Chapter 13

Impacts and Adaptations in Climate Change in Mariculture System

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Introduction

Climate change has been recognized as the foremost environmental problem of the 21st century and has been a subject of considerable debate all over the world. Climate change is predicted to lead to adverse, irreversible impacts on the earth and the ecosystem as a whole. Specific weather events are difficult to connect to climate change; global warming has been predicted to cause broader changes, including melting of glaciers, arctic shrinkage and sea level rise. Climate change has the implication of mass mortalities of several aquatic flora and fauna, including sea weeds, sea grasses, finfishes, shell fishes, corals and mammals.

in 2007, the International Panel on Climate Change (IPCC) has been highlighted various risks to aquatic systems from climate change, including loss of coastal wetlands, coral bleaching and changes in the distribution and timing of fresh water flows. The uncertain effects of ocean acidification will also profound impacts on marine ecosystems and in turn to mariculture also (Orr *et al*., 2005).

There are physical, chemical and biological hazards of climate change on aquaculture.

Physical hazards

i) **Temperature anomalies**: Higher air temperatures and an increased frequency of hot days and nights, heatwaves and abnormally cold events are more likely to occur. Fish stock performance (e.g. Growth, survival) and therefore productivity is affected by surface air temperature anomalies. Bu the effect could be advantageous for some farmed species.

ii) **Sea surface temperature changes (SST):** Each and every marine species is adapted to a particular temperature range in the environment. In mariculture, a change in SST may put some production systems at risk if the increase or decrease in temperature exceeds the optimal range for survival or growth.

iii) **Precipitation anomalies:** Likely increase in the frequency and intensity of heavy rainfall events on one hand, and a prolonged absence of precipitation on the other can impact mariculture productivity. Productivity is adversely affected by unforeseen changes, especially from erratic rain fall patterns.

iv) **Rising sea levels**: Sea levels are expected to increase more than the current IPCC projections, and the penetration of saline water to inland areas could result in some freshwater production systems unsuitable for the culture of such species. Wave surges and inundations also would lead to alteration of habitats of farmed species, eroding coastal strips or submerging coastal areas.

v) **Floods:** Flooding caused by abnormal heavy rainfalls – but often exacerbated by poor planning or the absence of coordinated action by different agencies – may become more severe as a result of global warming, rendering farming systems, input sources such as wild seed, and plant-based feed ingredients more vulnerable.

vi) **Drought:** Could be possibly more intense, or of longer duration, or both. The risks associated with drought are not well understood compared to those associated with floods or cyclones. The impact of drought can only be partly attributed to deficient or erratic rainfall, as drought risk appears to build up over time as a result of a range of drivers. These include: poverty and rural vulnerability; increasing water demand due to urbanization, industrialization and the growth of agribusiness; poor soil and water management; weak or ineffective governance; and climate variability and change (UNISDR, 2011).

vii) **Cyclones:** The growing intensity of tropical cyclones can cause the widespread destruction of infrastructure and the disruption of services that affect aquaculture production. Cyclones can delay the resumption of farming activities, and disrupt activities along the other segments of the value chain (seed and feed production and supply, post-harvest, transport and marketing). Cyclones also cause the silting-up of molluscs growing areas.

Chemical hazards

i) **Lower pH values (acidification)**: A number of studies have shown that lower pH values affect the development of shells of molluscs and corals.

ii) **Salinity changes:** Salinity may increase or decrease depending on changes in precipitation and evaporation. In coastal waters this arises by virtue of the heavy influx of floodwaters from rivers and estuaries. In rivers, changes are caused by the intrusion of seawater.

iii) **Low oxygen levels in culture waters**: An increased impact of upwelling of anoxic water results in low oxygen levels. Plankton respiration gets intensified as a result of higher temperatures. Eutrophication also occurs at many instances.

Biological hazards

Biological hazards are driven by physical and chemical factors:

i) **Eutrophication:** Rising temperature levels are likely to cause wide fluctuations in the thermal dynamics of water bodies, including increasing stratification and nutrient circulation, with implications in primary production and hence higher trophic levels. More intense eutrophication and algal blooms will have implications in local aquatic ecosystems and in aquaculture, especially in static water bodies like lakes and reservoirs.

ii) **Harmful algal blooms (HAB)**: Increase in temperatures, increase in frequency and extent of algal blooms, and changes in the diversity of zooplankton have been observed in semi-enclosed seas. This will cause severe financial implication as an offshoot of a biological hazard.

iii) **Pathogens and parasites**: Increase in prevalence, a shift in the distribution of pathogens and parasites, enhanced growth and reproduction of microbes are also biological hazards of climate change.

iv) **Pollution**: increase in pollution toxicity, including the dilution of micro-plastic as a result of rising water temperatures is another hazard that affect fisheries and mariculture.

