Part I – Keynote Addresses

Aquaculture and sustainable nutrition security in a warming planet

Keynote Address 1

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Abstract

According to World Food Summit 1996, food security exists when all people, at all times, have physical and economic access to enough safe and nutritious food to meet their dietary needs and food preferences for an active and healthy lifestyle. In order to be food secure, the food should be available and affordable. For the more than a billion people who do not get enough regular, healthy food, ill health and a shorter life expectancy are real risks. Children, and especially very young children, who suffer from food insecurity will be less developed than children of the same age who have had sufficient food. Aquaculture offers a significant opportunity for improving food security and nutrition by providing nutritious, yes affordable protein to many millions of people worldwide. The increase in global population, gradual depletion of finite resources required form sustainable expansion and development of aquaculture poses threats to future fish global protein supply. Over and above, the impacts of climate change are also posing threats to sustainable aquaculture development thus requiring focused implementation of mitigation and adaptation strategies. Current paper describes how aquaculture is perceived to contributes to improving food and nutrition security and the mitigations required for overcoming climate change and other environmental challenges for maintaining sustainability of the sector.

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Introduction

The most notable and significant changes associated with global warming are the gradual rise of global mean temperatures (Zwiers and Weaver, 2000) and a gradual increase in atmospheric green house gases (IPCC, 2007). 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 process of global warming shows no signs of abating and is expected to bring about long-term changes in weather conditions (FAO, 2008). Eleven of the last 12 years (1995–2006) rank among the 12 warmest years in the instrumental record of global surface temperature since 1850. According to the *United Nations Framework Convention on Climate Change*, the average temperature of the earth's surface has risen by 0.74 °C since the late 1800s and is expected to increase by another 1.8 to 4 °C by the year 2100. Global sea level rise, which has been occurring due to climate change, has accelerated since 1993. Mean sea-level has risen by about 0.1–0.2 mm/yr over the past 3 000 years and by 1–2 mm/yr since 1900, with a average value of 1.5 mm/yr. Some extreme weather events have changed in frequency and/or intensity over the last 50 years. More floods, hurricanes and irregular monsoons were experienced than in previous decades. Based on a range of models, it is likely that future tropical cyclones (typhoons and hurricanes) will become more intense, with larger peak wind speeds and more heavy precipitation associated with ongoing increases of tropical sea-surface temperatures. Some of the developing world's largest rivers are drying up because of climate change, threatening water supplies in some of the most populous places on earth. Many lakes, especially those in Africa have shown moderate to strong warming since the 1960s. The likelihood of wetlands completely drying out in dry seasons due to changes in temperature and precipitation is increasing. It is very likely that hot extremes, heat waves and heavy precipitation events will become more frequent. Climate change will affect food production by raising temperatures, changing rainfall belts and increasing the variability of the weather with more frequent extreme events.

Issues on nutrition security in a changing green house gases (GHGs) scenario

Food security is an increasingly important issue for the rural communities who rely on agriculture to meet their subsistence needs. Malnutrition is still the number one killer compared to other diseases. The main indicators used to measure the extent of food insecurity are the numbers and proportions of all people estimated to be undernourished (i.e. without access to sufficient food to meet their energy requirements for an active life) and the numbers and proportions of infants who are considerably below the norms of height for their age, weight for their height or weight for their age. Food security depends on the availability of food, its access and absorption.

The estimates show that that no less than 1.02 billion persons are currently undernourished. Undernourishment is overwhelmingly found in developing countries and is heavily concentrated in parts of Asia and in Africa south of the Sahara. Around two billion persons suffer from deficiencies in micronutrients, primarily of vitamin A, iodine and iron (UNSCN, 2004), making these the most common and often under-appreciated nutritional problems. In fact, many populations, those in developing countries more than those in developed ones, depend on fish as part of their daily diets. For them, fish and fishery products often represent an affordable source of animal protein that may not only be cheaper than other animal protein sources, but is preferred and a part of local and traditional recipes. In developing countries, a shift in diets towards more animal products will increase demand, and in industrialized countries, issues such as food safety and quality, environmental concerns and animal welfare will probably be more important than price and income changes.

