Impact of climate variation on breeding of major fish species in inland waters

CIFRI

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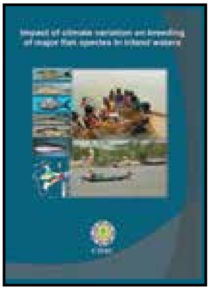

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Background

Changes in the climate of the earth have become evident both on global and regional scales in the past few decades. The most notable and significant changes associated with climate change are the gradual rise of global mean temperatures and a gradual increase in atmospheric green house gases, both of which have been aptly synthesized and documented (IPCC, 2007). Climate change is projected to impact broadly across ecosystems, societies and economies, increasing pressure on all livelihoods and food supplies, including those in the fisheries and aquaculture sector. Food quality will have a more pivotal role as food resources come under greater pressure and the availability and access to fish supplies will become an increasingly critical development issue (De Silva and Soto, 2009).

Our planet has experienced more floods (in 1960 approximately $7x10^6$ persons were affected but today the figure is $150\ x10^6$, annually), more hurricanes and irregular monsoons than in previous decades (De Silva and Soto, 2009).

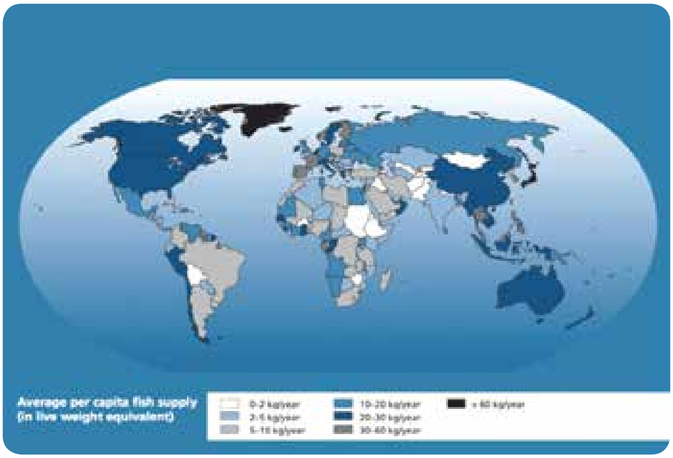


Fig. 1 Fish as food per capita supply (average 2003-2005) (Source: FAO, 2012)

Food fish production, as is the case in all other primary production sectors, is expected to be influenced and or impacted to varying degree by climate change in different parts of the world (De Silva and Soto, 2009) (Fig. 1).

Climate change is modifying fish distribution (Cheung *et al.*, 2009) and the productivity of marine and freshwater species. This has impacts on the sustainability of fisheries and aquaculture, and on the livelihoods of the communities that depend on fisheries. The projected sea level rise will affect coastal fishing communities, and changing patterns of rainfall and water use will impact inland (freshwater) fisheries and aquaculture. These effects of climate change can be direct, through changing water temperatures and associated phenologies, the lengths and frequency of hypoxia events, through ongoing ocean acidification trends or through shifts in hydrodynamics and in sea level.

The potential impact of the climate variation on fisheries and aquaculture have been elucidated by World Fish Centre as summarized below:

Table 1. Potential impact of climate variations on fisheries and aquaculture

Drivers	Biophysical Effects	Implications for fisheries and aquaculture
Changes in sea surface temperature	• More frequent harmful algal blooms; Less dissolved oxygen; Increased incidence of disease and parasites; Altered local ecosystems with changes in competitors, predators and invasive species; Changes in plankton composition.	• For aquaculture, changes in infrastructure and operating costs from worsened infestations of fouling organisms, pests, nuisance species and/or predators. For capture fisheries, impacts on the abundance and species composition of fish stocks.
	• Longer growing seasons; Lower natural mortality in winter; Enhanced metabolic and growth rates.	• Potential for increased production and profit, especially for aquaculture.
	• Enhanced primary productivity	• Potential benefits for aquaculture and fisheries but perhaps offset by changed species composition.
	• Changes in timing and success of migrations, spawning and peak abundance, as well as in sex ratios.	• Potential loss of species or shift in composition in capture fisheries; Impacts on seed availability for aquaculture.
	• Change in the location and size of suitable range for particular species.	• Aquaculture opportunities both lost and gained. • Potential species loss and altered species composition for capture fisheries.
Higher inland water temperatures	• Increased stratification and reduced mixing of water in lakes, reducing primary productivity and ultimately food supplies for fish species.	• Reductions in fish stocks.
	• Raised metabolic rates increase feeding rates and growth if water quality, dissolved oxygen levels, and food supply are adequate, otherwise possibly reducing feeding and growth. Potential for enhanced primary productivity	• Possibly enhanced fish stocks for capture fisheries or else reduced growth where the food supply does not increase sufficiently in line with temperature. • Possible benefits for aquaculture, especially intensive and semi-intensive pond systems.
	• Shift in the location and size of the potential range for a given species.	• Aquaculture opportunities both lost and gained. • Potential loss of species and alteration of species composition for capture fisheries.
	• Reduced water quality, especially in terms of dissolved oxygen; Changes in the range and abundance of pathogens, predators and competitors; Invasive species introduced.	• Altered stocks and species composition in capture fisheries; For aquaculture, altered culture species and possibly worsened losses to disease (and so higher operating costs) and possibly higher capital costs for aeration equipment or deeper ponds.

	• Changes in timing and success of migrations, spawning and peak abundance.	• Potential loss of species or shift in composition for capture fisheries; Impacts on seed availability for aquaculture.
Changes in precipitation and water availability	• Changes in fish migration and recruitment patterns and so in recruitment success.	• Altered abundance and composition of wild stock. Impacts on seed availability for aquaculture.
	• Lower water availability for aquaculture. Lower water quality causing more disease. Increased competition with other water users. Altered and reduced freshwater supplies with greater risk of drought.	• Higher costs of maintaining pond water levels and from stock loss. Reduced production capacity. Conflict with other water users. Change of culture species.
	• Changes in lake and river levels and the overall extent and movement patterns of surface water.	• Altered distribution, composition and abundance of fish stocks. Fishers forced to migrate more and expend more effort
Increase in frequency and/or intensity of storms	• Large waves and storm surges. • Inland flooding from intense precipitation. • Salinity changes. • Introduction of disease or predators into aquaculture facilities during flooding episodes.	• Loss of aquaculture stock and damage to or loss of aquaculture facilities and fishing gear. • Impacts on wild fish recruitment and stocks. • Higher direct risk to fishers; capital costs needed to design cage moorings, pond walls, jetties, etc. that can withstand storms; and insurance costs.
Drought	• Lower water quality and availability for aquaculture. • Salinity changes.	• Loss of wild and cultured stock. • Increased production costs. • Loss of opportunity as production is limited.
	• Changes in lake water levels and river flows.	• Reduced wild fish stocks, intensified competition for fishing areas and more migration by fishers.

(Source: The threat to fisheries and aquaculture from climate change. (World Fish Centre, Policy brief).

Changes in India's climate have been summarized (Anonymous, 2004) and some of the changes relevant to inland fisheries are: (i) an increase of 0.4°C in surface air temperatures over the past century at the national level; (ii) a trend of increasing monsoon seasonal rainfall along the west coast, in the northern state of Andhra Pradesh, and in north-western India matched with a trend of decreasing monsoon seasonal rainfall over eastern parts of the state of Madhya Pradesh, north-eastern India, and some parts of Gujarat and Kerala states; (iii) a trend of multi-decadal periods of more frequent droughts, followed by less severe droughts and an overall increasing trend in severe storm incidence especially along the coast of the states of Gujarat and West Bengal at the rate of 0.011 events per year and a rising trend in the frequency of heavy rain events; (iv) a rise in sea level between 1.06–1.75 mm per year (Unnikrishnan and Shankar, 2007) consistent with 1–2 mm per year global sea level rise estimates of IPCC; and (v) indications of recession in some of the Himalayan glaciers, the main source of water for perennial rivers such as Ganga, Indus and Brahmaputra, though the trend is not consistent across the entire mountain chain.

Temperature influencing fish reproduction has been reported as one of the dominant factors influencing the reproductive cycle of fishes. While rapid and high fluctuations will definitely be detrimental to fish reproduction, but temperature increase to the comfortable limits may be useful as maturation process of gonad of carps commences during February-March when the temperature gradually increases and completes prior to onset of monsoon in May-June. The environmental factors stimulate the endocrine gland, which helps in the maturation of gonads of carps (Das, 2009). Water temperature rise to a reasonable limit during winter months at the cold places like northern part of India would enhance fish growth including gonadal maturation. In Sri Lanka, temperatures are steady throughout the year in absence of winter, ranging between 24 to 32°C. The biannual monsoon in Sri Lanka had changed the reproductive pattern of Indian major carps and they attain gonadal maturity, twice a year facilitating induce breeding of the IMC throughout the year (Das, 2009).

