Chapter 8
Global Climate Change and Inland Open Water Fisheries in India: Impact and Adaptations

B. K. Das, U. K. Sarkar, and K. Roy

Abstract India has crossed the fisheries production of 10 million tonnes in 2015 and presently on its way to achieve the second blue revolution. Among all the major factors impeding sustainability of fisheries, factor of climate change is the recent addition. Climate change trends along major river basins of India have revealed a warming trend (0.2–0.5 °C), declining rainfall (257–580 mm) and shifting seasonality of rainfall occurrence. Rising sea levels (1.06–1.75 mm/year), receding Himalayan glaciers and frequent occurrence of extreme weather events are also a matter as per IPCC AR5. The present article discusses the contributions made by ICAR-CIFRI since 2004 on climate change vulnerability assessment framework, changes in breeding phenology of fishes, models on fish reproduction and diversity, thermal tolerance of fishes, carbon sequestration potential of wetlands and indigenous climate smart fisheries adaptation strategies. In addition, understanding the response and adaptation capacity of fishing and fishers to the physical and biological changes have also been discussed in the chapter.

Keywords Climate change · Open water fisheries · Impact and mitigation

8.1 Introduction

A comprehensive and exclusive database of climate change impact on fisheries production is non-existent in India. It is quite tedious to quantify and precisely focus on climate change effects on fish production statistics. In last 10 years (2005–2015) the inland fisheries production have increased from 3.52 MT to 6.92 MT, nearly a two fold increase with an average annual growth rate of 6.06 percent. Aquaculture and culture based fisheries alone contribute 70–80% of fish production from Inland waters. Rest is contributed by capture fisheries of wild fish stocks. The contribution of fisheries sector to the GDP has gone up from 0.46 per cent in 1950–51 to

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0.83percent in 2013–14. The share of fisheries in agricultural GDP has impressively increased during this period from a mere 0.84 per cent to 4.75 per cent.

Climate change is expected to alter the water temperatures, water levels and stream flow in the inland water bodies and have significant impacts. This may have an effect on inland fish species and their associated fisheries, and consequently will impact recreational and subsistence fishers, human communities, and economies. Climate change is predicted to affect aquatic ecosystems in diverse ways with implications for management of inland fishes and fisheries (Carlson and Lederman 2016). For example, the frequency of weather events that alter the availability and movement of water (e.g., droughts, heavy precipitation, heat waves) is predicted to increase with climate change (Saha et al. 2006). Rising sea levels are predicted to cause saltwater intrusion (i.e., replacement of freshwater by saltwater) in coastal aquifers (Iyalomhe et al. 2015), which may alter habitat suitability for freshwater and marine fishes. Climate change is altering the physical, chemical, and biological characteristics of freshwater habitats (Hartmann et al. 2013), with concomitant effects on freshwater and diadromous fishes. Warmer air temperatures resulting from climate change are expected to increase water temperatures, with effects on growth, reproduction, and survival of fishes and their prey (Hershkovitz et al. 2015, Kanno et al. 2015). Moreover, climate change is predicted to alter species interactions, the timing of important life history events (e.g., migration, spawning), and the spatial distribution of fish populations (Lynch et al. 2016). On a physiological level, effects of climate change on individual fish include reduced immune function, decreased cardiovascular performance, and changes in reproductive investment (Whitney et al. 2016). Chemical characteristics of water bodies, such as dissolved oxygen (Ito and Momii 2015), salinity (Bonte and Zwolsmen 2010), and nutrient concentrations (Moss et al. 2011), are directly influenced by these climate induced changes in thermal and hydrologic regimes. In recent years climate variability has threatened the sustainability of inland fisheries and dependent fishers in India. Some of the changes in the hydrology having potential repercussions on inland fisheries are: flood magnitude and frequency could increase owing to more intense precipitation events; water temperature will increase; low flows would be more severe owing to increased evaporation; peak stream flow would move from spring to winter owing to earlier thaw.

In nutshell, the fisheries sector is booming and contributing increasingly to the economic growth of the nation while climate change impact has become a concern that needs to be addressed. The present communication deals with climate change scenario in India, its probable impact on inland open water fisheries and suggest adaptation strategies for increasing their resilience to climate change.