Role of aquaculture in sustaining nutritional security

Food fish, whether captured or cultured, plays an important role in human nutrition and global food supply, particularly within the diets and food security of the poor. Food fish currently represents the major source of animal protein (contributing more than 25 percent of the total animal protein supply) for about 1 250 million people within 39 countries worldwide, including 19 sub-Saharan countries (FAO, 2009). Fish contributes more than 50 percent of protein intake for 400 million people from the poorest African and South Asian countries. Fish are important sources for many nutrients, including protein of very high quality, retinol (vitamin A), vitamin D, vitamin E, iodine and selenium. Evidence is increasing that the consumption of fish enhances brain development and learning in children, protects vision and eye health, and offers protection from cardiovascular disease and some cancers. The fats and fatty acids in fish, particularly the long chain n-3 fatty acids (n-3 polyunsaturated fatty acids (PUFAs)), are highly beneficial and difficult to obtain from other food sources. Of particular importance are eicosapentaenoic acid (20:5n-3, EPA) and docosahexaenoic acid (22:6n-3, DHA).

Aquaculture production is playing an increasing role in meeting the demand for fish and other fishery products. The combined result of development in aquaculture worldwide and the expansion in global population is that the average annual per capita supply of food fish from aquaculture for human consumption has increased by ten times, from 0.7 kg in 1970 to 7.8 kg in 2008, at an average rate of 6.6 percent per year (FAO, 2010). The importance of aquaculture in meeting the protein requirements from fish is evident from the fact that while kilogram per capita fish consumption rose from 14.9 in 1995 to 17.1 in 2008, the percentage contribution increased from 29 to 46 percent for the same period. Cultured food fish supplies currently account for nearly 50 percent of that consumed globally (FAO, 2009) and are targeted to increase to 60 percent by 2020 (FAO, 2008). With the improvements in culture practices, a more than six-fold increase in fish production and a four-fold increase in household fish consumption has occurred in Bangladesh (Gupta and Bhandari, 1999). Fish that command a good price (e.g. carps) will go to the market, whereas those that command a low price (e.g. tilapia) are used for household consumption (Dey *et al*., 2000).

Status of capture and aquaculture fisheries production

Total fisheries production (capture fisheries and aquaculture) was about 142 million tonnes in 2008. Of this, 115 million tonnes was used as human food, providing an estimated apparent per capita supply of about 17 kg, which is an all-time high, and the remainder going to non-food uses (e.g. livestock feed, fishmeal for aquaculture). Aquaculture accounted for 46 percent of total food fish supply, representing a continuing increase from 43 percent in 2006. The global production of food fish from aquaculture, including finfish, crustaceans, molluscs and other aquatic animals for human consumption, reached 52.5 million tonnes in 2008. The contribution of aquaculture to the total production of capture fisheries and aquaculture continued to grow, rising from 34.5 percent in 2006 to 36.9 percent in 2008. In the period 1970–2008, the production of food fish from aquaculture increased at an average annual rate of 8.3 percent, while the world population grew at an average of 1.6 percent per year.

Aquaculture production using freshwater contributes 59.9 percent to world aquaculture production by quantity and 56.0 percent by value. Aquaculture using seawater (in the sea and also in ponds) accounts for 32.3 percent of world aquaculture production by quantity and 30.7 percent by value. Although brackishwater production represented only 7.7 percent of world production in 2008, it accounted for 13.3 percent of total value, reflecting the prominence of relatively high-valued crustaceans and finfishes cultured in brackishwater. Although cultured crustaceans still account for less than half of the total crustacean global production, the culture production of penaeids (shrimps and prawns) in 2008 was 73.3 percent of the total production. The introduction of whiteleg shrimp (*Litopenaeus vanname*i) to Asia has given rise to a boom in the farming of this species in China, Thailand, Indonesia and Viet Nam in the last decade, resulting in an almost complete shift from the native giant tiger prawn (*Penaeus monodon*) to this introduced species in Southeast Asia. The ban on the introduction and culture of whiteleg shrimp was lifted in 2008 in India, and this will have a major impact on the country`s shrimp farming sector in the years to come.

