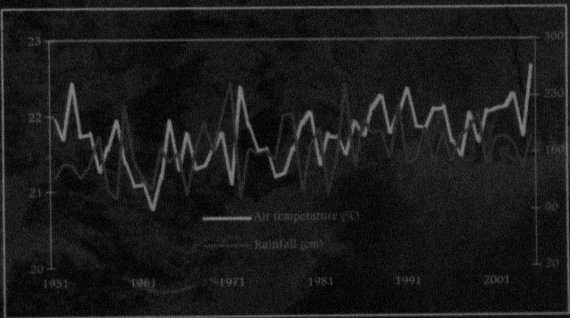
Impacts and Adaptation of Inland Fisheries to Climate Change in India



Central Inland Fisheries Research Institute
(Indian Council of Agricultural Research)
Barrackpore, Kolkata - 700120, West Bengal

भाकृअनुप
ICAR

Impacts and Adaptation of Inland Fisheries to Climate Change in India

Manas Kr. Das

&

P. K. Saha

Bull. No. -151 November - 2008

Central Inland Fisheries Research Institute

(Indian Council of Agricultural Research)

Barrackpore, Kolkata - 700120, West Bengal

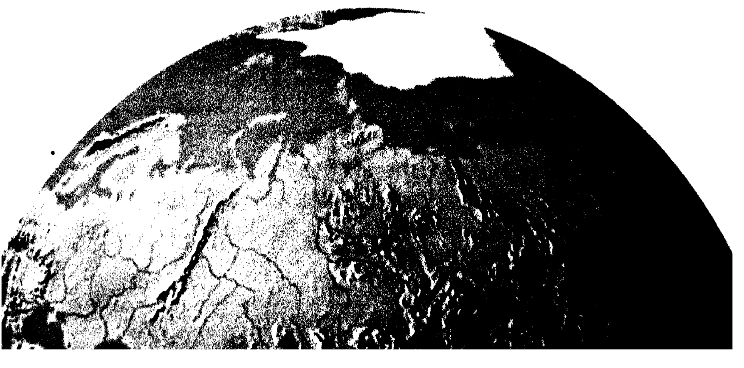
Impacts and Adaptation of Inland Fisheries to Climate Change in India

Manas Kr. Das
P. K. Saha

ISSN 0970-616X

Published by :
Director,
CIFRI, Barrackpore

Printed at
Eastern Printing Processor
93, Dakshindari Road, Kolkata - 48



Foreword

The recent scientific researches indicate that global warming is significantly alterring the life support systems on earth. The causative factors for such a situation are the green house gases viz., carbon-dioxide, methane, ozone and nitrous-oxide. These green house gases have resulted in warming of the climate by 0.74°C between 1906 - 2006. India has also been influenced by this global climate change as manifested by the rise in surface temperature, regional monsoonal variations, frequent occurrence of extreme weather events, rise in sea level and melting of the Himalayan glaciers.These changes are affecting the inland aquatic resources as manifested by increase in water associated temperature, changing flow pattern of rivers and wetlands, thereby impacting inland fisheries. As a result a perceptible alteration in the geographic distribution of fishes in river Ganges including spawning behaviour of the Indian major carps have been noticed. It is important that concerted effort be initiated to study the impact of climate change on inland fisheries and develop a strategic plan to mitigate any likely impacts on inland fisheries. An attempt has been made by the authors to document the present knowledge on the subject world wide and from the investigations carried out by CIFRI, under an ICAR Network Project on this important thrust area for XI plan.

K. K. Vass
Director
CIFRI

Acknowledgements

The authors are greatful to Dr. K. K. Vass, Director, CIFRI, Dr. S. Ayyappan, DDG(FY), ICAR and Dr. P. K. Aggarwal, National coordinator, ICAR project on climate change and Dr. M. K. Mukhopadhyay for their keen interest and help rendered in the work. The authors record their thanks to Shri P. K. Srivastava, S. Dey, M. L. Mondal and Sampat Majhi for their assistance.

Contents

IMPACTS AND ADAPTATION OF INLAND FISHERIES TO CLIMATE CHANGE IN INDIA

Manas Kr. Das and P.K. Saha

Introduction

The earths climate is showing perceptible changes on both gobal and regional scale. Climate change and its warming effects are now being felt across many parts of the world including India. In a developing country like India, climate change could represent an additional stress on ecological and socioeconomic systems that are already facing tremendous pressures due to rapid urbanization and economic development.With its huge and growing population and low-lying coastline, and an economy that is closely tied to its natural resource base, India is considered vulnerable to the impacts of climate change.This change of climate on a global and regional scales has started since the pre- industrial era. The unequivocal warming of the climate system is now evident. A diagrammatic representation of the changes that occur leading to global warming is depicted

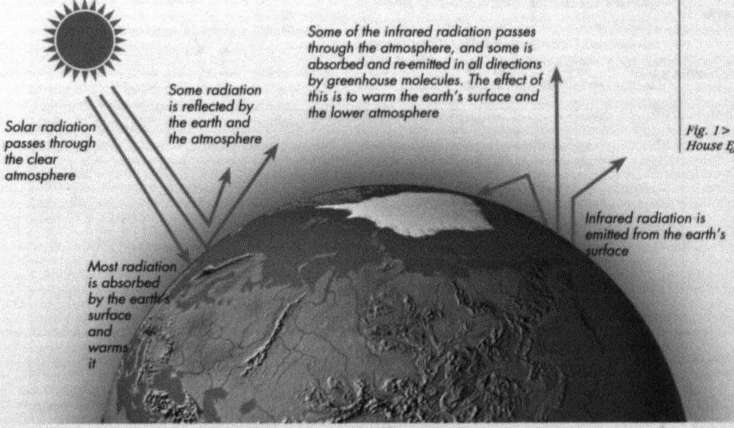


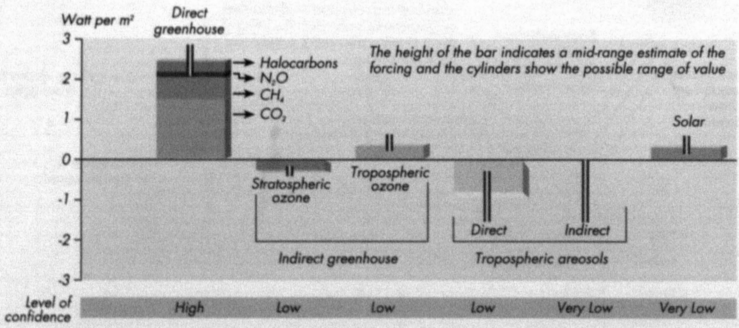
Fig. 1> The Green House Effect

Changes in the atmospheric abundance of green house gases (Carbon dioxide, Methane, Nitrous Oxide, CFCs, Ozone) and aerosols(primarily sulphate, organic carbon, black carbon, nitrate and dust), in solar radiation and in land surface properties alter the energy balance of the climate system. These changes are expressed in terms of radiating force, which is used to compare how a range of human and natural factors drive warming or cooling influences on global climate. Since the third Assessment Report (TAR), new observations and related modeling of greenhouse gases, solar activity, land surface properties and some aspects of aerosols have led to improvement in the quantitative estimates of radiative forcing. Increasing concentrations of the greenhouse gases and other trace gases have changed the radiative forcing of the atmosphere leading to a net warming .

Inter-Governmental Panel on Climate Change (IPCC) in its recently released report has reconfirmed that the global atmospheric concentrations of carbon dioxide, methane and nitrous oxide, greenhouse gases (GHGs), have increased markedly as a result of human activities since 1750 and now far exceed pre-industrial values determined from ice cores spanning many thousands of years (IPCC, 2007a). The CO2, methane and nitrous oxide concentrations in atmosphere were 280 ppm, 715 ppb and 270 ppb in1750 AD. In 2005, these values have become 379 ppm, 1774 ppb and 319 ppb, respectively (IPCC, 2007a). The increase in GHGs was 70% between 1970 and 2004. The global increases in carbon dioxide concentration are due primarily to fossil fuel use and land use change, while those of methane and nitrous oxide are primarily due to agriculture.

These increases in GHGs have resulted in warming of the climate system by 0.74°C between 1906 and 2005. Eleven of the last twelve years (1995-2006) rank among the 12 warmest years in the instrumental record of global surface temperature (since 1850). The rate of warming has been much higher in recent decades. This has, in turn, resulted in increased average temperature of the global ocean, sea level rise, decline in glaciers and snow cover. There is also a global trend for increased frequency of droughts, as well as heavy precipitation events over most land areas. Cold days, cold nights and frost have become less

Fig. 2> The Radiative Forcing



Source : Climate change 1995, The science of climate change, contribution of working group 1 to the second assessment report of the Intergovernmental panel on climate change, UNEP and WMO, Cambridge University Press, 1996.

frequent, while hot days, hot nights and heat waves have become more frequent.

