Chapter 15
Combating Climate Change Impacts for Shrimp Aquaculture Through Adaptations: Sri Lankan Perspective

J. M. P. K. Jayasinghe, D. G. N. D. Gamage, and J. M. H. A. Jayasinghe

Abstract Fisheries and aquaculture have been identified as important sources of food, nutrition, income and livelihoods for hundreds of millions of people around the world. World per capita fish supply has reached 20 kg in 2014. Aquaculture is one of the main contributors that provide a considerable percentage of fish for human consumption. By 2014, fish accounted for about 17% of the global population's intake of animal protein and 6.7% of all protein consumed. In addition, fish provided more than 3.1 billion people with almost 20% of their average per capita intake of animal protein. Global total capture fishery production in 2014 was 93.4 million metric tons (MT) while aquaculture production is estimated at 73.8 million MT, with a projected first-sale value of US$160.2 billion.

Global shrimp aquaculture production has reached 4.58 MMT in 2014 and may remain at the same level in near future. Shrimp culture makes vital contributions to national and global economies, poverty reduction and food security for the world's well-being and prosperity. Asia has always led the world production of cultivated shrimps. Expected changes in climate, extreme weather conditions and climatic events, sea level rise, ocean acidification and rise in temperature are expected to create significant impacts on coastal ecosystems and aquaculture in coastal areas. Adaptations for likely impacts of climate change are reachable through better management practices in site selection, pond construction and preparation, selection of post larvae for stocking, pond management, bottom sediment management and disease management together with reducing non-climate stressors such as pollution, conservation of sensitive ecosystems and adoption of dynamic management policies.

Keywords Shrimp aquaculture · Climate change adaptations · Better management practices · Food and nutritional security · Disease

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15.1 Aquaculture and Fisheries

Global total capture fishery production in 2014 has been estimated at 93.4 million MT (Fig. 15.1), with a contribution of 81.5 million MT from marine waters and 11.9 million MT from inland waters. There is an increase in the global supply of fish for human consumption irrespective of population growth during past five decades, increasing at an average annual rate of 3.2% during the period 1961–2013, resulting in increased per capita availability (FAO 2016). According to FAO 2016, world per capita fish consumption increased from an average of 9.9 kg in the 1960s to 14.4 kg in the 1990s and to 19.7 kg in 2013, and is targeted to increase beyond 20 kg in the future. Increase in production together with reduction in postharvest loses, efficient fish distribution chains, and growing demand linked to population growth, rising incomes and urbanization, value addition, product development have contributed for the increased per capita consumption of fish and fishery products.

FAO (2016) has compiled the information available on present status of World Fisheries and Aquaculture. Aquaculture is the culture of aquatic animals and plants in a controlled aquatic environment, mainly for consumption. Exploiting the fish from natural water bodies is referred to as capture fisheries. According to them around 56.6 million people were engaged in the primary sector of capture fisheries and aquaculture in 2014, out of whom 36% were full-time fishermen, 23% part time, and the rest were mainly occasional fishers.

In 2014, total aquaculture production was 73.8 million MT (Fig. 15.1—World capture fisheries and aquaculture production), with an estimated first-sale value of US$160.2 billion and included 49.8 million MT of finfish (US$99.2 billion), 16.1 million MT of molluscs (US$19 billion), 6.9 million MT of crustaceans (US$36.2 billion) and 7.3 million MT of other aquatic animals worth of US$3.7 billion

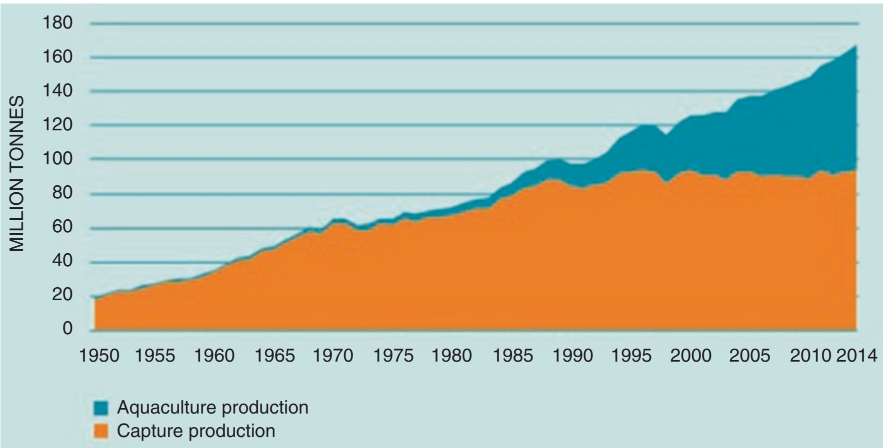

Fig. 15.1 Jayasinghe—World capture fisheries and aquaculture production (World Capture Fisheries and Aquaculture Production (FAO 2016)

(FAO 2016). Total aquaculture production contributes directly or in value added forms mainly for human consumption. Aquaculture has contributed 44.1% to the total production in 2014. All continents have shown the same general trend of an increasing share of aquaculture production to total fish production, except in Oceania.

15.2 Shrimp Aquaculture

15.2.1 Significance of Shrimp Aquaculture

According to (FAO/NACA 2001) Shrimp aquaculture has been identified as an industry that contributes significantly to national and global economies, poverty reduction and food security. Marine shrimp farming is a traditional aquaculture activity in many Asian counties. Extreme success of this aquaculture activity in Asia was mainly due to availability of coastal lands suitable for establishment of farms, successes in hatchery technology, and technological advances in the culture technology.

Traditional shrimp culture in South East Asia practices extensive type of culture in relatively large earthen ponds in low stocking densities using post larvae collected from wild. They mainly depended on natural productivity, tidal movements for water exchange and ponds were without mechanical aeration. Monoculture or polyculture with fish species was practised depending on the availability of fish fry in some countries.