Synthesis of the trends in aquaculture production, at five year intervals, for each of the cultured commodities (vis-à-vis finfish, molluscs, crustaceans and seaweeds), based on FAO Statistics (FAO, 2008) for three climatic regimes, viz.

tropical (23 °N to 23 °S), subtropical (24–40 °N and 24–40 °S) and temperate (>40 °N and >40 °S) revealed that production in the tropics accounted for more than 50 percent, the highest being for crustaceans, which approximated 70 percent. In Asia, irrespective of climate regime, the contribution of aquaculture to total fish production has been increasing over the last two decades, a trend that has been observed in many of the current major aquaculture-producing countries on that continent (De Silva, 2007).

Impact of climate change scenarios and concerns for aquaculture

Vulnerability to the impacts of climate change is a function of exposure to climate variables, sensitivity to those variables and the adaptive capacity of the affected community. Often, the poor are dependent on economic activities that are sensitive to the climate. To determine which among the fisheries of 132 nations were the most vulnerable, 33 countries were rated as “highly vulnerable” to the effects of global warming on fisheries. These countries produce 20 percent of the world’s fish exports and 22 are already classified by the United Nations as “least developed”. Inhabitants of vulnerable countries are also more dependent on fish for protein. Two-thirds of the most vulnerable nations identified are in tropical Africa. The thriving catfish farming in the Mekong Delta, Viet Nam (a highly vulnerable country) that provides 150 000 livelihoods with a production of 1 million tonnes valued at USD1 billion per year, would be jeopardized by saline intrusion due to sea level rise. African countries which depend greatly on fish for protein and have the least capacity to adapt to climate change are semi-arid with significant coastal or inland fisheries, i.e. higher vulnerability to future increases in temperature and linked changes in rainfall, hydrology and coastal currents. Island nations and others like Bangladesh would be greatly hit by the increase in frequency and intensity of storms and resulting flooding.

Drivers of climate change

Climate change impacts may be significant at a number of different scales ranging from global down to the local community level. By combining national or global-level indicators with case studies at the district or local community level, it may be possible to highlight and better understand a broader range of impacts (O’Brien *et al*., 2004). For example, while a large area may be exposed to the risk of flooding or drought, the adaptive capacity of different communities within that area may vary greatly.

Changes in average precipitation, potential increase in seasonal and annual variability and extremes are likely to be the most significant drivers of climate change in inland aquaculture. Reduced annual rainfall, dry season rainfall and the resulting growing season length are likely to create impacts for aquaculture and could lead to conflict with other agricultural, industrial and domestic users in water-scarce areas. Mean air temperature will not necessarily equate to increases seen in the temperature of aquaculture pond waters. The main climatic factors influencing the water temperature in an inland environment are solar radiation, air temperature, wind speed and humidity, in combination with the pond shape and size and its water levels. Turbidity and water colour also influence the amount of solar radiation absorbed. As aquaculture ponds are typically shallow and turbid, solar radiation is likely to be an important influence on temperature (Kutty, 1987). A change in temperature of only a few degrees might mean the difference between a successful aquaculture venture and an unsuccessful one (Pittock, 2003). Any increase in the intensity and/or frequency of extreme climatic events can damage aquaculture. The first and second assessment reports on ocean systems (Tsyban, Everett and Titus, 1990; Ittekkot *et al*., 1996) conclude that global warming will affect the oceans through changes in sea-surface temperature (SST), ice cover, ocean circulation and wave climate, which affect the ocean productivity, which indirectly affects aquaculture.

Ecological, physical and socio-economic impacts

The changes in drivers of climate change will in turn create physiological (e.g. growth, development, reproduction, disease), ecological (e.g. organic and inorganic cycles, predation, ecosystem services) and operational (e.g. species selection, site selection) changes. Increased precipitation can bring its own problems in the form of flooding. Floods may damage facilities, cause stock to escape, affect salinity and introduce predators or disease. Increase in monsoon intensity has been predicted over some Asian regions, while changes in the timing of the monsoon pattern and increased interannual variability could also be significant (Mirza *et al.*, 2001; Mirza, 2002). Sea level rise will have gradual impacts due to loss of land via inundation and erosion. Areas such as mangroves and salt marshes, which act as nursery grounds supplying seed for many aquaculture species and provide some coastal protection, may be lost as they are sandwiched between the rising sea and developed land behind them. Salinization of ground water may occur, especially in low-lying areas, reducing the availability of freshwater for aquaculture and other uses.