2. Evidence of Climate Change

Some observed changes in climate parameters in India has been consolidated by India's Initial National Communication, 2004 (NATCOM) to UNFCCC . Some of the changes of relevance to inland fisheries are described below:

• **Surface Temperature** : At the national level, increase of - 0.4° C has been observed in surface air temperatures over the past century.

• **Rainfall** : While the observed monsoon rainfall at the all-India level does not show any significant trend, regional monsoon variations have been recorded. A trend of increasing monsoon seasonal rainfall has been found along the west coast, northern Andhra Pradesh, and north-western India (+10% to +12% of the normal over the last 100 years) while a trend of decreasing monsoon seasonal rainfall has been observed over eastern Madhya Pradesh, north-eastern India, and some parts of Gujarat and Kerala (-6% to -8% of the normal over the last 100 years).

• **Extreme Weather Events** : Trends are observed in multi-decadal periods of more frequent droughts, followed by less severe droughts. There has been an overall increasing trend in severe storm incidence along the coast at the rate of 0.011 events per year. While the states of West Bengal and Gujarat have reported increasing trends, a decline has been observed in Orissa. Goswami et al,2006 by analysing a daily rainfall data set, have shown a rising trend in the frequency of heavy rain events.

• **Rise in Sea Level** : Using the records of coastal tide gauges in the north Indian Ocean for more than 40 years, Unnikrishnan and Shankar, 2007 have estimated, that sea level rise was between 1.06-1.75 mm per year. These rates are consistent with 1-2 mm per year global sea level rise estimates of IPCC.

• **Impacts on Himalayan Glaciers** : The Himalayas possess one of the largest resources of snow and ice and its glaciers form a source of water for the perennial rivers such as the Indus, the Ganges, and the Brahmaputra. Glacial melt may impact their long-term lean-season flows, with adverse impacts on the economy in terms of water availability and hydropower generation. The available monitoring data on Himalayan glaciers indicates that while recession of some glaciers has occurred in some Himalayan regions in recent years, the trend is not consistent across the entire mountain chain. It is accordingly, too early to establish long-term trends.

3. Impact on Aquatic Ecosystems

Fresh water is a finite resource and the basic amount of fresh water supply provided by the hydrological cycle does not increase. Water anywhere on the planet is an integral part of the global hydrologic cycle. A rise in average temperature in mountainous regions can alter the precipitation mix between rainfall and snowfall, with substantial increases in precipitation coming down as rain and a reduction in the amount coming down as snow. This change means more flooding and more runoff during the rainy season, but also less water held as snow and ice in the mountains for use in the dry season. Some of the changes in the hydrologic system (Arnell et al. 2001) that are relevant to fish and 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. This is evident in the USA where an increase in the proportion of annual precipitation associated with extreme has been occurring since the early 1900s across U.S.A and future scenarios (Kunkel & Andsagan 2001) suggest that this will continue into the future.

India is considered rich in terms of annual rainfall and total water resources available at the national level. However, these resources are unevenly distributed and result in spatial and temporal shortages, hence limiting availability across regions. Climate change and variability are likely to worsen the existing situation by further limiting water availability. Under a changed climatic regime for any given region, the combined effect of rainfall and more evapouration would have dire consequences. Both these would lead to less runoff, substantially changing the availability of freshwater in the watersheds. Also, potential changes in temperature and precipitation might have a dramatic impact on the soil moisture and aridity level of hydrological zones. With changes in the flows, annual runoff, and ground water recharge, water available for usage will further be decreased.

3.1 Rivers

The projections of water balance components for the 12 river basins of India Table 1 (IINC) depicts the comparison of water balance components expressed as percentage of rainfall for control as well as Climate Change Scenarios. It is observed that the impacts are different in different catchments. The increase in rainfall due to climate change does not result in an increase in the surface run-off as may be generally predicted. For example, in the case of the Cauvery river basin, an increase of 2.7 per cent has been projected in the rainfall, but the run-off is projected to reduce by about 2 per cent and the evapotranspiration to increase by about 2 per cent. This may be either due to increase in temperature and/or change in rainfall distribution in time. Similarly, a reduction in rainfall in the Narmada is likely to result in an increase in the run-off and a reduction in the evapotranspiration that is again contrary to the usual myth. This increase in run-off may be due to intense rainfall as a consequence of climate change. Therefore, it is important to note here that these inferences have become possible since a daily computational time step has been used in the distributed hydrological modeling framework. This realistically simulates the complex spatial and temporal variability inherent in the natural systems. It may be observed that even though an increase in precipitation is projected for the Mahanadi, Brahmani, Ganga, Godavari, and Cauvery basins for the Climate Change Scenario, the corresponding total run-off for all these basins has not necessarily increased (Table1). For example, the Cauvery and Ganga show a decrease in the total run-off. This may be due to an increase in evapotranspiration on account of increased temperatures or variation in the distribution of rainfall. In the remaining basins, a decrease in precipitation is projected. The resultant total run-off for the majority of the cases, except for the Narmada and Tapi, is projected to decline. As expected, the magnitude of such variations is not uniform, since they are governed by many factors such as land use, soil characteristics and the status of soil moisture. The Sabarmati and Luni basins are likely to experience a decrease in precipitation and consequent decrease of total run-off to the tune of two-thirds of the prevailing run-off. This may lead to severe drought conditions under a future Climate Change Scenario. The vulnerability of water resources has been assessed with respect to droughts and floods. Rainfall, run-off and actual evapotranspiration have been selected from the available model outputs, since they mainly govern these two extreme impacts due to climate change.

Table 1 : Comparison of change in Water Balance Components as percentage of rainfall

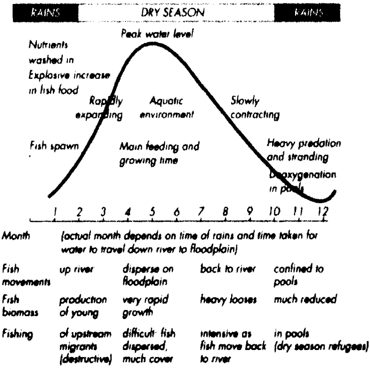
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Cauvery	Control	1309.0	661.2	50.5	601.6	46.0
	GHG	1344.0	650.4	48.4	646.8	48.1
Brahmani	Control	1384.8	711.5	51.4	628.8	45.4
	GHG	1633.7	886.1	54.2	698.8	42.8
Godavari	Control	1292.8	622.8	48.2	624.1	48.3
	GHG	1368.6	691.5	50.5	628.3	45.9
Krishna	Control	1013.0	393.6	38.9	585.0	57.7
	GHG	954.4	346.9	36.4	575.6	60.3
Luni	Control	317.3	15.5	4.9	316.5	99.7
	GHG	195.3	6.6	3.4	207.3	106.1
Mahanadi	Control	1269.5	612.3	48.2	613.5	48.
	GHG	1505.3	784.0	52.1	674.1	44.8
Mahi	Control	655.1	133.9	20.4	501.0	76.5
	GHG	539.3	100.0	18.5	422.7	78.4
Narmada	Control	973.5	353.4	36.3	586.8	60.3
	GHG	949.8	359.4	37.8	556.6	58.6
Pennar	Control	723.2	148.6	20.6	556.7	77.0
	GHG	676.2	110.2	16.3	551.7	81.6
Tapi	Control	928.6	311.2	33.5	587.9	63.3
	GHG	884.2	324.9	36.7	529.3	59.9
Ganga	Control	1126.9	495.4	44.0	535.0	47.5
	GHG	1249.6	554.6	44.4	587.2	47.0
Sabarmati	Control	499.4	57.0	11.4	433.1	86.7
	GHG	303.0	16.6	5.5	286.0	94.4

(Source: IINC, Ministry of Environment and Forest,2004)

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., snowmelt) 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. The range and variability of flows are just as important as the volume of water within a system. Flows also differ in their seasonal flow patterns, size and frequency, duration and the rate of rise and fall of a flow event. Changes in any of the flow characteristics are marked by a reduction in habitat complexity and the diversity of plants and animals. River flows interact with ground waters which may be recharged or contribute to the river flow (discharge) at different times of the year.

Further, flow variability directly affects many life cycle stages of fish; for example,flooding or its receding serves as a cue for migration and spawning as shown in figure 3 below. (Source: Brij Gopal, 2005)

Fig. 3 > Effect of flood and seasonal flow variation on fishes



3.2 Wetlands

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. Thus, riparian zone and the floodplain are important riverine habitats; they form a critical link between terrestrial and aquatic ecosystems.

Thus the 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 the fishery resources.