Intensive shrimp farming became a reality with the success in hatchery technology where larval life cycles of shrimps were completed in hatcheries making available post larvae for stocking in ponds. Shrimp farming at commercial level got established during late 1960s and early 1970s. Technological advances and high profitability led to semi-intensive and supra-intensive forms of farming, and worldwide distribution of farms. Taiwan was one of the pioneering countries which became a leading producer in the 1980s and was then producing 21% of Asia's cultured shrimps, the highest output for the region. Taiwan market collapsed in 1988 due to unsustainable farming practices leading to frequent disease outbreaks and environmental problems. Later Thailand became the leading producer in black tiger shrimp. Ecuador and Brazil are the pioneers in shrimp farming in South America. At present, shrimp farms are distributed in over fifty countries including Middle East.

15.2.2 Farmed Shrimp Species

Out of the many species of shrimps, desirable characteristics for farming have been identified in a few species. Relatively larger size, established hatchery technology, disease resistance, adoptability to pond environment and climate, availability of market, relatively higher growth rate are some of the main criteria used in selecting shrimps for culture operations.

Pacific white shrimp (*Litopenaeus vannamei*, “white shrimp”) native to the Pacific coast grows to a size of 23 cm. and accounts for 95% of the production in Latin America. It is easy to breed in captivity; this species has been now introduced to several Asian countries due to its resistance to white spot disease. But this species is susceptible to Taura syndrome virus (TSV). *Penaeus monodon,* (“black tiger shrimp”) is a native to the Indian Ocean and to the Pacific Ocean. It can grow to a larger size and is widely farmed in Asia. Due to high susceptibility to white spot disease, it is gradually being replaced by *L. vannamei*. Western blue shrimp (*Penaeus stylirostris*) is farmed in the western hemisphere. Chinese white shrimp (*Penaeus chinensis*), occurs along the coast of China and the western coast of Korea and is farmed in China. Kuruma shrimp (*Penaeus japonicus*) is farmed mainly in Japan and Taiwan. Indian white shrimp (*Penaeus indicus*) is a native of the coasts of the Indian Ocean and is widely bred in India, Iran and Middle East and along the African shores. Banana shrimp (*Penaeus merguiensis*) is another cultured species from the coastal waters of the Indian Ocean.

15.2.3 Farmed Shrimp Production and Trends

Shrimp aquaculture, which only began to make significant contributions to global shrimp production in the 1980s, overtook wild harvest in 2007 and has continued to claim a growing share of the market in each subsequent year. As of 2014, farmed shrimp production amounted to 4.18 MMT. Global Aquaculture Alliance’s (GOAL) 2016 survey of production trends in shrimp farming in main shrimp farming countries is presented in Fig. 15.2 (Shrimp aquaculture production and trends in major

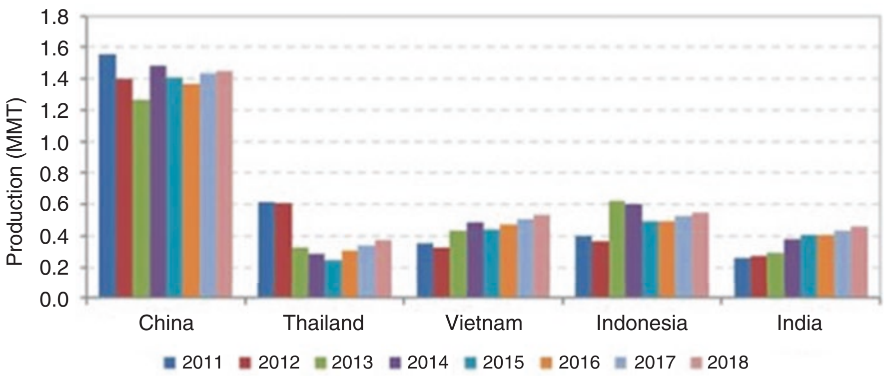

Fig. 15.2 Jayasinghe—Shrimp aquaculture production and trends in major farming nations in Asia (Shrimp aquaculture production and trends in major farming nations in Asia) (GOAL Shrimp Survey 2016)

farming nations in Asia). A general trend can be observed to increase the total production in year 2017 and 2018 in most of the main shrimp farming nations. Global production is expected to reach around 4.44 MMT in 2018. The Asian shrimp culture industry appears to be on the path of recovery after a substantial production drop in 2012 and 2013 in countries such as China and Thailand, caused by Early Mortality Syndrome (EMS). Contribution from Asia may reach 3.65 MMT by 2018, due to the expected increased inputs from Thailand, Indonesia, Vietnam and India. According to GOAL, 2016, China is expected to continue to remain as the leading producer.

15.2.3.1 Shrimp Aquaculture Industry in Sri Lanka

The fisheries industry including aquaculture plays an important role in the economy of Sri Lanka by providing livelihoods for around 2.6 million individuals including direct employment opportunities for 560,000 individuals. Others are involved in marketing, product development, value addition, processing for export, fish feed manufacturing, employment in fishery harbors and employment as technicians and laborers in fish farms and hatcheries. Generation of income, foreign exchange earnings and provision of reasonably priced protein for the rural and the urban masses in the country are other contributions. The industry contributes around 2% to the gross domestic production (GDP). The fisheries sector in Sri Lanka consists of coastal fisheries, offshore fisheries, and inland and coastal aquaculture. Coastal aquaculture has a great potential to diversify, secure income and food security among coastal communities in Sri Lanka. Shrimp farming industry provides the greatest contribution to the coastal aquaculture. The potential for this industry to provide a large number of jobs and export income makes its development very attractive to the Government of Sri Lanka. Figure 15.3 shows shrimp farming districts in Sri Lanka (Batticaloa and Puttalam).