8.2 Climate Change Trends

The latest climate change forecast based on IPCC (2014) AR5 predictions for regions of South-East Asia, of which India is a part, includes the following:

- Intense summer
- Increased occurrence of thunderstorms
- More non-seasonal rains causing gradual shifting of monsoon proper
- Accelerated hydro-cycle resulting in frequent occurrence of high-intensity short-duration dry season followed by low-intensity long-duration wet seasons in a loop
- Shortening of winter
- High Places (high altitude) will become warmer. Wet places will be wetter and dry places will be drier
- Rate of sea level rise and momentum of global warming showing no sign of recession and will continue to progress as predicted in IPCC (2014)

8.2.1 Climate Change Trends Along Major River Basins

Although high spatial differences occur in terms of changing climate along river Ganga but in general it can be mentioned that a warming temperature (+0.20 to +0.47 °C) and a decreasing total annual rainfall (−257 to - 580 mm) have occurred over the last 3 decades. On the contrary, along a southern peninsular river (River Cauvery), an extension of monsoon season (+14 days) and an increasing trend of annual rainfall (+80 mm) have occurred in addition to the warming temperature scenario. This depicts the high regional variability of both climate change and its anticipated impacts on fisheries making it hard to conclude a unanimous trend.

8.3 Impacts of Climate Change on Inland Fisheries

It has been found that the impact of climate change on inland fisheries is quite wide. It ranges from changes in range distribution, breeding and spawning behavior, growth rates, thermal tolerance, stress physiology, invasion of exotics to impact on aquatic primary productivity, habitat quality through sedimentation, water stress, aquatic weed proliferation and salt water intrusion. The major contributions made by ICAR-CIFRI under NICRA Project are summarized.

8.3.1 Impact of Enhanced Thermal Regime

8.3.1.1 Changes in Geographical Distribution and Diversity of Fishes

Expansion in the range of non-native warm water fishes (*Glossogobius giuris, Puntius ticto, Xenentodon cancila* and *Mystus vittatus*) from middle stretch of river Ganga up to Haridwar have been observed due to an increase in mean air temperature by +0.99 °C.

8.3.1.2 Effects on Growth, Stress and Reproductive Physiology

It is evident from the recent ongoing farming practices in the Uttarakhand hills (1200–1600 msl) that Indian major carps, particularly *Labeo rohita* are thriving well in the pond conditions at Pati, Champawat district, where it did not survived in earlier trials made during past 10–15 years back, due to low temperature. This could be due to decrease in frost duration in the region and resultant increase of water temperature. This indicates that the increased water temperature might support culture of Indian major carps in the upland regions in coming years. But at the same time this would be an alarming signal for existence of valuable trout fishery.

Increasing temperatures could bring the advantages of faster growth rates and longer growing seasons. Specific growth rates in IMCs remain comparatively high between water temperatures of 29–34 °C. However at temperatures near or beyond thermal tolerance limits, impairment of homeostasis occurs. The changes evident are hypercholesterolemia indicating impaired sterol mechanism, hyperglycemia and decreased blood sugar regulatory mechanism. Pituitary activation as evidenced by interrenal ascorbic acid depletion and cortisol elevation is pronounced. Oxygen consumption in both the fishes increased as judged by increased haemoglobin. Serum glucose, protein, triglycerides, T3 and T4 were increased in both in fast and slower rate of temperature increment. These indicate that the homeostatic mechanism of the fish is stressed which makes them highly susceptible to diseases.

All the stages of reproduction in fish viz., gametogenesis and gamete maturation, ovulation/spermiation, spawning and early development stages are affected by temperature. Temperature change modulates the hormone action at all levels of reproductive endocrine cascade. If stress is maintained then the effects start manifesting by the inhibition of reproductive function, cessation of ovulation, depression of reproductive hormones in blood and ovarian failure.

8.3.1.3 Changes in Breeding Behaviour and Recruitment

Fish farmers in aquaculture hatcheries of major fish breeding states are witnessing an extended breeding period of Indian major carps (*C. catla, L. rohita and C. mrigala)*. In recent decades the phenomenon of IMC maturing and spawning as early as March is observed due to increase in both mean air temperature and rainfall during pre-monsoon (Fig. 8.1).

An extended breeding period in golden mahseer *Tor putitora* and snow trout *Schizothorax richardsonii* primarily due to enhanced thermal regime and prolonged erratic monsoon was observed in recent years when compared with historical records.