The open water wetlands that are critical habitat of many species would be replaced by damp land although some form of vegetation would remain there. Lower water table would also leave some areas that currently have some form of wetland vegetation, dry for a longer period that would reduce biological productivity and in some cases would leave the land too dry to consider it as a wetland. A drier climate would also force farmers to increase the irrigation, which also reduce the water table.

3.3 Water Quality and pollutants

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.

3.3.1 Dissolved oxygen

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 (Table 2) Many other Indian fish species of Anabantidae ,Heteropneustidae and other catfishes are capable of tolerating oxygen depleted conditions.

Table 2

Fish species	Lethal Dissolved Oxygen mg/l
Catla catla	0.7
Labeo rohita	0.7
Cirrhinus mrigala	0.7
Hypopthalmicthys molitrix	0.3 – 1.1
Ctenopharyngodon idella	0.2 – 0.6
Cyprinus carpio	0.2 – 0.8

(Source : Varga and Chowdhury, 1992)

3.3.2 Eutrophication

Existing environmental problems for lakes and streams could be exacerbated by climate change. The potential interactions between climate change and traditional problems such as eutrophications and toxic substances are practically unexamined. They are briefly mentioned in some of the literature (Magnuson et al. 1997; Schindler 1997), but the available literature is meagre. Increases in more intense rain events and winter rain events should increase runoff and increase external loading (increasing apparent eutrophication); reduction in precipitation should reduce runoff and reduce external phosphorus loading (decreasing apparent eutrophication).

3.3.3 Effect of pollutants

Global warming is thought to be an overall effect of anthropogenic pollution. The relative toxicity of a typical pollutant such as the heavy metal copper is strongly found to be temperature dependent. The incipient lethal level for copper to brown trout was 0.47 μmol l^{-1} at 5°C and 0.08 μmol l^{-1} at 5°C (Beaumont et al., 1995). Various effect of copper were seen in fishes like structural damage to gill epithelia by severe copper exposure (Kirk & Lewis, 1993; Taylor et al., 1996) and disruption of the ion regulation. Sub-lethal exposure of copper at all concentration together with all temperature combinations caused less severe damage but the changes in the winter trout exposed to 0.47 μmol l^{-1} copper were quite substantial. These winter trout showed decline in swimming performance; only one out of six fish tested swam steadily at the lowest test speed of 0.3 m s^{-1}. The other swam only for 5-6 minute with burst and glides. However, they displayed no ability for aerobic exercise and they retained some capacity for anaerobic 'burst' swimming. This observation strongly suggests the effect of copper/acid exposure is on aerobic exercise.

4. *Impact on fish population*

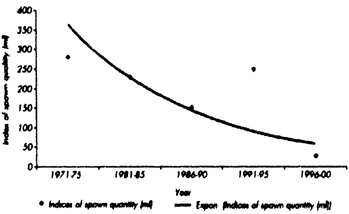
4.1 Breeding and recruitment of fishes in rivers

The Indian Major carps (IMC) constitute the most important fish species for inland fish production from the rivers and confined water bodies. IMC breed naturally in the rivers while in confined waters where aquaculture is practised it is bred artificially by hypophysation. The impact of climate change on the breeding of IMC has been different in the two aquatic ecosystems.

Time series data on various climate variables and inland fisheries related to the Ganges river system viz. water temperature, current velocity, rainfall, plankton availability, availability of spawn, fish landings etc. were collected consulting approximately 200 scientific papers. The data were analysed and compared with the present data collected through the ICAR Network Project on Impact, Adaptation and Vulnerability of Climate Change to Agriculture to evaluate the impact if any on inland fisheries (Annon, 2008).

River Ganges : The fish spawn or seed availability of Indian Major Carps (IMC) has declined in the middle stretch of river Ganges over the years. The failure of recruitment of young ones to the system is because of failure in breeding of the IMC. The fish spawn availability index declined from 281.03ml during 1970s to 27ml in recent years (1996 to 2000). It also showed a decreasing percentage of major carp seed (78.62% in 1961-1965 to 34.48% in 2000-04) where as minor carps increased (from 20.68% in 1961-65 to 52.95% in 1991 to 1995) and other fish seed showed an increasing percentage (from 0.7% in 1961-65 to 47.8% in 2000-04) in the total seed collection.

FIG. 4 > Indices of spawn quantity of Ganga river system during (1971-00)



Majority of fishes of the Ganges 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. A decrease in precipitation during the breeding months alter the required flow and turbidity of the water essential for breeding of IMC.

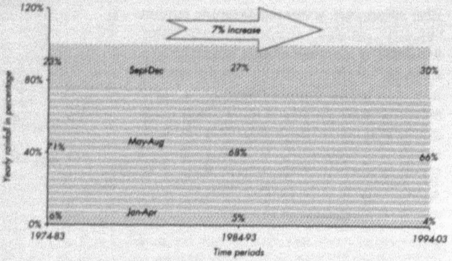


Fig 5 > Shifting of seasonal pattern of rainfall at Allahabad during 1974-2003.

Analysis of the monthly data of Allahabad from 1974 - 2003 split into three equal periods P1 (Jan-April) P2,(May-Aug) and P3 (Sep.-Dec) revealed that the percentage of total rainfall in the peak breeding period(May- Aug.) declined by 5% whereas it increased by 7% in the post- breeding period when resorption of eggs of IMC sets in.

This shift in the rainfall pattern (Fig. 5) 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.

4.2 Geographic distribution of fish in river Ganges

Temperature has long been a focus of biogeographic studies because of its overwhelming influence on the physiology of exothermic organisms (Hutchins, 1947). Because fish are exothermic organisms, their survival, growth, egg development and even competitive ability all are temperature dependent. Biogeographic distributions often provide insight into thermal limits for ectotherms such as fish whose physiology and reproductive success are strongly influenced by temperature. These thermal limits can be used to project distributional changes following climate change by assuming fish will migrate along isotherms to remain within a suitable thermal envelope (Rahel, 2002) .The thermal limits of some Indian fishes are tabulated below (Table 3).

Table 3 : Thermal grouping of fishes from river Gangaes

Sl. no.	Cold Water Species	Spawning Temp. (°C)	Optimum Thermal Habitat		Reference
			Temp. Tolerance	Optimum Temp.	
1.	*Salmo trutta fario*	18	10 to 21	15 to17	Vass (2000)
2.	*Salvelinus fontinalis*	18	10 to 21	15 to 17	Vass (2000)
3.	*Salmo gairdneri*	18	10 to 21	15 to 17	Vass (2000)
4.	*Barilius barila*				
5.	*B. shacra*	24.5 to 27.2			Vass (2000)
6.	*B. bendelisis*	23 to 28.5	18.5-35		Vass (2000) Sehgal (1973)
7.	*B. vagra*	20.5 to22.5			Badola & Singh, 1984
8.	*Acrossocheilus hexagonolepis*				
9.	*Tor putitora*	19.7 to 20.8	10-30	15-25	Vass (2000) Vass & Gopakumar (2002)
10.	*T. tor*	19.9 to 28.4	4 to 30	15-25	Desai (1982) Vass & Gopakumar (2002)
11.	*T. khudree*	24	10-30	15-30	Chondar (1999), Vass & Gopakumar (2002)
12.	*T. chilinoides*	22 to 28			Vass (2000)
13.	*T. mosal*	72 to 83°F			Chondar (1999)
14.	*Labeo dero*	23.5-25			Vass (2000)

