indirectly. Here, we consider the interactions between aquaculture and climate change, beginning with a consideration of how climate change is likely to affect the aquatic physicochemical environment and ecology, and how this in turn affects aquaculture. Using a vulnerability framework, we analyse how increased exposure to climate-related hazards is likely to affect the aquaculture value chain. We then assess aquaculture's contribution to climate change. We consider priority actions needed to mitigate the effects of aquaculture on – and to promote adaptation to – climate change, ending with some specific recommendations. Where possible, we make specific reference to the RNEA.

Impacts of climate change on the physical environment and ecology

Our best estimates of how the climate in the Region is likely to change between now and the end of the present century is more fully considered elsewhere in these proceedings. In sum, and ignoring topographical influences on microclimate, we can expect the climate in the region to become increasingly hotter and drier. The impacts of climate change on the aquatic physical environment and ecology are summarized in Figure 2.30. Seawater temperatures will increase. Combined with sea-level rises, changes in inshore salinities and in wind speeds and direction, currents and seawater mixing patterns can be expected, changing the distribution of species, aquatic productivity and the incidence of harmful algal blooms. Coastal areas and estuaries are likely to see the greatest changes in biophysical conditions and ecology. Inland, changes in the levels and pattern of precipitation are likely to increase the incidence of flooding and affect groundwater and surface water reserves. Temperature rises will increase evaporative water losses, change stratification and mixing patterns of lakes, aquatic community composition and aquatic productivity (for reviews, see Handisyde *et al*., 2006; Allison, Beveridge and van Brakel, 2009; Brierley and Kingsford, 2009; Cheung *et al*., 2009).

Climate change – aquaculture interactions

It is increasingly recognized that social, economic and ecological systems are dynamic, interacting and interdependent (Folke, 2006). Interactions between climate change and aquaculture are two-way – aquaculture contributes to climate change, and climate change affects aquaculture. The impact of the interactions on linked social-ecological systems, however, must be considered in the context of other pressures: changes in population size and demographics, environmental degradation, market, globalization, energy prices, health and economic recession.

Impacts of aquaculture on climate change

A century of abundant, inexpensive fossil fuels has fostered energy-intensive food production and trade. Contemporary food production systems consume many times more energy than they produce (Pimentel and Pimentel, 2008). It is largely through energy consumption, and the resultant release of GHGs, that aquaculture affects climate change.

Life cycle analysis (LCA) is a process, developed in the early 1960s, to evaluate the environmental impacts of a product or service (Hendrickson, Lave and Matthews, 2005) and can be readily applied to estimate the global warming potential (GWP) of different types of aquaculture. An LCA involves the development of a model of the particular aquaculture process, in which boundaries are defined (e.g. is the analysis concerned only with the culture of a particular aquatic plant or animal or should it also consider upstream and downstream activities such as the production and transport of feeds to the farm, post-harvest processing and transport of products to markets?). An inventory is produced of the energy associated with different upstream, on-farm and downstream processes, and the impacts quantified in terms of GWP.

There have been several analyses of the impact of aquaculture on climate change (e.g. Ellingsen, Olaussen and Utne, 2009; Pelletier *et al*., 2009). Among the more recent is that by Henriksson (2009), who examined the GWP (in terms of kilograms of CO_2 per tonne of production) of different types of Asian aquaculture. Confining his analyses to upstream and on-farm processes, he determined that the GWP of shrimp and fish culture is greater than that of oyster farming, while the GWP of extensive fish farming is less than that associated with more intensive aquaculture practices. For shrimp and fish culture, the greatest GWP was found to be generally linked to feed use; the exception was for very intensive *Pangasius* catfish farming systems in the lower Mekong River, where pumping accounted for the greatest proportion of GWP. However, Henriksson's analysis did not account for the GWP associated with land clearance (e.g. mangroves) for ponds or consider the GWP associated with carbon trapped in organically enriched aquaculture pond muds (for further discussion, see Bunting and Pretty, 2007; Downing *et al*., 2008;). His calculations also excluded post-harvest processing and transport to markets, which in the case of exported processed aquaculture products may greatly increase – and indeed account for most of – the GWP.