Shrimp farming in Sri Lanka is presently restricted to North Western Province and Eastern Province. According to recent surveys; the total number of farms is around 950 with an estimated area of about 4500 ha. Sri Lanka produces 7000 MT of farmed shrimp annually and 30–40% of the production is exported. Nearly 2000 MT shrimps of shrimps including wild-captured are consumed locally. Penaeus monodon is the main species cultured. The majority of grow out shrimp farms in Sri Lanka follow semi-intensive culture practice. Farmed shrimp exports account for approximately 50% of the total export earnings from Sri Lankan fisheries sector.

15.3 Food and Nutritional Security and Aquaculture

Aquaculture has been identified as the fastest growing food production sector in the world. An increasing trend has been observed for aquaculture indicating a 12-fold increase during the last few decades. Industry has recorded average annual growth

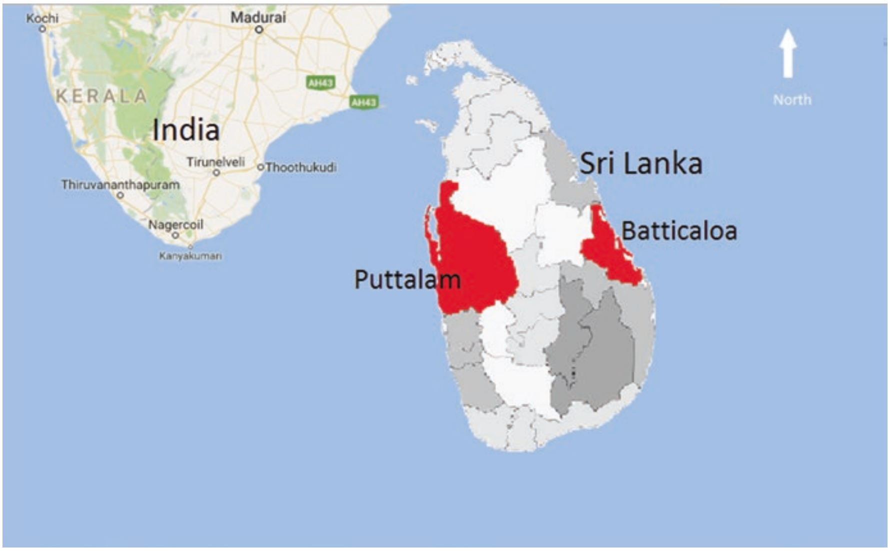

Fig. 15.3 Jayasinghe—Shrimp farming districts in Sri Lanka (Batticaloa and Puttalam)

of around 8% in recent past. World Bank (2013) has estimated that the demand for farmed aquaculture products will exceed 93 MMT by 2030. The issue is therefore to increase production while minimizing external environmental impacts and continue to lowering natural resource footprints of aquaculture. The nutritional value and health benefits of aquaculture products, the importance of aquaculture activities as a source of income and livelihoods and the efficiency of aquaculture products to produce/transform proteins have been identified as main contributory factors for human nutrition and food security through aquaculture.

According to HLPE (High Level Panel of Experts on food security) 2014, Fish contributes to food security and nutrition directly through availability of nutrient-rich food both at the household and at local, provincial and national market levels (Fig. 15.4—Conceptual representation of the different pathways between fish and food security and nutrition). Indirect pathways involve the trade of fish and generation of revenues, at household level or at higher (national) levels, including through income for crew-members and for those involved in fishery related activities such as fish processing factory workers. Income allows access to other food commodities. In Sri Lanka high valued aquaculture products are exported but cheaper fishery products such as canned and dried fish are imported maintaining a positive trade balance.

15.3.1 Fish as a Critical Food Source

According to HLPE 2014, capture fisheries and aquaculture provide 3.0 billion people with almost 20% of their average per capita intake of animal protein, and a further 1.3 billion people with about 15% of their per capita intake. This share can

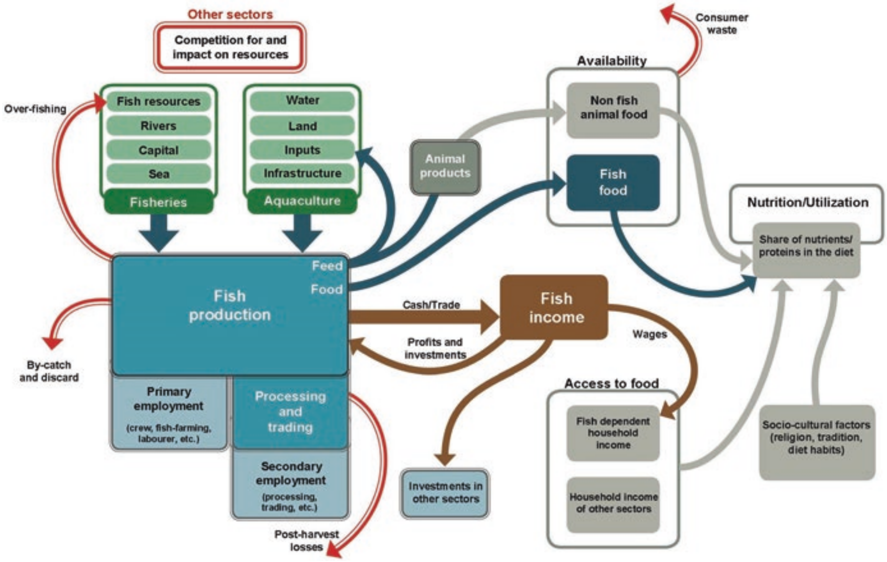

Fig. 15.4 Jayasinghe—Conceptual representation of the different pathways between fish and food security and nutrition (Different pathways by which fish contributes to food security and nutrition (HLPE 2014)

exceed 50% in some countries. In Sri Lanka 65% of the animal protein consumed comes from fish and fishery products. Fish provide a very significant proportion of protein in the human diet in most small island states like Maldives where 60% protein comes from fish. The continual growth in fish production, mostly from aquaculture since the 1990s has contributed significantly to increase the supply of fish during the last two decades.