Table 3 : Thermal grouping of fishes from river Ganges *(Contd.)*

Sl. no.	Cold Water Species	Spawning Temp. (°C)	Optimum Thermal Habitat		Reference
			Temp. Tolerance	Optimum Temp.	
15.	*Schizothorax molesworthi*	10 to 17.5	5-25	15-20	Vass (2000) Vass & Gopakumar (2002)
16.	*S. longipinis*	13 to 14	15-25	15-20	Sehgal & Ramkrishna (Unpublished Data)
17.	*S. plagiostomus*	18 to 21.5	5-25	15-20	Vass (2000) Vass & Gopakumar (2002)
18.	*S.nasus*	10 to 17.5	15-25	15-20	Vass (2000) Vass & Gopakumar (2002)
19.	*S. niger*	9.5-20	5-25	15-20	Vass & Gopakumar (2002)
20.	*S.richardsonii*	14-18	5-25	15-20	Vass & Gopakumar (2002)
21.	*S. esocin us*	10 to 17.5	5-25	15-20	Vass (2000) Vass & Gopakumar (2002)
22.	*Glyptothorax pectinopterus*	23.2 to 28.5			Vass (2000)
23.	*G.kashmirensis*	14 to 16			Vass (2000)
24.	*Schizothorax planifrons*	16.8to 17.2			Vass (2000)
25.	*S. curvifrons*	18 to 19			Vass (2000)
26.	Nemacheilus corica	20.2 to 21.5			Vass (2000)
27.	*Cyprinus carpio communis*	22	15 to 26	20-25.9	Vass (2000) Vass & Gopakumar (2002)
28.	*Cyprinus carpio specularis*		10 to 45		Chondar (1999)
29.	*Barilius borne*	25 to 28			Chondar (1999)
30.	*Oreinus richadsonii*	14 to 21			Jhingran (1991)
	Warm water species				
31.	*Notopterus chitala*		6 to 44		Jhingran (1991)
32.	*Neolissochilus hexagonolepis*	21.4 to 26.7			Jhingran (1991)
33.	*C. cotla*	28	18.3 to 37.8		Jhingran (1991) & Chaudhuri (1963)
34.	*Cirrhinus cirrhosa*	20 to 27			Jhingran (1991) & Chaudhuri (1963)
35.	*C. mrigala*	31.1-33.6	16.7 to 39.5	Optimum 18.3 to 37.8	Alikunhi et al. (1964) & Mukherjee et.al. (1946c)
36.	*C. reba*	22.8 to 30.2	<8		Rao, et al. (1964)
37.	*Ctenopharyngodon idella*	18 to 30	< 0 to 40		....
38.	*T. mossambicos*		Can tolerate <8-9	Optimum 10-12	Jhingran (1991) & Stickney (1994)
39.	*A. testudeneus*				
40.	*C. punctatus*				
41.	*H. tassilis*				
42.	*C. batrachus*		39 to 41		
43.	*P.ticto*		is the upper		Jhingran, (1991)
44.	*R. daniconius*		lethal limit		
45.	*M. tengra*				
46.	*Glossogobius giurus*				

Table 3 : Thermal grouping of fishes from river Ganges *(Contd.)*

Sl. no.	Cold Water Species	Spawning Temp. (°C)	Optimum Thermal Habitat		Reference
			Temp. Tolerance	Optimum Temp.	
47.	*H.molitrix*		23 to 29	> 15°C fishes start normal feeding & growth	Chondar (1999)
48.	*Labeo boggut*	28.2			Chondar (1999)
49.	*L colbasu*				
50.	*L. fimbriatus*	29-30			Sukumaran (1969)
51.	*L. rohita*	31.1-33.6	Minimum tolerable temp.57°F		Alikunhi et al (1964), & Jhingran (1968)
52.	*Puntius dubius*	27 to 30			
53.	*P. javanicus*		15 to 45	25 to 35	Chondar (1999)
54.	*Thynichthys sandkohol*	28.4 to 29.6			Madras Fish. Dept. Report
55.	*Mystus aor*	22.3 to 31			Saigal (1982)
56.	*M. seenghala*	22.3 to 31			Saigal (1982)
57.	*Wallago attu*	80 °F			Ahmed (1944a)
58.	*Clupisoma garua*	62 to 68 °F			Chondar (1999)
59.	*Silonia silondia*		7 to 40		Chondar (1999)
60.	*C. batrachus*				
61.	*H. fosilis*	26 to 29			Chondar (1999),
62.	*Channa marulius*	28 to 31	4 to 45		Chondar (1999)
63.	*C. punctatus*	26 to 29			Chondar (1999)
64.	*C.striatus*		<11		Bhattacharya (1946)
65.	*C.reba*	22.8 in Bhavani & 30.8 in Cauvery			
66.	*Puntius chilinoides*	8.9			Badola & Singh (1984)
67.	*Puntius hexastich us*	8.9			Badola & Singh (1984)

The distributional shifts of species can include abandonment of areas currently occupied if future temperature exceeds physiological tolerances (Rahel et al. 1996) as well as colonization of new areas if previously unsuitable temperature conditions are ameliorated (Shuter and Post 1990). This approach has been termed "forecasting from historical analogy". In freshwater we should expect to see fish distribution migration pole ward or higher in elevation as species track suitable temperature. Areas now supporting high yields of sport or commercial species may become marginal, whereas areas at the margin of species distributions may become optimal (Minnis and Moore 1995). Of course such changes in fish distribution assume species will be able to migrate along watercourse to final suitable thermal habitat. Thus for predicting fish species response to climate change thermal limits based on biogeographic distribution is a useful approach.

With this background the distributional pattern of fishes of river Ganges were analysed from the published records available. It reveals that a large number of fish species which were predominantly available in the lower and middlestretch of river Ganga in 1950s are now recorded from the upper Ganges stretch i.e upto Tehri. It is indicative of colonization of new areas. (Das, 2007).

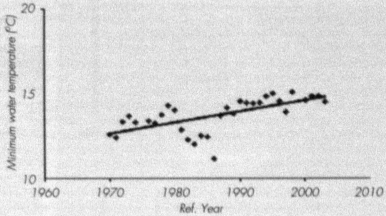


Fig. 6 > Mean minimum water temperature at Haridwar during 1970-03

Fish: There is a perceptible shift in geographic distribution of the fishes of river Ganga. The warm water fish species *Glossogobius giuris, Puntius ticto, Xenentodon cancila, Mystus vittatus* earlier available only in the middle stretch of river Ganges are now available in the colder stretch of the river around Haridwar. In the Haridwar stretch during the period 1970-86 the annual mean minimum water temperature was 12.9 °C (13°C), while during the period 1987-2003 it increased to 14.5°C, an increase of 1.5°C is thus evident. As a result the stretch of river Ganga around Haridwar has become a congenial habitat for these warm water fishes (Fig. 6).

Mahseer *Tor putitora* descended during (Dec. 2005- Jan.2006) for the first time upto Karnal where it formed 1.18% to 1.4% the total fish population. The average minimum atmospheric temperature during Dec-Jan 06 ranged from 5.1-8.9°C and max temperature between 17.3-21.4°C .The water temperature being 4.0- 8.5°C and15.0-20.0°C respectively around Karnal. The descending run in river Jamuna upto Karnal may have been to avoid low temperature in the upland. The normal preferred temperature of the fish species is 15- 28° C. (Annon, 2008).

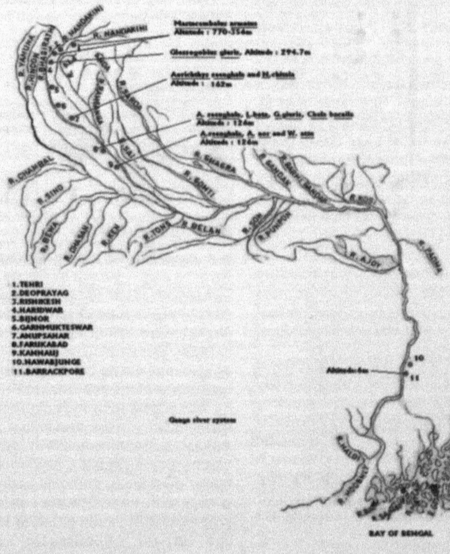


Fig. > Changes in Biogeographical distribution of Gangetic fishes

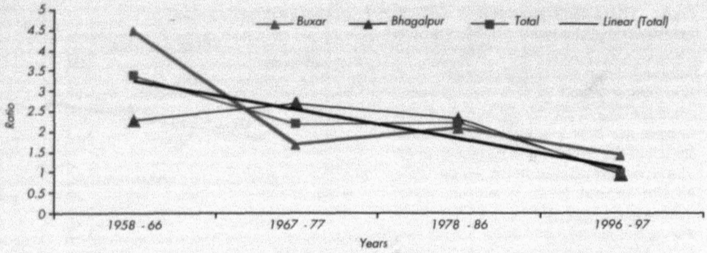


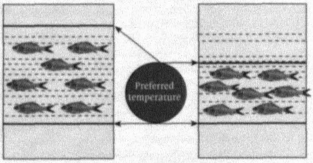
Fig 7 > Prey-predator ratio

4.3 Growth

Water temperature strongly affects metabolism, consumption, growth (Kitchell et al 1977), fish behaviour, habitat selection (Brandt 1993), spawning (Facey and Grossman 1990) foraging (Person 1986) 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). Investigations conducted by Brandt et al.2002 in the Great Lake basin (Lake Michigan) indicated that increase in length of the thermal conditions for high growth rate was shown to be the main cause of increase in fish growth rate potential for all species under climate warming. Clearly any effect of climate warming on the top predators will depend on prey availability and prey fish populations. One of the more subtle effects of changes in the thermal structure was the impact on prey densities.

Analysis of the data (Das et. al. 2008)of the various stretches of river Ganga to study the relationship indicate that the predator (large cat fish) and prey (miscellaneous groups of fish and prawns) ratio in middle stretch (Buxar) and lower stretch (Bhagalpur) has markedly narrow down from 1:4.17 to 1:1.41 and 1:2.27 to 1:0.93 respectively in four decades (1958-1997) period.(Fig. 1)

Climate warming may produce a large volume of thermal habitat for the fish and if the same number of prey is distributed across this large volume of habitat, prey densities encountered by a predator would be reduced. Reduced prey densities would reduce the predator encounter rate with prey, which would reduce predator consumption rate. This is shown conceptually.