Impacts of climate change on aquaculture

Impacts of climate change on aquaculture are summarized in Figure 2.30. Some of the impacts will manifest themselves via climate-change-induced modifications to the aquatic physicochemical environment and ecosystem structure and function; others, such as increased storm frequency and intensity, will have a direct impact on aquaculture systems and operations. Sea-level rise will change the availability of sites for coastal aquaculture. Within limits, increases in temperature may stimulate growth and production, beyond which growth and food conversion may suffer, and stress and susceptibility to pathogens increase, depressing production and increasing production costs. Certain areas may thus become more suitable for aquaculture, others less so, as a study of impacts of climate change on Norwegian aquaculture indicates (Lorentzen and Hannesson, 2006). Acidification of the seas will reduce the rate of calcification of molluscs, slowing mollusc growth and reducing production. Reduced rainfall in the region, combined with population growth, will reduce availability and, possibly, increase the costs of using freshwater for aquaculture production (Dugan *et al*., 2007; Nguyen Khoa, van Brakel and Beveridge, 2008). Extreme weather events are predicted to increase, increasing the vulnerability of marine fish cages, ponds, shellfish rafts and longline production systems to damage (Handisyde *et al*., 2006; Brierley and Kingsford, 2009).

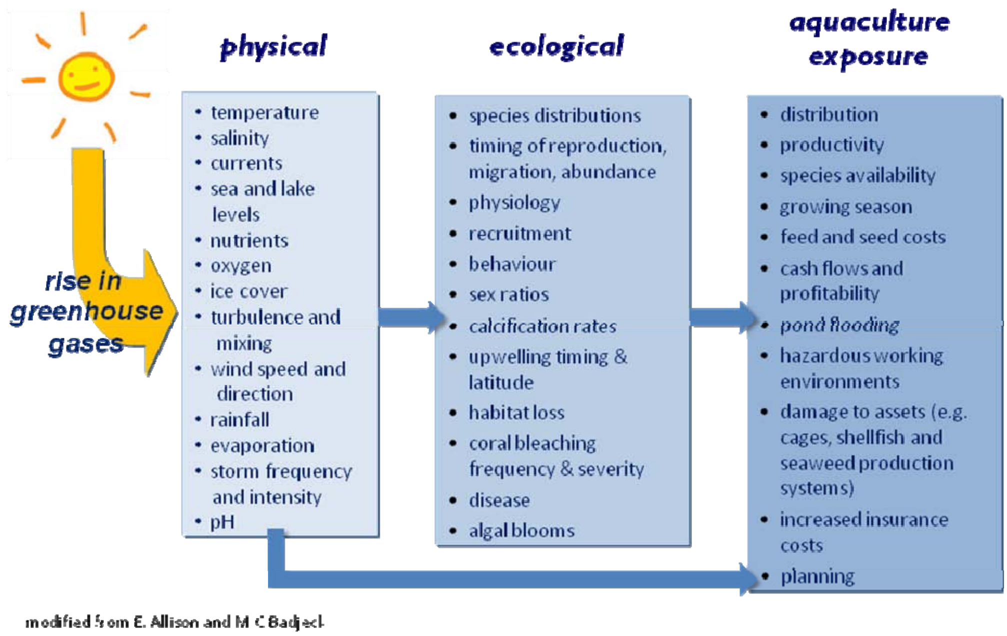

Figure 2.30 Impact of climate change on the biophysical environment of aquatic ecosystems

A vulnerability framework is useful in determining potential and realized vulnerability at a range of scales (Figure 2.31). Individuals whose livelihoods are most exposed to climate change, e.g. those who live in low-lying coastal areas and work as fishers or aquaculture labourers, and who are particularly sensitive to impacts through lack of assets, social marginalization or poor health, are likely to be among the most vulnerable. However, if for example, the individuals who are potentially most affected by virtue of exposure and sensitivity are young, have had a reasonable education, belong to well-organized producer organizations and are supported by strong institutions with well-considered policies, then they are more likely to be able to adapt to the impacts of climate change than those who lack such adaptive capacity.

