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Inland Fisheries and Climate Change: Vulnerability and Adaptation Options

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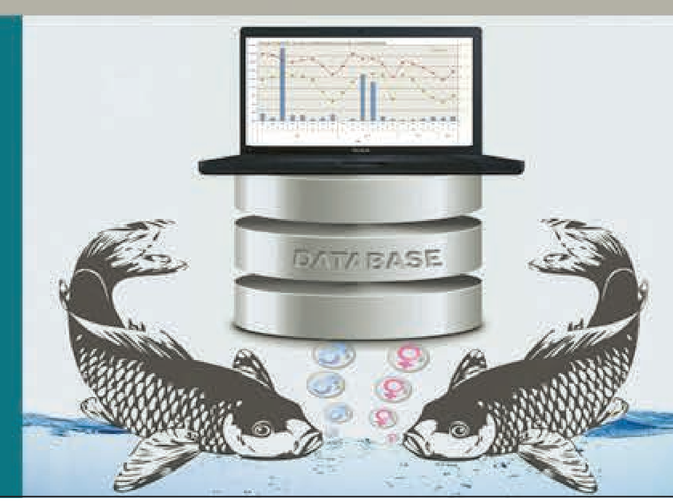

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INLAND FISHERIES & CLIMATE CHANGE: VULNERABILITY AND ADAPTATION OPTIONS

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PREFACE

The global climate in the past few decades is showing perceptible changes and is projected to impact across ecosystems, societies and economies worldwide, increasing pressure on all livelihoods and food production systems including those in inland fisheries.

The greatest concern for India at present is that nearly 700 million rural population depends on climate sensitive sectors like agriculture, forests, fisheries and natural resources for their subsistence and livelihoods. Therefore the issue of highest importance in India is reducing the vulnerability of its natural and socio-economic systems to the projected climate changes.

Addressing climate change requires a good scientific understanding as well as coordinated action at the national and state level. Central Inland Fisheries Research Institute initiated research on climate change way back in 2004 under the ICAR research project "Impact, Adaptation and Vulnerability of Indian Agriculture to Climate Change" and is being continued under the ICAR Project National Initiative on Climate Resilient Agriculture (NICRA). In the last 11 years the Institute has emerged as the nodal organization on climate change research on Inland fisheries in the country.

This policy brief highlights the predicted impacts of climate change on physical and ecological features of the aquatic ecosystems and on inland fisheries sector in India. The role of the sector in climate change mitigation and the opportunities and threats to the people and communities dependent on the sector as determined by their vulnerability are discussed. The adaptation options available are also suggested.

It is earnestly felt that the key issues highlighted will create an awareness and understanding among the policy decision makers about climate changes and their impacts on inland fisheries; vulnerability and opportunities for adaptation and mitigation available in the inland fisheries sector in the country.

Authors

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CONTENTS

INLAND FISHERIES & CLIMATE CHANGE: VULNERABILITY AND ADAPTATION OPTIONS

1. INTRODUCTION

Climate change is one of the most important global environmental challenges of 21st century. India has reasons to be concerned about climate change. Nearly 700 million rural populations directly depend on climate-sensitive sectors (agriculture, forests and fisheries) and natural resources (such as freshwater, mangroves, coastal zones, grasslands and biodiversity) for their subsistence and livelihoods. Any adverse impact on water availability due to recession of glaciers, decrease in rainfall and increased flooding in certain areas would threaten food security, cause further degradation of natural ecosystems and its resident species that sustain the livelihood of rural households. Occurrence of sea-level rise and increased extreme events will adversely impact the coastal eco-system and the dependent population. The impacts are already being felt in India. During the period 2014-15 the food production in the country declined to a four year low of 251.12 million tonnes due to droughts, flood, hailstorms and unseasonal rains. The significance of animal and fisheries sector for food security of the fast growing nation like India is enormous. These sectors play a critical role in the socio-economic development and welfare of India's rural population, not only as a source of nutrient-rich food but also provide family income and generate gainful employment particularly among the landless, small and marginal farmers.

India is bestowed with vast and varied inland open-waters *viz.* lakes, reservoirs, wetland, rivers, and estuaries, the traditional sources of fisheries, supporting a large number of landless poor fishers. In recent times, however, fish production from these resources has declined steadily due to increased man-centric interventions. The resultant impact has been an erosion of livelihood base for the traditional fishers, who depend exclusively on these resources for their livelihood and nutritional security. Of concern is the fact that the impact of climate change is already perceptible in these inland aquatic ecosystems and on fisheries, increasing pressure on all livelihoods and food supplies. Though living resources are self-renewable, more so are the aquatic living organisms, especially fish, provided they can be utilized rationally on a sustainable basis maintaining harmony with the aquatic environment.

2. SIGNIFICANCE OF FISHERIES AND AQUACULTURE IN INDIA

Inland fisheries and aquaculture play a significant role in the economy of India. Though often overlooked, the following points would provide a glimpse of the economic importance of the sector. Fisheries and aquaculture sector in India provides nutritious food, has high potential for rural development, domestic nutritional security, employment generation, as well as export earnings. India occupies third position in fisheries and second in aquaculture production. The Fishery sector has shown a steady growth in India and hence it is called the sunrise sector. Indian share in global fish production is 4.36% with 9.92 % in inland and 2.28% in marine. Its contribution to the National GDP is 1.07%, and to National Agriculture and allied activities is 5.84 %. The Export potential is 18% of the agricultural exports. The sector provides direct and indirect engagement to 14 million people. India relies on fisheries for around 13.5% of its national animal protein intake and the average per capita fish protein consumption is 0.51 kg/capita/yr. But the contribution of fish to the total animal protein consumption for the non-vegetarian population is much higher than the overall Indian average (Dey *et al.,* 2005). Thus any potential direct or indirect effects of climate change will have immense implication on regional food security especially in the eastern Indo-Gangetic states of India. It is therefore imperative to think of the vulnerability and adaptation strategies of the sector in dealing with the impacts of climate change.

3. NEED TO DIFFERENTIATE THE CLIMATE CHANGE IMPACT ON INLAND FISHERIES PRODUCTION FROM TERRESTRIAL FOOD PRODUCTION SYSTEM

Fish being a poikilothermic animal the habitat temperature will profoundly affect its metabolism, manifested by growth rate, total production, reproductive competence, seasonality, recruitment and susceptibility to diseases and contaminants. Therefore variations in the ambient temperature will have a significant effect on the productivity, yield, and spatial distribution of fish stock and fish culture activities.

The food production system of inland fisheries for example, unlike terrestrial food production system depends on wild populations whose variability depends on the environmental processes governing the supply of young stock, and feeding and predation conditions through the life cycle. There are also a number of migratory fish species like Hilsa and Mahseer traversing hundreds of kilometers to complete their life cycle and production process. Climate variations in many cases can upset the process altering the spatial distribution of fish stock, fishing activities and culture. It might create winners and losers but most often jeopardizing the large number of dependent fishers of a geographical area.

Fishing in inland waters is an open access activity requiring little capital and often function to supplement protein food to weaker section of the society- playing an important role in adaptive strategy. Fishing is frequently integral to mixed livelihood strategies, in which people take advantage of seasonal stock availability or resort to fishing when other forms of food production and income generation fall short. Fishing communities that depend on inland fisheries resources are likely to be particularly vulnerable to climate change. Climate change is only one among many environmental and anthropogenic stresses faced by inland fisheries but is likely to exacerbate the difficulties of achieving sustainable inland fisheries production.

4. CONSTRAINTS HAMPERING SUSTAINABILITY OF INLAND FISHERIES

In recent years, clear signs of modification and degradation of ecosystems, over-exploitation of commercially important inland capture fish stocks have become discernible. These factors threaten the long-term sustainability of inland fisheries and its contribution to the food basket of the country. The potential inland fish production is estimated at over 5.0 million tonnes annually and capture fisheries contribute more than 30% from the inland open waters. Aquaculture plays a major role as the prime producer of fish. Rivers are the primary sources of precious germplasm and breeding ground for a large number of fish species. However, over the years, the fish yield from the different rivers systems of India is showing a declining trend. Considering the current environmental status of the inland aquatic resources, substantial increase in fish production from rivers is unlikely. However, the reservoirs and floodplain lakes in the country offer considerable opportunity for enhancing fish production. The major factors impeding sustainability of inland fisheries are the following: -

- **Damming of rivers:** The flow regime/environmental flow down-stream of many rivers has been affected leading to loss of fish habitat, biodiversity and other ecosystem functions.

- **Rampant encroachment of open-water resources**: High economic demand of land for real estate has accelerated the pace of encroachment of open-waters, especially wetlands, leading to loss of inland open-water fishery resources as they are either being filled-up or allowed to get polluted. The closure of riverine access into the wetlands by erecting bunds has been a major cause of failure in natural fish seed recruitment into such waters. Increasing levels of eutrophication in wetlands has resulted in predominance of macrophytes causing disruption in natural food-chain and depleted fish stocks.