5 . Impact on fish

5.1 Breeding of fish in hatcheries

The Indian Major Carps *C. catla, L. rohita and C. mrigala* form the predominant species around which inland aquaculture is centered in India. These fishes unlike in rivers where natural spawning occurs do not breed in confined waters and are bred in captivity by the technique of hypophysation during their maturity in the monsoon season June-August, (Chaudhuri, 1963). However, in recent years the phenomenon of IMC maturing and spawning as early as March is observed. Investigation was conducted (Dey et. al 2007, Annon, 2008) to ascertain the impact of climatic variables,

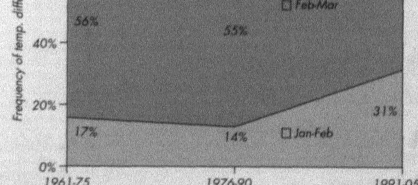
viz., elevated temperature and rainfall on the breeding of Indian major carps and impact on the fishers in 50 fish hatcheries in four districts viz. North 24 Parganas, Bankura, Burdwan & Hooghly of West Bengal.

Trend of temperature alteration : Analysis of the air temperature data(1986-2005 recorded by IIMT Pune) for the four districts investigated during breeding months (March to September) indicate that the mean maximum air temperature has increased by 0.37°C and the mean minimum air temperature increased by 0.67°C in the 24 Parganas (N) district; by 1.57°C in district Bankura and in Burdwan district the mean minimum air temperature increased by 0.18°C.

Simultaneously the differences of temperature between the months Jan-Feb, Feb-Mar and Mar- April during the period 1961-05 indicated a shift towards higher temperature during Jan- Feb months.Analysis of the data was done taking the frequency of occurrence of (4°C and above) difference of temperature between the three consecutive months as a basis for evaluating the shift of elevated temperature towards cooler months Jan-Feb .It revealed that the frequency of occurrence of this temperature differences was maximum in February-March (avg.55%) and March-April (avg.30%) during previous three decades (1961-90). But, such trend was not evident in the recent one and a half decade(1991-05) where the frequency of occurrence of (4°C and above) difference in minimum temperature shifted towards colder months i.e., January- February (from 14% to 31%) ; February-March (from 55% to 46%) and March-April (from 32% to 23%) . (fig. 8).

The analysis of air temperature data showed that both mean maximum and mean minimum air temperature have increased by 0.67°C and 0.37°C respectively during last two decades in the district 24 Parganas (N) West Bengal during the breeding season (March -September). Putting the recorded air temperature in the worked out relationship equation w=1.1504, a - 3.7305, R2=0.9634 between air and water temperature, (where w=water temperature

Fig. 8 > Shift of temperature differences during 1961-05



in °C, a = air temperature in °C and R2=correlation coefficient) it has been derived that the mean maximum and minimum water temperature has increased 0.78°C and 0.43°C respectively in the district during the period.

Trend of shifting pattern of rainfall : Since rainfall is another important criteria that triggers the early maturation of brood fish the rainfall pattern of some of the districts of West Bengal were analysed. The analysis of the rainfall data (1976-05) collected by IIMT Pune, showed that the proportion of annual total rainfall occurring in monsoon months (May-August), was 68% during 1976-85, but this proportion gradually declined to 65% (May-Aug) during 1985-95 & 62% during 1996-05. But an increasing trend was evident in post monsoon months (in Sept-Dec) the proportion increased to 30% during 1976-05 at DumDum district (Fig. 9) whereas this was 23% during 1976-85. Similar pattern rainfall distribution were observed at Kolkata district of West Bengal during 1976-05 (Fig.10).

Fig > Advancement of breeding period

Fig. 9 : Rainfall pattern at DumDum during 1976-05

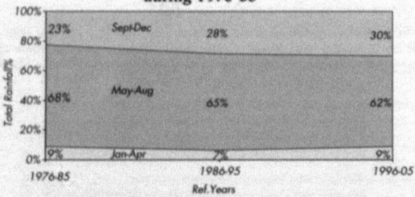
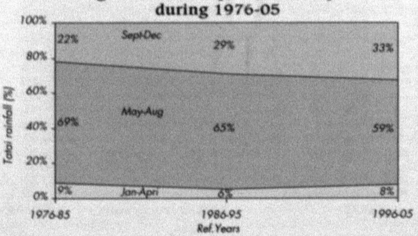
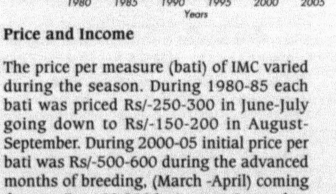


Fig.10 : Rainfall pattern at Alipur during 1976-05



Analysis of interaction with fishers and operators of 50 fish hatcheries show that 90-95% indicated temperature rise as the main reason for advancement of the breeding season of IMC, with 90-95% reasoning to demand and high sell price of seed. The increase in income is attributed to more quantity of spawn by 90-95% respondents. The study also observed that the breeding period of the major carps have advanced in all the districts by 1-2 months since last twenty years (Fig. 11).

Fig. 11. Advanced breeding period of IMC at different hatcheries of Naihati, 24 Prgs. (N)



Price and Income

The price per measure (bati) of IMC varied during the season. During 1980-85 each bati was priced Rs/-250-300 in June-July going down to Rs/-150-200 in August-September. During 2000-05 initial price per bati was Rs/-500-600 during the advanced months of breeding, (March -April) coming down to Rs/-180-200 in August -September. Fig 12. In spite of the enhanced cost of production in the last two decades the high price of the IMC spawn initially with extended season of sale has raised the income of the fish seed hatcheries and fishers.

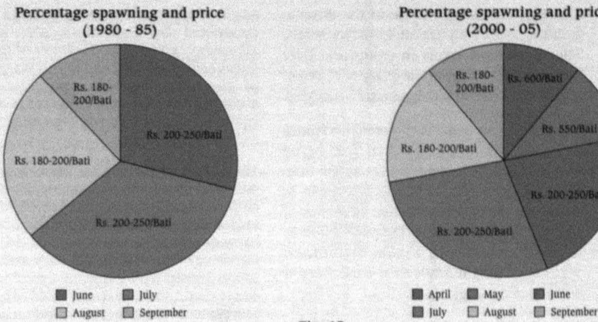


Fig. 12

Thus the alteration in climate has had a positive impact on the breeding of the Indian Major Carps in fish hatcheries in the aquaculture sector unlike in rivers where there was a negative effect.

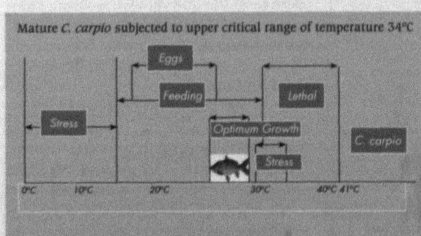
5.2 Impact on reproductive integrity

All the stages of reproduction in fish viz., gametogenesis and gamete maturation, ovulation/spermiation, spawning and early development stages are influenced by temperature. Imbalance or rapid change in temperature are stressful to fish and may also be linked with other stressors . The primary effect of stress is the activation of sympathetico-chromaffin tissue and hypothalamic-pituitary pathways resulting in the release of respective catcholamines and corticosteroid hormones in the blood streams. These will increase the metabolic processes to reduce the stress response in fish. 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.

Fish are obligate poikilotherms (ectotherms) some of which can perceive temperature changes of less than 0.5°C. Investigation was conducted on *C. carpio* subjected to enhanced temperature. The optimum range of the fish is 15-32°C and its upper critical range is 30-41°C. It spawns optimally in the range of 12-30°C.

Mature female *C. carpio* fish were subjected to an enhanced temperature of 34°C to study the effect on the reproductive integrity of the fish (Das et. al. 2008). Observation on the levels of cholesterol in the ovary and liver, hormone Estradiol in serum, Gonadosomatic and Hepatosomatic index was done for 21 days to assess the impact on the reproductive competence of the fishes.

Fig 13 > Effect of enhanced temperature on reproductive integrity of fishes



There has been a decrease in the Gonado somatic index and serum estradiol levels. The cholesterol levels in ovary and liver increased. Histology of the ovary of *C. carpio* exhibited impaired vitellogenesis in oocytes.

Functional homeostasis of steroid hormones is important in life cycle of fish being seasonal breeders. Any change in the fine-tuning of the steroid hormones leads to disruption of the reproductive efficiency of the fish and depletion of the population in the long run. During sexual maturation synthesis of gonadotropin and steroid hormones are high.

There has been an accumulation of liver and ovarian cholesterol (a precursor of steroid hormones) as a result the hormone estradiol has depleted. Estradiol stimulates liver to produce vitellogenin. 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.