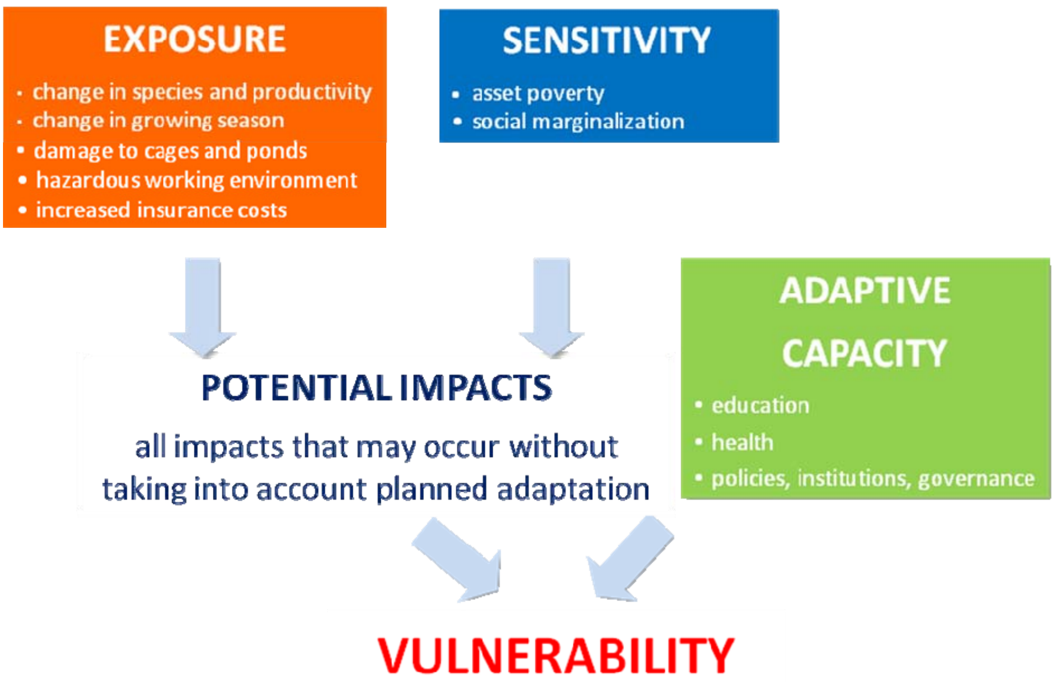

Figure 2.31 A vulnerability framework to determine how exposure and sensitivity interact to determine potential impacts and how, when considered in conjunction with adaptive capacity, these translate into vulnerability of individuals, communities or society

A value-chain approach should be adopted to fully assess the vulnerability of aquaculture to climate change. Aquaculture producers are dependent on a range of inputs, including seed and feed. The availability and prices of the raw materials used in aquaculture feeds, for example, are dependent upon climate change and other shocks. Aquaculture uses 85 percent of global fish oil and 50 percent of global fishmeal supplies (FAO, 2009). The El Niño Southern Oscillation, whose frequency and severity are affected by global warming (Collins *et al.*, 2005), determines the productivity of the coastal Pacific ecosystems of Peru and Chile, upon which much of the world's industrial fisheries depend. Availability and price of other key ingredients, such as soybean, will depend upon weather-determined harvests and changing demands for biofuels. Post-harvest processing and market chains tend to be highly energy-intensive and thus sensitive to energy prices (Pimentel and Pimentel, 2008).

The vulnerability of the value chains of various types of aquaculture will have significant effects on fish-related aspects of food security. We can anticipate changes in the availability of various farmed aquatic products as aquaculture production options change in response to climate change. The stability of supplies can be expected to be disrupted as a result of increased seasonality of production and varying supply chain costs. Access to fish for food will change as other foods become more or less affordable. Farmed fish may well be utilized in different ways, in response to climate-induced changes in availability; for example, farmed tilapia, which are currently widely available in Egyptian markets, may become less accessible in the future if value chains shift towards supermarkets in order to try to satisfy the growing demand from middle-class consumers (see De Silva and Soto, 2009).

As may be anticipated from the vulnerability framework (see Figure 2.30), aquaculture-related food security will be most vulnerable where exposure is greatest (e.g. in areas with greatly increased/decreased rainfall and increased temperatures, increased storm frequency), where there are substantial numbers of poor people with livelihoods dependent on degraded environments (i.e. are highly sensitive) and in parts of the world with poor governance and no extreme weather adaptation programmes. Consider, for example, the Mekong Delta, which is particularly exposed to sea-level rises (Adger, 1999). The Mekong Delta has one of the largest aquaculture industries in the world, producing an estimated 1.5 million tonnes of farmed *Pangasius* catfish, worth an estimated USD1.5 billion and upon which some 200 000 livelihoods are dependent.

Mitigation and adaptation: tackling aquaculture – climate-change impacts

Two strategies are needed: mitigation of aquaculture impacts on climate change; and building adaptation of the aquaculture value chain to climate change.