Impact of climate variation on the breeding of Indian major carps in hatcheries

2.1 Survey of fish hatcheries

Based on the structurally-designed questionaire, survey of fish hatcheries were conducted in the the states of Assam, West Bengal, Odisha, Bihar, Andhra Pradesh, Madhya Pradesh and Uttar Pradesh. Time series data were collected from the hatchery record and through personal inverview. Collection of data has been completed for all the states. Data processing and analysis have been completed for the states of Assam and West Bengal and the the results are presented below:

2.2 Relationship between spawning characteristics and climatic variables

The preliminary data analysis for the states of Assam and West Bengal shows clear indication of advancement of the onset of breeding and a longer breeding period for the Indian major carps in the hatcheries. These two spawning characteristics were further investigated in relation to the changes of climatic variables such as temperature, rainfall and period of monsoon. The time series data on climatic variables were collected from Indian Meteorological Department.

2.2.1 Assam (Nagaon District)

Relation between the duration of breeding period and rainfall

The duration of breeding (number of days) increases with the increase in the number of rainy days. Statistical analysis showed significant positive correlation of $R^2 = 0.66$ (p-value <0.05). Fig. 2 depicts the relationship of breeding period with monsoon period.

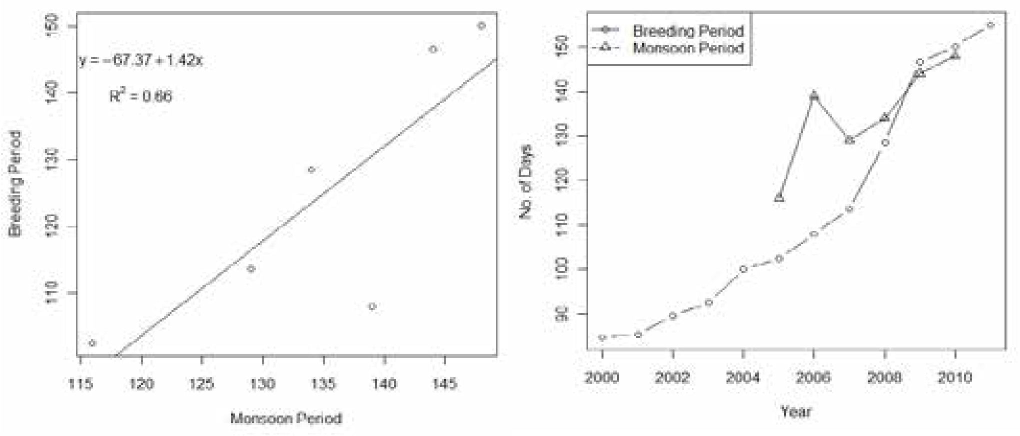


Fig. 2 Relationship between breeding periods with monsoon period of hatcheries in Nagaon district of Assam

Influence of temperature and rainfall on the onset of breeding

The exact number of days for the onset of breeding was computed considering the base line at 1st January of each year. In majority of the cases, the onset of breeding of IMC has advanced to early March. Quantitative analysis of temperature and rainfall data exhibited an increase in temperature in successive months of March and April (Fig. 3). Specifically, there was a sharp increase in March temperature after 1995. Rainfall during March remains almost stable while during April showed an increasing trend. Rise of temperature during March could possibly be one of the attributes for advancement of onset of breeding during early March. Multiple linear regression was fitted considering number of days since 1st January of the year as dependent variable and March temperature and rainfall as independent variable. The coefficient of determination $R^2 = 0.423$ was found to be marginally significant (p-value=0.08). Moreover it was found that contribution of March temperature is relatively more than March rainfall in explaining advancement of onset of breeding. As compared to the year 2000 the predicted advancement of onset of breeding is approximately 30 days (Fig. 4).

$$\textit{Onset of breeding} = 217.298 - 5.000 \times \textit{March Temp} - 0.001 \times \textit{March Rainfall}$$

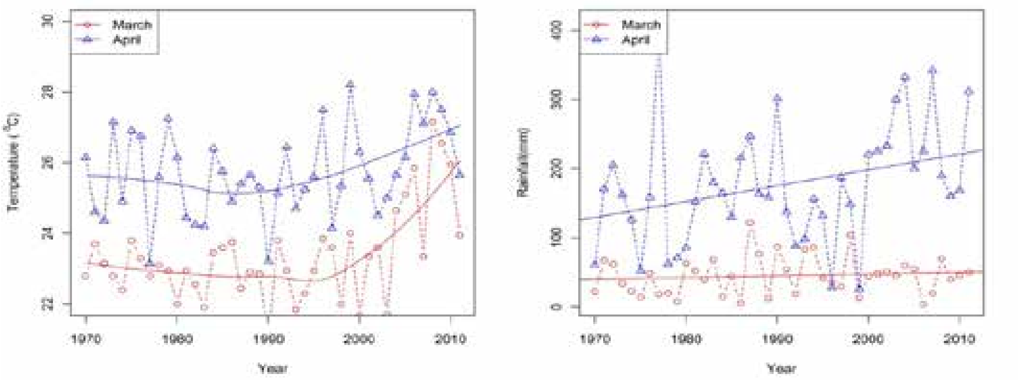


Fig. 3 Trend of temperature and rainfall during March and April at Nagaon District of Assam

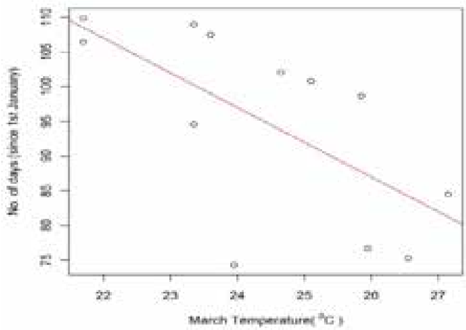


Fig. 4 Relationship between start of breeding and March temperature

2.2.2 West Bengal (North 24 Paraganas District)

Influence of temperature and rainfall on the onset of breeding

In the district under study, almost similar pattern of increasing trend of March and April temperature was observed over the years (Fig. 5). Rainfall was very sparse and fluctuating and did not show any prominent trend an indicative relationship between onset of breeding and March temperature, though not statistically significant is depicted in Figure 6. It indicates onset of breeding days since 1st January of the year decreases with the increase of March temperature. So there is a possibility of advancement of breeding period as the colder month become relatively warmer.

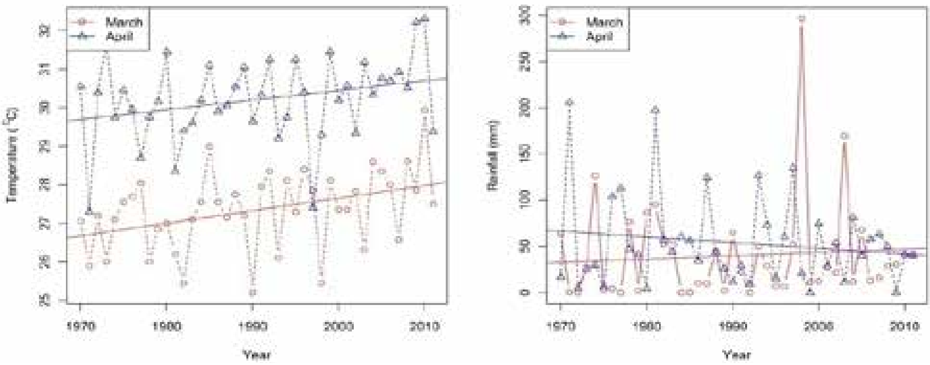


Fig. 5 Time series trend of temperature and rainfall of March and April in West Bengal

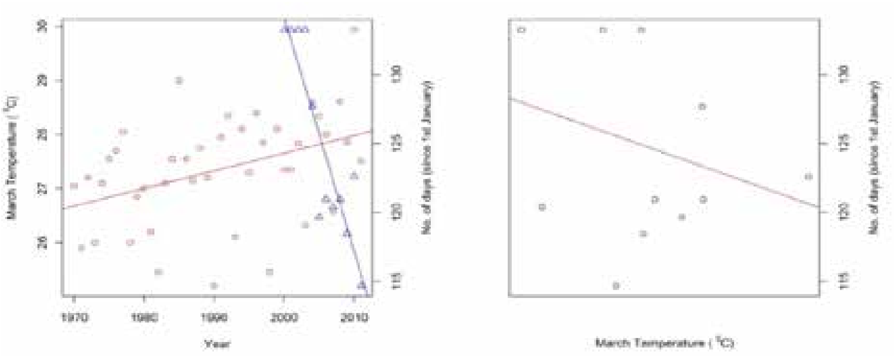


Fig. 6 Relationship with March temperature with onset of breeding in West Bengal

Breeding period vs monsoon period

An indicative positive relationship between breeding period and monsoon period was observed, though not statistically significant (Fig. 7).