- **Large-scale destruction of estuarine habitats and mangrove wetlands:** The estuarine ecosystems of the country including the mangrove wetlands are stressed due to man-centric interferences, making conservation of fish/shell fish difficult.

- **Multiple usages and multiple-ownership**: The inland open-waters have many stakeholders being multiple ownership resources and lack the required policy framework for priority setting of use. In the face of continued demand on inland water for other sectors and unabated anthropogenic stress on our rivers, substantial increase in fish productivity has not been possible.

- **Over-exploitation**: Access to fishing in the open-waters in majority of the states is unregulated. With dwindling fish stocks in rivers and wetlands the increasing demand of fish has led to over exploitation. The mechanization of fishing for example, in lower part of Hooghly-Matlah estuary has increased the fishing effort thus producing more fish biomass. Wanton killing of brooders and juveniles of target species is a common feature in majority of the rivers and wetlands leading to decline in their fishery.

- **Rapid shift in biodiversity and fish stock**: In rivers and wetlands, the process of shift in biodiversity and composition of fish stock has assumed a serious dimension. In majority of the rivers dominated by carp fishery is being replaced by small-bodied miscellaneous fishery with less market acceptability and resultant lower remuneration to fishers. Unregulated entry of exotic fish species has also resulted in decline of indigenous fish species.

- **Livelihood loss of fishers:** Fishers are faced with dwindling fish to fish upon, resulting in the loss of their livelihood. This situation has very often resulted in their migration as labourers to other sectors for economic sustenance.

- **Climate change:** It will exacerbate the threats posed to the Inland fisheries by the other anthropogenic stressors. The concerns for climate-induced threats to fisheries take place in the context of widespread overexploitation of fisheries, which reduces the scope for adaptation and increases risks of stock collapse through a combination of climate-related stresses and heavy exploitation pressure.

Thus sustainability of inland fisheries needs to be addressed in an integrated way by considering the issues of all the anthropogenic interferences holistically.

5. POTENTIAL IMPACTS OF PROJECTED CLIMATE CHANGE RELEVANT TO INLAND FISHERIES IN INDIA

5.1. *Water resources*

Changes in key climate variables, namely temperature, precipitation, and humidity, may have significant long-term implications for water quality and quantity of water. River systems of the Brahmaputra, the Ganga, and the Indus, which benefit from melting snow in the lean season, are likely to be particularly affected by the decrease in snow cover. A decline in the total run-off for all the river basins, except Narmada and Tapti, is projected in India (by India's Initial National Communication, 2004 NATCOM to UNFCCC). A decline in run-off by more than two-thirds is also anticipated for the Sabarmati and Luni basins. Rivers differ a great deal in the amount of water they carry depending upon the precipitation in their catchments and other sources of water (e.g. snow melt), as well as factors that determine runoff, infiltration and evaporation. Flow is an important factor determining the physical structure of a river and thus maintaining in-stream habitats. For wetlands adjoining rivers the hydrological processes in the watershed, and the rate of downstream discharge, determine the depth, duration and frequency of inundation of the floodplain, which periodically becomes a part of the river. The area of floodplain immediately adjacent to, and influenced by the river is often distinguished as the riparian zone. The riparian zone and the floodplain are important riverine habitats; they form a critical link between terrestrial and aquatic ecosystems. River flows determine the nature and strength of a river's interaction with its floodplain, and consequently the diversity of habitats and biotic communities. Any human activity that directly or indirectly impinges upon the flows has an impact on fishery resources. Due to sea level rise, the freshwater sources near the coastal regions will suffer salt intrusion.

5.2. *Vulnerability to extreme events*

Heavily populated regions such as coastal areas are exposed to extreme climatic events, such as cyclones and floods. About 40 million hectares of land in India is flood prone, including most of the river basins in the north and north eastern belt, affecting about 30 million people on an average each year. Whereas large areas in Rajasthan, Andhra Pradesh, Gujarat and Maharashtra and comparatively small areas in Karnataka, Orissa, Madhya Pradesh, Tamil Nadu, Bihar, West Bengal and Uttar Pradesh are frequented by drought. Such vulnerable regions may be particularly impacted by climate change.

5.3. *Coastal areas*

A mean sea level rise (SLR) of 15-38cm is projected along India's coast by the mid 21st century and of 49-59cm by 2100. In addition, a projected increase in intensity of tropical cyclones poses a threat to the heavily populated coastal zones in the country (India's Initial National Communication, 2004).

The IPCC, 2014 climate projections related to the fisheries sector in general indicate i) Rise in sea level which could flood millions of people living in low lying areas of south, southeast and east Asia such as Vietnam, Bangladesh, India and China ii) Increase in tropical cyclones resulting in a likely increase in hurricane related losses iii) Increasing salinity of ground water as well a surface water resources especially along the coast of India, China and Bangladesh and iv) an expansion of areas under water stress .

6. PATH WAYS BY WHICH INLAND FISHERIES WILL BE AFFECTED BY THE PROJECTED CLIMATE CHANGE

While many of the changes depicted below impede development of fisheries and aquaculture, but at the same time provide opportunities for adaptation.

Change	Effects	
Enhanced water temperature	Culture system	? Reduced water quality (depleted dissolve oxygen) ? Enhanced primary productivity ? Increased growth and food conversion ? Increased disease incidence ? Enhanced breeding period in hatcheries
	Operational	? Changes in level of production,(ponds, hatcheries) ? Increase in capital costs (aeration, deeper ponds)
	Rivers	? Geographic shift of fishes, altered species richness ? Breeding failure ? Habitat loss/gain ? Increased invasion of exotic species
	Wetlands	? Increased stratification and reduced mixing of water in lakes and reservoirs. ? Reducing primary productivity and food supply to fish species.
Changes in precipitation (Floods) Habitat availability	Culture system	? Salinity changes ? Escape of fish stock ? Structural damage ? Introduction of disease /predators
	Operational	? Loss of fish stock ? Damage to facilities ? Higher capital costs for flood resistance ? Higher insurance costs
	Rivers	? Changes in fish migration and recruitment pattern and recruitment success. ? Changes in habitat availability for various stages of fish and fish food organisms
Intense storm surges (coastal region)	Culture	? Inundation and flooding ? Salinity changes ? Escape of fish/prawn stock ? Introduction of disease and predators
	Operational	? Loss of prawn/ fish stock ? Damage to facilities ? Higher insurance costs

Drought (as an extreme event, as opposed to gradual reduction in water availability)	Culture system	? Salinity change ? Reduced water quality ? Limited water volume for aquaculture ? Increased competition with other water users
	Operational	? Loss of fish stock ? Limited production
Sea level rise		? Loss of land ? Changes in habitat availability for various stages of fish and fish food organisms in the estuary system. ? Loss of coastal ecosystems such as mangrove forests
Water stress (as a gradual reduction in water availability due to increasing evaporation rates and decreasing rainfall)	Culture	? Decrease in water quality ? Increased diseases ? Reduced pond level ? Altered and reduced freshwater supply
	Operational	? Cost of maintaining pond level artificially ? Conflict with other water users ? Loss of fish stock ? Reduced production capacity ? Change of culture species
Human adaptation to changes in climate	Aquatic ecosystems including Fish and Fisheries Exacerbation of negative impact	
	Example 1 : Increased demand of water for irrigation	
	Supply side options	? Increasing supply ? Expensive ? Environmental impact
	Demand side options	? Reducing demand ? Increase irrigation efficiency ? Higher prices ? Changes in cropping pattern
	Example 2 : Flood Management /flood Control	
	Supply side options	? Increasing flood protection with levis and reservoirs ? Expensive ? Environmental impact ? Catchment source
	Demand side options	? Improvement in flood warning system and information

7. IMPACT ON INLAND ECOSYSTEMS

For inland waters, projected changes in surface water availability are the most obvious threat to fisheries production. There is a close relationship between floodplain area, river flow and wetland surface area and total fish production. Therefore, the decline in surface water availability in many parts of country predicted is a threat to inland fish production.

Some of the significant alterations in the climate variables relevant to inland fisheries recorded in the Ganga basin area (Das *et al*., 2013) are elaborated.

7.1. *Changes in temperature and rainfall pattern in Ganga basin*

Seasonal pattern of rainfall in the middle stretch of river Ganga: Analysis of the monthly data of rainfall in the middle stretch of the river Ganga at Allahabad from 1979-2009 split into three equal periods (Jan-April), (May-August) and (September-December) revealed that the percentage of total rainfall in the peak breeding period (May- Aug.) declined by 7% whereas it increased by 4% in the post- breeding period of Indian Major Carps (IMC) the most important commercial fishery in the river (Figure 1).