Although the GWP of aquaculture is relatively small in relation to other food-producing sectors, mitigation measures are nonetheless essential. The focus should be on reducing the most energy-dependent activities: on-farm use of energy for pumping, feeds and feeding, post-harvest processing and transport to markets. However, coastal areas that sequester and store large amounts of carbon, such as mangroves and sea grass meadows (Chmura *et al.*, 2003; Nellemann *et al*., 2009), should be avoided as aquaculture sites. Aquaculture pond sediments can also accumulate substantial amounts of carbon, which must be handled carefully in order to minimize GWP (Bunting and Pretty, 2007; Allison *et al.*, 2009). In pilot trials in the Nile Delta, crops of winter wheat have been successfully grown on pond sediments after fish have been harvested, the stubble flooded at the start of the following aquaculture season boosting fry and fish growth (A. Nasr Allah and D. Kenawy, personal communication).

The vulnerability framework is particularly useful in identifying the principles and actions that should be taken to reduce the vulnerability of aquaculture to climate change: reduce exposure and sensitivity, and build adaptive capacity (see Figure 2.30). Some of the solutions are technical; for example, climate forecasting and modelling can be used to estimate wave climate and currents and to identify appropriate aquaculture technologies (Perez, Telfer and Ross, 2003; Beveridge, 2004). However, many of these technologies are considerably more costly to develop and operate and may be unsuitable for some species, casting doubt on their economic viability, while construction of climateproof cages and other systems is likely to be associated with increased GWP. Other technological solutions include, for example, substituting fishmeal with vegetable protein and developing diets and feeding practices that optimize use of increasingly scarce and expensive marine lipids. It may also prove possible to selectively breed strains of fish that better convert vegetable oils into n-3 highly unsaturated fatty acids (HUFAs). Adoption of an innovation systems approach, which focuses on the flow of technology and information among people, enterprises and institutions, may improve the identification and help strengthen the implementation of innovation.

Adoption of aquaculture can also help to build sustainable livelihoods. In Malawi between 2000 and 2005, some 5 000 smallholders adopted aquaculture. Analysis of performance has shown that farmers grew a wider range of crops, recycled more on-farm wastes, and in drought years experienced smaller decreases in production than smallholders who did not have a farm pond (Dey *et al*., 2007; 2010).

Conclusions and recommendations

Aquaculture both contributes to and is vulnerable to climate change. Climate change will interact with other pressures, such as population growth, changes in markets and trade barriers and energy prices, to affect aquaculture and aquaculture-related food security. In order to assess impacts, a value-chain approach is essential. There will be winners and losers, with present centres of aquaculture production conceivably moving away from particularly hot and dry regions. Impacts will be disproportionately felt among different sectors of society, those with greatest sensitivity and least adaptive capacity and being most dependent on degraded environments – i.e. the socially marginalized, poor farmers, fishers and consumers – being most vulnerable. Adoption of aquaculture has also been shown to help build resilience to the effects of climate change.

A vulnerability framework, which is consistent with the EAF being promoted by the FAO and partners, offers a useful perspective to identify and prioritize actions (see elsewhere in these proceedings).

Aquaculture, although a relatively small contributor to the generation of GHGs, must nonetheless minimize its GWP by not exploiting areas with high amounts of sequestered carbon, by designing better feeds and optimizing their use, by taking care of the fate of organically enriched fish-pond sediments and by minimizing energy consumption associated with post-harvest processing, transport and marketing. Evidence from other sectors suggests that mitigation may not be that costly. However, it is likely that fiscal and economic incentives will be introduced to encourage such changes, although ultimately it will be consumers who, through choosing what to eat, may play the more important role in promoting mitigation.

References

Adger, N. 1999. Social vulnerability to climate change and extremes in coastal Vietnam. *World Development*, 27: 249–269.

Allison, E.H., Beveridge, M.C.M. & van Brakel, M. 2009. Climate change, small-scale fisheries and smallholder aquaculture. *In* M Culberg, ed. *Fish, trade and development,* pp. 73–87. Stockholm, Royal Swedish Academy of Agriculture and Forestry.

Beveridge, M.C.M. 2004. *Cage aquaculture*. Third edition. Oxford, UK, Blackwell. 355 pp.

Brierley, A.S. & Kingsford, M J. 2009. Impacts of climate change on marine organisms and ecosystems. *Current Biology*, 19.

Bunting, S.W. & Pretty, J. 2007. *Aquaculture development and global carbon budgets: emissions, sequestration and management options*. Centre for Environment and Society Occasional Paper 2007-1. Colchester, UK, University of Essex. 39 pp.

Cheung, W.W.L., Lam, V.W.Y., Sarmiento, J.L., Kearney, K., Watson, R., Zeller, D. & Pauly, D. 2009. Large-scale redistribution of maximum fisheries catch potential in the global ocean under climate change. *Global Change Biology*, (in press).