Omega-3 (n-3) fatty acids are widely recognized as essential nutrients for the health and well-being of humans, particularly with respect to the n-3 long-chain polyunsaturated fatty acids (LC-PUFA), eicosapentaenoic (EPA; 20:5n-3) and docosahexaenoic (DHA; 22:6n-3) acids, that exert a range of health benefits through their molecular, cellular and physiological actions. Fish has been identified as a major dietary source of n-3 LC-PUFA for human. Recommended daily intake levels of EPA and DHA vary regionally, based on the scientific and health advisory information available. However there is a general agreement that population should consume at least two portions of fish per week, one of which should be oily. With the global population increase, decline in natural fishery resource and the population’s demand for fish and fishery products, fatty acid requirement has to come from aquaculture. Fish is also an important provider of a range of micronutrients not widely available from other sources in the diets of the poor. More and more attention is being given to fish products as a source of vitamins and minerals which can be an excellent source of many essential minerals such as iodine, selenium, zinc, iron, calcium, phosphorus and potassium, but also vitamins such as A and D, and several vitamins from the B-group.

15.3.2 Relative Resource Efficiency of Aquaculture Production Systems

Aquaculture systems have been identified as efficient converters of feed into protein when compared to other animal husbandry systems such as poultry, piggery and cattle farming. It has been estimated that poultry converts about 18% of the food consumed and pigs about 13% as compared with 30% in the case of fish (Hasan and Halwart 2009).

HLPE (2014) indicates that the production of 1 kg of beef protein requires 61.1 kg of grain while 1 kg of pork protein requires 38 kg as compared with 13.5 kg in the case of fish.

Generally the species used in aquaculture are poikilothermic animals where their body temperature fluctuates with the environmental temperature and no energy is required to maintain a constant body temperature using energy as in the case of terrestrial farmed animals used in animal husbandry. For aquatic vertebrate animals the aquatic media they live in provide the physical support and they need only minimal skeletal support that they need not allocate large proportion of the food they eat to maintain the body.

Aquaculture production systems have a lower carbon footprint per kilogram of output when compared with terrestrial animal production systems. Nitrogen and phosphorous emissions from aquaculture production systems are much lower when compared with beef and pork production systems. It is an advantage that some of the aquaculture production systems such as bivalves can absorb nitrogen and phosphorous emissions from other systems (HLPE 2014). According to FAO 2016, climate change will affect food security in Asia by the middle of the twenty-first century. South Asia appears to be most severely affected.

15.3.3 Classification of Shrimp Aquaculture Systems

Shrimp culture systems are classified into three, namely, extensive, semi-intensive and intensive. The classification is based mainly on pond facilities, stocking density, food supply, water management, yield, technical know-how and skills of the farmer and other major inputs. While semi-intensive and intensive farming have gained some progress in recent years, the extensive system still remains the major practice possibly because of the relatively large landholdings (50–300 ha) per farmer. In order to shift to the semi-intensive or intensive system, farmers require greater amount of inputs, high-level technical know-how, and supervision (Apud 1985).

When considering water management, closed, open, semi-closed and complete recirculation are the available options. In open system water is extracted from the water source and effluents are discharged to the water source without treatment.

Most of the small-scale farmers adopt this system as they do not have enough farm area to treat water. In the semi-closed option incoming water to the farm is treated using a reservoir but effluents are discharged without treatment to the water source. Complete recirculation is the most sustainable option where water is completely circulated within the system. Physical, chemical and biological treatments are used to improve the water quality. The pressure on water source is minimal and risks of disease outbreaks are minimal. Most of the small-scale farmers adopt the closed system. They chemically treat the water in the culture pond itself before stocking. The culture period is less and the water quality is managed within the pond using probiotics. The size at harvest and period of culture are relatively low in this option.

15.4 Climate Change Impacts on Aquaculture

Several climate change impacts on shrimp culture have been identified in India (Muralidhar et al. 2010a, b). Those can be generalized to the region. Farmers have prioritized those impacts in the order of seasonal changes in weather, heavy rains, floods and cyclone in shrimp farming area and high temperature, floods, low/unseasonal rainfall, and rise in water level in coastal shrimp farming areas. These are the most felt effects by farmers. The seasonal changes considered were mainly temperature variations and delay in monsoon.

15.4.1 Expected Changes in Climate of Sri Lanka and Impacts on Shrimp Culture in Sri Lanka

15.4.1.1 Climate of Sri Lanka

Sri Lanka is an island in the Indian Ocean and located in southeast of India, between 5°55′ and 9°51′ N latitude, and 79°41′ and 81°53′ E longitude. There are three climatic zones, namely wet zone, dry zone and the intermediate zone. There are two seasonal wind regimes. South-west monsoon prevails from May to September and the north-east monsoon from December to February. These wind regimes together with topography are responsible for distribution and amount of rainfall. In Sri Lanka, climate change has been identified to increase the frequency and intensity of natural disasters, floods, droughts and cyclones. Storm surges are predicted to become more frequent and to be more devastating. Alterations in monsoonal patterns, deviations and fluctuations in annual rainfall are also predicted. Greater spatial variation between wet and dry areas in rainfall is expected and it may result in wet areas becoming more wetter and dry areas becoming drier. These identified shifts are likely to adversely affect aquaculture.

15.4.2 *Effects of Climate Change on Shrimp Culture*

Change in global climate can create significant impacts in the oceans and on the coastal environment where coastal aquaculture activities are flourishing. Climate change may result in new hazards and increase the frequency and intensity of existing hazards. Various processes related to climate change can cause significant changes particularly with respect to salinity and temperatures in brackish water bodies influencing aquaculture production, quality of the product and health of the aquaculture organisms.

Different elements of climatic change, can cause identifiable effects in the shrimp farming environment leading to health problems, decrease in production and quality of the product, premature harvests and economic loss or complete crop failure. The stress generated through changes related to climate change leading to incidences of disease can be identified as a main problem.