The anadromous Indian river shad *Tenualosa ilisha* commonly known as ‘Hilsa’ forms a very important commercial fishery along the lower stretch of River Ganga especially in West Bengal. Gonadal maturation and spawning of Hilsa in river Ganga is influenced by water temperature. To be precise, water temperatures between 29–32 °C are necessary for attainment of gonadal ripeness and subsequent

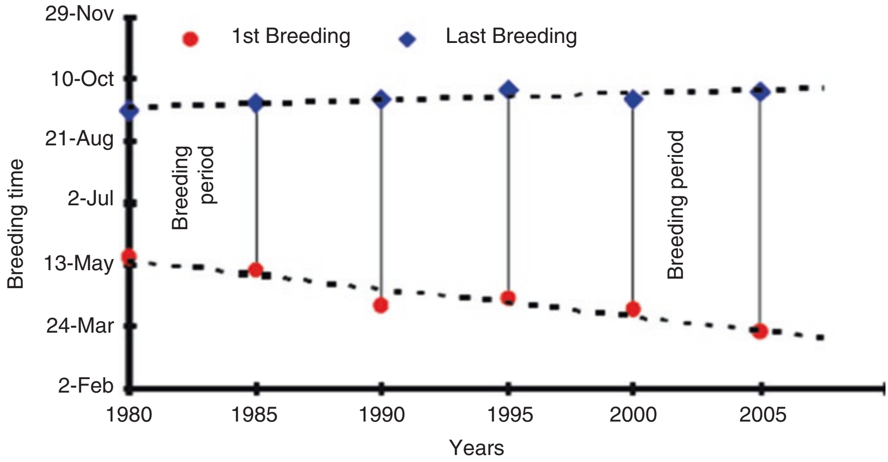

Fig. 8.1 Graph showing advancement and extension of breeding in Indian Major Carps

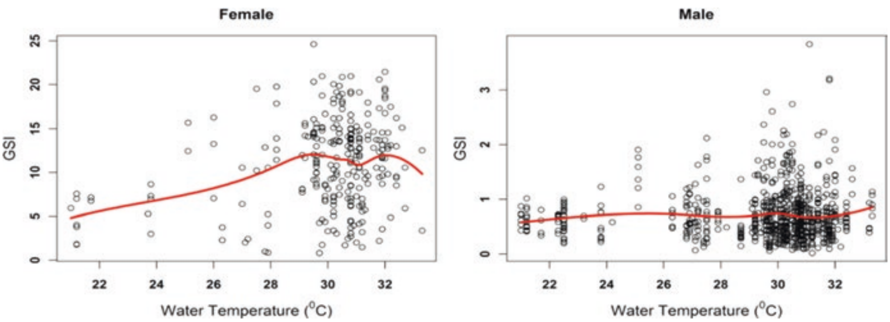

Fig. 8.2 Optimum water temperature for breeding of Hilsa in Ganga lower stretch

spawning in this species. Earlier studies had reported optimal water temperature range between 26–30 °C was ideal for spawning of Hilsa in River Ganga but recent studies of CIFRI have updated this range to 29–32 °C stating that if the projected water temperature in the region due to global warming lies within this range then spawning will not be disturbed given that the precipitation remains normal (Fig. 8.2).

8.3.1.4 Thermal Tolerance Limits of Fish

A total of around 15 commercially important freshwater inland fish species were screened for their *ex-situ* upper thermal tolerance levels. It was found that for most of the fish species the tolerance limits ranged around 39–41 °C among which catfishes, snakeheads and gobies were the most thermally tolerant fish species while the carps were weaker in terms of their upper thermal tolerance. Bottom dwelling fish species are generally more tolerant to water and thermal stress followed by pelagic and surface inhabiting fishes. Fishes with accessory air breathing organs adapted better under warm and low water conditions. Fingerlings show better acclimatization potential to warmer waters in comparison with adults.

8.3.1.5 Changes in Water Quality

Primary productivity in inland waters might increase under enhanced thermal regime. Although global warming manifested into warmer water temperatures round the year may initially result in increased fish food organisms (algal population > zooplankton) in rivers but in the long run this effect might not remain beneficial especially during summer. As surface water temperatures increase with predicted climate change, the solubility of dissolved oxygen (DO) in those waters will decrease. A tendency of progressive eutrophication also exists in the semi closed or closed water bodies owing to the enhanced availability of nutrients under high temperature-low water conditions.

8.3.2 Impact of Changing Precipitation Pattern

8.3.2.1 Changes in Fish Assemblage Pattern

Under a continuously warming climate scenario, highest congregation or assemblage of fishes in specific stretches of river is expected to coincide with the periods of maximum rainfall. Models have been developed for predicting fish assemblage patterns in specific stretches of river Ganges under variable climatic conditions (Fig. 8.3).