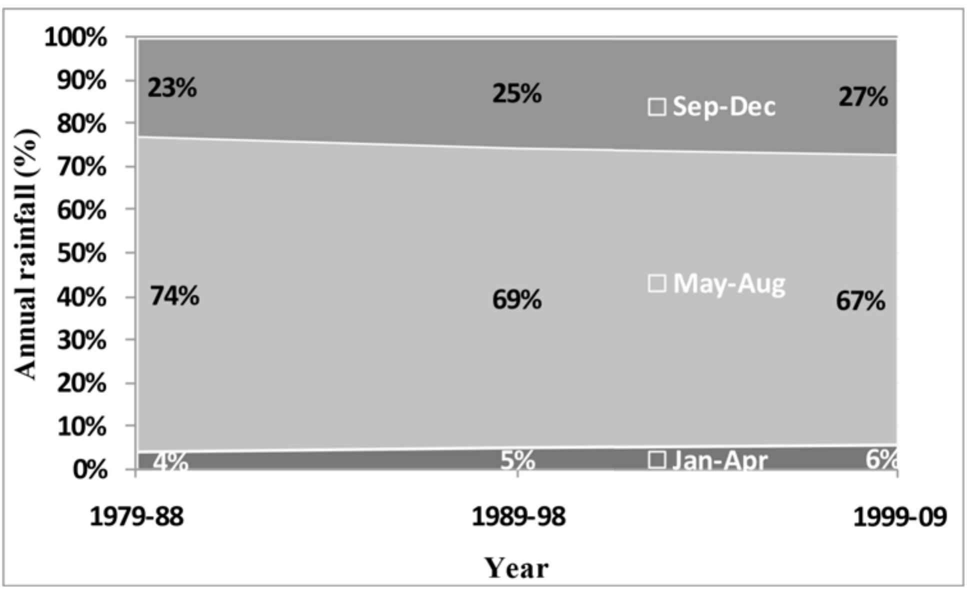

Figure 1. Shifting seasonal pattern of rainfall at Allahabad during 1979-09
Reproduced from (Ref. No 21)

7.2. *Water temperature changes in the upper stretch of river Ganga*

The annual mean minimum water temperature in the upper colder stretch of river Ganga at Haridwar during the period 1980-2009 increased by 0.99ºC (Figure 2). As a result the stretch of river Ganga around Haridwar has become a more congenial habitat for warm water fishes of the middle stretch of the river.

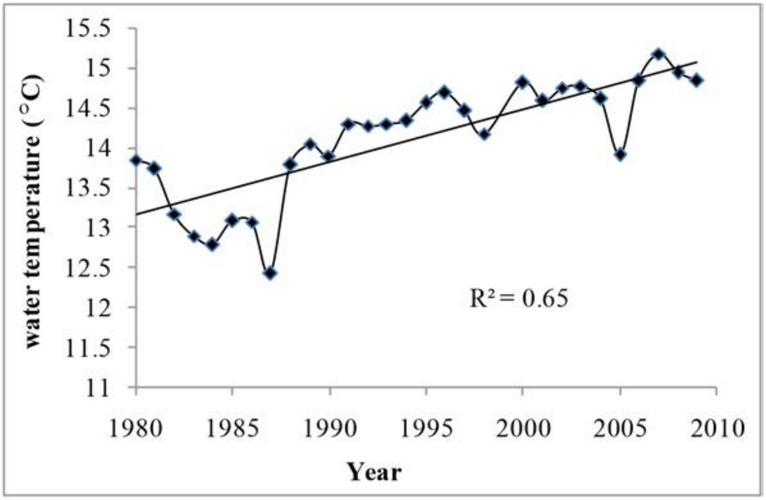

Figure 2. Annual trend in mean minimum water temperature at Haridwar (1980-2009) Reproduced from (Ref. No 21)

7.3. *Pattern of air and water temperature and rainfall changes in Gangetic plains (West Bengal)*

Temperature alteration: In India an increase in temperature is witnessed with the end of the winter months January-February through spring and finally to summer from the months of April-May. This increase in temperature is not linear but with sudden temperature increase within a short period of time. The months January to April are the transition months from winter to summer. Analysis of the air temperature data (IMD, 1980-2009) during the breeding months of the Indian carp fishes ie., (April-August) from four districts in the Gangetic plains of West Bengal, India where aquaculture hatchery farms are located indicate that the mean minimum air temperature increased by 0.67 ºC in the 24 Parganas (N) districts and by 0.1 ºC in district Bankura. The differences of temperature between the months January - February, February - March and March-April during the period 1964-09 indicated a shift towards higher temperature during Jan- Feb months. (Vass et al., 2009, Das et al., 2013)

Seasonal pattern of rainfall: Since rainfall is another important criteria that triggers the early maturation of brood fish, the rainfall data (1980-2009) of the 24 Parganas (N) collected by IIMT Pune were analysed. It showed that the proportion of annual total rainfall occurring in the monsoon months (May-August) 68% during 1980-89 gradually decreased to 63% during 1990-99 and also during 2000-09 and increased in post monsoon months (September-December) from 24% during 1980-89 to 28% during 1990-99 and 29% during 2000-09 at Dum Dum, 24 Parganas (N) (Figure 3). Similar pattern of rainfall distributions was observed at Alipore district of West Bengal during 1980-09.

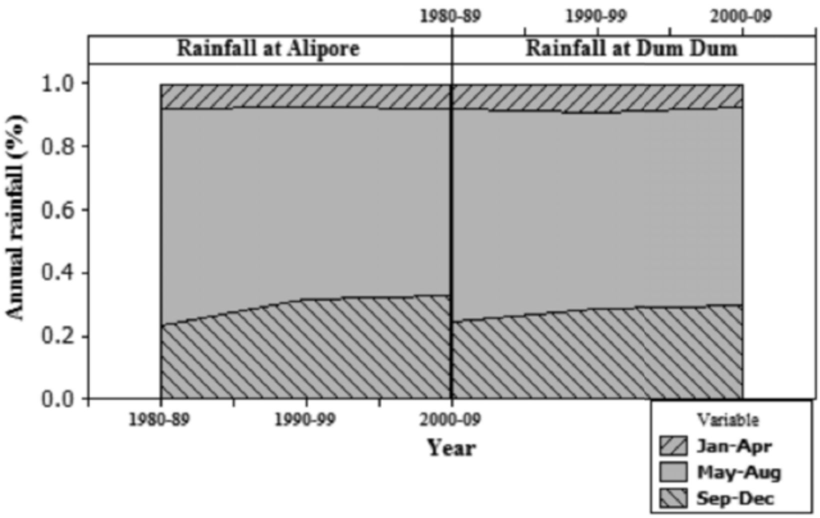

Figure 3. Shifting seasonal pattern of rainfall at Alipore and Dum Dum during 1980-2009 Reproduced from (Ref. No 21)

7.4. *Pattern of rainfall during drought in West Bengal*

Analysis of the rainfall data (IIMT Pune) of West Bengal for the period 1999-2009 indicated that during the drought year 2009 the amount of rainfall in March was 20.6mm (-25%), April - 2.0mm (96%), May - 229.2mm (+146%), June -69.6 (-71%), July - 278.7 (-11%), August -329.6 (+6%) and September - 293.9 (+9%) respectively. In the district of North 24 Parganas, and Bankura (Figure 4) rainfall during the fish breeding months (March to September) was deficient by 29%, and 27%, respectively during 2009 in comparison to the time period 1999-2008. Majority of the fish hatcheries are located in these districts.

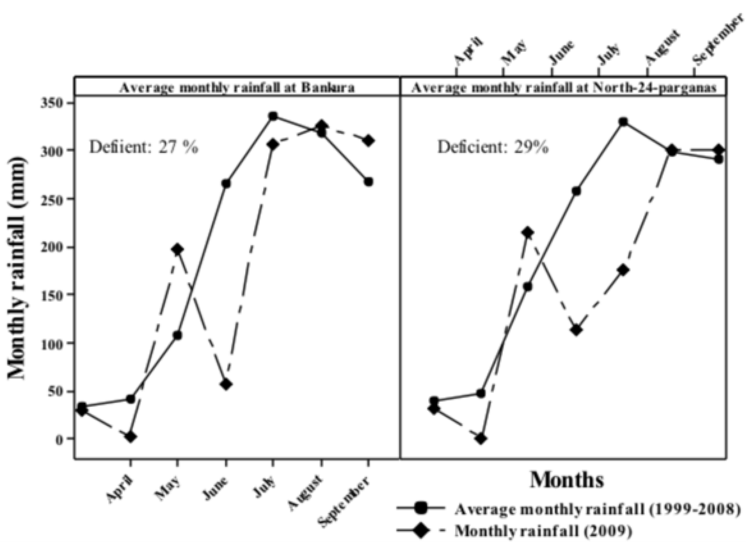

Figure 4. Averages rainfall distribution during 1999-08 compare with 2009 for deficit in rainfall of Bankura and North 24 Parganas districts of West Bengal. Reproduced from (Ref. No 21).

7.5. *Potential Impact of cyclones*

Tropical cyclones are major hazards in tropical coastal regions, both in terms of loss of life and economic damage. Such cyclones originate in the Bay of Bengal during the spring (April-May) and fall (October- November) inter-monsoon.