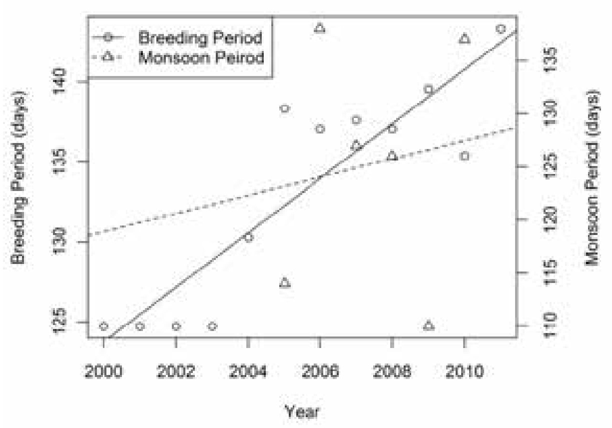


Fig. 7 Relationship between breeding period with monsoon period of hatcheries in North 24 Paraganas district of West Bengal

2.3 Presention of Fish Hatchery data in e-atlas

2.3.1 E-atlas

The survey data (2011) related to various parameters viz., onset of breeding, ownership category, period of breeding, climate parameters, etc are presented in the GIS platform. It is user friendly and interactive in nature similar to any other map browser like google maps, A standalone software was developed for deployment etc. Some of the snapshot of the software are shown in the following figures. E-atlas for Assam and West Bengal have been completed and similar user interface are being developed for the other states (Figs. 8 - 11).

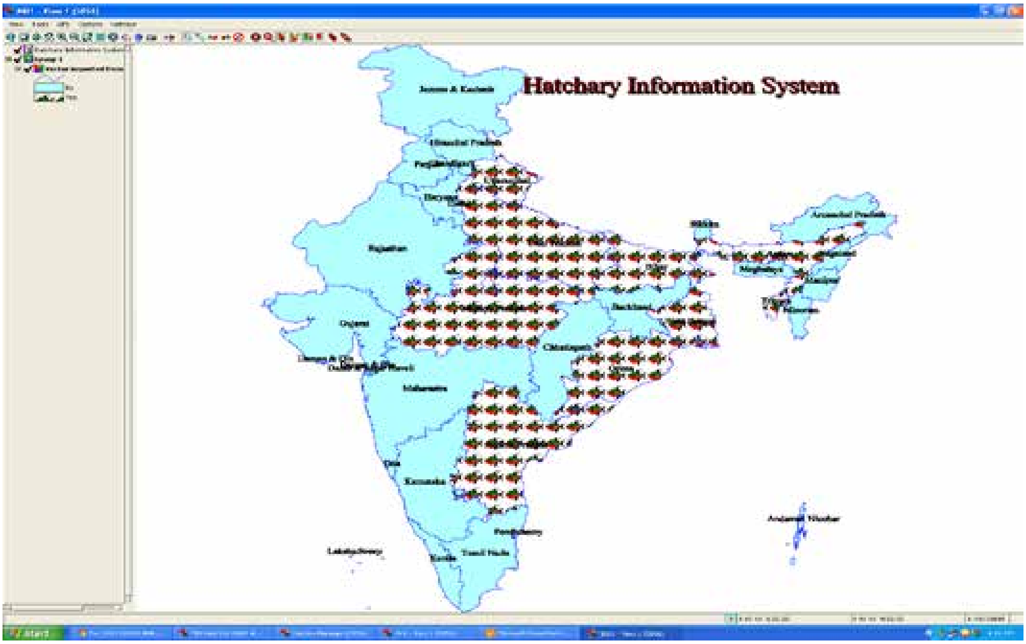


Fig. 8 Screenshot of user interface of E-atlas depicting the states under study

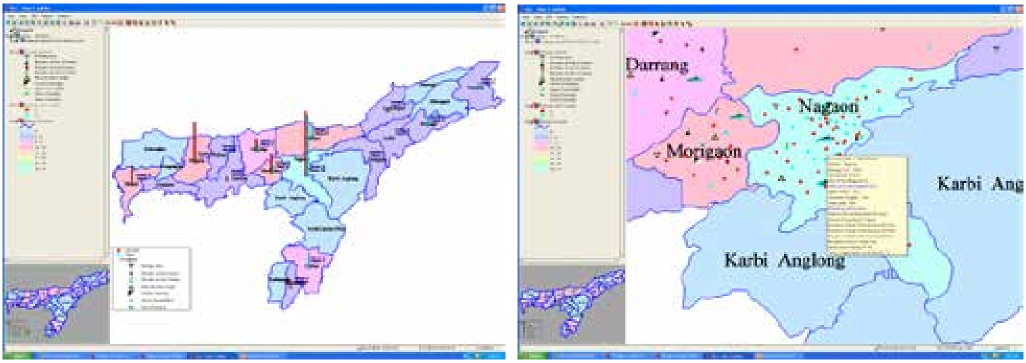


Fig. 9 Screenshot of hatchery distribution map of Assam and latest information of a hatchery in Nagaon district

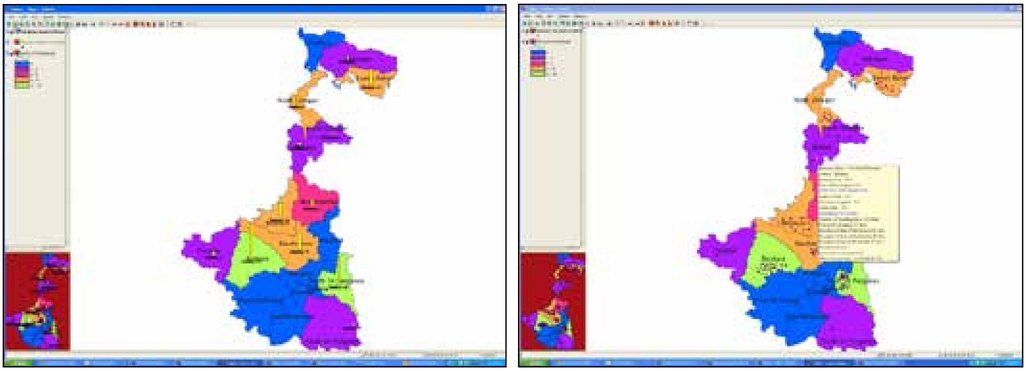


Fig. 10 Screenshot of hatchery distribution map of West Bengal and latest information of a particular hatchery in North 24 Parganas district

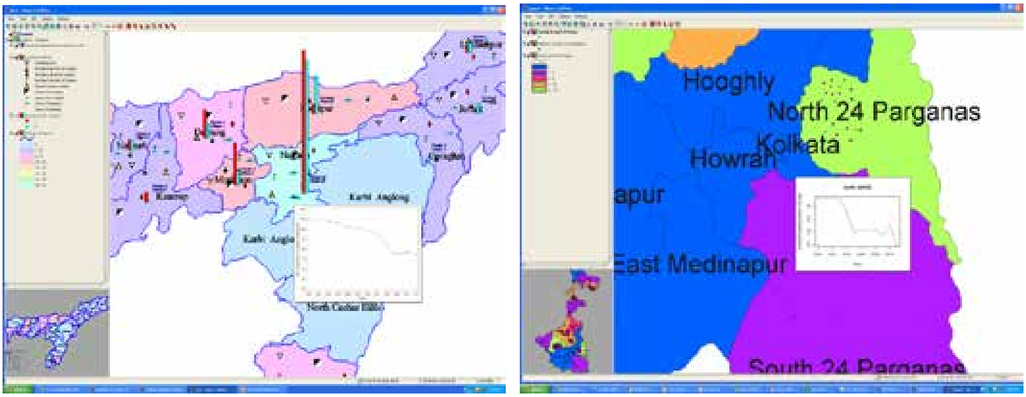


Fig. 11 Screenshot of E-atlas depicting advancement of onset of breeding in Nagaon district of Assam and in North 24 Parganas district of West Bengal

Variation of gonadal maturity of Indian major carps in relation to climate variables

3.1 Introduction

Indian major carps (*Labeo rohita, Catla catla* and *Cirrhinus mrigala*) samples were collected monthly from different fish farms and carp hatcheries of selected districts of Assam, West Bengal, Andhra Pradesh, Madhya Pradesh and Uttar Pradesh to analyse information on gonadal maturity stages, spawning behavior, gonadal recrudescence period, fecundity, etc. along with secondary information such as ambient temperature and rainfall for the last twenty five years (Fig. 12). About fifty numbers of fish samples of each fish species were collected in each month and all relevant parameters recorded.

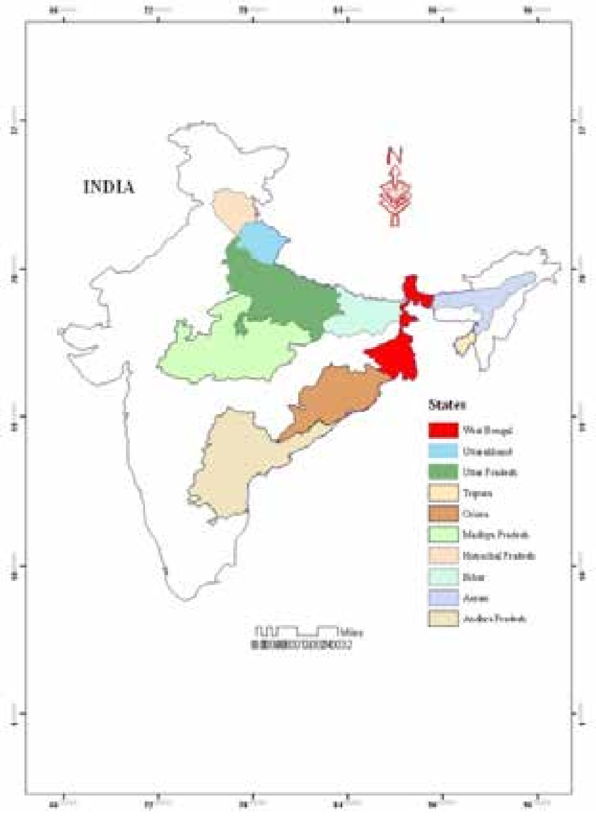


Fig. 12 Study area

3.2 West Bengal

3.2.1 Monthly variation in the maturity stages

Temperature is one of the important factors influencing the reproductive cycle in fishes. In the present study the observations on the monthly variation in the maturity stages of the female gonads of the Indian major carps in West Bengal revealed maturity stages VI and VII in higher percentage in the ovaries in *C. catla* during June-July; *L. rohita* during May-August and in *C. mrigala* during April-June (Fig. 13).