5.3 Impact on Fish Health

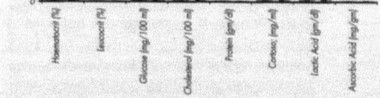
5.3.1 Fluctuating temperature

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. These effects would often become additive or synergistic with those of other adverse (e.g. low pH, algae, oxygen shortage). 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.

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.

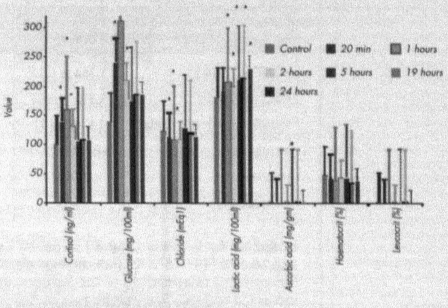
The results indicated that the homeostatic mechanism of the fish is stressed. The changes evident is hypercholesterolemia indicating impaired sterol mechanism, hyperglycemia and decreased blood sugar regulatory mechanism. Pituitary activation as evidenced by interrenal ascorbic acid depletion and cortisol 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. (Fig. 14). Obviously adaptation to the stress of elevated temperature occurs. But if the sresss of enhanced temperature is of chronic nature as in a climate warming scenario then the tolerance limits would be exceeded in fishes.

Fig. 14 : Physiological response in *L.rohita* subjected to sublethal temperature rise (28 to 35°C)



Low temperature : The physiological effect of cold shock on *Labeo rohita* was studied in the laboratory by Dutta etal,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 (Fig 15).

Fig. 15 : Physiological response in *L.rohita* subjected to cold shock 5oC; 3 min



In another study (Annon 2008) conducted to assess the impact of low temperature on fish. *L. rohita* juveniles were subjected to gradual lowering of the ambient temperature from 28°C to 13°C (critical temperature for *L. rohita*). The result indicated significant rise in plasma cortisol with hyperglycemia. There has been a cessation of feeding and sudden burst of activity followed by a state of total cessation of activity. But death did not occur as the fishes recovered when placed in.

5.3.2 Fish Disease

Information regarding the correlation of climate warming with freshwater fish parasites or diseases are not available. In a climate warming scenario temperature changes though sublethal can place a stress of considerable magnitude on the homeostatic mechanism of fishes, (Houston, 1971) 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). Transcending the confines of culture ponds, the EUS has plagued the natural fish population of open water bodies. Environmental factors play a key role in the initiation and spread of this fish disease (Das, 1993). The disease outbreak occurs at the time of waning of rainfall and onset of gradual stagnation and fall in water temperature. The intense disease outbreak occurred throughout India during the decade 1990, which also coincides with one of the warmest decade of the century.

5.4 Impact on fish growth

Growth of fish under simulated temperature regime

Normal of 29°C and three levels of temperature; 4°C (33°C), 5°C (34°C) and 6°C (35°C) above normal, were selected for feeding efficiency and growth performance study in fish in relation to increase in ambient temperature (Annon, 2008). Advance fry of *Labeo rohita* (1.39 ± 0.01291 g.) acclimated in laboratory conditions and adapted to formulated pelletised artificial feed. Rate of survival of test fishes was 100% in all the thermally regulated chambers, which indicated that the thermal range of 29°C to 35°C was not fatal for the *Labeo rohita* fingerlings within 13 weeks of exposure.

Specific growth rate:The specific growth rate (SGR) of fishes varied with the change in ambient temperatures. The SGR was maximum at 34°C (1.91 ± 0.10) temperature in which the food conversion efficiency of the fishes was also at the highest level of 1:0.7055. The SGR increased by 7.9% in 33°C compared to 29 °C and further by 17.18% at 34°C. At 35 °C the SGR of the fishes decreased by 16.23% of that of 34°C.

The fishes at the end 92 days exposure showed progressive increase in above mentioned values in the thermal range between 29°C and 34°C but the trend reversed with further increase in temperature by 1 °C to 35°C. The gain in weight considered as ultimate achievement of all the physiological activities of a living organism and also index for evaluating the physiological efficiency was by 319.16 ± 37.00% of initial in 29°C. With 4°C increase in temperature from 29°C to 33°C the value

Table 4: Initial weight, final weight, specific growth rate, weight gain, food conversion ratio and survival% of *L. rohita* fingerlings at four different temperatures (29 °C, 33 °C, 34 °C & 35 °C)

Parameters	Different temperature levels			
	29°C	33°C	34°C	35°C
Initial wt (grams.)	1.36a ± 0.16	1.40b ± 0.17	1.39b± 0.20	1.43c ± 0.17
Final wt (grams)	5.32a ± 0.36	5.99b ± 0.28	7.457ab ±0.36	5.9c ±0.26
Specific growth rate (%/day)	1.51a ±0.11	1.63ab ±0.28	1.91ab ± 0.10	1.60c ±0.10
Wt. gain %	319.61 a ± 37	358.89 a b±33	497.75 ab ±48	347.93 c ± 37
FCR	1.0087	1.044	0.7055	1.1724
Survivality %	100	100	100	100

raised up by 12.29 % (358.89 ± 33.00 %) and 38.69% (497.75 ± 48.00%) further when the ambient temperature of the fishes was increased to 34°C. The weight gain in fishes exposed to 35°C unlike increasing between 29°C and 34°C showed decline by 30.10% (347 ± 37.00%) compared to that of 34°C.

5.5 On osmoregulation of anadromous fishes

The anadromous species such as the Indian shad T. ilisha have a characteristic of early development in freshwater followed by seaward movement and again they return towards freshwater for spawning. And this seaward migration is highly seasonal either in spring or fall, at a time of temperature change. So temperature may be a controlling factor in determining the timing of development and migration. In American shad, high salinity tolerance develops at the time of larval-juvenile metamorphosis (July), several months before the peak of downstream migration (October). At the end of the migratory period ion losses occur in laboratory-reared and wild fish, coincident with increased gill Na^+, K^+-ATPase activity. Ion losses are delayed in fish maintained at elevated temperature (summer), indicating that higher temperature will permit a longer period of fresh water residence for shad. Less is known about the impact of global warming on the osmoregulatory function of anadromous fishes. More research is needed on the salinity tolerance and physiological changes that occur during migrations.

6. Adaptations in fisheries

The present scenario of fisheries needs a little mention to appreciate the adaptation issues of Inland fisheries in response to climate change.

India is a major maritime state and an important aquaculture country in the world with third position in fisheries and second in aquaculture.

Fisheries sector has high potential for rural development, domestic nutritional security, employment generation, gender mainstreaming as well as export earnings.

The sector has grown steadily so called the sunrise sector (Table 5).

Table 5

Fish production	1950-1951 (Mt)	2004-2005 (Mt)
Annual	0.75	6.3
Marine Fish	0.53	2.78
Inland Fish	0.218	3.52

(Source : DAHD & F, 2005)

The sector's contribution to National GDP is 1.04% and its contribution to National Agriculture and allied activities is 5.34 %

Indian share in global fish production is 4.36% with 9.92 % in inland and 2.28% in marine.

It provides direct and indirect engagement in fisheries sector to14 lakh people.

Export potential is 18 % of agricultural exports(50 products).

The projected composition of fish demand and supply is given in Table 6.

Table 6

Projected Fish Demand / Supply

	2005- 06	2012	Source
Total demand of Fish	5.8 - 6.0	9.74	Fisheries Div. ICAR, 2006 NCAP, 2006 Kumar, 2005
Domestic demand		5.9	
Total Supply of Fish	6.2	9.6	Fisheries Div, 2006 NCAP, 2006
Marine	2.96	3.15	
Inland	0.68	1.12	
Aquaculture	2.72	5.33	

To meet the projected demand emphasis is on the expansion of Inland Fisheries in general with emphasis on Fresh water Aquaculture (Table 7).

Table 7

Resource	Present production 2006, (Mt)	Projected production 2012,(Mt)
Marine capture fisheries	2.95	3.10
Mariculture	0.007	0.05
Enhanced inland fisheries	0.68	1.12
Cold water fisheries	0.0003	0.001
Coastal aquaculture	0.113	0.25
Freshwater aquaculture	2.6145	5.088

Source (Fisheries Div.ICAR,2006)

Freshwater aquaculture has grown from a share of 46% in mid 1980s which increased to 80% in recent times. It is one of the fastest growing enterprise in agriculture.

Success of Aquaculture sector has important implications both in terms of food security and as a source of income, for a growing number of people. Consequently any potential direct or indirect effects of climate change need to be taken seriously.

Aquaculture is based on approximately 75 species of carps, catfishes, murrels prawns and mollusc.