These cyclones with tremendous speed hit the coastline and inundate the shores with strong tidal wave, severely destroying and disturbing coastal resources. The intrusion of seawater into the upstream riverine zone through estuaries, creeks and inlets has high probability to alter the chemical composition of the inland waters.

To assess the potential impact of such extreme events like cyclones and storms in the coastal Gangetic districts of West Bengal, the district South 24 Parganas was selected for studying the impact in relation to inundation of the aquaculture areas of the district during such extreme events. The district has the highest water area under aquaculture and is the highest fish and prawn producing district in the state.

Investigations were conducted in the water areas of South 24 Parganas during the occurrence of cyclone Aila in May 2009. Due to its occurrence intrusion of saline water from the Bay of Bengal into the Hooghly- Matla estuarine system and simultaneously the agricultural fields and inland water areas close to the 81 Km coastline of the district 24 Parganas occurred. The average water salinity in the rivers Hooghly and Matla increased from 12 to 17 ppt and in the inland confined water from 8 to 23 ppt. As a result agriculture and aquaculture activities were disrupted (Das and Sharma, 2010; CIFRI/NPCC Annual Reports, 2005-2011).

Digital Elevation Model generated for the coastal areas of South 24 Parganas district showed that during cyclones at a sea level rise of 1m, 3% land area and at 2m rise in sea level 11% of land area of the district respectively will be submerged. Thus 11% land area constituting agricultural fields and aquaculture pond is highly vulnerable to the extreme events of cyclones and storms in the district (Figure 5)

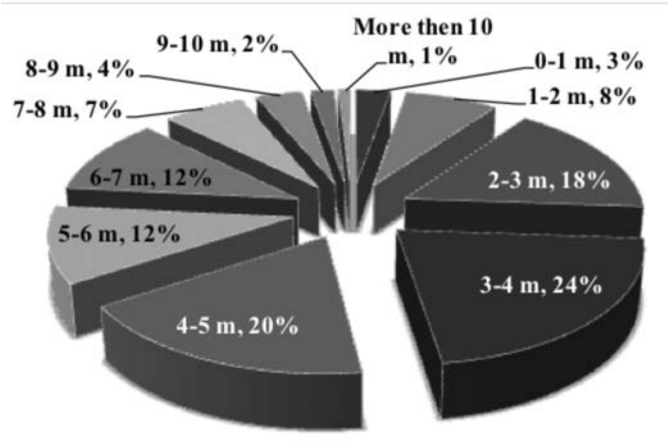

Figure 5. Land submergence (%) under different sea level rise (m) scenario South 24 Parganas Reproduced from (Ref. No 21)

7.6. *Mangroves*

The sustainability of the existing (6000 km^2) of mangroves in India may undergo major alteration in coming years due to climate change and other anthropogenic activities. Mangroves greatly help coastal protection. Mangrove loss will reduce coastal water quality, reduce biodiversity, fish and crustacean nursery habitats, adversely affect adjacent coastal habitats, and seriously affect human communities that rely on mangroves for numerous goods and services. Mangrove enhancement can augment resistance to climate change (CIFRI, NPCC, 2009).

7.7. Impact on water quality of inland aquatic resources

Eutrophication: Existing environmental problems for lakes and streams could be exacerbated by climate change. In India majority of the wetlands located in Assam, West Bengal and Bihar are in various stages of eutrophication. Changes in hydrological regimes in inland waters could exacerbated eutrophication and make stratification more pronounced and consequently impact the food webs and habitat availability and quality (Ficke *et al*., 2007), both aspects in turn could have a bearing on aquaculture activities, in particular inland cage and pen aquaculture.

7.8. *Effect on water quality and pollutants*

Warming effect has an overall effect on anthropogenic pollution. The aquatic systems are the ultimate sink of anthropogenic inputs of contaminants. Acute releases of toxic substances either by human activities or natural causes increase the mortality of fish population. The toxicity of many xenobiotics to fish is altered by changes in water temperature. Temperature alone may be a lethal factor with some thermal limits that may be altered by toxicants.

Warming effect could exacerbate the existing environmental problems for rivers and wetlands. It may change the chemical composition of water that fish inhabit; the amount of oxygen in water may decline, while pollution and salinity levels may increase. For example, water holds less oxygen at higher temperature as such fish require more oxygen as temperature rises. Indian major carps and the exotic carps cultured in India are appreciably tolerant of warm water and low oxygen conditions. Many Indian fish species of Family *Anabantidae, Heteropneustidae* and other catfishes are capable of tolerating oxygen-depleted conditions.

8. IMPACT ON INLAND FISH

8.1. *Breeding and recruitment of fish in river Ganga*

The fish spawn availability index in river Ganga declined from an average of 1529 ml during (1965-69) to an average of 568 ml in recent years (2005 to 2009) (Figure 6) (Natarajan, 1989; CIFRI Annual Report, 1965-2009). It also showed a continuing deterioration of Indian major carps seed with decreasing percentage of major carp seed where as other fish seed increased in the total seed collection.

Majority of fishes of the Ganga river system breed during the monsoon months i.e. June to August because of their dependence on seasonal floods, which inundate the Gangetic floodplain areas essentially needed for reproduction and feeding. The monthly data of rainfall from the middle stretch of the river at Allahabad from 1979-2009 revealed that the percentage of total rainfall in the peak breeding period (May-August) declined by 7% whereas it increased by 4% in the post- breeding period when resorption of eggs of Indian Major Carps sets in (Figure 1). This shift and decrease in the rainfall pattern resulting in the alteration of the required flow and turbidity during breeding season is a major factor responsible for failure in breeding and consequent recruitment of young ones of Indian major carps in the river Ganga (Das et al. 2013). An adequate flood level during the monsoon months (June-September) is required in the river Ganges for inundating the floodplains where majority of the Gangetic carps breed. This phenomenon has a close relationship with the spawn availability in river. Similar decline in availability of Asian carps spawn as a result of breeding failure due to inadequate water discharge and velocity is also recorded in Yangtse river in China (Duan et al., 2009).

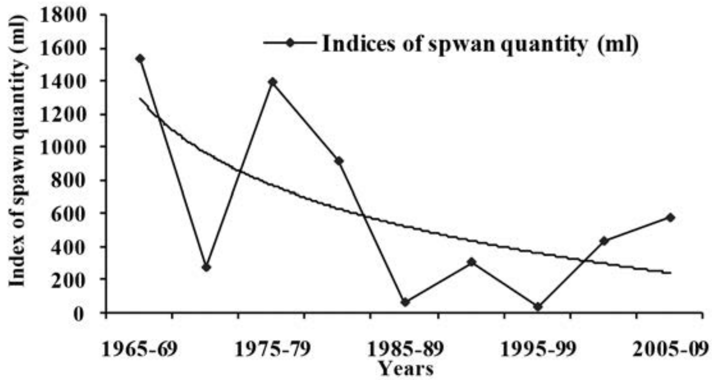

Figure 6. Indices of spawn quantity in middle stretch of River Ganga during 1965 to 2009
Reproduced from (Ref. No 21)

8.2. *Breeding of fish in aquaculture farms*

Extended breeding period: In recent years 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)*. These fishes are bred in captivity by the technique of hypophysation during the monsoon season (June- September). In recent decades the phenomenon of IMC maturing and spawning as early as March is observed. To take the specific example of West Bengal we find that the average minimum and maximum temperature throughout the state has increased and rainfall pattern has changed. Analysis of the air temperature data (1999-2009) recorded by IIMT Pune, during the maturing and breeding months of Indian fishes carps i.e., (January-April and May-September) from two districts North 24 Parganas and Bankura, West Bengal in the gangetic plains of India where aquaculture hatchery farms are located indicate that the mean maximum and the mean minimum air temperature and the mean minimum water temperature has increased and higher temperature is witnessed during colder months. Data collected from the hatcheries indicate that during 1980 the breeding of Indian Major carps started during the last week of May, whereas during recent years 2005-2008 breeding programmes in the hatcheries were initiated during mid April. As a result an extended breeding period of Indian major carps by 40-60 days with breeding season extending from 110-120 days (Pre1980-85) to 160-165 days (2000-2008) is evident in fifty fish seed hatcheries in four districts of West Bengal, India *viz*. North 24 Parganas, Bankura. (Figure 7) (Dey et al., 2007, Das et al 2013). Temperature is one of the important factors influencing the reproductive cycle in fishes. This climatic factor along with rainfall and photoperiod stimulate the endocrine glands which help in the maturation of the gonads of Indian major carp.