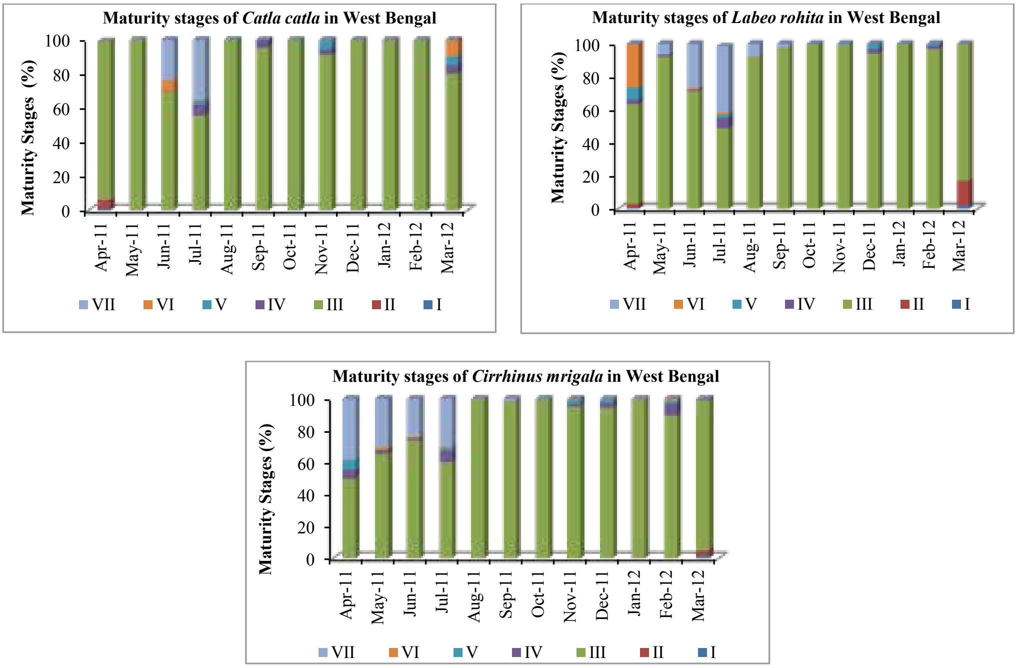


Fig. 13 Maturity stages of IMC in West Bengal

3.2.2 Relation of GSI with rainfall and temperature

In West Bengal the average temperature is on the rise over the last 60 years. The average minimum and maximum temperature throughout the state has increased in the range of 0.1 to 0.9°C and rainfall pattern has changed (Das *et al.*, 2013). In *C. mrigala*, higher GSI (17.19-26.13) recorded when rainfall range is 73.0-243.0 mm and the mean maximum temperature is 35.6°C in May. In *L. rohita* high GSI value was recorded in June & July when rainfall was 243 and 147 mm and the mean maximum temperature range of 34.0°C & 33.4°C and in *Catla catla*, maximum GSI value was obtained in June when rainfall recorded was 243.0 mm immediately followed by July when GSI value was registered as 21.5 with the corresponding rainfall as 147.0 mm and the mean maximum temperature range of 34.0°C & 33.4°C (Fig. 14). This is in agreement with the previous findings where, changes in (water) temperature had been shown to correlate well with gonadal weights and therefore with gonado-somatic index (Lam, 1983; Mananos *et al.*, 1997; Mylonas and Zohar, 2007). In summer spawners, water temperature and long days have a key role in both initiating and concluding the spawning season. This has been shown for many fish like major carps (Sen *et al.*, 2002; Dey *et al.*, 2005, 2007; Bhattacharyya and Maitra, 2006), Japanese sardine (Matsuyama *et al.*, 1991). The results of the present study were also corroborated with the study of Lone and Hussain (2009) on *L. rohita*.

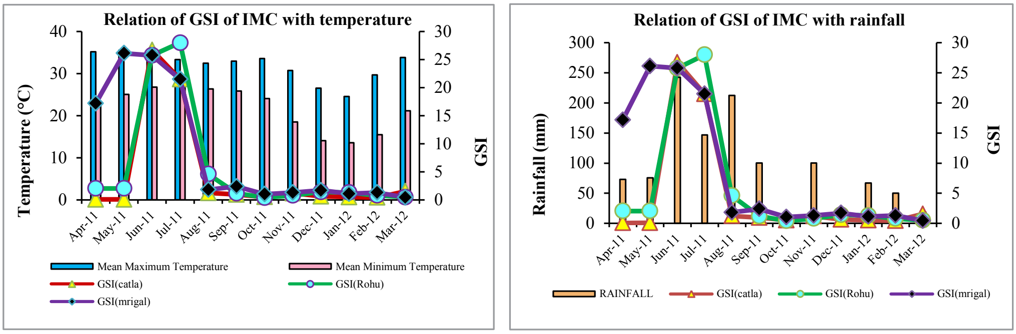


Fig. 14 Relation of GSI with rainfall in West Bengal

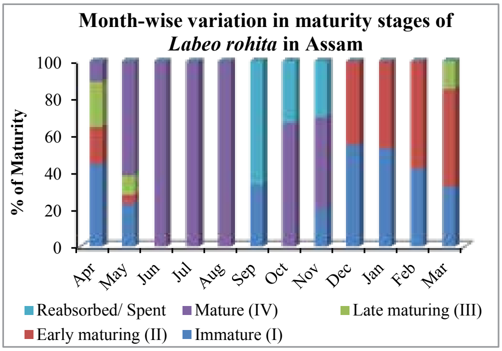
3.3 Assam and Tripura

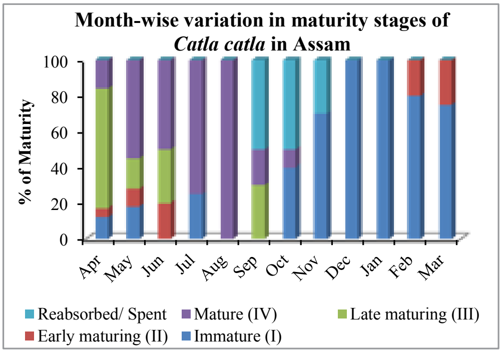
3.3.1 Monthly variation in the maturity stages

The species *L. rohita* collected from Assam recorded 100% of mature gonads in the month of June, July and August while 11.11% and 61.53% in April and May respectively. In *L. rohita* collected from Tripura in the month of April, external morphology of ovaries were 50% immature, 25% early maturing and 25% late maturing phase, which changed to immature 30%, early maturing 3.33%, late maturing 3.33% and mature 63.33% in July (Fig. 13). In October 50% gonad were found reabsorbed with rest 30% immature and 20% late maturing phases (Fig. 15).

The month-wise variation in the maturity of *C. catla* in Assam depicted that gonads attained 100% maturity in the month of August. In Tripura, the gonadal maturity stages of *C. catla* showed that in April, 40% immature, 10% early maturing and 50% late maturing; in July the stages were 30% immature, 30% late maturing and 40% mature.

While gonadal maturity was 80% during April, it increased to 100% from May to August in case of *C. mrigala* samples collected from Assam (Fig. 15). In Tripura, *C. mrigala* showed 100% matured gonads in the month of April and 70% in July.