Precipitation

Variability in the amount of precipitation under different scenarios of monsoon could negatively impact aquaculture. Delay in onset of monsoon leads to high salinity build up, especially in low tidal amplitude areas, and conflict with other users for using freshwater to dilute high salinity. High rainfall resulted in a rapid drop in salinity to levels that were lethal for kuruma prawn (*Marsupenaus japonicus*), causing mass mortality of the farm crop (Preston *et al*., 2001). The impacts are likely to be felt most strongly by the poorest aquaculturists, whose typically smaller ponds go dry more quickly and who may suffer from shortened growing seasons, reduced harvests and a narrower choice of species for culture. Algal blooms, depletion of dissolved oxygen and consequent production losses in inland and coastal ponds may occur, particularly in summer months when water exchange becomes difficult. Changes in suspended sediment and nutrient loads resulting from altered rainfall patterns will affect aquaculture ponds. Elevated nutrient levels can stimulate algal blooms containing toxins that accumulate in oysters, posing a threat to public health (Nell, 1993).

Temperature

The negative impacts of higher water temperatures in inland waterbodies include deteriorated water quality, worsened dry season mortality, introduction of new predators and pathogens, and changes in the abundance of food available to fishery species. If the temperature rise causes increase in metabolic rates of aquatic species greater than the increase in food supply, then there will be a negative impact on growth performance. Increased water temperatures and other associated physical changes such as shifts in dissolved oxygen levels have been linked to increases in the intensity and frequency of disease outbreaks (Goggin and Lester, 1995; Harvell *et al.,* 2002; Vilchis *et al.,* 2005) and more frequent algal blooms in coastal areas (Kent and Poppe, 1998). Water temperature also can have a direct effect on survival of larvae and juveniles, as well as on growth of aquatic organisms, by acting on physiological processes. Changes in temperature would change plankton community structure. Dinoflagellates have advanced their seasonal peak in response to warming, while diatoms have shown no consistent pattern of change (Edwards and Richardson, 2004). Temperature changes will have an impact on the suitability of species for a given location. Since fish are poikilothermic, climate changes will significantly alter their metabolism, resulting in reduced growth rate and total production, increased vulnerability to disease and changes to reproduction seasonality. Hence, increase in temperature due to climate change will have a much stronger impact on aquaculture productivity and yields.

Consequent lengthening of the growing season for cultured fish and shellfish and increased production of aquaculture species by expanding their range are positive impacts of high temperatures in mid to high latitudes. In cooler zones, aquaculture may also benefit, as rising temperatures could bring the advantage of faster growth rates and longer growing seasons. Raised metabolic rates increase feeding rates and growth if water quality, dissolved oxygen levels and food supply are adequate, a possible benefit for aquaculture, especially for intensive and semi-intensive pond systems. McCauley and Beitinger (1992) predict that for every 1 ºC rise in temperature, the optimum range for the culture of channel catfish (*Ictalurus punctatus*) will shift approximately 240 km north. A simple linear growth model of roho labeo (*Labeo rohita*) fingerlings provides a reliable projection of growth with unit rise of temperature within the range of 29 to 34 °C. In fish farm hatcheries on the gangetic plains in West Bengal, a positive impact on breeding was observed in the advancement and extension of the breeding period of Indian major carps by 45–60 days. Almost all fishers and operators of fish hatcheries indicated that rise in temperature is the main reason for advancement of the breeding season of Indian major carps, along with the increasing demand and high price of seed early in the season.

Extreme climatic events

Cyclones and floods can cause damage to infrastructure, inundation of ponds and loss of stock (Ponniah and Muralidhar, 2009; Muralidhar *et al.,* 2009). Changes in salinity of pond water would result in yield reduction and the introduction of disease or predators into aquaculture facilities along with the flooded water, resulting in crop losses and impacts on wild fish recruitment and stocks in the waterbodies. Drought also had a great impact on aquaculture, and rise in salinity in the waterways will leads to drop in the culture area. Since climate change is expected to affect the availability of freshwater and the flow in rivers, it is essential to forecast the water availability for aquaculture. The potential increase in flood frequency, intensity and duration may have negative consequences for aquaculture in terms of loss of stock and damage to aquaculture facilities (Handisyde *et al*., 2006).