Impact of climate change on Aquaculture

The main climate change related drivers – warming of water bodies, rising sea levels, acidification of the seas, changes in weather patterns and extreme weather events – have direct and/or indirect impacts on aquaculture, and the evidence of such impacts has been well documented (FAO, 2009). The links between each driver and its impacts on aquaculture have been broadly established by numerous studies, with varying degrees of confidence. The predicted rise in seawater acidification will affect the physiology of bivalves both in terms of growth and reproduction, and may affect the quality of shells. On the other hand, warming can also increase spat fall and growth rates, as well as extend the latitudinal range of farming, which are positive effects. Indirect effects of climate change include changes in circulation patterns and productivity in the sea (Brochier *et al.*, 2013) that will affect the production of fishmeal/oil; physical impacts affecting the production of terrestrial fish feeds; and physical impacts and adaptation in other sectors that negatively affect aquaculture, e.g. priority water use for agriculture under climate change. Many studies have examined the indirect effect of climate change on the spread and occurrence of disease in farmed aquatic organisms, in addition to shifts in the distribution of parasites and pathogens. Vibriosis, for instance, is one of the diseases that may be profoundly affected by climate change since vibrios grow preferentially in warm waters (> 15^{o} C) and at low salinity (< 25 ppm).

The impacts include:

a) Biological: An increased prevalence and virulence of pathogens as a result of higher levels of stress on cultured organisms; a shift in the distribution of pathogens and parasites; harmful algal blooms; the disruption of shell formation in molluscs and crustaceans; a disruption in reproductive patterns; shortage of fish meal and fish oil; reduced availability of natural seed; but also faster growth, higher feed conversion efficiency and higher yield from a higher temperature as long as it does not exceed the species' range of tolerance.

b. Environmental: The loss or alteration of habitat, eutrophication, harmful algal blooms, severe damage to corals, salinity intrusion – but also an expansion of the range of cultivation of some species.

c. Social and economic: the loss of arable land and culture areas due to salinity intrusion, coastal erosion and floods; the loss or disruption of livelihoods from the biological and environmental impacts, and from the loss of stock and destruction of physical structures; physical dislocation; increased public health problems.

Vulnerabilities

Culture environment

Many aquaculture systems are highly vulnerable to natural hazards. Sites are usually located in low lying areas; on areas that are fragile and ecologically sensitive and prone flooding; in water resources which may not hold sufficient water for floating cages or pens over a prolonged drought, and therefore become eutrophic; along rivers and estuaries that could dry up or be inundated with little warning. Coastal areas, and even enclosed or protected bays, are invariably exposed to tidal surges and cyclones. Pond systems, whether brackish or marine, are susceptible to the effects of high temperature, erosion and siltation. Mariculture would be highly exposed to harmful algal blooms (HABs) and oxygen depletion from the upwelling of anoxic water.

Species and systems: Several approaches to assessing the vulnerability of species and systems are possible when devising institutional and structural adaptation strategies for farmers and at a local level. However, the most practical approach would probably be to categorize aquaculture units by geography – such as inland, coastal and arid – tropical – and then by farm density and production intensity. Within the same location and with the same farmed species, the combination of technology, farm management practice and area management could reduce the vulnerability of an aquaculture system.

With respect to a specific impact on a specific species, molluscs in coastal aquaculture are probably the most vulnerable to acidification. Pearl culture in the Pacific is the biggest export earner for the region; in 2007, pearl, giant clams and shrimp made up most of the US$211 million total export value of aquaculture commodities from the Pacific region (Bueno, 2014). A rise in sea temperature and an increased acidification of the ocean would stress pearl oysters and could affect pearl formation. Pacific cyclones have time and again destroyed onshore and nearshore installations and growing facilities.

Farmed trout, of which 22 % is based on improved stocks, and farmed Atlantic salmon, 95 % of which derives from genetically improved stocks (Gjedrem and Baranski, 2009), would be vulnerable to direct impacts (i.e. temperature rise beyond a tolerable range) and the indirect impact of reduced availability of plant- and fish-based raw materials for feed (Troell et al., 2014).

A study in Norway has shown better productivity of Atlantic salmon with warmer seawater: on average, a percentage increase in SST increases the production level by about 9 % relative to no change in the sea temperature level; but the increase diminishes with increasing SST level (the effect is positive but diminishes as temperature rises). Furthermore, a higher temperature increases the bacterial density in the water and the frequency of algal blooms. Mortality rate will increase for all age groups. If the amplitude and/or average temperature increase to the level where the physiology of the fish is compromised, the probability of mortality rises. Global warming is counterproductive for the industry if the sea temperature increases too much (Lorentzen, 2008).