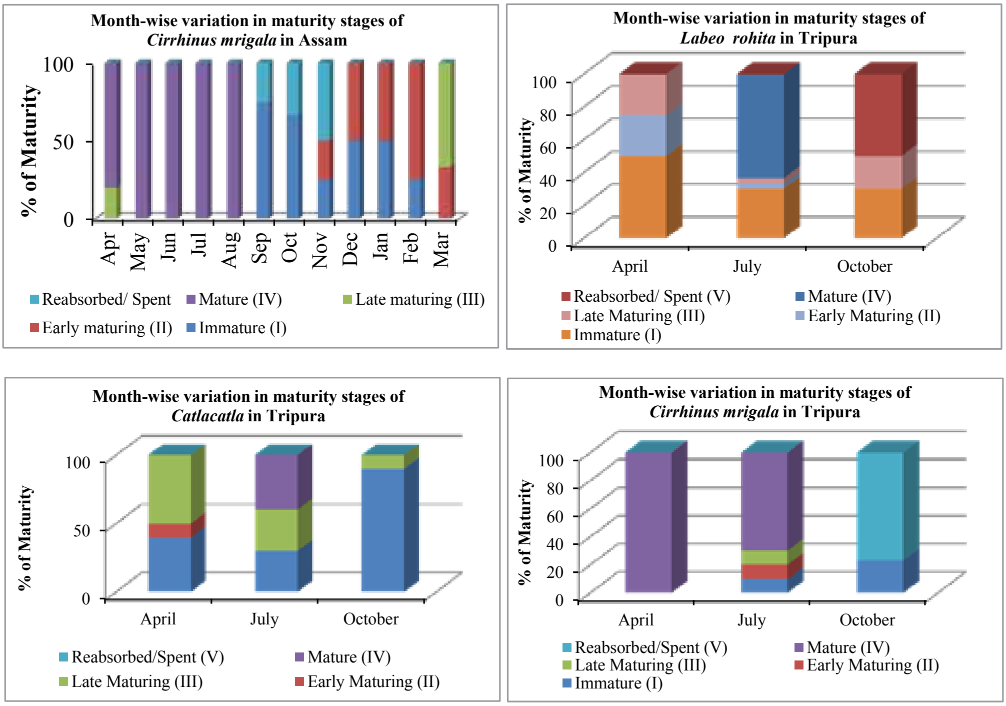


Fig. 15 Maturity stages of IMC in Assam & Tripura

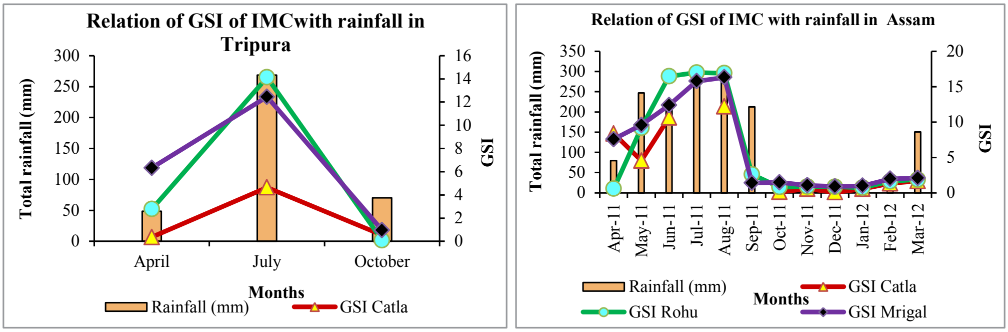


Fig. 16 Relation of GSI with rainfall in Tripura & Assam

3.3.2 Relation of GSI with rainfall and temperature

In Assam, it has been observed that particularly for Rohu and Mrigal, in month of July, GSI values had been maximum when the precipitation value was also the maximum of all months recorded. With a slight less rainfall in subsequent month August GSI values for Rohu and Mrigal had almost been similar to that recorded for July. In August, GSI of Catla had been the maximum. During September to December 2011, there had been a fall in precipitation values and likewise to it, GSI values of all three IMC had been on a decline. During January to March 2012, there had been an increase in precipitation values and GSI values had also been on the rise. Particularly with adequate precipitation, GSI values had been the maximum or very near to the maximum value; it can be inferred that adequate rainfall is having an important positive impact on attainment of the final gonadal maturity stage of all three IMC in Assam conditions. Similar observations were recorded by Parameswaran *et al.* (1970) in Assam except for *Catla catla* where the maximum average diameter of ova was obtained during May. At Tripura centre, it has been observed that except Catla, GSI values of both Rohu and Mrigal had been maximum in the month of July, when the rainfall (precipitation) value was also the maximum (268.8mm) of the three months recorded. During early winter, i.e., October, GSI value of the three IMC had been the lowest (less than 1). GSI value of Rohu and Mrigal recorded in July was between 12.49 - 14.13, which may give an indication that the fishes are in spawning phase (Fig. 16).

It appeared that maturity of the Indian major carps in the study areas has advanced by nearly one month (from April to March) and it is extending nearly one month (from July to August). Secondary data collected from various fish hatcheries of Assam and Tripura states through structured questionnaires have also revealed the same result.

This study indicated that temperature was one of the important factors responsible for the advanced breeding of IMC. Unlike in the past when breeding season was restricted to monsoon from June-September (Chacko and Kuriyan, 1948; Menon, *et al.*, 1959; Sarkar *et al.*, 2010).

3.4 Andhra Pradesh

3.4.1 Monthly variation in the oocyte maturity stages

In *C. catla* the maturity stage VII gradually increased from May onwards and was maximum in the month of August whereas stage III was observed over all the months with highest occurrence in February and lowest was recorded in the month of August. In *L.rohita*, stage VII increased from May onwards with a maximum value in the month of June to August, then started decreasing from September Maximum stage III in Rohu was observed in the month of April and decreased by August. In *C. mrigala*, stage VII started increasing from May to September, then decreased in October (Fig. 17). The highest GSI for all the fish species was recorded in the month of August. The GSI value started increasing from the month of May to August and then declined. The highest value of GSI was correlated with the maximum number of stage VI and VII in the month of May to August. It was also evident that with the increase of temperature and rainfall, the GSI value also increased (Fig. 18). The results corroborated with the study of Sarkar *et al.* (2010) and Das *et al.* (2013).

3.4.2 Relation of GSI with rainfall and temperature

The highest temperature is recorded in the month of May whereas the lowest in the month of January. The average maximum temperature during the season was 41.02°C and average minimum temperature was 17.92°C. Maximum rainfall was found in the month of May which decreaed with the time. The stage III was present in all the months (Fig. 16). Similar influences of temperature on gonadal activity were demonstrated in other cyprinid species such as *Cyprinus capio* (Davies *et al.*, 1986), *Notemigonus crysoleuces* (de Vlaming, 1975) and *Carassius auratus* (Kawamura and Otsuka, 1950).