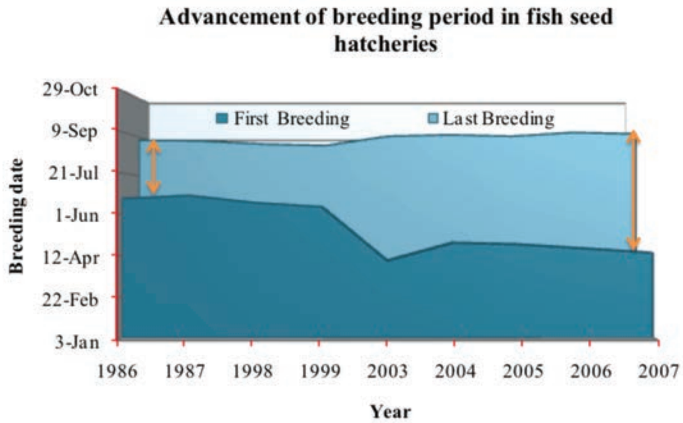

Figure 7. Advancement of breeding period in fish seed hatcheries

8.3. *Geographic distribution of fish in river Ganga*

The study conducted by CIFRI from 2005 to 2009 record presence of several species of fish in the upper stretch of river Ganga from Deoprayag to Haridwar never recorded earlier from this stretch but found in the middle warmer stretch of the river as revealed by the published records available (Menon, 1954). These are the warm water fish species *Glossogobius giuris, Puntius ticto, Xenentodon cancila* and *Mystus vittatus,* earlier available only in the middle stretch of river Ganga and are now available in the colder stretch of the river around Haridwar. Thus a perceptible shift in geographic distribution of the fishes of river Ganga has occurred in the upper colder stretch of river Ganga. At Haridwar during the period 1980-2009 the minimum water temperature increased by 0.99ºC (Fig. 2) as a result the stretch of river Ganga around Haridwar has become a more congenial habitat for warm water fishes. (Das *et al*., 2013).

8.4. *Effect on the reproductive behaviour of fish*

Investigations were conducted by CIFRI on the spawning behavior of anadromous fishes, *T.ilisha* in relation to selected climatic variables in River Hooghly. (NICRA, Annual report, 2012)

Influence of water temperature on spawning of T. ilisha : The impact of temperature on spawning behavior of *Tenualosa ilisha* was investigated by regression analysis of gonadal maturity(GSI) on water temperature.

The patterns of different stages of maturity (female *T. ilisha*) in relation to water temperature showed that the VIIth stage of maturity attained peak in the water temperature range between 30°C and 31°C (Figure 8,9). It indicated that temperature range between 29°C and 32°C could be conducive for spawning. It is suggested that forecasted temperature based on time series data could be plugged in into this model for predictive GSI for increased or decreased temperature. For example, if the projected temperature in the region lie between 29°C and 32°C the spawning will not be disturbed. Earlier studies report optimal temperature range of 26°C to 30°C for spawning of *T. ilisha.* However, the present study indicates favourable spawning temperature range up to 32°C.

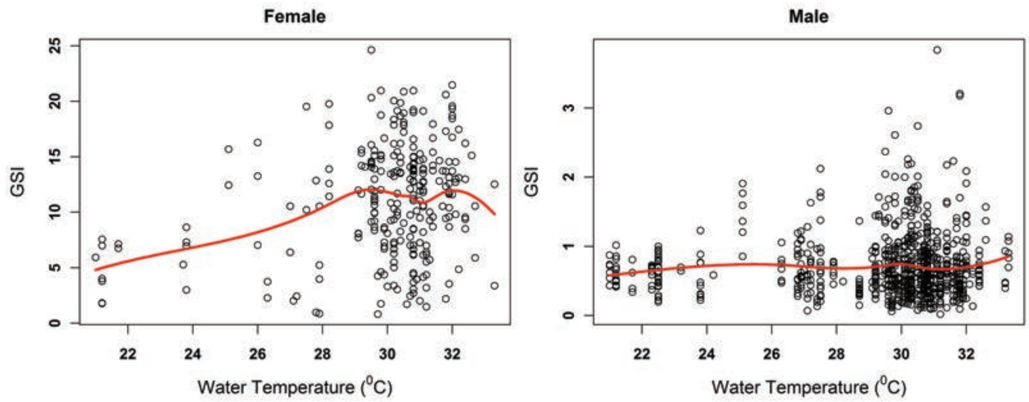

Figure 8. Relationship between GSI and water temperature

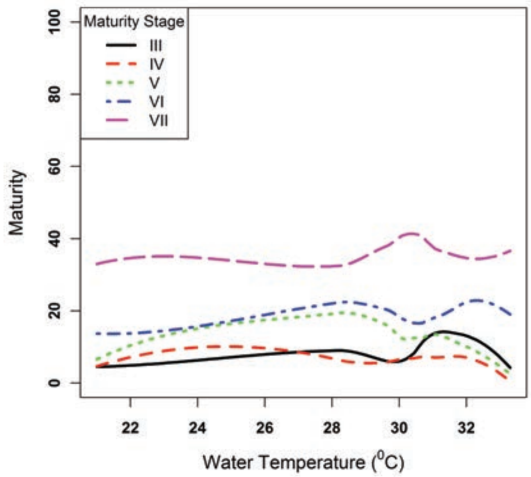

Figure 9. Relationship between maturity stages and water temperature

8.5. *Influence on the Reproductive integrity of fish*

All the stages of reproduction in fish viz., gametogenesis and gamete maturation, ovulation/spermiation, spawning and early development stages are affected by temperature. Imbalance or rapid change in temperature are stressful to fish and may also be linked with other stressors. 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. Temperature change modulates the hormone action at all levels of reproductive endocrine cascade. Investigation was conducted on *C. carpio* subjected to enhanced temperature. The optimum range of the fish is 15-32ºC and its upper critical stress range is 30-41ºC. It spawns optimally in the range of 12-30ºC.Mature female *C. carpio* fishes were subjected to an enhanced temperature of 34ºC to study the effect on the reproductive integrity of the fish. A decrease in the Gonado somatic index occurred. There was accumulation of liver and ovarian cholesterol, as a result depletion of the hormone estradiol was evident. Histology of the ovary of *C. carpio* exhibited impaired vitellogenesis in oocytes. Failure of incorporation of vitellogenin due to increased temperature (which is mainly responsible for increase in gonadal weight) has resulted in lower GSI and estradiol level in serum. (Das *et al*., 2008, CIFRI/ NPCC Annual Report 2012).

8.6. *Growth of Fish*

Water temperature strongly affects metabolism, consumption, growth fish behaviour, habitat selection, spawning, foraging, and predator-prey interaction. Previous work has shown that the growth rate potential provides a good measure of habitat quality (Tyler and Brandt, 2001) and effectively incorporates biotic and abiotic characteristics of the environment in a metric that directly relates to the fitness of fish (Brandt & Kirsch 1993; Mason *et al*., 1995).

Temperature changes will have an impact on the suitability of fish species for a given location. In temperate areas increasing temperatures could bring the advantages of faster growth rates and longer growing seasons. Investigations were conducted by Das *et al*. (2013), at CIFRI to assess the impact of unit rise in temperature on the growth of Indian Major Carp, *Labeo rohita* fingerlings reared simulating temperature rise in tropical countries in seven thermostatic aquarium for five weeks at water temperature of 29ºC, 30ºC, 31ºC, 32ºC, 33ºC, 34ºC and 35ºC. Fish reared at 34ºC water temperature exhibited a significantly ($P<0.05$) faster growth (SGR-2.36 % body weight per day) than those at other temperatures. The change in growth rates were insignificant between 29ºC, 30ºC, 31ºC and 32ºC treatment groups but growth rates significantly increased in the temperatures ranging from 32ºC to 34ºC and thereafter it decreased. Carp reared at 34ºC grew significantly faster (18.38 cg in a day) than those at 29-33ºC and 35ºC. It would take average 54-55 days for a carp to double in weight at 30ºC to 33ºC and 35ºC, but at 34 ºC it would take only 35-36 days.

A linear growth model of *Labeo rohita* fingerlings growth has been developed using the data generated. This simple growth model provides a reliable projection of growth (SGR %) with unit rise of temperature within the range of 29º to 34ºC**.**

8.7. *Fish health*

Fluctuating temperature very often disturb the homeostasis of fish and subject them to physiological stress and shift in habitat or mortality. In the climate warming scenario fishes will be subjected to the hazard of rapid temperature changes. It is more so in the tropical waters where daily variations in water temperature and thermocline in deep water bodies will assume significance. It is essential to understand that these temperatures change though sublethal, can place a stress of considerable magnitude on the homeostatic mechanism of fishes at the primary, secondary and tertiary level.

8.7.1 *High temperature*: Investigation were conducted by Das et al., 2002 on the alteration occurring in the levels of various stress sensitive blood and tissue parameters of the fish *L. rohita and Rita rita*, acclimatized at 29°c and subjected to a rapid sublethal rise to 35°c and then maintained at this temperature. The results indicated that the homeostatic mechanism of the fish is stressed. 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. Simultaneously it is observed that compensatory responses were initiated in the fishes within 72 hrs. Obviously adaptation to the stress of elevated temperature occurs. But if the stress of enhanced temperature is of chronic nature as in a climate warming scenario then the tolerance limits would be exceeded in fishes.