Indian Major Carp -catla ,rohu,mrigal together contribute major share of over 2.0 mt with exotic carps silver carp, grass carp and common carp forming the next important group.

A number of technologies have contributed to the growth of this sector.

With this background let us have a view of the states* of importance for fisheries in terms of adoption of aquaculture technologies where adaptation would be of importance in response to climate change.

Adaptation options in Inland Fisheries

Enhanced water temperature

Changes in Culture system

- Reduction in dissolved oxygen, water quality deterioration,
- Enhanced primary productivity,
- Increased growth and food conversion,
- Increased disease incidence,
- Enhanced breeding period in hatcheries
- Exotic species introduction

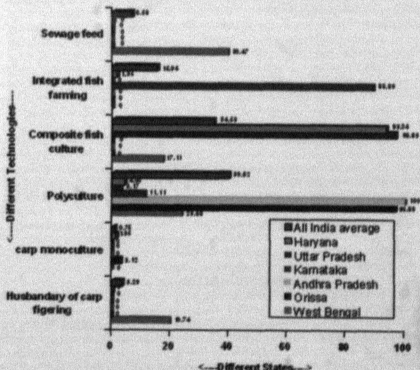


Fig. Adoption % of freshwater aquaculture technologies (Histogram)
Source: Pillai & Katiha, 2004

- Changes in level of production from ponds and hatcheries
- Enhanced operating cost
- Increase in capital costs due to creating deeper ponds with aeration facilities

Changes in the Rivers

- Geographic shift of fishes
- Habitat loss or gain
- Fish breeding alteration/ changes
- Decrease in fish and related biota species richness, alteration in species composition for capture fisheries
- Exotic species invasion

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

Floods

Changes in culture system

- Salinity changes
- Escape of fish stock
- Structural damage
- Introduction of disease /predators
- Loss of fish stock
- Damage to aquaculture facilities
- Higher capital costs for flood resistance like construction of embankments, etc.
- Higher insurance costs

Changes in the Rivers

- Geographic shift of fishes
- Habitat loss or gain
- Fish breeding failure
- Decrease in fish and related biota species richness

Adaptations options : These options can only be exercised in culture systems

- Embankments for frequent and shallow flood protection
- Harvesting fish at smaller size
- Giving importance to fish species that require short culture period and minimum expense in terms of input
- Continuous supply of seed from hatcheries or in other words raising production of seed from hatcheries

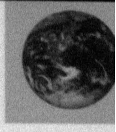
Drought

Changes in culture system

- Salinity change
- Water quality deterioration
- Limited water volume
- Loss of fish stock
- Limited fish production

Adaptation options :

- Smaller ponds that retain water for 2-4 months can be used for fish production with appropriate species (catfish, tilapia etc.) and management practices.



Storms (coastal region)

Changes in culture system

- Inundation and flooding
- Salinity changes
- Escape of fish/prawn stock
- Introduction of disease and predators
- Loss of prawn/ fish stock
- Damage to facilities
- Higher insurance costs

Adaptation options :

- 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

Alteration in rainfall and water availability

Changes in culture system:

- Deterioration in water quality
- Increased diseases
- Reduced pond level
- Altered and reduced freshwater supply
- Cost of maintaining pond level artificially
- Conflict with other water users,
- Loss of fish stock,
- Reduced production capacity,
- Change of culture species

Changes in Rivers:

- Geographic shift of fishes
- species richness decrease
- breeding failure
- Habitat loss/gain

Adaptation options :

- Extending coverage of freshwater aquaculture areas

- 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
- Small ponds (50-200m2) of seasonal nature (1-3) 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

Human adaptation to changes in climate

Negative impacts on Aquatic ecosystems and fisheries can be further aggravated by human adaptation to changes in climate. For adaptation to the increased demand of water for irrigation the supply side option aims at increasing supply. Increasing the water source for irrigation is expensive and has potential environmental impacts.The demand side options 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. For flood management, supply side options include increasing flood protection with levees and reservoir; these are expensive and have potential environmental impacts.Demand side options include improvement in flood warning systems and information and to curb floodplain development. So a variety

of options are available; influences on fish and fisheries depend on the details of such choices. The demand side options in most cases, would appear to be better choices for those interested in fish and fisheries.

Development of a unified strategy :

A common framework should be created at the country level that can be used towards implementing the integrated watershed management strategy starting from Gram Panchayat (village council) to the river-basin level in a unified manner. Integrated watershed management does not merely imply the amalgamation of different activities to be undertaken within a hydrological unit. It also requires the collection of relevant information, so as to evaluate the cause and effect of all the proposed actions. This framework will need regular maintenance and updating to fully reflect the most accurate ground truth data. Local planning and management strategies have to be evolved and validated through the proposed framework, so as to generate and evaluate various options suitable for local conditions. This would greatly help inland fisheries development in future.

Reference

Ahmed, N. (1944). The spawning habits and early stages in the development in the carp, *Labeo gonius* (Hamilton) with hints for distinguishing eggs, embryos and larvae of *Labeo gonius, Cirrhina mrigala* and *Wallago attu*. *Proc. Nat.Inst. Sci. India*. 10(3): 343-54.

Alikunhi, K.H., A. Dutta, V.D.Singh and G.P.Dubey (1964). Observation of the breeding of carps in bunds, near Nowgong, Madhya Pradesh, during July-August 1964.*Bull. Cent. Inst. Fish. Edu. Bombay*. 1: 22.

Annon 2008, Final Report of first phase (2004-07) of ICAR National Project 'Impact, Adaptation and vulnerablity of Indian Agricultures to climate change — *Impact of Climate Change of Inland. Central Inland Fisheries Research Institute, Barrackpore*.

Arnell, N., C. Liu, R. Compagnucci, Li. Da Cunha, K. Hanaki, C. Howe, C. Hailu, I. Shiklomanov, E. Stakhiv, et al. 2001. Hydrology and water resources. Chapter 4, pp. 190-233. in J.J. Mc Carthy, O.F. Canziani, N.A. Leary, D.J. Dokken and K.S.White, editors. Climate Change 2001: Impact, adaptation and vulnerability. Cambridge University Press, Cambridge, United Kingdom

Badola S.P and H.R.Singh . (1984). Spawning of sone important fish of the Garhwal Himalaya. *J. Bombay Nat. Hist. Soc*. 81: 54-58.

Badola, S.P. & Singh, H.R. (1980). Food and feeding habits of fishes of the genera *Tor, Puntius and Barilius. Proc. Indian Natn. Sci. Acad.* B46: 58-62.

Beaumont, M.G., Butter, P.J. and Taylor, E.W. 1995. Exposure of brown trout, *Salmo trutta*, to sub-lethal copper concentrations in soft acidic water and sub lethal copper concentrations and its relationship to decreased swimming performance. *Journal of Experimental Biology*, 198: 2213-

Bhattacharya, H. (1946). On the life history of Ophicephalus striatus (Bloch). *Pro. Ind. Sci. Congr.* 33(3): 128-129.

Brandt Stephen B., Doran M. Mason, Michael J. McCormick, Brent Lofgren and Timothy S. Hunter.2002.Climate Change: Implications for fish growth performance in the Great Lakes. *American Fisheries Society Symposium*, 32: 61-76. American Fisheries Society.

Brandt, S. B. and Kirsch, J.1993.Spatially explicit models of striped bass growth potential in Chesapeake Bay. *Transactions of the American Fisheries Society* 122:845-869.

Brandt, S.B. 1993. The effect of thermal fronts on fish growth: a bioenergetics evaluation of food and temperature. *Estuaries*, 16:142-159.

Chaudhuri, H. (1963). Induced spawning of Indian major carp. *Proc. Nat. Inst. Sci. India*. 29B(4): 478-487.

DAHD &F. 2005. Handbook on Fisheries statistics, 2004. Department of Animal Husbandry, Dairying and Fisheries, Ministry of Agriculture, Goverment of India, New Delhi,166 pp

Das, M.K. (2007). Environment and Fish Health: A Holistic Assessment of Inland Fisheries in India. *In* U. C. Goswami (ed.). *'Natural and Anthropogenic Hazards on Fish & Fisheries'*. Narendra Publishing House, Delhi, India. pp 137-151.

Das, M.K. and Das R.K. 1993. A review of the fish disease Epizootic Ulcerative Syndrome in India. *Environment and Ecology*, 11: 134-145.

Das, M.K., Dutta T., Acharya S. and Bhowmik, S.2002. Sublethal temperature stress in juvenile, *Labeo rohita* (Ham) and *Rita rita* (Ham): Some physiological changes. *Indian Journal of Experimental Biology*, 40:

Das, M.K., Maurey, P., Brahmane, M.P., Mukhopadhyay, M.K. & Saha, P.K. 2007a. Impact, Adaptation and Vulnerability of Inland Fisheries to Climate Change. *Journal of IAEM, Vol. 34(2), 68-76*

Desai, V.R. (1982). Observation of some aspects on the fishery and biology of Tor tor (Ham.) from river Narmada, Hoshangabad, Madhya Pradesh (Ph. D. thesis).