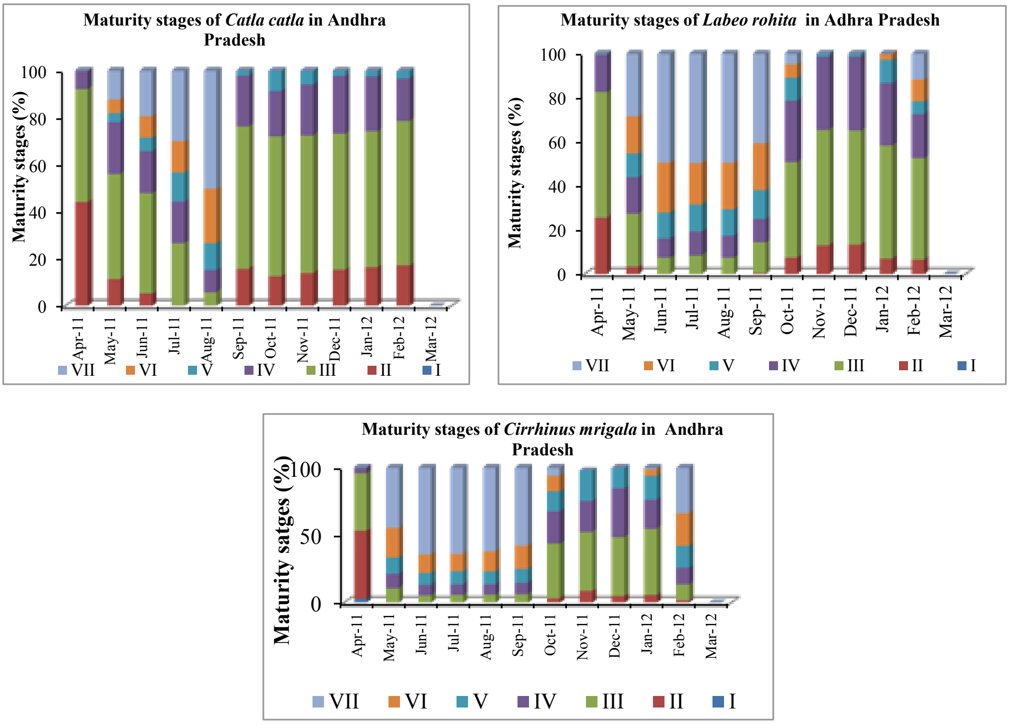


Fig. 17 Maturity stages of IMC in Andhra Pradesh

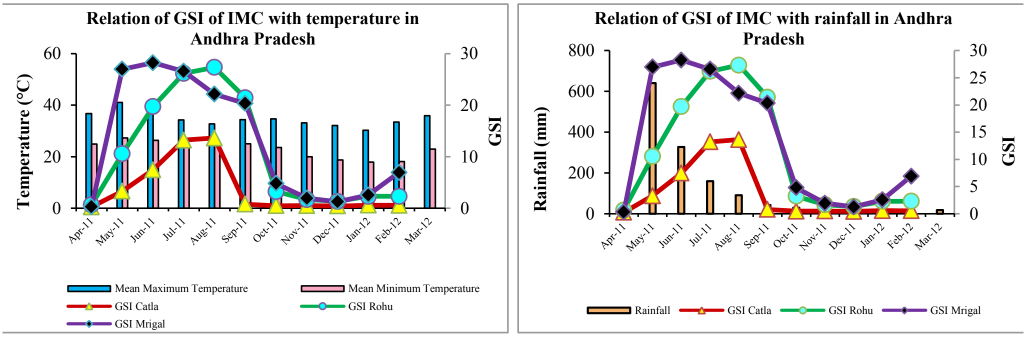


Fig. 18 Relation of GSI with rainfall in Andhra Pradesh

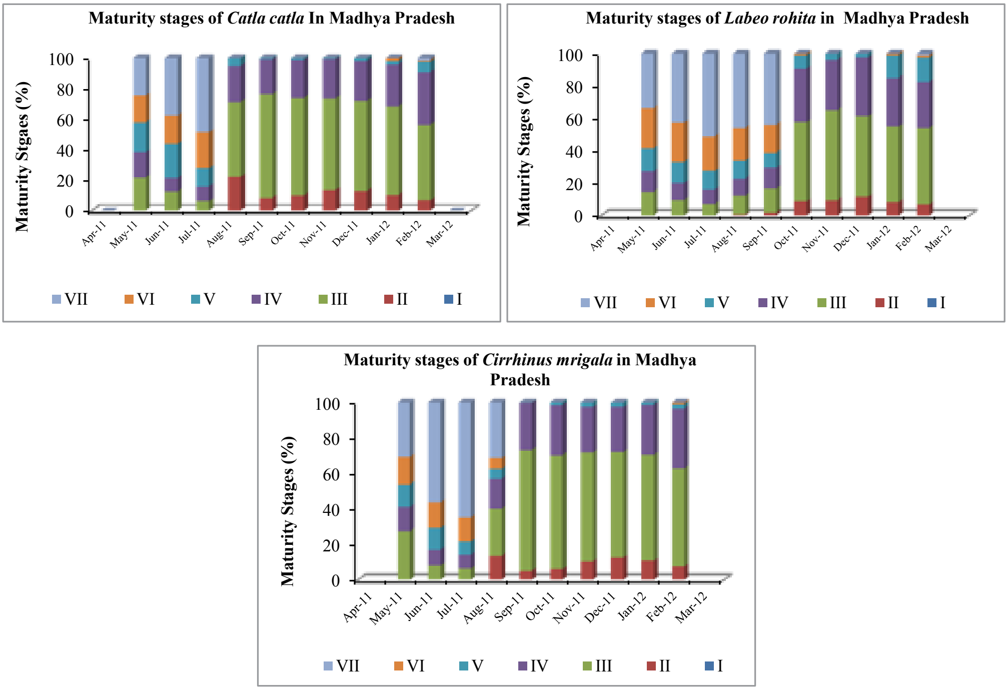


Fig. 19 Maturity stages of IMC in Madhya Pradesh

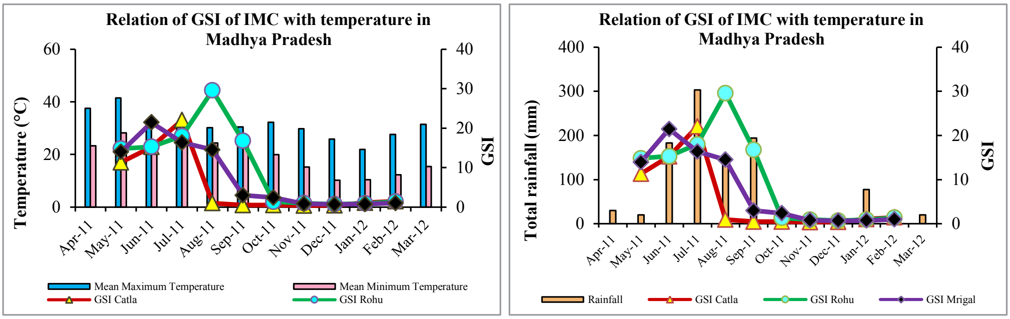


Fig. 20 Relation of GSI with rainfall in Madhya Pradesh

3.5. Madhya Pradesh

3.5.1 Monthly variation in the maturity stages

In *C. catla*, stage VII gradually increases from May to July and stage III starts decreasing from May to July and thereafter stage III shows an increasing trend in September. In *L. rohita*, it was evident from the graph that in the month of July, the stage III was at its minimum whereas stage VII was at the peak. The stage VII increases from May with increasing temperature to September. The VI and VII stages were absent from October onwards and reappear in February. In *C. mrigala* stage VII increases from May to August, then decreases and further reappears from February with increased temperature (Fig. 19).

It is evident that the breeding season of all the three fishes occurs from the month of May to August/September except in case of Catla where breeding season was recorded from May to July, which is corroborated by the higher GSI values during these months.

3.5.2 Relation of GSI with rainfall and temperature

The graph shows the relationship of GSI value of Indian major carps with rainfall and temperature and also variation of maturity stages over the months and year in Madhya Pradesh. The highest temperature was recorded in the month of May and lowest in January (Fig. 20). The average maximum temperature during the season was 41.55°C and average minimum temperature was 21.88°C. The gonadal development of fish with increasing temperature was also evident with appearance of stage VI from January onwards in *C. catla*. In Catla, the highest peak of GSI was observed in July which suddenly falls and becomes lowest in December. The GSI value increases from May to September and then starts decreasing from October in Rohu. In Mrigal, the highest GSI value was recorded in the month of June and lowest in December. The GSI value increases from May onwards with lowest in December. The GSI value again shows an increasing trend from January with increasing temperature. The highest rainfall was recorded in the month of July.

3.6. Uttar Pradesh and Uttarakhand

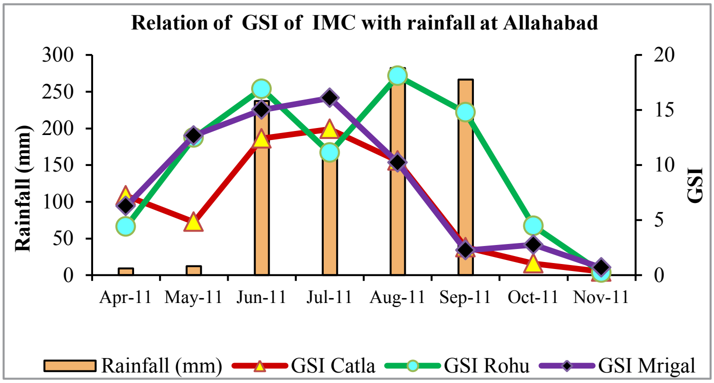


Fig. 21 Relationship of GSI with rainfall in IMC of Allahabad

In Uttar Pradesh, it was observed that the GSI values of the three species of IMC were high in the month of June-July; it indicates that the fishes are in spawning phase of gonadal maturation. The rainfall recorded during this period was 237.3 mm. *C. catla and C. mrigala* recorded maximum GSI values (13.28 and 16.1 respectively) during April – November 2011, when the rainfall was quite less (171 mm) compared to the maximum recorded (Fig. 21).

Impact of climatic variations on the breeding behavior of Mahseer, snow trout, rainbow trout and Indian major carps were assessed in the states of Uttarakhand and Himachal Pradesh Mahaseer recorded the maximum GSI value (9.88) in August when the precipitation was also maximum (282.3mm). GSI of snow trout had been maximum when the precipitation value (266.4mm) had almost touched the maximum value (282.3mm). In months with no rainfall, the GSI for snow trout registered a steep decline. Similar had been the condition of trouts particularly in November (Fig. 22).

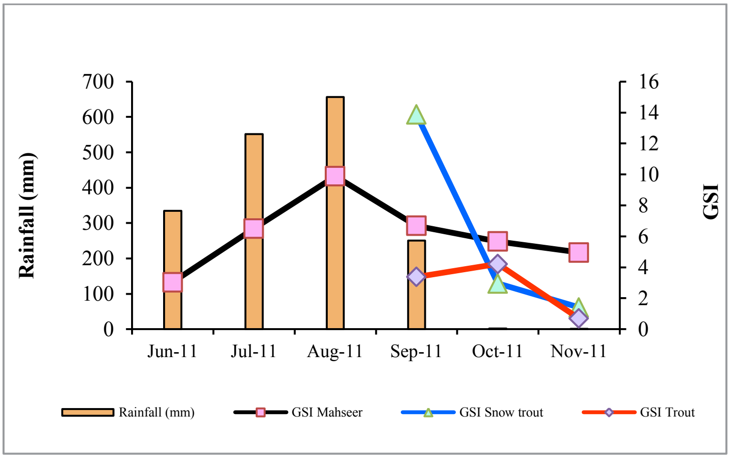


Fig. 22 Relationship of GSI with rainfall in cold water fishes of Uttarakhand

4.1. Rainbow trout (*Oncorhynchus mykiss*)

In the earlier studies conducted at Champawat farm, Uttarakhand (1620 msl) during 2000-2003, it was observed that the rainbow trout male attained sexual maturity after 2nd year and female after 3rd year in the climatic conditions of the farm. The ambient water temperature during the period was recorded between 4.5-20.5°C. Recently both male and female sexes were observed in full maturity just after completion of 2nd year in age and the fishes were bred successfully at the farm during January 2011. The advancement in maturity could be attributed to slight increase in water temperature (5.0-21.5°C) and decrease in the duration of low temperature regime.