Sea level rise

Sea level rise (SLR) leads to loss of land due to inundation and would lead to reduced area available for aquaculture, loss of freshwater fisheries and aquaculture due to reduced freshwater availability, changes in estuary systems and shifts in species abundance and the distribution and composition of fish stocks and aquaculture seed. Seawater intrusion into freshwater aquifers is an increasing problem with rising sea level (Moore, 1999). Higher sea levels may make groundwater more saline, harming freshwater fisheries, freshwater aquaculture and agriculture, and causing loss of coastal ecosystems such as mangroves and salt marshes, which are essential to maintaining wild fish stocks as well as supplying seed to aquaculture.

Aquaculture diversification due to a shift to brackishwater species resulting from reduced freshwater availability is a possibility. Increased areas might be suitable for the brackishwater culture of high-value species such as shrimp and mud crab. About 829 ha of seawater inundated areas in the Andaman and Nicobar Islands are suitable for brackishwater aquaculture after the 2004 tsunami (Pillai and Muralidhar, 2006). Increase in inland salinization in Bangladesh may have serious impacts on agriculture, with a 0.5 million tonne reduction in rice production predicted in association with a 0.3 m sea level rise. It is possible that culture of brackishwater species in these affected areas may be able to provide alternative sources of income and nutrition. A one meter sea level rise in the Mekong Delta is predicted to inundate 15 000 to 20 000 km^2, with a loss of 76 percent of arable land. Sea level rise and reduced river flows are causing increased saltwater intrusion in the Mekong Delta, threatening the viability of catfish aquaculture. Such culture areas must be shifted further upstream to mitigate climatic change effects. On the other hand, climate impacts could make extra pond space available for shrimp farming (De Silva and Soto, 2009). It is predicted that the future sea level rise along the 1 030 km long Andhra Pradesh coast in India will place the 43 percent (442.4 km) of coastal area that is very low-lying under very high risk. If the sea level rises by 0.59 m as predicted by

IPCC (2007), an area of about 565 km^2 would be submerged under the new low-tide level along the entire Andhra Pradesh coast, of which 150 km^2 would be in the Krishna-Godavari delta region alone, affecting the livelihoods of hut-dwelling fishing communities and small-scale aquaculturists (Nageswara Rao *et al.,* 2008).

Oceanographic variables

Aquaculture depends heavily on capture fisheries for fishmeal and in certain areas, for seed and hence, there is an urgent need to find plant protein-based alternatives to fishmeal and to domesticate species for which there is still a dependence on wild broodstock. Climate change could have dramatic impacts on fish production which would affect the supply of fishmeal and fish oil. Tacon, Hasan and Subasinghe (2006) estimated that in 2003, the aquaculture sector consumed 2.94 million tonnes of fishmeal globally (53.2 percent of global fishmeal production), considered to be equivalent to the consumption of 14.95 to 18.69 million tonnes of forage fish/trash fish/low-value fish, primarily small pelagics. The potential for adverse impacts of climate change on global fishmeal production is well illustrated by periodic shortages associated with climate fluctuations such as El Niño. Expansion of aquaculture industries is placing increasing demand on global supplies of wild-harvest fishmeal to provide protein and oil ingredients for aqua-feeds. About 30 percent (29.5 million tonnes) of the world fish catch is used for non-human consumption, including the production of fishmeal and fish oil that is employed in agriculture, in aquaculture and for industrial purposes. Depending on the species being cultured, they may constitute more than 50 percent of the feed.

Building climate-resilient aquaculture

Climate change is likely to be a powerful driver of change, and it has to be accepted that humans cannot control ecosystems and that social-ecological stability is the exception rather than the norm. To cope with climate change that is likely to be both rapid and unpredictable, aquaculture systems must be resilient and able to adapt to change. Resilient aquaculture systems are those that are more likely to maintain economic, ecological and social benefits in the face of dramatic exogenous changes such as climate change and price swings. Resilience requires genetic and species diversity, low stress from other factors, and “healthy” and productive populations. Effective ecosystem approach to aquaculture (EAA) should lead to resilient social-ecological systems. In the face of uncertainty, aquaculture food production systems should be established which are diverse and relatively flexible, with integration and coordination of livestock and crop production.