Dey, S., Srivastava, P.K., Maji, S., Das, M.K., Mukhopadhyaya, M.K. and Saha, P.K. 2007. Impact of climate change on the breeding of Indian Major Carps in West Bengal *J. Inland Fish. Soc. India*, 39 (1):26-34.

Dutta Tanusree, Acharya Subhendu and Das, Manas Kr. (2002). Physiological effect of cold shock in juvenile *L. rohita* (Hamilton-Buchanan). *Indian Journal of Fisheries*, 49(2) : 223-227.

Facey, D.E. and Grossman.G.D.1990.The metabolic cost of maintaining position for fourth North American stream fishes: effects of season and velocity. *Physiological Zoology*, 63: 757-776.

Fisheries Division, Icar, 2006. Projections in fisheries, Fisheries Division, ICAR, New Delhi.

Gopal Brij, 2005. Degraded catchments and regulated river flows: Major Challenges for Riverine Fisheries. Lecture, National Seminar on Management Challenges in Fisheries of Rivers and Associated Ecosystems - Issues and Strategies, *Inland Fisheries Society of India*.16-17 April, Barrackpore.

Goswami B.N., Venugopa V. Sengupta I. D., Madhusoodanam M.S., Xavier Prince K., 2006 Increasing Trend of Extreme Rain Events Over India in a Warming Environment .*Science*, 314, 1442 p 15

Houstan, A.H. 1971. Some comments upon acid base balance in teleost fishes and its relationship to environmental temperature, *Comparative Biochemistry Physiology*, 40 A: 535.

Hutchins, L.W.1947.The basis for temperature zonation in geographic distribution. *Ecological Monograph*, 17:325-335.

Indians National Communication to the United Nations Framework Convention on Climate Change, 2004. *Ministry of Environment and Forests, Government Of India.*

IPCC, 2001a. Climate Change 2001: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change. [McCarthy; J.J. *et al.* (eds)]. 1052pp.

IPCC, 2001b. Climate change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change. [Houghton, J.T., *et al.* (eds)] 881 pp.

Jhingran, V. G. (1991). Book. *Fish and Fisheries of India*.. Corporation, Delhi (India). 750pp.

Jhingran, V.G. (1968). Synopsis of biological data on Catla, *Catla catla* (Ham.). *FAO Fish Symp.* (32), Rev. 1.

Kirk, R.S. and Lewis, J.W.1993. An evaluation of pollution induced changes in the gills of rainbow trout using scanning electron microscopy. *Environmental Technology*, 14: 577-585.

Kitchell, J.F., Stewart, D.J. and Weininger, D. 1977.Applications of a bioenergetics model to yellow perch (*Perca flavescens*) and walleye (*Stizostedion vitreum vitreum*). *Journal of the Fisheries Research Board of Canada*, 34: 1922- 1935.

Kumar P. Dey, M.M. and Ferdinand J. Paraguas 2006. Fish supply projections by production Environments and species types in India. Agricultural Economics Research Review, Vol. 19 pp. 327-351.

Kunkel, K.E. and Andsager, K.2001. Climate change and heavy precipitation in the Great Lake Basin. Page 70. Abstracts from the 44th Conference on Great Lake Research June 10-14, 2001, Green Bay, Wisconsin. International Association of Great Lakes Research.

Magnuson,J.J.,Webster,K.E.,Arsel,R.A.,Bowser,C.J.,Dillon,P.J., Eaton,J.G., Evans,H.E., Fee, E.J., Hall, R.I., Mortsch, L.R., Schindler, D.W. and Qwrin,F.H. 1997.Potential effects of climate change on aquatic ecosystems.Laurentian Great Lakes and Precambrian Shield region. Chapter 2, Pages 7-53 in C.E. Cushing, editor Freshwater ecosystems and climate change in North America, a regional assessment. *Advances in Hydrological Processes. Wiley (Also in Hydrological Processes- an International Journal)* 11: 819-1067.

Mason.D.M., Goyke, A.P. and Brandt, S.B.1995. A spatially explicit bioenergetics measure of habitat quality for adult salmonines; comparison between lake Michigan and Ontario.*Canadian Journal of Fisheries and Aquatic Sciences*, 52: 1572-1583.

Meisner, J.D., Shutter, B.J.1992. Assessing potential effects of global climate on tropical freshwater fishes. 28(1) *Geojournal*, 21-27.

Minns. C.K. and Moore, J.E. 1995. Factors limiting the distribution of Ontario's freshwater fishes, the role of climate and other variables and the potential impacts of climate change. Pages 137-160 in R.J. Beamish editor, Climate change and northern fish populations. *Canadian Special Publication Fisheries and Aquatic sciences*, 121.

Mukherjee, H.K. & S.R. Mazumadar (1946c). On the life history of *Labeo calbasu* (Ham.) *J. Dept. Sci. Calcutta Univ.* 2(1): 1-22.

National Centre for Agricultural Economics and Policy Research (NCAP), 2006. Food demand by 2011-2012 . Internal communication, National centre for Agricultural Economics and Policy Research, New Delhi.

Persson, L. 1986. Temperature induced shift in foraging ability in two fish species, roach (*Rutilus rutilus*) and perch (*Perca fluviatilis*): implications for coexistence between. *Journal of Animal Ecology*, 55: 829-839.

Pillai, N. G. K. and Pradeep K. Katiha 2004. *Avolution of Fisheries and Aquaculture in India*, p240. Central Marine Fisheries Research Institute, Kochi - 18.

Rahel J. Frank.2002. Using current biogeographic limits to predict fish distributions following climate change: *American Fisheries Society Symposium*, 32: 99-110, American Fisheries Society.

Rahel, F.J., Keleher, C.J. and Anderson, J.L. 1996. Potential habitat loss and populations fragmentation for cold water fish in the North Platte River drainage of the Rocky Mountains: response to climate warming. *Limnology and Oceanography*, 41: 1116-1123.

Rao, D.S. and Govind, B.V. (1964). Hydrology of Tungabhadra reservoir. India J. Fish. 11A(1): 321-344.

Robert R. Stickney (1994). Principles of Aquaculture. by. Wiley. 520 pp.

S.K. Chondar. (1999). Book. *Fish & Shell Fish Biology*. SCSC Publishers (India). 514pp.

Schinder, D.W.1997. Widespread effects of Climate warming on freshwater ecosystems in North America. *Hydrological Processes*, II: 1043-1067.

Sehgal & Ramkrishna (Unpublished Data) and ibid

Sehgal, K.L. (1973). Fisheries survey of Himanchal Pradesh and some adjacent areas with special reference to Trout, Mahseer and allied species. *J. Bombay Nat. Hist. Soc.* 70(3): 458-471.

Shuter, B.J. and Post, J.R. 1990. Climate, population viability and the zoogeography of temperate fishes. *Transactions of the American Fisheries Society*, 119: 314-336.

Sukumaran, K.K. (1969). Growth, maturation and fecundity of cultivated fishes. FAO/UNDP Regional Seminar on Induced Breeding of Cultivated Fishes. Calcatta. Fri/IBF/5: 53p.

Taylor, E.W., Beumont, M.W., Butter, P.J., Mair, J. and Mujallied, M.S.I. 1996. Lethal and sublethal effects of copper upon fish: a role for ammonia toxicity? In Toxicity of aquatic pollution, *ed.* E.W.Taylor, *Society of Experimrntal Biology Series* 57,pp 85-113, Cambridge, Cambridge University Press.

Tyler, J.A.and Brandt. S.B. 2001. Do spatial models of growth rate potential reflect fish growth in a heterogeneous environment? A comparison of model results. *Ecology of Freshwater Fish.*, 10: 43-56.

Unnikrishnan A.S. and Shankar D. 2007. Area Sea Levels trends along the North Indian Ocean Coasts consistent with global esti-mates? *Global and Planetary Change*, 57, 301. p 15

Varga, M.M.R.I. & Chowdhury, S. N., 1992. Manual on polyculture and integrated fish farming in Bangladesh. *FAO Field document - BGD/87/045/91/11*

Vass, K. K. (2000). Breeding Biology of Trout. 155-168. In book: Cold water aquaculture and fisheries. (eds. H. R. Singh & W. S. Lakra), Narendra Publishing House. Delhi. India.

Vass, K.K. & Gopakumar, K. (2002). Coldwater Fisheries and Research Status. 3-29. In book: Highland Fisheries and Aquatic Resource Management. (eds. K. K. Vass and H. S. Raina), National Research Centre on Coldwater Fisheries (ICAR) Bhimtal Nainital (Uttaranchal).