15.4.2.1 Precipitation

Sri Lanka is hot and humid with significant variation in climate over time and space. This variation is reinforced by the country's topography, which creates its unique rainfall pattern. The precipitation patterns have changed over the time. Historically, decreasing trend for precipitation has been observed over the past 30–40 years, although it is not statistically significant. The number of rainy days has decreased. There is an increasing trend for the frequency of extreme rainfall events, which would lead to more floods. Modifications in seasonal pattern in precipitation, changes in the extent, extreme heavy rainfall, prolong droughts are the most significant key factors of climate change that can affect shrimp aquaculture in coastal areas. Most of the shrimp farms are situated in the dry zones of the countries. Changes in rainfall patterns and more prolonged droughts in the dry zone areas would allow to greater evaporation which would negatively impact the shrimp aquaculture (Muralidhar et al. 2010a, b). When considering the situation in Sri Lanka evaporation is normally high in shrimp farming belt resulting in high salinities.

Timely onset and delay in onset of monsoon causes an increase in salinity of water especially in area where tidal influence is low. Culture ponds are to be diluted to reduce the salinity to acceptable levels. Larger volumes of fresh water have to be sourced exploiting the ground water resource which leads to conflicts with other users of fresh water and the depletion of the ground water resource. Prolonged droughts may also lead to increase in salinity beyond the acceptable and optimal levels of the cultured shrimp (Muralidhar et al. 2010a, b; Jayasinghe and Wijesekara 2014). In contrast, increased rainfall can result in sudden drop in salinity and other associated water-quality problems like high turbidity and changes in dissolved oxygen and nutrient levels. In areas where acid sulphate soils are converted to shrimp farming, draining of acidic water into ponds with flood water will result in sudden lowering of pH. The stress generated can lead to conditions which cause disease and related poor production and mass mortality of the farm crop. In periods of low salinity, water exchange gets restricted, leading to accumulation of pollutants and accumulation of toxic metabolic end products in the pond environment. Physical damages to the farm infrastructure such as pond dikes and sluice gates due to flooding as a result of heavy rain are evident. Floods allow shrimps to escape from ponds, and floods also contaminate pond water with poor quality water and wild organisms (Abery et al. 2009). Mass mortalities in shrimps are recorded during floods due to rapid oxygen depletions and sudden lowering of pH (Jayasinghe and Wijesekara 2014).

The impacts are more severe for small-scale farmers as they have located their farms in floodplains and in lagoon reservations. Shortened growing season and premature harvests are other factors that affect farmers in general (Muralidhar et al. 2010a, b). In Sri Lanka there is a crop calendar developed based on resource availability where farmers of different zones are given different periods of the year for their farming practices (Jayasinghe and Wijesekara 2014). Expected changes and deviations in rainfall pattern and intensity can severely disturb the crop calendar as well as changes occurring in sedimentation and nutrition loading in the ponds that can stimulate toxic algal blooms which are a threat to shrimps.

15.4.2.2 Temperature

Increase in temperature has significant consequences on coastal, marine and inland fisheries as well as on aquaculture. Water and air temperatures are expected to rise. Increased water temperatures lead to other associated physical changes in pond environment, such as shifts in dissolved oxygen levels. These have been linked to more frequent algal blooms and increase in the intensity and frequency of disease outbreaks. Changes in temperature of only a few degrees have significant negative impacts on aquaculture, and only a few positive impacts. The farm performance of tropical and sub-tropical species such as *P. monodon and P. merguiensis* can be increased with increase in water temperature up to a certain extent (Muralidhar et al. 2010a, b). Rise in temperature is a threat to cold-water species such as *M. japonicus* (Jayasinghe 1991). But in Sri Lanka, *Penaeus monodon* is the main culture shrimp species. Increased water temperatures especially during the dry season lead to greater evaporation in culture pond. Resultant increases in pond salinity stress the shrimp resulting in less appetite, high concentrations of toxic gases and overgrowth of algae. Low dissolved oxygen, delay in molting, slow growth, introduction of new predators and pathogens are other associated problems (Abery et al. 2009, Jayasinghe and Wijesekara 2014). Metabolic rates of shrimps will increase with increase in environmental temperature and this may result in higher food conversion ratios (FCR) affecting farm performance and profits. Increase in water temperatures has been related to increases in the intensity and frequency of disease outbreaks in shrimp culture systems in several countries.

15.4.2.3 Extreme Weather Condition and Climatic Events

When considering intensity of the extreme natural disasters and frequency of occurrence has been increased in recent years. Sri Lanka being a small island in the Indian Ocean in the path of two monsoons is likely to be affected by weather related hazards. Floods are mostly due to monsoonal rains or effects of low pressure systems developed in and around the country and droughts are due to failure of monsoonal rain which are the most common hazards experienced in Sri Lanka (Ministry of Disaster Management 2014). The intensity and frequency of extreme climate events, mainly the floods and droughts have increased in recent years as a consequence of global warming leading to an increase in natural disasters. The country has already experienced 2 years of serious drought and one major flood event within the first 5 years of the twenty-first century (Imbulana et al. 2006). The natural hazards such as droughts, floods, landslides, cyclones, and coastal erosion currently cause significant damage in Sri Lanka.

15.4.2.4 Cyclones

Since Sri Lanka is located outside the cyclone belt, severity of cyclone is lower in the Island when compared to Indian subcontinent. However, Sri Lanka has been influenced by cyclones occurring in the Bay of Bengal (Sri Lanka Disaster Knowledge Network 2009). It has been observed that intensity and severity of cyclones have been increased during the past few decades. But this situation may change in the future with climate change. Impacts of cyclones are mainly related to damages associated with infrastructure such as electricity lines, roads and farm buildings. Biological hazards of cyclones include contaminations across the ponds and spread of diseases.