Aquaculture is the best adaptation of fisheries to climate change, due to its ability to respond to demand, improve efficiency of resource use and overcome disease shocks. Improving efficiency of resource use is mainly through improved feeding technology, diet formulation, conversion and integration on a global scale, and zero exchange systems, recirculation systems, integration with irrigation and intensification (e.g. striped catfish, *Pangasianodon hypophthalmus*, production of up to 300 tonnes/ha in Viet Nam). Aquaculture's ability to respond to disease shocks is through better site selection and vaccines in salmon, use of low and zero water exchange systems, the selective breeding of disease-free and disease resistant stocks in shrimp, and the introduction of new species in oysters.

Farming systems and diversification in fresh and brackishwater

Increasing investment in aquaculture and aquatic ecosystems is an investment in the "liquid assets" of adaptation. Aquatic ecosystems play a crucial role in buffering and distributing climatic shocks, whether from storms, floods, coastal erosion or drought. Aquaculture provides opportunities to adapt to climate change by integrating aquaculture and agriculture, which can help farmers cope with drought while increasing livelihood options and household nutrition. Water from aquaculture ponds can help sustain crops during periods of drought while at the same time, the nutrient-rich waters can increase productivity. Farmers can use saline areas no longer suitable for crops (expected to increase due to sea level rise) to cultivate fish. The impacts on small-scale farmers and commercial-scale large farmers may be different. For example, for small-scale farmers, providing food and/or income at the household or community level may be seriously affected by an extreme event such as a flood, which may result in an immediate reduction in the availability of food and money. Small-scale farmers may not have sufficient financial resources to overcome these situations.

The integration of aquaculture, fisheries, agriculture and other productive or ecosystem management activities has an integral role to play in the future of the aquaculture industry. The techniques include ranching, integrated agriculture-aquaculture (IAA), integrated multitrophic aquaculture (IMTA) and links with renewable energy projects. Integration is a key element of the ecosystem approach to aquaculture (EAA), which "is a strategy for the integration of the activity within the wider ecosystem in such a way that it promotes sustainable development, equity, and resilience of interlinked social and ecological systems" (Soto *et al*., 2008). Trends include the expansion of the farming of low-trophic-level fish, the culture of more efficient shrimp species (i.e. *Litopenaeus vannamei* vs *Penaeus monodon*), more efficient feed conversion, lower protein and fishmeal content in diet, use of zero water exchange systems, closed breeding cycles, domesticated specific pathogen free (SPF) and specific pathogen resistant (SPR) stocks, and the more efficient use of fishmeal and fish oil inputs.

Improved planning and management of current aquaculture areas will be achieved through enforcement of aquaculture waste-treatment regulations, the introduction of aquaculture species adapted to high temperatures and changed salinities, the promotion of polyculture and fish-rice rotation in relevant areas, and the use of integrated water management for rice agriculture and brackishwater aquaculture. Assessment of new species and the tools and techniques needed by fishers to adapt to changed aquatic habitats due to increases and fluctuations in salinity levels in estuaries will be needed. IMTA, a practice in which the by-products (wastes) from one species are recycled to become inputs (fertilizers, food) for another, will be increasingly implemented.

Water management

Although global trade and technological innovation are key drivers in providing stable and resilient global systems, the most destabilizing global water-related threat is increasing food prices and hunger. Water is becoming increasingly scarce in some parts of the world. Most of the freshwater used by humans goes to irrigation. There will be increasing pressure to use that water for human and industrial uses. Moreover, some groundwater aquifers are being overdrawn, calling into question the long-term sustainability of current levels of irrigation. Water scarcity may thus either restrict production or increase its cost. Aquaculture will have to compete with agriculture as well as industrial and domestic users for a limited water supply which may often be supporting a growing population. The relative value of aquaculture products in relation to non-fish alternatives will be significant, as well as the productivity of capture fisheries (Brugère and Ridler, 2004). Water stress due to decreased precipitation and/or increased evaporation may limit aquaculture in some areas. This may take the form of increased risks associated with a reduced water supply on a continual basis, or by reducing the length of a routine growing season. Increased variation in precipitation patterns and droughts may increase the risk and costs of aquaculture in some areas as provision for these extremes has to be made.