8.7.2 *Low temperature*: Physiological distress has been observed in cultured IMC fish at low temperature. Observation during the cold wave in Punjab when the air temperature dropped to 2-4°c and water temperature to 10-15°C the carp culture was affected. There was perceptible decline in growth and mortality in some cases (NRM division, ICAR, 2003). The physiological effect of cold shock on *Labeo rohita* was studied in the laboratory by Dutta et al., 2002. The low temperature shock at 5°C was given to juveniles of the fish for 5 min. and subsequently transferred to aquarium water of 28°C for recovery. A significant decrease occurred in anterior kidney ascorbic acid level. There was a rise in plasma cortisol within 20 min after the shock. Plasma chloride levels decreased significantly but subsequently recovered. Plasma glucose level increased due to glycogenolysis in muscle and liver. Plasma lactic acid level increased and persisted upto 24 hrs of recovery. At present *L. rohita* has acclimated to cold water aquaculture. Records show that in cold water regions the Indian major carps cannot withstand water temperature below 10 ^{0}C and do not grow at all if temperature is below 16 ^{0}C.The gradual climate changes have already started its appearance since a few decades. It is evident from the ongoing farming practices in the Uttarakhand hills (1200-1600 msl) where Indian major carps, particularly *Labeo rohita* is thriving well in the pond conditions at Pati, Champawat district, while it could 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 1.0-1.5 ^{0}C 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 (CIFRI/ NICRA, Annual report, 2012).

8.7.3 *Impact on Fish Disease:* Information regarding the correlation of climate warming with freshwater fish parasites or diseases are not available. However fishes are subjected to the hazards of rapid temperature changes in tropical waters for various reasons. These effects often become additive or synergistic with those of other adverse stimuli (e.g. low water pH, algae, oxygen storage). In a climate warming scenario the situation may be more acute. These temperature changes through sublethal can place a stress of considerable magnitude on the homeostatic mechanism of fishes, leading to infection by parasites. In India the only freshwater fish disease, which had been very menacing and virulent, was the Epizootic Ulcerative Syndrome (EUS). Environmental factors play a key role in the initiation and spread of this fish disease. The disease outbreak occurs at the time of waning of rainfall and onset of gradual stagnation and fall in water temperature. The disease outbreak throughout India occurred intensely during the decade 1990, which also coincides with one of the warmest decade of the century.

8.8. *Potential impact on Cage culture in wetlands and reservoirs*

In coming years it is expected that the utilizable land and water area will diminish and will be a major limiting factor for development of inland fisheries. Globally cage culture being a technology using water in a non-consumptive manner has been focused as an important area for enhancing fish production. But the difficulty in its wider adoption in India lies in the fact that it has not yet been widely adopted by the end users in the inland water bodies.

Factors to be considered in implementing cage culture technology in the light of potential climate alterations: In India the lentic systems (reservoirs and wetlands) where cage culture technology is projected to be implemented would be altered in a scenario of climate change. These water bodies are projected to witness increased eutrophication and produce more pronounced stratification resulting in oxygen depletion in the dawn hours and sudden changes in wind patterns and rainfall could result in upwelling bringing deep/bottom oxygen depleted waters to the surface, with adverse effects on cultured stocks and naturally recruited fish stocks in the water body (Ficke *et al*., 2007). It is therefore important that implementation of cage culture activities should consider i) the carrying capacity of each water body where cage culture practices are to be implemented ii) avoiding very shallow areas and limited water circulation zones for installing the cages.

8.9. *Impact of water scarcity*

A case study on the impact of deficient rainfall and high temperature during the drought period of 2009 on the fish seed hatcheries in two districts Bankura and 24 Parganas (N) of West Bengal was conducted by Das et al, 2011. These two districts have the capacity to produce 5604 to 13400 million spawn in a year (Hand Book on Fishery Statistics, 2009). The drought conditions in 2009 affected 92% of the fish seed hatcheries in the districts.

Impact on Spawn production and demand: The fish seed production in the district North 24 come down from 4532 million during 2008 to 4368 million spawn during 2009 (Hand Book on Fishery Statistics, W.B. 2009). The production in the hatcheries of Bankura was stable with some hatcheries forced to cease fish breeding for 20-25 days as there was no buyers (Figure 10).

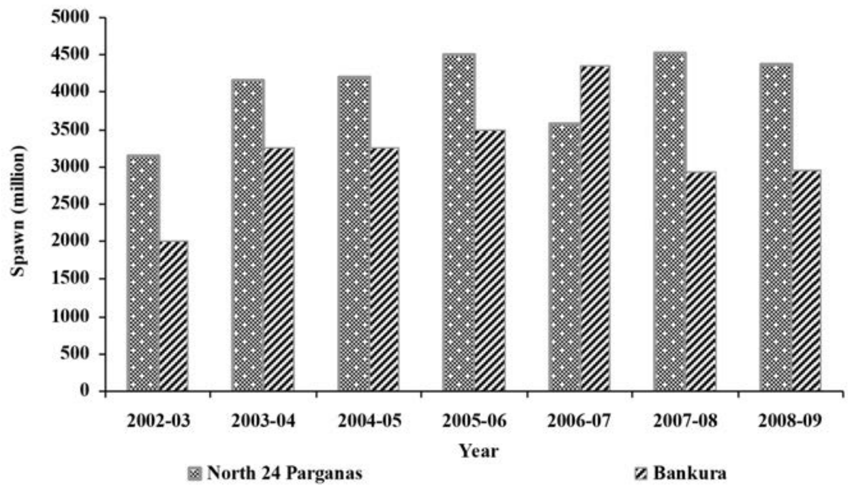

Figure 10. Fish seed production in districts of Bankura and North 24 Parganas Reproduced from (Ref. No 21)

During the drought the demand and sell price of fish seed came down drastically. As a result of scarcity of rainfall the nurseries and rearing ponds either had very little water level or were dried up completely rendering them unsuitable to stock the fish seed. During previous years 1999-2008 the price of fish seed during the months March-April was Rs. 600/bati which came down to Rs. 450-500/bati during 2009. During other season the price per (bati) ranged between Rs.220-250 previously but came down to Rs.100-120 per bati during 2009 as there were few takers.

9. DEVELOPING MODELS TO UNDERSTAND THE IMPACTS OF CLIMATE CHANGE ON INLAND FISHERIES

Time series data on inland fish catch and fish species richness on inland aquatic resources (rivers) in India are meager and scattered. Concerted effort to correlate the data on fish catch and fish species richness in the rivers with the climatic and other habitat parameters is lacking. To overcome these lacunae, projections on climate variables impact on riverine fish species were investigated by CIFRI in the 14 major rivers of India. In this investigation the variations in freshwater fish species richness were analysed in 14 major rivers of India distributed in four climatic zones of India with a macro ecological approach to identify predictors of freshwater fish species richness in rivers of India under climate change scenarios. The data of seven ecological variables related to climate of the fourteen major rivers of India for the years 1994–2009 were quantitatively analysed for determining their influence on fish species richness. A predictive model has been developed. The most influential determinants of species richness were the factors such as: surface area of the river basin (0.439) followed by fish habitat availability potential (0.326) a synthesis of the variables rainfall, discharge and sediment load. The predicted loss of fish species is evident at a 10% alteration in the ecological variables of the rivers in most of the rivers and can be useful for river planners and conservationists (Das et al 2012).

Such projections need to be developed as the first step for future analytical and empirical models, and for planning better adaptations options.

10. VULNERABILITY ASSESSMENT

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 the absence of such quantified data implementing adaptation measures is difficult.

At present studies on the assessment of vulnerability of small scale fisheries sector and fishers to climate change in the countries of Africa and South Asia are inadequate though fish forms 50 percent of the essential animal protein intake of 400 million people of this region (World Bank 2004; FAO 2007). Studies on the assessment of climate change vulnerability on fisheries sector has been done at the global level (Allison et al. (2005); McClanahan et al. (2008); Allison et al. 2009). However, vulnerability assessment at the local scale focusing impact of climate variability on the small-scale fishers of the tropical region is meager.

The definition of vulnerability as provided by the Intergovernmental Panel on Climate Change (IPCC) is “the degree to which a system is susceptible to or unable to cope with adverse effects of climate change, including climate variability and extremes”. There are three main components of vulnerability (V) as defined by the IPCC: exposure (E), sensitivity (S) and adaptive capacity (AC) having a simple relation as V= f(E, S, AC) (Metzger et al. 2005). These three components may be combined together in many ways to form relationship among themselves in a highly context-specific manner.

ICAR through the All India Network Project on Climate change (NPCC) and the National Initiative on Climate Resilient Agriculture (NICRA) has taken up the initiative to develop vulnerability maps for the agriculture and fisheries sector in India.

The first significant contribution towards development of vulnerability index and vulnerability mapping of the inland aquatic resources and fisheries to climate variability was conducted in 14 districts of the highest fish and fish seed producing state in India, West Bengal by Central Inland Fisheries Research Institute.