Analysis of catch composition from fish landings at specific stretches of River Ganga and Cauvery indicated a reduction in the share of commercially important indigenous fishes like IMCs in the Ganga catch while the contribution of exotics especially Common carp, Tilapia and other exotic fishes like African catfish, Suckermouth catfish have increased significantly to the extent of 25–50%. Simultaneously a warming trend, decreasing monsoonal rainfall and increasing rainfall during pre and post monsoon prevailed in Allahabad. Similarly in a southern peninsular river, Cauvery, comparison with historical records of fish composition revealed a decline of various earlier abundant fish species like *Hemibagrus punctatus, Puntius carnaticus, Gonoproktopterus dubius, Tenualosa ilisha, Cirrhinus cirrhosa* alongside an unusual increase in abundance of exotic species *Oreochromis mossabicus, O. niloticus* and transplanted *Catla catla.* The climatic trend during the same period showed a decrease in the number of rainy days during south west monsoon and an increase during the north east monsoon.

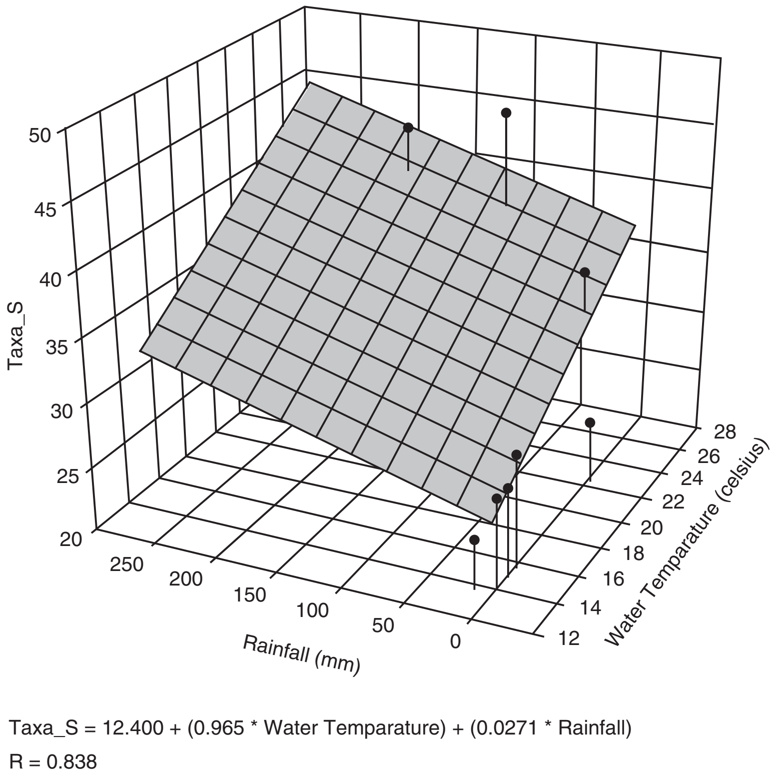

Fig. 8.3 A typical multi-parameter 3D scatter-mesh regression model for predicting fish assemblage

8.3.2.2 Changes in Recruitment and Riverine Fish Seed Availability

The fish spawn availability index of IMCs in river Ganga declined from an average of 1529 ml during (1965–69) to an average of 568 ml in recent years (2005–2009) due to decreasing trend of rainfall exclusively during breeding months (May–August) (Fig. 8.4).

8.3.2.3 Changes in Breeding Periodicity and Adaptation of Reproductive Phenology

Recent studies with some commercially important target fish species in River Ganga and associated wetlands has hinted that region-specific changes in breeding periodicity of some riverine catfishes and floodplain inhabiting snakeheads may likely occur through extension, shortening or shift in breeding season primarily due to changes in rainfall pattern followed by rise in mean air temperature manifested into

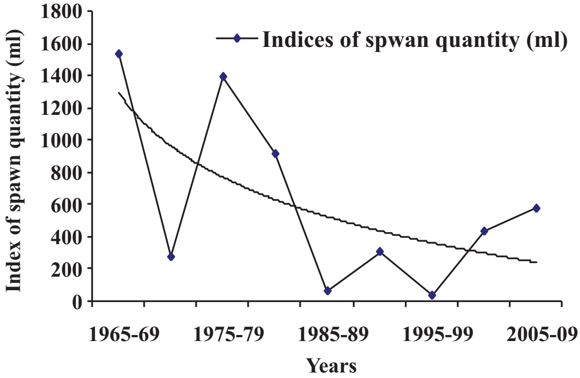

Fig. 8.4 Graph showing decreasing riverine fish seed availability of IMC (Sharma et al. 2015)

water temperature. Among the two climatic variables *i.e.* - Temperature and Rainfall, the latter seems to impart higher influence on breeding behaviour in natural open waters in a warm tropical climatic setup like that of India. Region-specific adaptation in reproductive phenology based on local trends of changing climate along River Ganga has also been suspected for some fishes.