15.4.2.5 Droughts

Dry and intermediate zones are vulnerable to droughts from February to April. Droughts occur in the south-eastern, north central and north-western areas of Sri Lanka due to low rainfall during monsoons. However if there is a substantial drought in the normal rainy season from May to June, it can extend into September. According to Global Facility for Disaster Reduction and Recovery (GFDRR) annual report for year 2011, in the past 30 years droughts have affected more than six million people (GFDRR 2011). Puttalam is the most vulnerable district to drought with respect to aquaculture. Frequency and intensity of droughts have resulted in reduction in the culture area due to the rise in salinity as well as lack of freshwater. Salinity can increase beyond the optimum level which is considered 10–25 ppt for black tiger shrimp within few days due to evaporation. It leads to poor survival and growth of shrimps as salinity plays an important role in the growth of culture organisms through osmoregulation of body minerals from that of the surrounding water.

However black tiger shrimp can tolerate a wide range of salinity. But optimum range is required for better survival and growth.

15.4.2.6 Floods

Climate risk and adaptation country profile study conducted by GFDRR 2011, has mentioned that floods are increasing from 1974 to 2004 and that floods have affected more than ten million people in the last 30 years. Floods are associated with extreme rainfall conditions. The south-west monsoons and the north-east monsoons cause flooding in different parts of the country. The main shrimp farming area, the Puttalam District is vulnerable to flooding. Floods have a higher frequency of occurrence in Sri Lanka than other natural disasters. However flood intensity and occurrence had been low in Puttalam District before shrimp farming was initiated. Construction of farms in floodplains and lagoon reservations has obstructed the receding floods and floods are more frequent now in this district. Flooding can affect inland aquaculture and capture fishery due to pollution, sedimentation and any adverse changes in water quality parameters of surface water bodies that sustain this fishery (Abery et al. 2009). Further it causes sudden reduction in salinity which reduces production in shrimp culture systems. Concentration of the metabolic end products increases within the ponds due to inability of farmers to exchange water from the lagoons and estuaries. Increasing flooding can cause inundation of the farms, erosion of bunds, and damage infrastructure facilities such as buildings, electrical installations, sluices, shutters and screens resulting in loss of crop and introduction of predators and pathogen (Muralidhar et al. 2010a, b). Sudden fall in pH has been recorded in water in coastal areas due to oxidation of pyrites in coastal sediments during heavy floods after prolonged dry spells (Jayasinghe 1991).

15.4.2.7 Sea Level Rises (SLR)

Sri Lanka is expected to be affected by global warming associated SLR. The increasing concentration of GHG is a key contributor to increasing atmospheric temperature leading to rise in sea level. In addition the thermal expansion of oceanic waters with increasing temperature, changing precipitation, melting of snow/ice and other factors contribute to partial inundation. SLR is one of the indicating factors of global warming. Geological subsidence, sedimentation are also important contributors to SLR. Global SLR is reported to be around 1.7 ± 0.5 mm per year from 1901 to 2010 during which sea level has increased by around 19 cm. In the case of Sri Lanka, SLR is estimated at 0.3 m by 2010 and 1.0 m by 2070. It is slightly higher than the global average predicted for SLR.

Coastal regions of Sri Lanka play a vital role in the economic growth of the country. SLR is a major challenge in the administration and management of coastal zones. Higher sea levels lead to inundation of coastal ecosystems such as mangroves and salt marshes, which play a major role in ecological functions. The goods and services provided by these ecosystems are essential to the sustainability of coastal aquaculture. Loss of land and availability of freshwater are other concerns. Water quality in the lagoons and estuaries is subjected to change due to increased salt water input and alterations in present water quality management practices are needed. A recent study conducted on hazard profile of Sri Lanka with sea level rise has identified that Puttalam District has the highest impact of sea level rise as it is located in lower elevation. Further the study reveals that the total available brackish water area by the year 2100 is estimated at 14800 ha in Puttalam and 2700 ha in Batticaloa due to the inundation as a result of sea level rise.

15.4.3 Health and Climate Change

Diseases are the most feared threat, or one of the most feared threats to shrimp farming. Major viral, bacterial, fungal and other diseases recorded in shrimp culture systems are listed in Table 15.1. White spot disease in Indo-Pacific region, Taura syndrome virus (TSV) in South America and early mortality syndrome (EMS) have been identified as major threats in the recent history. Spread of pathogens and diseases is thought to be a major threat under climate change scenarios. The issue of WSV must be made a priority in the Indo-Pacific region as this is the main threat to the industry in that region in identifying adaptations. Better management practices (BMPs) including relevant biosecurity measures are considered as main adaptations.

Currently, WSV has no treatment. Avoidance is the best way to prevent disease outbreaks (Menasveta 2002 and Zhan et al. 1998). Implementation of proper management practices to reduce environmental stress is one of the best methods to reduce the risk of disease. (OIE 2011; Walker and Mohan 2009; Corsin et al. 2005;

Table 15.1 Common diseases/pathogens observed in the shrimp farming industry in the Indo-Pacific region

Viral diseases	Bacterial and fungal diseases	Other diseases
White spot syndrome virus (WSSV) Yellow head Virus group (YHV) Taura syndrome virus (TSV) Monodon baculovirus (MBV) group Infectious hypodermal and haematopoietic necrosis virus (IHHNV)	Vibriosis: – Hatchery vibriosis – Luminescent vibrio – White faecal disease – Early mortality syndrome (EMS/AHPNS) Other bacteria: – Rickettsia Fungal: – Larval mycosis – Fusariosis	Epicommensals and parasites: – *Leucothrix mucor* – Peritrich protozoans – Gregarines – Microsporidians Nutritional imbalances Toxic syndromes and environmental extremes

Lightner 2005). BMPs are the main tool for handling stress generated through climate change impacts.

Extensive investigations have been carried out in many countries to examine the effect of management practices on minimizing risks of disease outbreaks. A study conducted by MPEDA/NACA 2003, in India has identified several BMPs to reduce disease risks in small-scale shrimp farms.