The study developed a vulnerability assessment framework using selected indices of climate exposure, sensitivity and adaptive capacity relevant to inland fisheries (Das et al. 2014) (Figure 11). Application of this framework showed that the differential vulnerability of inland fisheries to climate variability exhibited among the districts of West Bengal reflected different spatial combinations of climate exposure, sensitivity and adaptive capacity. The low adaptation capacity of people of Nadia, Mursidabad, East Medinipur, Howrah and Malda ranked the districts most vulnerable though moderately exposed to climate variability. Whereas, the cyclone risk coastal districts of North 24 Parganas and South 24 Parganas, where the economy of the people is significantly dependent on inland fisheries were less vulnerable (Figure 12). The relative low vulnerability scores of sensitivity components in these districts moderated their vulnerability. However, these two districts were highly vulnerable when exposed to extreme climatic conditions as evident in these districts during the devastation caused by cyclone Aila in 2009. The low adaptive capacity of the fishers in the districts limited their capacity to cope up with the extensive loss to fish production and infrastructural facility associated with such extreme climate conditions. The low adaptive capacity of the fishers was related to the homogenous livelihood pattern, less opportunity to diversify the livelihood sources and decreasing availability of natural aquatic resources. Thus the research provides a practical analytical tool to understand the contribution of the indices of the sector to climate vulnerability at district level and forms an important basis for policy makers to develop appropriate adaptation strategies to minimize the risk of fisheries sector.

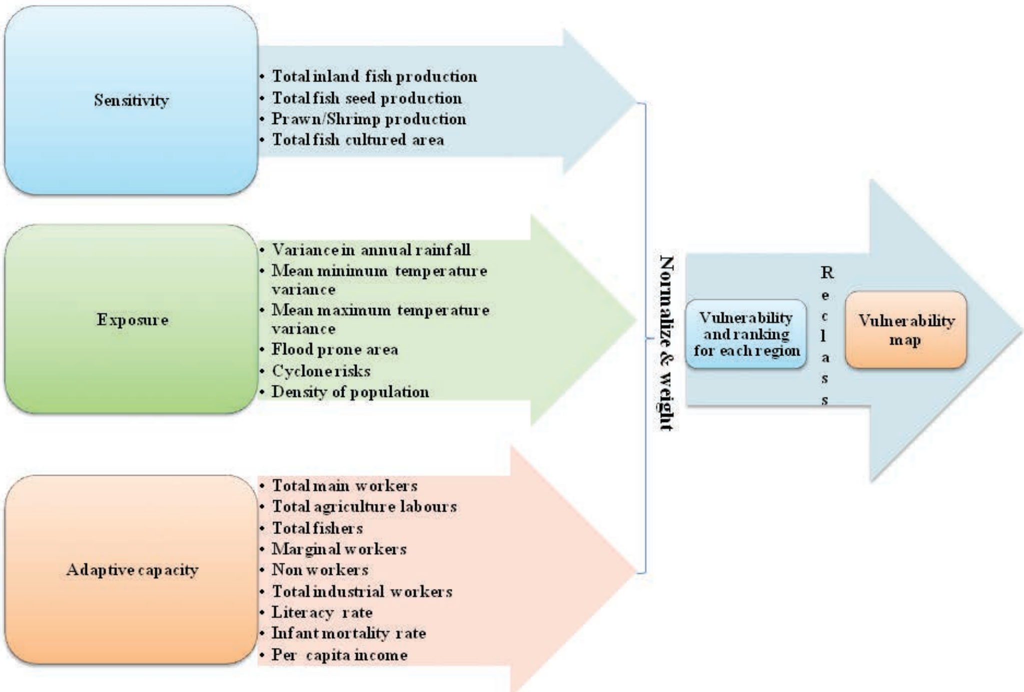

Fig.11 Construction of vulnerability Index Reproduced from (Ref. No 19)

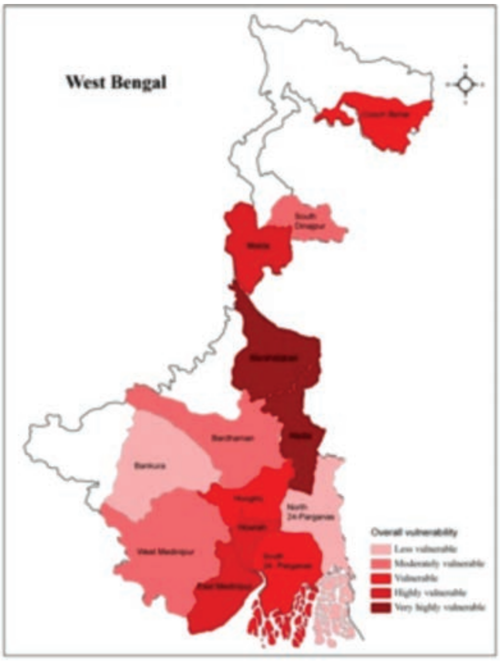

Fig 12 Mapping of vulnerability index for West Bengal based on overall vulnerability, sensitivity, exposure and adaptive capacity components. Reproduced from (Ref. No 19)

11. HOW WOULD INLAND FISHERIES COPE WITH CLIMATE CHANGE

For sustainability of the inland fisheries and aquaculture sector, climate change notwithstanding, there are several issues to be addressed. Strategies to promote sustainability and improve the supplies should be in place before the threat of climate change assumes greater proportion. While the fisheries sector cannot do much to mitigate climate change, it could contribute to reduce the impact by following effective adaptation measures. Options for adaptation are limited, but they do exist. The impact of climate change depends on the magnitude of change, and on the sensitivity of particular species or ecosystems (Brander, 2008). 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 livelihood and economic output, and ensure ecosystem safety. These objectives call for addressing the concerns arising out of climate change, and evolve adaptive mechanisms and implement action across all stakeholders at national, regional and international levels (Allison *et al*., 2004; Handisyde *et al*., 2005; Leary *et al*., 2006; WorldFish Center, 2006; FAO, 2008). Though, the international Climate Convention-related meetings continue to focus on mitigation of greenhouse gas emissions as a global public good but it is heartening to see a visible shift at present in the global discussions towards adaptation as a local public good. The adaptation options in response to the climate variations advocated by Central Inland Fisheries Research Institute for developing climate resilient and sustainable inland fisheries are elaborated below:

11.1. *Enhanced temperature*

Growth of Fish: Temperature changes will have an impact on the suitability of species for a given location. For the Indian Major Carps the growth rate increases up to 33ºC but from 34ºC and above feeding is reduced and growth diminishes.

Enhanced breeding period of fish: An extended breeding period of Indian major carps by 40-60 days is now available to farmers. This has provided opportunities to the farmers to avail of the extended breeding period in producing valuable fish seed and supplement their income

Geographical shift of fishes: A perceptible shift has been observed in geographic distribution of the warm water fish species, towards the colder stretch of the river Ganga up to Haridwar. As a result fishers would have an enhanced yield and diversity in their fish catch from the stretch.

Adaptation options

- ✍ These options can primarily be affected in the culture system as detailed:
- ✍ 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

11.2. Flood

Increased flooding may expand the number and quality of water areas available for cultivating fish. The experience during the unprecedented floods in Bihar during 2008 affecting huge loss to life, property, agriculture and fisheries showed that the post flood management measures provided opportunities to fisheries and aquaculture in offsetting some of the losses incurred by the people.

Adaptation options

Post-flood:

- ✍ The floods affected 6051 ha of fish culture areas in various districts of Bihar.
- ✍ The post flood fish seed requirement for stocking this area at the rate of 50 kg /ha of 5-10g size of fish was 300750 kg (300 t) of fish seed.
- ✍ Thus 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

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

11.3. *Intense storm surges and sea level rise*

Increased flooding may expand the number and quality of water areas available for cultivating fish. This will have wider applicability as coastal- floodplain zones expand with rising sea level and storm surges. During the cyclone *Aila* devastation in 2009 a total of more than 70% people were either made homeless or had their livelihoods disrupted. Damages included loss of income, destruction to fish ponds, bheries and gear, as well as other assets. Fishers were totally dependent on fishing and wild fish seed collection from natural resources as the only source of income.

Adaptation options

Post ingress:

- The ingressed saline water inundated paddy fields which became unfit for agriculture. These areas 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-ingress

- 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 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

11.4. *Drought*

During the drought prevailing in West Bengal in 2009, the deficit in rainfall was within the range of 25% and 37% during the fish breeding months (April to Sept) in districts of Bankura and N 24 Parganas. respectively compared to previous years. This has created a situation of water scarcity in fish rearing and culture ponds of West Bengal. Breeding commenced in the month of March but the total number of successful days were restricted to 98 during 2009 in comparison to 150-155 days in previous years .The total fish spawn production came down to 40 lakhs/100 kg fish brooders from 130-140 lakhs/100kg in fish seed hatcheries in Bankura.

Adaptation options

Pre-drought

? 80 % of the hatcheries affected by drought condition diverted from rearing Indian Major Carps to other fish species like Pangasius (*Pangasius sutchi*), *Puntius javanicus* and *C. garipenus*, which favourably adapt to water stress and high temperature condition.