Most of the female brooders showed maximum gonado-somatic indices (GSI) during December 2011 to February 2012 while the peak (25.08) values were observed in the month of February, 2012. GSI in male trouts showed higher values during October 2011 to January 2012 while peak (5.32) value was observed in November 2011.

4.2 Mahseer (*Tor putitora*)

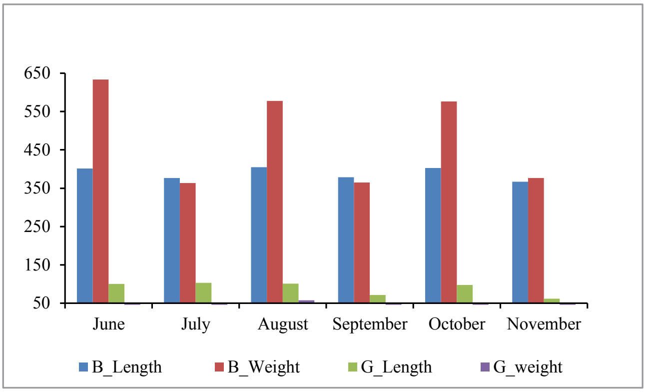


Fig. 23 Average monthly variations in gonadal and body sizes of female mahseer

Mahseer stock is not maintained in the hatcheries, so wild stock was collected by netting operations conducted by State Fisheries Department (only during April to July) at Bhimtal lake and also from the river Kosi at Ramnagar, Uttarakhand during the mentioned period. During peak winters the stock was unavailable at these sites (Vass *et al.*, 2009; Das *et al.*, 2013).

Golden mahseer repeatedly breeds during April-July, but in and around Bhimtal (altitude 1300-1500 msl) the breeding was observed during late July to mid-September in the year 2011. Preferred ambient water temperature for breeding of mahseer is between 18-22°C.

High gonado-somatic index in females was recorded during July 2011 to September 2011, but peak value (11.01) was observed in the month of August. Ovary occupied 40% of the abdominal cavity in the month of June (Fig. 23). Malik and Negi (2007) observed highest GSI value of *Tor putitora* in winter and in rainy season in Saptsarovar and downstream respectively.

4.3. Snow-trout (*Schizothorax richardsonii*)

The spawning of snow-trout in the upstream tributaries commences during August to October. The fish breeds during end of August to mid-September in and around Champawat situated at an altitude between 1500-1700 msl. The ambient water temperature during breeding season was observed to be 18-20°C. Due to unavailability of snow-trout stocks in any of the hatcheries in the country wild stock was collected from experimental fishing from Gandaki, Lohawati streams and rivulet Ladhiya in Champawat district of Uttarakhand. Sundar (2011) studied the breeding biology of a snow trout, *Schizothorax longipinnis*, from the river Jhelum, Kashmir.

Body weight of the female snow-trout collected from riverine sources ranged between 60-165 g, while that of males from 11-150 g. Surprisingly 10-20 g males were also observed in full oozing conditions. Maximum gonado-somatic index in females was recorded during the period September-October 2011 and peak value (21.26) was also observed in the month of September 2011. Spawning stage (VI) of ovary was predominant in the females during September 2011. Mahanta (2012) recorded that breeding performance of rainbow trout was better due to high rainfall, better ova house practices and appropriate feeding.

Impact on the breeding behavior of estuarine fishes

Investigation was conducted to assess the potential impact of climate variation on the breeding of the Indian shad *Tenualosa ilisha* and mullet *Liza parsia* in the Hooghly-Bhagirathi river stretch, Breeding, maturity and spawning pattern of Indian shad (*T. ilisha*) and mullet (*Liza parsia, Mugil cephalus*) was studied. The study area includeds upstream Farrakka (Latitude = 24° 47.603"N Longitude = 87° 54.565"E) to downstream Frasergunj (Latitude = 21° 34.834"N, Longitude = 88° 14.223" E) covering 529 km of river length including 18 sampling stations (Fig. 24). Two of the sites viz. Canning and Raidighi were included for sampling of mullet only and remaining sites were selected for sampling of *T. ilisha*.

Fig. 24 Sampling stations in Bhagirathi-Hooghly stretch

5.1 Tenualosa ilisha

Seasonal variability of GSI and maturity stages

The spawning related parameters, such as egg maturity stages, Gonado-somatic Index (GSI) of the collected samples were analyzed for period March, 2011 to December

2011. GSI of male ranged from 0.5 to 6 whereas the same of female varied between 2 and 25 (Fig. 25). Extent of variability of GSI of males is somewhat lower than that of female. For both the sexes, peak of GSI was attained during August and September whereas, De and Saigal (1986) reported the peak values of GSI and the minimum values of relative condition for female hilsa in September and October. De (1986) also accounted that the mature ovary occurred in late September to early March, indicating that the spawning season lasts for about 6 months. However, in the present study, another peak was observed for male in March. In this month females also exhibited higher GSI indicating potential breeding. The oocyte maturity stages of female over different months showed that the VIIth stage maturity attained peak during June to August (Fig. 26). Considering the peaks of GSI and higher stages maturity, the potential peak spawning season was during August and September. Another peak of GSI of male with reasonably good GSI of female in the month of March was indicative of another spawning season during March as observed in previous study (Lehman, 1953; Pillay, 1958; Mathur, 1964). Minimum length and weight of matured female are 208 mm and 120g respectively. The same for males were 170mm and 62g respectively. According to Pillay (1958), in the Hooghly the female hilsa matures at 200mm, while in the Godavari, Pillay and Rao (1963) found species as high as 370 mm at first maturity. The observed sizes at first maturity of the Ganga hilsa at Allahabad and Varanasi are thus higher than that of Hooghly hilsa and lower than that of Godavari hilsa. It has further been observed from the study of Mathur (1964) that male hilsa matures at a length of about 200mm. Thus a change in weight at first maturity is observed as compared to that in length at first maturity.

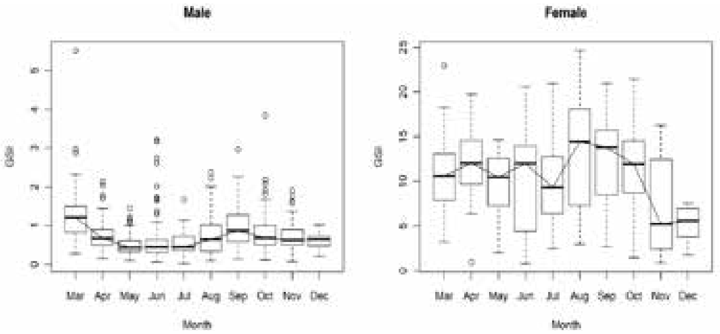


Fig. 25 Seasonal patterns of GSI of *T. ilisha* for Hooghly estuarine region

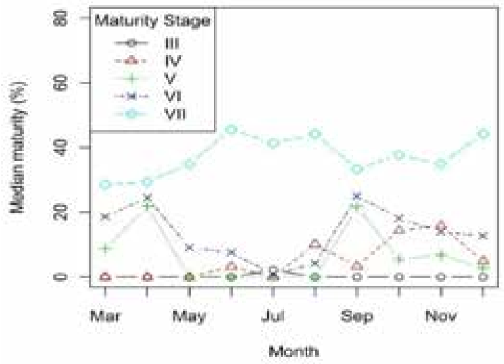


Fig. 26 Seasonal patterns of maturity stages of *T. ilisha* in Hooghly estuarine region

5.1.1 Influence of climatic factors in relation to spawning of T. ilisha

Water temperature and maturity

Investigations on the American shad have shown that temperature is one of the important factors affecting its migration (Leach, 1925 and Talbot, 1953). In the present study, potential impact of temperature on spawning behavior was investigated. Regression analysis of GSI on water temperature was done as a first step. For this study the data for the month of April to December 2011 was used. Loess model was employed to uncover the underlying relationship between the GSI and water temperature.

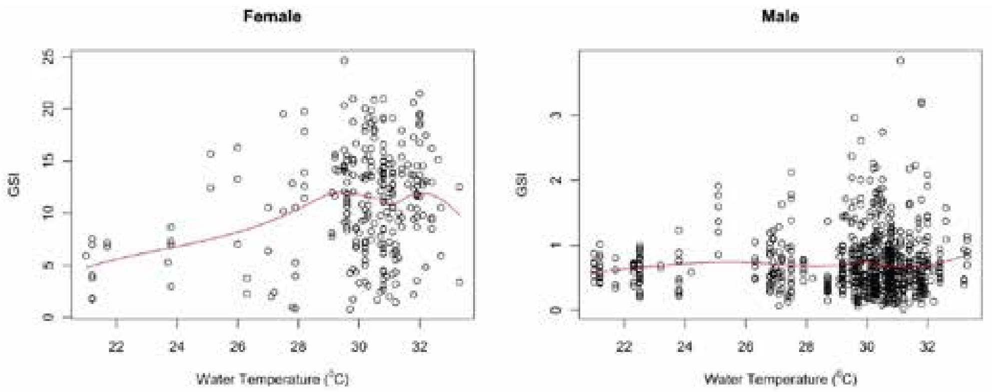


Fig. 27 Relationship between GSI and water temperature

The relationship indicates that GSI attains two peaks at 29°C and 32°C respectively (Fig. 27). The same statistical tools were employed to identify patterns of different states of maturity in relation to water temperature (Fig. 28). In this case also we observed that VIIth stage of maturity attained peak in the water temperature range between 30°C and 31°C. These two findings 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.