15.4.4 National Climate Change Policy

Being an island nation subjected to tropical climate patterns, Sri Lanka is highly vulnerable to climate change impacts. Extreme weather events such as high intensity rainfall, flash floods and extended dry weather periods are now becoming frequent events in Sri Lanka. In addition to adaptive measures, Sri Lanka will fall in line with the global efforts to minimize the greenhouse gas emissions within the framework of sustainable development and principles enshrined in the United Nations Framework Convention on Climate Change (UNFCCC) and its Kyoto Protocol (KP).

The National Climate Change Policy of Sri Lanka provide guidance and directions to address the adverse impacts of climate change efficiently and effectively. The National Climate Change Policy includes a vision, mission, goal and a set of guiding principles followed by broad policy statements under Vulnerability, Adaptation, Mitigation, Sustainable Consumption and Production, Knowledge Management and General Statements. Collaborative action at all levels is necessary to transform this policy into a meaningful set of actions to meet the challenges of climate change. The Climate Change Secretariat (CCS) already plays a vital role in developing the institutional and regulatory mechanisms to address climate change. The National Climate Change Adaptation Strategy could provide a framework in which to develop this synergy further.

In coastal areas where aquaculture development takes place, Coast Conservation and Coastal Resources Management Department (CC&CRMD) is responsible for the implementation of the Coastal Zone Management plans. Department of Fisheries and Aquatic Resources (DFAR), Department of Wildlife Conservation (DWC), the Department of Forest Conservation (DFC), the Urban Development Authority (UDA) and the District Secretaries of coastal districts are cooperating with CC & CRMD in developing and implementing policy decisions for mitigating impacts of climate change and in planning processes. Farmer societies, Universities involved in aquaculture education and research are also consulted during policy development processes.

Necessity to include climate change in coastal planning and ecosystem restoration has been identified by CC&CRMD. Several policy decisions that have been implemented are directed towards conservation of remaining mangrove areas and restoration of degraded mangrove sites to enhance the capacities to minimize the impacts.

15.4.5 Farmer Conceptions

Shrimp farmers are aware of some aspects of climate change through several information sources such as radio, television, newspapers and interactions with extension and university students. They have experienced above-average rainfall, changes in rainfall pattern, unusual droughts and have initiated adaptation strategies. Sea level rise, water level changes, inundation of coastal areas, and water temperature rise have not been experienced yet by the farming community.

15.4.6 Better Management Practices as Adaptations for Climate Change

Better management practices (BMPs) are the key to the sustainability of the aquaculture industry. BMPs increase the total production, size at harvest, product quality, general health of shrimps and environmental sustainability. BMPs are developed in many areas from site selection to processing of end-products and includes site selection, pond preparation, water quality management, sediment management, selection of post larvae and health management. BMPs can also be used as adaptations to minimize the impacts of climate change. There are technical interventions and management interventions in better management practices that can be used in climate-compatible development.

Network of Aquaculture Centers in Asia-Pacific (NACA) has been involved in development and adoption of good conduct regulations, known as BMPs, since 2000 in a number of countries in the Asia-Pacific region (Mohan and DeSilva

(2010); Padiyar et al. 2008; NACA/FSPS/MOFI 2005). Many BMPs are derived from the Food and Agriculture Organization (FAO) Codes of Conduct for Responsible Fisheries (FAO/NACA/UNEP/WB/WWF 2006; Bene 2005; Barget et al. 2003). Several studies (FAO 2011; Umesh et al. 2009; ASEAN 2005; Engle and Valderrama 2004; MPEDA/NACA 2003) have revealed that recommended and developed BMPs have reduced the risk of disease outbreaks and improved social, ecological and economic sustainability and food safety. A programme was undertaken in Sri Lanka by IDRC, CIDA and Wayamba University of Sri Lanka in a project titled “Promoting Rural Income from Sustainable Aquaculture through Social Learning in Sri Lanka” in which the development of cluster-specific BMPs were identified for the sustainability of the industry in Sri Lanka.

15.4.6.1 Management and Technical Interventions

BMPs identified as management interventions useful in adapting to climate change impacts are given in Table 15.2. Shrimp aquaculture is increasingly constrained by changes in temperature, precipitation, drought, extreme weather conditions and storms/floods that affect farm performance, infrastructure and livelihoods of farming community. Ecological changes, inundation of low-lying lands and salt water intrusions may cause substantial dislocation of communities and disruption to farming systems. Management interventions identified under pond preparation, post larvae selection, pond management and biosecurity mainly focuses on adapting farming practices to minimize or to avoid climate change impacts that stress the shrimps, leading to disease outbreaks and to manage overall farm performance and the quality of the product.

Variation and extreme fluctuations in salinity, sudden changes in pH, lowering of oxygen levels, plankton blooms, and accumulation of metabolic toxic end products are some of the adverse changes expected in pond environment due to climate change. These factors can make shrimps more vulnerable to diseases. Alterations in crop calendar, slow growth, feeding problems, molting problems, poor product quality, brood stock collection problems, and poor farm performance are also identified to be impacts of climate change. Management adaptations listed under pond preparation, selection of post larvae for stocking, pond management during the culture cycle and implementation of the biosecurity (Table 15.2) can address the majority of the problems associated with climate change, improving the health and overall farm performance, ensuring the sustainability of shrimp farming.