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.
- Increasing infrastructure sophistication of hatcheries for assured seed production of 34,000 million carp fry, 8000 and10000 million scampi and shrimp PL respectively.

11.5. *Water stress*

Prediction for water availability as a result of climate change in India indicates water stress in coming years. This would result in decreasing water availability in the major river basins of India. The Gangetic plains and delta are regions of significant aquaculture activity contributing to income and providing livelihood to thousands of fishers. Thus judicious use of this primary resource is of topical importance for sustaining fisheries and aquaculture in reservoirs, wetlands and other ponds and tanks. The comparative water needs for unit production are given below:

Table 1. Specific water demand (m3/t) for different animal food products* and comparison with needs for aquaculture

Product	Water demand
Beef, mutton, goat meat	13 500
Pig meat	4 600
Poultry	4 100
Milk	790
Butter + fat	18 000
Common carp	
(Intensive/ponds) a	21 000
Tilapia (extensive/ponds) a	11 500
Pellet fed ponds b	30 100

Source: *data from Zimmer and Renault, 2003

Pond aquaculture when practiced for culturing shrimp and carnivorous finfish species is water consuming. Other enhancement technologies such as cage culture which is totally non-water consuming, except for the need for feeds should be encouraged.

Adaptation options

- 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 m^2) of seasonal nature (1-4) months can be used for rearing /culture of appropriate species of fish/prawn
- Increasing infrastructure sophistication of hatcheries for assured seed production of 34,000 million carp fry, 8000 and10000 million scampi and shrimp PL respectively

11.6. *Carbon sequestration*

Aquaculture in India and in other Asian countries is predominantly dependent on fish species (carps) feeding low in the food chain and act as carbon sink and aid in carbon sequestration. Aquaculture of Indian and exotic carp uses minimal industrial energy but has a potential significance in the carbon cycle, fixing CO_2 through phytoplankton. Aquaculture thus has the scope of alternative practices being adopted in response to climate change and reduces the sectors contribution to GHG emission.

Adaptation options

Adoption of simple techniques of providing a suitable and/or enhanced food source(s) for cultured stock through measures to increase phytoplankton and periphyton growth could be a major energy saving measure.

Periphyton-based practices have developed independently and are used to catch fish in open waters in various parts of the world. In I*ndia (West Bengal)* the practice is known as *Komor* or *Huri*, in Bangladesh it is called *Katha*, in West Africa *Acadja*, and in Cambodia *Samarahand*. In West Bengal the practice is essentially fixing vertically unused bamboo sticks, tree branches to act as substrates for colonization by the plankton, microbes, invertebrates and other organisms that make up periphyton, in the various household tanks so commonly found in the rural areas. The farmers in this part of India and Bangladesh traditionally believe that *shaola* (periphyton) growing on the substrate form food for the fish and serve as protection against poaching of fish. Indian major carps are grown in these ponds for fish culture to sustain the rural population. In Bangladesh the best result has been achieved if the surface area of the substrate is equal to approximately 50-100% of the pond's surface area. The technology seems to hold promise for the farming of any herbivorous fish, which is capable of harvesting periphyton from substrates.

11.7. *GIS mapping for vulnerability assessment*

Assessment of coastal areas: For assessing the impact of cyclones preparation of Digital Elevation maps of the susceptible coastal areas of the country is essential. Digital Elevation Map on coastal areas of South 24 parganas frequently impacted by cyclones was generated by CIFRI. It is observed that 3% land will be submerged in case of 1m sea level increase. But it is also observed due to cyclonic sea ingress upto 2m agricultural fields and aquaculture pond are affected. A total of 11% area of South 24 Parganas is highly vulnerable to cyclonic events.

Adaptation options

Salinity intrusions that render areas unsuitable for agriculture, particularly for traditional rice farming, could provide additional areas for culturing valued shrimps and other estuarine fish species. If these shifts are to be made, major changes in the supply chains have to be adopted at the national level.

Sea level rise and saline water intrusion will also impose ecological and habitat changes, including mangroves that act as nursery grounds for many euryhaline species. Mangrove enhancement measures should be undertaken on a priority basis in the affected coastal areas for developing resilience to cyclone impact.

12. DEVELOPMENT OF A UNIFIED STRATEGY

It is important to understand that climate change adaptation needs to be considered in the broader context of environmental and social change. While some of the impacts of climate change to particular areas water resources, and consequently, to ecosystems and livelihoods are expected, particularly in the long term. At the same time several other anthropogenic impact for example, construction of a dam on the river or cutting down of mangrove forests are likely to induce changes in the area, often within a much shorter time scale. There is thus a need for integrated assessment of different changes impacting water resources and environment at multiple spatial scales instead of separate assessments focusing merely on climate change or, for that matter, on hydropower development, irrigation, land use changes and so forth.

Throughout their history people have responded to changes, first and foremost, in the spatial context of their social and environmental conditions. However, as the different sectors are threatened differently by climate risks, they are responding differently to the climate change impacts. For example, negative impacts on aquatic ecosystems and fisheries can be further aggravated by human adaptation to changes in climate .A specific example is the demand of water for irrigation by farmers. For adaptation to the increased demand for irrigation water the supply side option will aim at increasing supply. Increasing the water source for irrigation is expensive and has the potential environmental impacts. The demand side options on the other hand aim at reducing demand. They include increasing irrigation efficiency through improved technology and higher prices for water, and changes in cropping pattern by switching to crops that require less or even no irrigation. So a variety of options are available; influences on the aquatic ecosystem and fisheries sector would depend on the details of such choices. The demand side options in most cases would appear to be better choices for those interested in conserving the aquatic ecosystem and fisheries.

13. FUTURE DIRECTIONS AND RECOMMENDATIONS

To improve our ability to project the implications of climate change for inland fisheries in India, key biophysical, social and economic knowledge gaps need to be addressed.

First, there is a level of uncertainty regarding the physical and biogeochemical changes anticipated in the Indian waters. Large number of experts has opined that Global Climate Models such as those used by the IPCC perform poorly at regional and sub-regional scales, and there is a need to improve such models, and their coupling with the dynamics of inland freshwaters.

Second, we need to understand better the transfer of primary productivity to fish and fisheries and the potential impacts of climate change on the productivity of a range of inland ecosystems. There is insufficient understanding of the links between projected climate change, environmental responses, fish stock and aquatic ecosystem responses,

Third, we must improve our understanding with regard to evolutionary adaptation and behavioral responses to changed climatic conditions, and the indirect effects on the interactions between species in inland food webs.

Fourth, Understanding the response and adaptation capacity of fishing and fishers to the physical and biological changes. At present few, studies have specifically looked at the socio-economics of the Indian fisheries sector in relation to climate change. Exploring the synergistic dual exposure of inland aquatic ecosystems to climate change and other anthropogenic activity appears essential for effective adaptation and mitigation options to be developed. Addressing these knowledge gaps will clearly require both interdisciplinary and within-discipline studies.

It is felt that the following areas require appropriate intervention of research programmes i) A lack of appropriate methodology and limited availability of appropriate data for vulnerability assessment to identify priority areas for action. *Improving parameterisation of 'risk exposure' to climate change viz., projected changes in precipitation, storm and flood frequencies (based on historic observations), and sea level rise ii) Improving parameterisation of sensitivity and adaptive capacity using regional demographic data to refine some of the indices of sensitivity and adaptive capacity currently calculated at national level iii)* Gaps in scientific knowledge should not delay climate change mitigation and adaptation policy actions. Thus, it is important to develop adaptation policies for the inland fisheries sector, which could be updated and adapted as new knowledge emerges. There are various 'no-regret' policies which have large co-benefits for other ecosystem services iv) There is a general consensus among scientists that human impacts on inland aquatic ecosystems through overfishing, habitat destruction, pollution, etc. reduce adaptive capacity of the ecosystems and organisms to climate and other environmental changes. Fishing threatens some of the unassessed stocks, particularly species that are vulnerable to exploitation such as carps and hilsa. Recovery of depleted fisheries stocks depends largely upon reducing fishing effort to allow existing year classes to survive to maturity. By rebuilding over-exploited fish populations and ecosystems, and improving habitat quality for inland organisms, society and the fishing industry would gain from more productive fish stocks, higher biodiversity and higher resilience and adaptive capacity to climate change v) Improving education and communication within the inland fisheries industry and with other stake holders about climate change could be important for effective implementation of climate change mitigation and adaptation policies. Such measures would allow the fisheries industry to develop capacity and to respond effectively to threats or opportunities posed by climate change.

The most feasible ways to build adaptive capacity at the local level in India are essentially the same as those needed for example in livelihood diversification and, more generally, in poverty reduction and sustainable development. Enhancing climate change adaptation should therefore build on these initiatives, and integrate climate change needs with the routine policies, measures and activities which are undertaken by the government and different stakeholders as a part of the sustainable development priorities of India thereby contributing to climate goals at little or no cost.

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