Tilapias would have a high resilience on a regional basis in subtropical and tropical climates. Several fast-growing strains, including salt-tolerant ones have been bred. The hatchery technology is relatively easy and inexpensive, and now widespread. Tilapias are known to be highly adaptable to a range of environmental parameters, and known for their ability to adapt to and compete with other species over a wide range of ecological conditions. Tilapias are among the most widely bred species for commercial production; they are farmed in 140 countries and territories, and account for nearly 7 % of world production of farmed aquatic animals, and more than 10 % of farmed finfish (FAO, 2016). As a species group, Cyprinids should also have a high resilience: comprising several species, it is grown over a wide climatic range is artificially bred and the broodstock and hatchery technology is widely adopted. Two species, bighead and silver carps, are largely non-fed. Carps are versatile and can flourish in a wide variety of habitats including those which are highly degraded. They can tolerate a wide range of temperatures and environmental conditions. They have a higher tolerance to low oxygen levels, pollutants and turbidity than most native fish, and are often associated with degraded habitats, including stagnant waters.

Furthermore, in the major producers such as Bangladesh, China and India, the predominant culture practice is polyculture of more than two species of carps, or of carps and other finfish species such as tilapia, Pangasius and Clarias catfish; it is a highly diversified culture system, which is generally recognized as resilient.
The high dependence of several developing countries on marine shrimp for export earnings and the high exposure of – mostly coastal – brackish water culture areas to many climate change hazards – coastal storms and tidal surges, flooding, erratic rainfall, and temperature anomalies – make marine shrimp culture highly vulnerable. This being said, in practically all the penaeid shrimp farming countries in Asia and Latin America a large proportion of the recurring and heavy losses have been from disease.

Utilizing a series of indicators of exposure, sensitivity and adaptive capacity in a GIS model, Handisyde et al. (2006) have been identified Bangladesh, Cambodia, China, India, Philippines and Viet Nam as the most vulnerable countries worldwide. Climate change could therefore prevent aquaculture from being a good source of nutritious food and livelihoods in these countries.

Climate change Adaptation

Adaptation, defined later in this section, essentially involves four basic concepts: vulnerability, resilience, adaptive capacity and sustainable livelihood.

Vulnerability to climate change comprises a combination of exposure to climate change variables, sensitivity to those variables, and the capacity to adapt and build resilience to climate change. An assessment of vulnerability is usually seen as the first step in the adaptation process. A comprehensive discussion on Vulnerability Assessment is provided by Brugère and De Young (FAO, 2015).

- Exposure: the degree to which a system is susceptible to, or unable to cope with, the adverse effects of climate change, including climate variability and extremes.
- Sensitivity: the degree to which a system is affected adversely or positively by climatic stresses. Some use "dependency" as a measure of how serious the impact would be on each of the attributes that determine the overall well-being of the system.
- Adaptive capacity: the ability of a system to adjust to climate change, to mitigate potential damage, to take advantage of opportunities, or to cope with the consequences. Adaptive capacity is context specific, as illustrated by aquaculture being located in fragile ecosystems in coastal, low-lying and highly exposed areas, and/or in a social context where farmers in an area have poor access to key services, or there is a lack of social cohesion, or where policies which aim to encourage investment in adaptation are absent or poorly designed.

Adapting to climate change essentially involves:
(a) Reducing exposure,
(b) Decreasing sensitivity, and
(c) Strengthening adaptive capacity.
One of the most important factors that shape the adaptive capacity of individual farmers, farm households and farming communities is their access to, control over and ability to use natural, human, social, physical and financial resources productively, i.e. the livelihood capitals.

Purposes of an adaptation measure and examples of management measures
Reduce exposure to climate hazards: Conserve natural sea defenses, i.e. mangrove; Build/improve artificial river banks and sea defenses (seawall, embankment); Risk-based zoning (also considering longer-term changes) and site selection (for areas being developed for aquaculture); Raise and fortify pond dikes; dig deeper ponds; Implement safer, flexible and resistant cages, rafts and other holding systems; Upgrade pumps and sluices; Short cycle aquaculture techniques; closed aquaculture production system, i.e. recirculation aquaculture, aquaponics; Shift production units to less exposed areas, relocate;

Minimize fish stress, ensuring plenty of oxygen; facilitate and enforce safety-at-sea measures.