Low external input sustainable aquaculture – organic farming

Organic aquaculture has attracted the attention of consumers, environmental advocates and entrepreneurial innovators. It reduces overall exposure to toxic chemicals from pesticides that can accumulate in the ground, air, water and food supply, thereby lessening health risks for consumers. Some of its other merits include curbing top soil erosion, improving soil fertility, protecting groundwater and saving energy. Moreover, organic standards prohibit the use of genetic engineering in production, which again reassures consumers. The growing interest in organic aquaculture has prompted governments to regulate the sector. Standards and certification procedures are being developed and tested. They are the necessary tools to promote investment. In the absence of international standards, interested parties are developing their own specific organic aquaculture standards and accreditation bodies. These standards often vary significantly from place to place, certifier to certifier, and species to species.

Ecosystem approach to aquaculture

The ecosystem approach to aquaculture (EAA) is the mechanism to attain sustainable development in aquaculture through stressing holistic, integrated and participatory processes. None of the principles that underlie the EAA are new; they can all be traced in earlier instruments, agreements and declarations. The EAA pulls them together formally as tools for the effective implementation of the *Code of Conduct for Responsible Fisheries* (FAO, 1995). The basic objectives of EAA are maintaining ecosystem integrity/ecological well-being, improving human well-being and equity promoting and enabling good governance. In practice, the key features of EAA are applying precautionary approaches, using best available knowledge, acknowledging the multiple objectives and values of ecosystem services, embracing adaptive management, broadening stakeholder participation, understanding and using a full suite of management measures, and promoting sectoral integration.

EAA addresses adaptation through creating resilient communities (ecosystem, human, governance), decreasing vulnerability (impacts, adaptive capacity, sensitivity), enhancing intersectoral collaboration (e.g. integrating fisheries into national adaptation and disaster risk management (DRM) strategies), promoting context-specific and community-based adaptation strategies, allowing for quick adaptation to change, and promoting natural barriers and defences. It addresses mitigation (increased sequestration and decreased emissions) through understanding the role of aquatic systems as natural carbon sinks, supporting a move to environmentally friendly and fuel-efficient fishing practices (harvest and post-harvest) and governance/responsible practices, eliminating subsidies that promote overfishing and excess capacity. Mitigation and adaptation together are addressed through safeguarding the aquatic environment and its resources against adverse impacts of mitigation strategies and measures from other sectors, avoiding maladaptation and benefiting from win-win synergies.

Breeding for climate change

Taking advantage of their short generation time and high fecundity, it would be possible to selectively breed fishes to tolerate the higher temperature, salinity and increased diseases that are likely to impact aquaculture due to climate change. Despite significant increase in a wide range of physiological information available on the link between environmental stress and some indicators of host response, the influence of different abiotic stressors on gene expression has been understudied. The research should focus on the evolution of physiological and genetic adaptations to osmotic and thermal stress in aquatic animals. Biologists typically work on one trait at a time (e.g. aspects of drought tolerance). With simultaneous changes in temperature, precipitation and pathogen dynamics, the breeding challenge will be enormous. The molecular and mechanistic basis of the osmotic stress response and how it relates to other environmental stress responses have to be understood. Drought, thermal and salinity tolerance, and resistance to disease are traits that need to be engineered into aquatic species for climate change adaptations.

Selection for species with effective thermoregulatory control will be needed. Integrated research will be needed in the broader field of species improvement and in assessments of the production chain from geneticists to consumers. Breeding technologies have been successful in developing hormonal sex-reversal in tilapia, genetically male tilapia, hormone induced spawning in *Pangasianodon,* triploid oysters and selective breeding for disease resistance. Genetic engineering was developed to develop genetically modified (GM) feed ingredients (e.g. soya, rapeseed (canola) oil), and aquaculture species (e.g. salmon, tilapia).