8.3.2.4 Changes in Environmental Flows and Habitat Availability

Sub-optimum environmental flows in rivers and water stress in wetlands are the primary threats for inland fisheries. On the other hand, changing rainfall pattern during pre-monsoon and/or post-monsoon may either result in earlier flow pulse or delayed flow pulse in rivers having serious consequences on larval survivability and reproductive success of seasonally breeding fishes. Studies have been initiated on this line to map the possible impacts species-wise.

Floodplain wetlands are perceived to be the most impacted due to changing precipitation pattern (Sarkar et al. 2016). Studies on some floodplain wetlands revealed that problems like *Water stress, Wetland accretion/sedimentation, Aquatic weed proliferation, Loss of wetland connectivity with Parent River* are expected to aggravate in future climate scenario which may likely cause decline in fish production from these waters due to habitat unavailability.

8.3.3 Impact of Inter-Annual Climatic Variability and Extreme Climatic Events

8.3.3.1 Impact on Culture Fisheries Production from Inland Waters

It was found that inter-annual climatic variability have much lesser impact on fish production than management decisions like stocking and feeding. If proper fish culture management protocols are consistently maintained then fish production might increase in future without much detrimental impact caused due to local trends of changing climate.

8.3.3.2 Vulnerability of Low Lying Coastal Areas

Inland coastal lowlands are most vulnerable to extreme weather events like storm surges and sea level rise. Studies in District South 24 Parganas, West Bengal after occurrence of a tropical cyclone *Aila* had revealed massive salt water intrusion into coastal low lands due to ingression of Sea water from the Bay of Bengal. Saline waters intrusion from the Bay of Bengal into the inland water areas of Coastal South 24 Parganas, West Bengal increased water salinity from 8 to 23 ppt. These fertile lands were rendered unfit for agriculture which later turned out to be good sites for brackishwater aquaculture of highly priced seabass and mullets as an alternative livelihood. It was observed that during cyclones causing sea level may rise from 1 to 2 meters causing 3 to 11% of the land area of the district to be submerged.

8.3.3.3 Impact of Storm Surges and Floods

Storm surges and subsequent flooding are most likely to cause inundation and flooding of culture waters, unanticipated salinity changes, introduction of pathogens/diseases, introduction of exotics and predators, escape of cultured fish/prawn stocks, dispersal of preferable microscopic fish food organisms, damage to culture facilities and increased insurance costs.

8.3.3.4 Impact of Water Stress and Drought

Droughts are often associated with reduced/limited water level, cessation of fish hatchery functioning, decreased dissolved oxygen concentration, increased salinity, algal bloom, ammonia toxicity, increased occurrence of fish diseases and mortalities. Moreover there also occurs an increased social conflict on water use.

8.3.3.5 Vulnerability of Fisher Folk

The greatest limitation towards developing an effective adaptation strategy for climate change in India is the lack of vulnerability assessment framework and vulnerability mapping of various climate sensitive sectors of Indian economy. In order to address that issues ICAR-CIFRI under Project NICRA had innovated such a tool capable of comprehensively assess the vulnerability of inland fisheries at spatio-temporal scale from the regional trends of changing climate and vulnerability index and vulnerability mapping of the inland aquatic resources and fisheries was conducted in 14 districts of West Bengal. Low adaptive capacity of the fishers limited their capacity to cope up with the extensive loss to fish production and infrastructural facility associated with extreme events of climate change (Fig. 8.5).