Reduce sensitivity: Farm more tolerant species to the important stressors i.e. temperature, salinity, acidification; Reduce dependence on wild-caught seeds; Reduce dependence on fish meal and fish oil; Reduce Feed Conversion ratios and improve feeding efficiency; -Diversify species or product range; Diversify livelihoods; Integrated farming systems.

Increase adaptive capacity: Better weather forecasting, water/environment monitoring, early warning systems; Improved disease surveillance systems; Insurance for crops and farm physical assets; Durable and reliable access assets i.e. roads, power distribution system, water supply system, communications system; Organize and professionalize farmers with the appropriate attention to gender, e.g. fostering women's associations; Establish networks, societies, cooperatives; strengthen social capital; Improve access to markets and fair trade; Fair employment rules and enforcement; Establish Aquaculture Management Areas; Improve access to training and improved technology; Promulgate clear and policies and regulations.

Resilience: The converse of vulnerability, resilience in the social-ecological context is the system's capacity to absorb recurrent disturbances in order to retain essential structures, processes and feedbacks (Adger et al., 2005). Resilient social-ecological systems incorporate diverse mechanisms for living with and learning from change and unexpected shocks. Disaster management thus requires multilevel governance systems that can enhance the capacity to cope with uncertainty and surprise by mobilizing diverse sources of resilience.

Options: Adaptation and mitigation responses are underpinned by common enabling factors. These include effective institutions and governance, innovation and investments in environmentally sound technologies and infrastructure, sustainable livelihoods, as well as behavioral and lifestyle choices (IPCC, 2014). These enablers are expanded into a list of ten options under three categories, namely: structural/physical, social and institutional (IPCC, 2014).

Spatial planning: This comprises marine and terrestrial zoning for siting of aquaculture facilities (subtidal and terrestrial systems) and mangrove areas to balance aquaculture needs with terrestrial development and shoreline protection with rising sea level. In addition, the need to think long term about requirements for current coastal activities to shift landwards as shorelines retreat over time.

Structural/Physical: Engineered and built environment (e.g. seawalls and coastal protection); - Technology (e.g. genetic diversification, new farming systems and technologies, early warning systems and technologies etc.).

Social (including resource management): Educational (e.g. integration of awareness-raising into education with the appropriate gender focus); - Informational (e.g. hazard and vulnerability mapping, early warning system, community based adaptation planning, participatory scenario development); - Services (e.g. emergency services, social safety nets and social protection); - Behavioral (e.g. accommodation, retreat, migration, livelihood diversification, changing aquaculture practices); - Organizational (e.g. aquaculture area management under the Ecosystem approach to Aquaculture (EAA) (FAO and World Bank, 2015)).

Institutional: Economic (e.g. financial incentives including taxes and subsidies, payments for ecosystem services, insurance, microfinance); Laws and regulations (e.g. building standards, defining property rights and land tenure, marine-protected areas, farming and fishing quotas, ethical employment, appropriate incentives); - Government policies and programmes (e.g. mainstreaming climate change into national and regional adaptation/development plans, integrated coastal zone management, fisheries management, community-based adaptation, disaster planning and preparedness.

The ecosystem approach to aquaculture (EAA) is a crosscutting enabler – a strategy that can be implemented at different geographical and management scales – and considers climate change as a relevant external driver requiring adaptation measures. Such measures are included in the aquaculture management plans. The following tables (1 and 2) provide two perspectives on adaptation options. The first gives examples of specific impacts and the mostly structural and social adaptation options to deal with the impacts. The second is a broader, strategic classification of impacts on ecological well-being, human welfare and sector governance, and describes adaptation options that are mostly institutional and social.

Potential adaptation measures

- Shift aquaculture to non-carnivorous commodities
- Selective breeding for increased resilience in aquaculture
- Moving/planning siting of cage aquaculture facilities

- Change aquaculture feed management: fishmeal and fish oil replacement; find more appropriate feeds
- Ecosystem approach to fisheries/aquaculture and adaptive management
- Change aquaculture feed management
- Building aquaculture facilities to withstand increased storm damage
- Encourage native aquaculture species to reduce impacts if fish escape damaged facility

The following table gives a brief on the aquaculture systems on its impact and adaptation to climate change:

Aquaculture system/culture environment	**Impact +/-**	**Kind of impact**	**Adaptation**
		Driver: Temperature	
Cage, pond finfish in all environment	-	Temperature rises above optimal range of tolerance; temperature dips below optimal range of tolerance.	Breed for higher tolerance; short-cycle aquaculture; move production sites to lower altitudes/latitudes (in the northern and southern hemispheres according to temperature changes and trends); for pond systems, build deeper ponds
All systems/all environments: finfish	+	Higher temperature could stimulate faster growth, higher yield.	Intensify production; increase feed input; improve management practice; tighter control of oxygen availability.
Marine, brackish- and freshwater	-	Increase virulence of otherwise dormant pathogens; rampant growth of parasites; shift in their distribution.	Monitoring of environmental variables as well as diseases and pathogens; tighter biosecurity measures in general (including early warning and better dissemination of information); increase investment in vaccines and other environmentally friendly prevention methods
Crustaceans and carnivorous finfish	-	Shortage of fish meal and fish oil	Fish meal and oil replacement; shift to non-carnivores; better feed management practice.
All fed fish	-	Shortage of terrestrial feed ingredients	Better feeds, better feed management practices; shift to non-fed species.

Capture-based aquaculture (e.g. bivalves and crustaceans)	-	Shortage of wild seed and spat fall	R and D in artificial breeding; hatchery production; incentives for more efficient access and use of available seed.
Reef fish culture based on wild seed	-	Destruction of coral habitats; loss of wild seed fishery of mostly high value reef fish species.	R&D in artificial breeding; hatchery production
Drivers: Rising sea levels and floods			
All systems in coasts, river basins and deltas	+/-	Salinity intrusion	Shift upstream; switch to euryhaline species; however, pond culture of milkfish, seabass or saline tolerant tilapia in brackish water would, for example, have to be completely based on commercial feed as fertilization is ineffective in high salinity water. Research and explore new fertilization methods in saline systems
	+/-	Erosion of topsoil and loss of land	Opportunity for alternative system i.e. from crop farming to aquaculture
	+/-	Destruction of dikes and water channels, pond siltation	Flood control dams; stronger and taller pond dikes, greenbelt establishment or conservation; better risk maps, improved siting, appropriate monitoring and early warning systems.
	+/-	Habitat changes or loss; less wild seed.	Switch to inland aquaculture; recirculation aquaculture system; aquaponics.
Driver: Marine circulation and temperature changes			
Culture of carnivorous finfish	-	Reduced catch from artisanal fishing of low-value fish for feed; reduced availability of fishmeal and	Switch to commercial feed formulations (pellets); switch to terrestrial-based feeds and other byproducts.

		fish-oil.	
Mariculture: fish and mollusc	-	Increased fish stress due to suboptimal physiological conditions.	Contingency for emergency management, early harvest and/or relocation
	-	Increased fish stress due to suboptimal physiological conditions.	Contingency for emergency management, early harvest and/or relocation.
	-	Increase in harmful algal blooms	Improved monitoring and early warning systems; physical barriers and other mitigation systems on site; Contingency for relocation of growing sites.
	-	Reduced spatfall.	R and D in artificial breeding; hatchery production; incentives for more efficient access and use of available seed.
	+	Warmer temperature increases spatfall and growth rates, extends latitudinal range for farming.	Mollusc farming offers an alternative to fish culture
		Driver: Acidification	
Most shelled molluscs, including species that produce pearl		Adverse effect on shell formation and deposition, probably on pearl development, too	Move—if at all possible—to other production zones; switch to freshwater aquaculture; For pearls: culture in deeper waters, new sites; R&D for low pH tolerant strains
Seaweed		Exploratory study shows macro-algae may tolerate long-term elevations in CO_2 levels but macroalgal habitats are altered significantly as pH drops.	
Finfish		Not well understood but could affect larval development	
		Driver: Water stress from prolonged, intense drought	
Pond culture		Limits to water supply.	Conservation; efficient allocation and use of water; recirculation aquaculture systems, integration aquaculture-agriculture (e.g.

			aquaponics).
Culture-based fisheries	-	Water level drops very low in lakes, reservoirs, oxbow lakes, rivers	Risk mapping to choose more suitable waterbodies; faster growing species; more efficient water-sharing with other users
	-	Decreased availability of wild seed	Artificial breeding; hatchery produced seed.
Cage culture		Eutrophication and upwelling; algal bloom.	Appropriate monitoring of environmental variables and early warning, insurance, relocation
		Shorter water retention period of lakes, reservoirs, oxbow lakes, rivers.	Faster growing species; more efficient water sharing with other users.
Drivers: Extreme events: tropical cyclones, heavy and prolonged rainfall causing floods			
All systems but especially coastal aquaculture		Destruction of structures, facilities; loss of stock; escape of cultured fish; Floods and the heavy run-off of freshwater into coastal aquaculture site especially those for seaweed lowers salinity and stimulate growth of epiphytes that suffocate the seaweed.	Stronger structures; early warning systems; recirculation aquaculture system; aquaponics; greenbelt conservation; coastal embankment; insurance.