Technical interventions useful in adapting to climate change are given in Table 15.3. These interventions will avoid the selection of shrimp farm sites in environmentally sensitive areas and provide possible interventions to reduce possible adverse impacts. Strategic Environment Assessment (SEA) is a systematic decision support process, aiming to ensure that environmental and possibly other sustainability aspects are considered effectively in policy, plan and programme making. Environment Impact Assessment (EIA) can look into all possible impacts of climate change and suggest mitigation and adaption measures. Recommendations of EIA

Table 15.2 List of BMPs identified as management interventions useful in adapting to climate change impacts

Area of activity	Intervention
Preparation of ponds for shrimp farming	Observing a 2-month fallow period after every harvest Drying and cleaning the pond bottom Removal of sediments accumulated during the previous culture cycle Ploughing and harrowing the pond Use of lime and dolomite to pond bottom to evaluate the pH of the soil and the lime requirement Use of stock tank or reservoir to store and treat water to be used for filling the pond
Selection of post larvae (PL) for stocking	PCR screening and other quality checks to select healthy larvae PL acclimatization to the pond environment before stocking
Pond management during the culture cycle	Fertilizer application to pond water to improve the natural productivity Dolomite and lime application to pond water to adjust the pH of the pond water Feed monitoring using feed trays Application of vitamins, minerals Water exchange during the crop cycle as and when necessary Regular monitoring of pond water for dissolved oxygen (DO), pH, salinity, and alkalinity of pond water Regular monitoring of ammonia, hydrogen sulphide Monitoring of Vibrio counts in pond water to assess pathogenic and beneficial bacterial populations PCR screening of shrimps after 1 month of stocking Conducting regular monitoring for growth and general health of shrimps Regular monitoring of bottom sediments of the pond Aeration of pond and proper positioning of aerators Use of only treated water to replenish the pond
Implementation of biosecurity measures	Use of bird nets to prevent the entry of birds Peripheral fence to prevent the entry of crabs as they can act as carriers for pathogens Filter water through twin net bag filter Peripheral fence to prevent the entry of dogs and other domestic animals Establish foot baths and disinfection of equipment Use of appropriate probiotics after monitoring the bacterial counts Allocation of separate sets of equipment for different ponds to avoid contamination

will prevent destruction of sensitive ecosystems such as mangroves, salt marshes and sea grass beds, and ensure their ecosystem services, reduce the possible adverse environmental impacts of bad site selection and reduce vulnerability to floods and heavy rainfall. Farmers will fall in line with conditions laid down in Environmental Protection Licence (EPL) to minimize the adverse impacts of shrimp farming operations. Acidification of water and sediments due to oxidation of pyrite in acid sul-

Table 15.3 List of BMPs identified as technical interventions useful in adapting to climate change impacts

Area of activity	Intervention
Strengthening of legal frame work	Establish coastal zone management plan incorporating shrimp farming zones Strategic Environmental Assessment (SEA) for potential shrimp farming zones Environmental Impact Assessment (EIA), Initial Environmental Assessment (IEA) for shrimp culture projects Environmental Protection Licence (EPL) for operation of shrimp farms Develop standards for shrimp farm effluents
Site selection for shrimp farms	Selection of supra tidal areas to establishing shrimp farms Avoidance of intertidal areas for establishing shrimp farms Avoidance of areas with pyritic soils that exhibit acid sulphate soil conditions Avoidance of environmentally sensitive areas such as mangroves, salt marshes and sea grasses Establish buffer zones, mangrove belts in-between farms Restoration/rehabilitation of degraded mangrove areas Avoid floodplains and lagoon reservations for establishment of farms
Infrastructure facility	Electricity supply for farms, use of renewable energy sources Desilting of lagoons/estuaries and water ways used as sources of water and sources for discharge of effluents Rehabilitation of water resources used to extract water Establish weather forecasting and early warning systems on natural hazards Address the problem of sand bar formation across the river outfalls Establish disease surveillance system to forecast disease/epidemic situations in shrimp farming areas Promote more environmentally friendly systems such as complete recirculation systems. Low intensity shrimp culture and organic shrimp culture Facilitate polyculture systems Develop an efficient information exchange system among stakeholders
Other interventions	Strengthening farmer organizations Establish crop calendar to minimize the pressure on water source and maximize the utilization of existing facility Organize administrative zones and sub-zones for shrimp farming Strengthening of farmers and awareness programmes for farmers

phate soil areas and other consequences of acidification such as increased solubility of iron, manganese and aluminium can be avoided by not setting up farms in acid sulphate soil areas. Restoration of mangroves, concept of shrimp farms in mangroves, establishment of buffer zones and green belts can improve resilience to rising sea levels. Figure 15.5 shows a shrimp farm constructed in a mangrove area. Mangrove areas can act as a protective belt (Fig. 15.6).

In addition, reduction of soil erosion pressure on environment and hydrology are other benefits. Mangroves have a capacity to absorb pollutants, purify water and to enhance the carrying capacity of the environment to sustain shrimp farming. Restoration/rehabilitation of mangroves with suitable species can create bio-shields

Fig. 15.5 Jayasinghe—Shrimp farm constructed in mangrove area

Fig. 15.6 Jayasinghe—Mangrove belt bordering a lagoon

to protect against cyclones, floods and extreme climatic events. Reducing the impact of floods can be facilitated through clearing of sand bars in river mouths. Effective communication and information exchange will enhance the adaptivity for climate change impacts by farmers.

Some of the BMPs discussed are also helpful in mitigation of climate change impacts. Reduction in energy utilization is possible through use of renewable energy, promotion of low intensity shrimp culture, biological treatment of water, and organic shrimp culture reducing CO_2 emissions. Carbon absorption and sequestration, protection of biodiversity are some of the important contributions of shrimp farming with mangroves.

Our experience in Sri Lanka indicates that majority of the farmers are very receptive for the adoption of BMPs. In addition to climate change adaptations, adoption of BMPs have contributed towards increased farm production, quality of the harvest, size at harvest, food conversion efficiency. BMPs have reduced the incidences of diseases, improving overall sustainability of the industry. Those who are not very receptive are small-scale cluster farmers with inadequate exposure to current issues and financial constraints.

Aquaculture extension services are to be strengthened to create more awareness on impacts of climate change on aquaculture industry and to enhance the adaptation response to possible impacts of climate change.

In summary it can be concluded that aquaculture contributes significantly towards national and global economies towards poverty reduction and food and nutrition security of communities, via a food production system with low carbon footprint and low nitrogen and phosphorous emissions. Combating climate change impacts on industry through adaptations will ensure the sustainability of the industry.

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