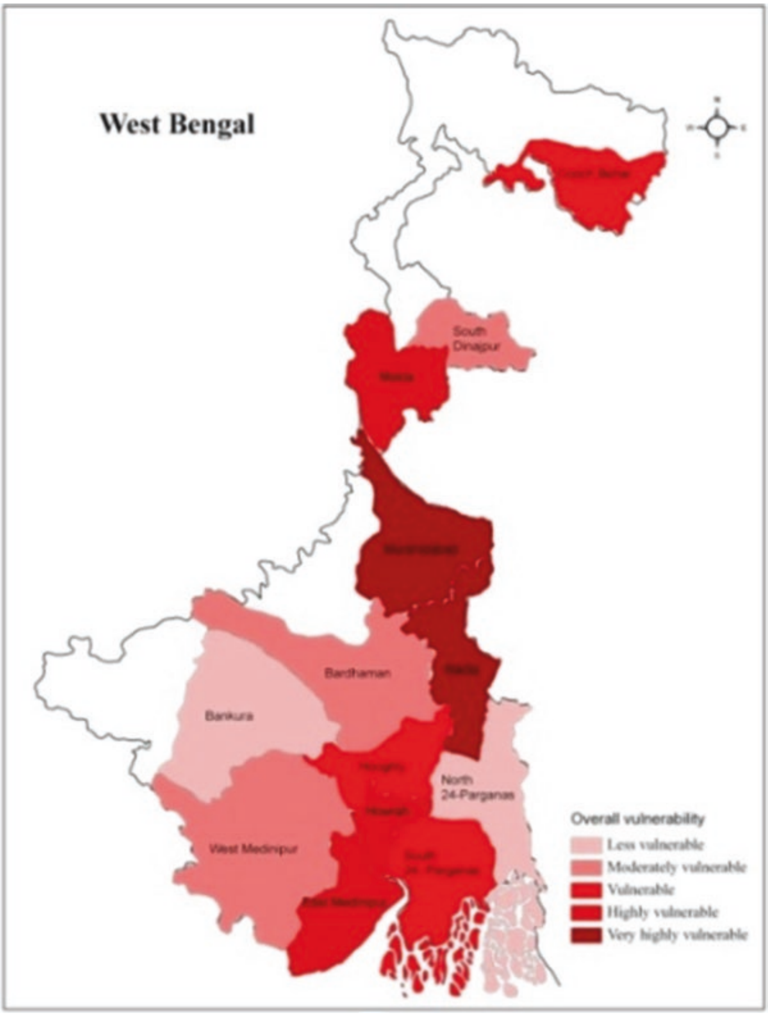

Fig. 8.5 Graph showing vulnerability map of West Bengal's fisher folk to climate change (Sharma et al. 2015)

8.4 Climate Change Adaptation in Inland Fisheries

Approaching climate change typically involves actions that either reduce the amount of carbon dioxide and other greenhouse gases (GHGs) in the atmosphere or prepare the fishing community for the impacts associated with climate change via adaptation. Even though it is hard to generalize the impacts of climate change on fisheries, climate change is very likely going to lead to fluctuations in fish stocks which in turn will have major economic consequences for many vulnerable communities and national economies that heavily depend on fisheries (Brander 2010).

The important adaptive measures that can rejuvenate the fisheries sector are as follows:

- Rebuilding stocks and improving fisheries governance
- Managing declining incomes if fish catches fall, and efforts aimed at diversification and fostering alternative livelihood activities
- Disaster preparedness and response
- Aquaculture development and ecosystem based adaptation

For inland fisheries, adaptation involves adjusting fishing pressure to sustainable levels. Setting catch limits based on changes in recruitment, growth, survival and reproductive success can be done via adaptive management, monitoring and precautionary principles. This may also require changes in craft or gear types.

8.4.1 General Adaptation Measures

Some climatic situation specific general adaptation measures as recommended by the CIFRI over the years are tabulated below (Table 8.1).

Additionally, some climate change impact specific adaptation measures for inland fisheries as recommended by FAO (De Silva and Soto 2009) are listed in Table 8.2.

8.4.2 Climate Smart Adaptation Strategies for Wetland Fisheries

Consequences of climate change like extreme precipitation events (heavy rain storm, cloud bursts etc.) and prolonged dry spells had occurred in various states. In order to mitigate the adverse effect of climate change in wetland fisheries, potential advisories were recommended to the fishers/ stakeholders of different wetlands of West Bengal and Assam. The details are given below.

Creation of deep pools in shallow wetlands have been adopted in several wetlands of Assam and West Bengal for providing summer time refuge to fishes and also maintain base stocks for recruitment in the next season.

Holding fish in net pen enclosures have been advised in 30 wetlands of Assam and 3 wetlands in West Bengal for safeguarding fish stocks against escape during monsoon and also to sustain the livelihood of dependent fishers through a provision of temporary pre-summer enclosure during water deficient months.