Mangroves – bioshield against sea level rise

Nature has provided biological mechanisms for protecting coastal communities from the fury of cyclones, coastal storms, tidal waves and tsunamis. Mangrove forests constitute one such mechanism for safeguarding concurrently the ecological security of the coastal areas and the livelihood security of fisher and farm families living in the coastal zone. Mangrove forest establishes in coastal areas where river water mixes with seawater. These areas are called estuarine or brackishwater coastal zone environments. Mangrove forests located in the estuarine environment are intersected by a number of small creeks and channels and in many cases, large open waterbodies are also found associated with them. Mangrove forests and associated tidal creeks, channels and lagoons together constitute mangrove wetlands. These mangrove wetlands mitigate the adverse impact of storms, cyclones and tsunamis in coastal areas; reduce coastal erosion and on the other hand, provide gains to land by accreting sea and adjacent coastal waterbodies. They also function as breeding, nursery and feeding grounds for many commercially important crustaceans, fish and molluscs and enhance the fishery potential of adjacent coastal waters by providing them with large quantities of organic and inorganic nutrients. The 26 December 2004 tsunami has created a widespread interest in the restoration of degraded mangrove forests, the promotion of joint mangrove management systems involving local communities, and the raising of bio-shields and shelterbelts along the coastal zone.

Planned adaptation measures – early warning systems and others

In the context of climate change, the primary challenge to the fisheries and aquaculture sector will be to ensure food supply, enhance nutritional security, improve livelihoods and economic output, and ensure ecosystem safety. These objectives call for identifying and addressing the concerns arising out of climate change, evolving adaptive mechanisms and implementing actions across all stakeholders at the national, regional and international levels. Adapting to climate change involves reducing exposure and sensitivity and increasing adaptive capacity. Projections on climate change impact on aquaculture need to be developed as the first step for future analytical and empirical models, and for planning better management adaptations. Governments should consider establishing weather watch groups and decision support systems on a regional basis. Specific policy documents with reference to the implications of climate change for aquaculture need to be developed. These documents should take into account all relevant social, economic and environmental policies and actions, including education, training and public awareness related to climate change. Effort is also required in respect of raising awareness of the impacts, vulnerability, adaptations and mitigation related to climate change among the decision-makers, managers, aquaculturists and other stakeholders in the aquaculture sector (Muralidhar *et al.,* 2010). It is necessary to increase awareness on the potential to develop adaptive livelihoods, improve governance and build institutions that can help people and integrate aquaculture into overall climate change and rural development policies.

Trends in fish culture in a warming planet may affect the nutrition and livelihood security of the poor. Poor people are vulnerable to many events and factors that create poverty, wherein it is very difficult to improve livelihoods. They are generally hardly aware of adaptive strategies and potential solutions in these situations. Strategies to promote sustainability and improve supplies should be in place before the threat of climate change assumes greater proportion. While the aquaculture sector contributes little to greenhouse gas emission, it could contribute to reducing the impacts by following effective adaptation measures. Mitigation strategies should primarily address global energy policy. Investigation into whether there is potential for low-cost, effective sequestration of GHGs by aquacultural systems should be supported. Much further research is needed to better understand the complex impacts of climate change on aquaculture and to devise coping strategies. Fisheries and aquaculture make a minor but significant contribution to greenhouse gas emissions during fishing operations and the transport, processing and storage of fish; compared to actual fishing operations, the emissions per kilogram of postharvest aquatic product transported by air are quite high. Intercontinental airfreight emits 8.5 kg of CO_2 per kilogram of fish transported. This is about 3.5 times that for sea freight and more than 90 times that from local transportation of fish where it is consumed within 400 km of capture.

Conclusions

Action is urgently needed to mitigate the factors driving climate change, as well as to adopt adaptive measures aimed at countering the threats to food and livelihood provision. In addition to laws, regulations and voluntary codes of practice that aim to ensure environmental integrity, some of the means of achieving the environmental and social responsibility goals include innovative, less-polluting production techniques such as those based on the EAA. In this regard, tools and indicators have to be developed for the purpose of assessing and monitoring not only the impacts of aquaculture on the environment, but also the impacts of the environment on aquaculture and site selection. In terms of improving social responsibility, governments are defining minimum wages, improved labour conditions, worker welfare systems, etc. which are being embraced by many lobbyists. Certification systems for aquaculture practices and products are beginning to include standards for monitoring social responsibility and equity. If we practice “green aquaculture”, we can achieve the goal of “fish for all and forever”.

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