Chmura, G.L., Anisfeld, S.C., Cahoon, D.R. & Lynch, J.C. 2003. Global carbon sequestration in tidal saline wetland soils. *Global Biogeochemical Cycles*, 17: 221–229.

Collins, M. 2005. El Niño- or La Niña-like climate change? Climate Dynamics, 24: 89–104.

De Silva, S.S. & Soto, D. 2009. Climate change and aquaculture: potential impacts, adaptation and mitigation. *In* K. Cochrane, C. De Young, D. Soto & T. Bahri, eds. *Climate change implications for fisheries and aquaculture. Overview of current scientific knowledge* pp. 151–212. FAO Fisheries and Aquaculture Technical Paper No. 530. Rome, FAO. 212 pp.

Dey, M.M., Kambewa, P., Prein, M., Jamu, D., Paraguas, F.J., Pemsl, D.E. & Briones, R.M. 2007. WorldFish Center. Impact of the development and dissemination of integrated aquaculture technologies in Malawi. *In* H. Waibel & D. Zilberman, eds. *International research on natural resource management,* pp. 118–140. Rome, FAO, and Cambridge, UK, CAB International.

Dey, M.M., Paraguas, F.J., Kambewa, P. & Pemsl, D.E. 2010. The impact of integrated aquaculture-agriculture on small-scale farms in Southern Malawi. *Agriculture Economics*, (in press).

Downing, A.A., Cole, J.J., Middelburg, J.J., Striegel, R.G., Duarte, C.M., Kortleainen, P., Prairie, Y.T. & Laube, K.A. 2008. Sediment organic carbon burial in agriculturally eutrophic impoundments over the last century. *Global Biogeochemical Cycles*, 22: 221–230.

Dugan, P., Sugunan, V.V., Welcomme, R.L., Bene, C., Brummett, R.E. & Beveridge, M.C.M. 2007. Inland fisheries and aquaculture. *In* D. Molden, ed. *Water for food, water for life: a comprehensive assessment of water management in agriculture*, pp. 459–483. London, Earthscan, and Colombo, International Water Management Institute.

Ellingsen, H., Olaussen, J. & Utne, I. 2009. Environmental analysis of the Norwegian fishery and aquaculture industry: a preliminary study focusing on farmed salmon. *Mar. Policy,* 33: 479–458.

FAO. 2009. *The State of World Fisheries and Aquaculture 2008*. Rome. 176 pp. (also available at ftp://ftp.fao.org/docrep/fao/011/i0250e/i0250e01.pdf).

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

Handisyde, N.T., Ross, L.G., Badjeck, M.-C. & Allison, E.H. 2006. *The effects of climate change on world aquaculture: a global perspective.* Final Technical Report, DFID Aquaculture and Fish Genetics Research Programme. Stirling, UK, Stirling Institute of Aquaculture. 151 pp.

Hendrickson, C.T., Lave, L.B. & Matthews, H.S. 2005. *Environmental life cycle assessment of goods and services: an input-output approach*. London, Resources for the Future Press.

Henriksson, P. 2009. *Energy intensity in tropical aquaculture*. University of Stockholm (Masters thesis).

Lorentzen, T. & Hannesson, R. 2006. *Climate change and productivity in the aquaculture industry*. Stiftelsen for Samfunns- og naeringslivsforskning. Report [SNF Rep.] 02/06. Bergen, Norway, SNF. 89 pp.

Nellemann, C., Corcoran, E., Duarte, C.M., Valdés, L., De Young, C., Fonseca, L. & Grimsditch, G., eds. 2009. *Blue carbon. a rapid response assessment*. United Nations Development Programme, GRID-Ardenal.

Nguyen Khoa, S., van Brakel, M. & Beveridge, M.C.M. 2008. Is water productivity relevant in fisheries and aquaculture? *In*: *Proceedings of the 2nd Forum on Water and Food, Addis Ababa, Ethiopia, 12–14 November 2008*.

Pelletier, N., Tyedmers, P., Sonesson, U., Scholz, A., Ziegler, F., Flysjo, A., Kruse, S., Cancino, B. & Silverman, H. 2009. Not all salmon are created equal: Life Cycle Analysis (LCA) of global salmon farming systems. *Environ. Sci. Technol*., (in press).

Perez, O.M., Telfer, T.C. & Ross, L.G. 2003. Use of GIS based models for integrating and developing marine cages within the tourism industry of Tenerife (Canary Islands). *Coastal Management*, 31: 355–366.

Pimentel, D. & Pimentel, M. 2008. *Food, energy and society*. Third edition. Boca Raton, USA, CRC Press.