Creation of weed refuge, *branch pile refuge* in weed/algae infested wetlands also needs to be popularized as these will effectively make use of the proliferating

Table 8.1 General adaptation measures for inland fisheries under changing climate

Situation	Adaptation measures
Enhanced temperature	*Making changes in feed formulations and feeding regimes of fishes*
	Exploring substitution by alternate species of fish
	Providing monetary input to the changes in operational costs in ponds and hatcheries
Pre-flood	*Harvesting fish at smaller size*
	Giving importance to fish species that require short culture period and minimum expense in terms of input
	Increasing infrastructure sophistication of hatcheries for assured seed production of 34,000 million carp fry, 8000 and10000 million scampi and shrimp PL respectively
Post-flood	*Continuous supply of fish seed from hatcheries or raising of fish seed in hatcheries is required.*
	Cage culture in large water logged bodies for raising seed from fry to fingerlings
Storm surge	*Early detections systems of extreme weather events*
	Communication of early warning system
	Accept certain degree of loss
	Development and implementation of alternative strategies to overcome these culture periods
	Maximizing production and profits during successful harvest
	Suitable site selection and risk assessment work through GIS modelling
	Increasing infrastructure sophistication of hatcheries for assured seed production of 34,000 million carp fry, 8000 and10000 million scampi and shrimp PL respectively
	The ingressed saline water inundated coastal low lands which become unfit for agriculture provided temporary opportunities for converting these areas into ponds for fish culture with saline tolerant fish species viz., Mugil parsia, M. tade and Lates calcarifer
Pre-drought	*Hatcheries affected by drought condition may divert from rearing Indian major carps to other fish species which favourably adapt to water stress, oxygen deficiency and high temperature conditions.*
Post-drought	*Smaller ponds that retain water for 2–4 months can be used for fish production with appropriate fish species (catfish, tilapia etc.) and management practices.*
Water stress	*Multiple use, reuse and integration of aquaculture with other farming systems*
	Intensification of aquaculture practices in resources of wastewater and degraded water such as ground saline water
	Smaller ponds (100-200 m2) of seasonal nature (1–4) months can be used for rearing /culture of appropriate species of fish/prawn

aquatic weeds/algae under climate change scenario, in three ways i.e. serve as fish refuge, support fisheries and promote carbon sequestration in wetlands.

Interventions made by ICAR-CIFRI on climate smart wetland fisheries planning: The indigenous fisheries strategies practiced by the fisher folk in the wetlands are not given much importance by the fisher folk themselves as they are constantly in

Table 8.2 Impact specific adaptation measures for inland fisheries under changing climate (adopted from De Silva and Soto 2009)

Impact	Adaptation measure
Reduced yields	Access higher-value markets
	Increase fishing effort (risks overexploitation) moving/planning siting of cage aquaculture facilities
	Migration as fish distribution changes (risks overexploitation)
	Research and investments into predicting where fish populations will move to.
Increased yield variability	Diversify livelihood portfolio (e.g. algae cultivation for biofuels or engage in non- fishery economic activity such as ecotourism)
	Precautionary management
	Ecosystem approach to fisheries/aquaculture and adaptive management
	Shift to culture-based fisheries
Reduced profitability	Diversify livelihoods, markets and/or products
	Reduce costs to increase efficiency
	Shift to culture-based fisheries
Increased risk	Weather warning systems
	Improved communication networks
	Workshops to train data gathering and interpretation
	Monitoring of harmful algal blooms
	Improved vessel stability/safety
	Compensation for impacts
Increased vulnerability for those living near rivers	Early warning systems and education
	Rehabilitation and disaster response
	Post-disaster recovery
	Encourage native aquaculture species to reduce impacts if fish escape damaged facility

search of better production systems. But after CIFRI sensitized the climate smart nature of these ignored traditional fishery strategies through several awareness-cum-training programmes, a new attitude among 70–90% fisher folk community towards these pre-existing traditional methods had emanated recently.

8.4.3 *Climate Change Resilient Adaptation Strategies for Riverine Capture Fisheries*

Particularly for riverine fisheries, adaptation should involve adjustment of fishing pressure to sustainable levels. This may be accomplished through setting catch limits (based on changes in recruitment, growth, survival and reproductive success), adaptive management, stock monitoring and precautionary conservation initiatives. This may also require changes in craft or gear types. Rebuilding of depleting stocks should be given highest priority followed by aquaculture development in the associated floodplains along the river basin to diversify the income of fishers.

8.4.4 Wetland Fishery and Conservation as a Tool to Adapt and Mitigate Climate Change

Wetland ecosystems are perhaps among the largest carbon (C) sinks in the world. Soils of wetlands play an important role in global C-cycle. According to Ramsar secretariat about 1/3rd of the world terrestrial carbon is trapped and stored in wetlands, double of that of forests. As per the estimations, C sequestration potential of restored wetlands (over 50 year period) comes out to be about 0.4 tonnes C/ha/year (IPCC 2001). From the studies of ICAR-CIFRI, the rate of C accumulation in the floodplain wetlands in Eastern Indian conditions was estimated to be >0.15 Mg/ha/year which is almost double of the global estimates given for large lakes and inland seas, and also greater than terrestrial upland soils. Primary producers (phytoplankton, aquatic weeds) are the major pathway of carbon capture. In terms of carbon harvested through fish flesh (*i.e.* blue carbon), detritivorous and bentho-pelagic fish species have highest carbon uptake from wetland system compared to surface inhabiting planktivores.

8.4.5 Policy Document on Climate Change and Inland Fisheries

ICAR-CIFRI, in 2015, had published a comprehensive policy paper under Project NICRA encompassing various issues and forecasted situations of climate change with its implications on inland fisheries of India. The policy paper titled "Inland Fisheries and Climate Change: Vulnerability and Adaptation Options" stands out to be the very first of its kind and is expected to augment knowledge of researchers, experts and aid policymakers in devising climate smart policies for the sustainable development of inland fisheries in the country. The document not only provides research based information of climate change impacts on various aspects like aquatic ecology, fish biology, fisheries socio-economics and vulnerability but also recommends DO's and DON'Ts for specific climatic scenarios or weather events. The recommendations of this document have been well consulted and appreciated by states like Assam and Orissa through incorporation in their state action plans for fisheries development.

8.5 Recommendations to Offset Negative Impact of Climate Change

- Following some principle of responsible fisheries in rivers, reservoirs and wetlands *viz.* closed season, closed area, mesh size regulations, by-catch reduction devices and catch limit (CPUE) regulations. This is to avoid recruitment overfishing and growth overfishing of already stressed fish stocks in natural ecosystems under changing climate.
- Proper pre-damming environmental impact assessment to be done for ascertaining environmental flow requirements of the river systems in order to sustain ecosystem services and avoid habitat fragmentation. It is required for minimizing anthropogenic impacts on the already impacted river systems due to climate change.
- Creation of temporary pre-summer enclosures (pen), creation or conservation of deep pools in deepest parts of the wetlands and rivers. This will serve as summer refuge to fishes or sustain fisheries under low water conditions.
- Creation of weed refuge, branch pile refuge in weed/algae infested wetlands. This will effectively make use of the proliferating aquatic weeds/algae under climate change scenario, in three ways *i.e.* serve as fish refuge, support fisheries and promote carbon sequestration in wetlands.
- Immediate implementation of dredging/de-silting programmes in the wetlands using a combination of mechanical and manual methods.
- Promote culture fisheries in reservoir with planktivorous or herbivorous fishes low in the food chain. Such fishes have highest carbon assimilation efficiency. Short duration crop cycles in seasonal waters and long duration crop cycles in perennial waters is recommended.
- Promote wetland fishery from carbon economics point of view, *i.e. – to convert invaluable inorganic carbon into high value organic carbon of fish flesh.*
- Identification of indigenous fisheries and aquaculture strategies those are capable of adapting to present state of climate change. Such practices can be optimized with scientific intervention for promoting climate change resilient fisheries.
- Carry out wet lab experiments with brood stock, fish larvae of commercially important inland fish species in heat chambers to assess the chronic changes in physiology at neuro-endocrinal levels when fishes are subjected to realistic elevated temperatures and water stress.
- Research on carbon sequestration in wetlands with more emphasis of Green House Gas (GHG) emissions from different types of wetlands and assessment of carbon sequestration potential. Assessment of carbon footprint in enclosure based fish culture like cages /pens and promotion of wetland fisheries from carbon economics point of view need to be done.

8.6 Conclusion

The impact of climate change on inland fish production is mixed in nature ranging from being detrimental to beneficial in various cases. The true impact of climate change on inland fisheries production should be reflected from the revenue generated and environmental costs incurred. This is due to the fact that localized loss of certain fish stocks due to habitat degradation, recruitment failures, changes in reproductive phenology, larval survivability, disease outbreak, range contraction, competitive displacement by non-native alien species is often offset by a new replacement to restore ecological integrity under natural conditions. Climate change often acts in conjunction with anthropogenic impacts. The already climate stressed aquatic ecosystems and fishes living therein should not be stressed further through adding more anthropogenic impacts. Environmental impact assessment and code of conduct for responsible fisheries should be given higher priority than before in order to minimize or offset climate change impacts on inland fisheries. Public awareness and capacity building of stakeholders on climate change will aid in effective implementation of the policies and to respond effectively to the threats or opportunities posed by climate change.

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