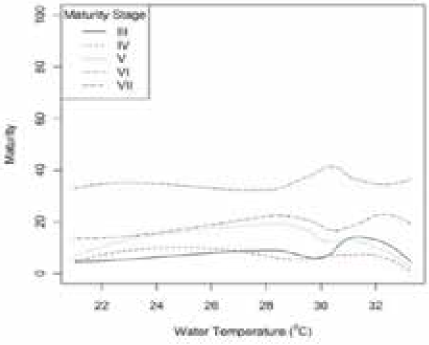


Fig. 28 Relationship between maturity stages and water temperature

Water salinity and maturity

The relationship of GSI and maturity stages with salinity is shown in Figures 29 and Figure 30. As *T. ilisha* migrates to freshwater zone for spawning, both the parameters showed highest values in very low salinity zone.

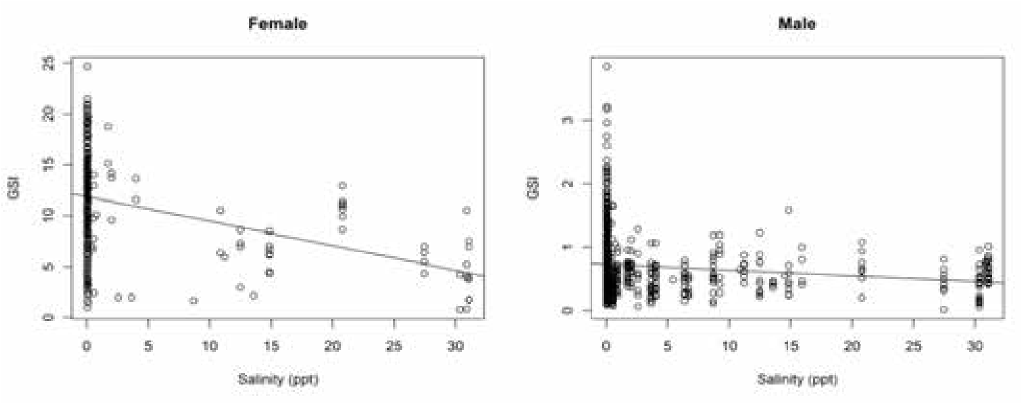


Fig. 29 Relationship between GSI with salinity

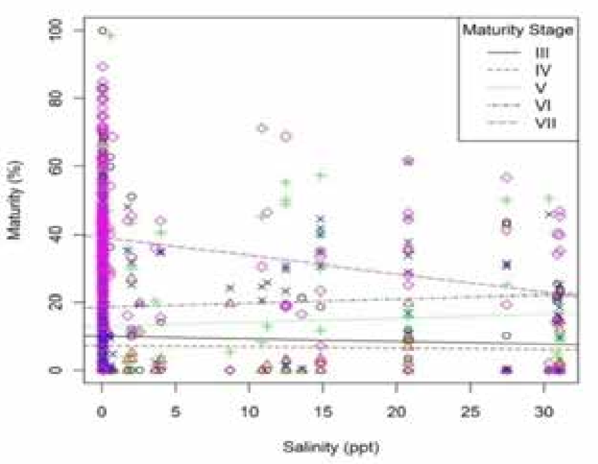


Fig. 30 Relationship between maturity stages and Salinity

5.2 Mullet

Observation of oocyte maturity stages and estimation of GSI have been done for mullets with reference to *Liza parsia* (Mugiliformes: Mugilidae) collected from Raidighi and Canning centre during June 2011 - February 2012. Standard methods were followed for estimation of GSI and maturity stages and results were presented for the period between June, 2011 to December, 2011. Das *et al.* (2013) studied the circannual changes in morphological, ultrastructural and hormonal activities of the ovary of an estuarine grey mullet, *Mugil cephalus* and reported that the gonadosomatic index and follicular population per ovary began to rise from September to October (prebreeding), reached peak during November and December (breeding) and declined from January to August (post-breeding phase).

5.2.1 Monthly variation of oocyte maturity stages of mullet (Liza parsia)

During June to October 2011, it has been observed that percentage occurrences of oocyte stages are dominated by the stages III and IV. From October 2011 to January 2012, a diminishing trend of occurrence of stage III (84.45% to 17.92%) is evident. In November, the percentage occurrence of stage VII was 16.31%, reaching a maximum of 49.22% in December and again decreasing in January to 31.27% (Fig. 31). Oocyte diameter of *Mugil cephalus* was reported to be increased during pre-breeding, attained maximum size in breeding and drastically reduced in post breeding phase. But the follicular populations per milligram of ovary per microscopic field were moderately high in pre-breeding, least in breeding and highest in post-breeding (Das *et al.*, 2013).

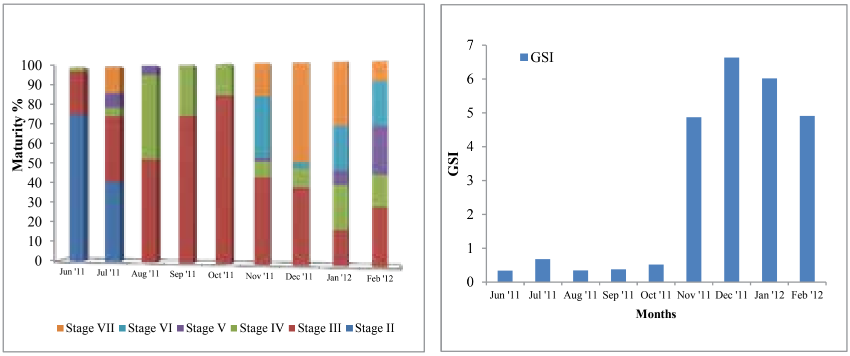


Fig. 31 Percentage occurrences of oocyte maturity stages & mean GSI of Liza parsia

5.2.2 GSI and climate parameters

June to October 2011, recorded lower GSI values (<1). Maximum GSI (6.63) with stage VII oocytes reached in December and, decreased to 6.02 in January. Mean female GSI value was recorded to be the maximum when the water temperature was the minimum (22.77°C). In month of January, water temperature is expected to be little lower than December; mean GSI recorded for the month of January (6.02) is almost same to that recorded for December. Mean GSI values with respect to rainfall and water temperature have been represented graphically in Fig. 32. The result corroborated with the study of Begum *et al.* (2010) and according to the GSI and egg diameter, the reproduction period of *Liza parsia* was determined to be in November to March with two peaks in the months of December and February.

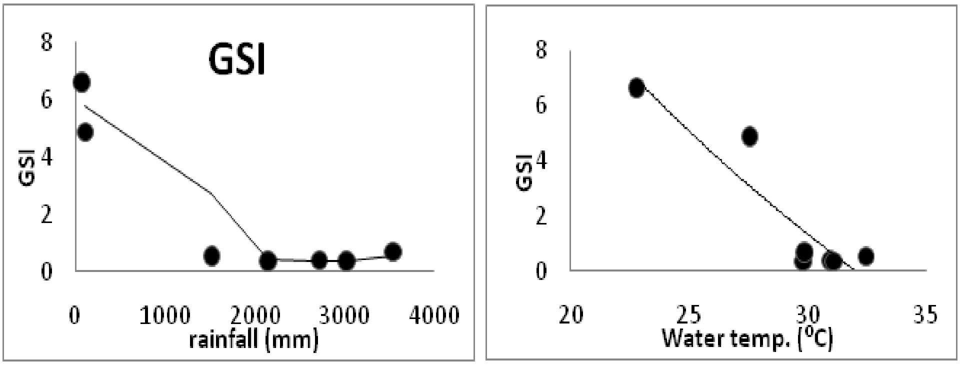


Fig. 32 Relationship between GSI with rainfall and water temperature

Correlation between monthly water temperature and percentage occurrence of maturing (stage III) oocytes and ripe (stage VII) oocytes in ovaries of *Liza parsia*

Percentage occurrence of maturity (stage VII) was found to be maximum in ovary samples studied for the month of December, when water temperature was the minimum. It is evident that along with an increase in water temperature, in different months, GSI value is showing a diminishing trend; and is equally applicable for percentage occurrence of stage VII oocytes.

During winter, particularly during December - January, the species breeds in natural waters as indicated by the presence of yellow-coloured ripe pair of ovaries (in spawning phase) in almost all sampled females with a high proportion of stage VII oocytes. Higher GSI values in these two months also support this fact.

Adaptation of inland fisheries to cope up with climate variations

Fig. 33 Culture and marketing of Clarias gariepinus (African catfish)

Adaptations options of inland fisheries to climate change

The relevant adaptive strategies to cope up with the impact of climate change as advocated by Das *et al.*(2013) are elaborated below:

Loss of fish is the prime concern during floods, thus provision for continuous supply of spawn from fish hatcheries is needed. Management practices should promote selection of fish species that require short culture periods and harvesting of fish at smaller sizes.

Smaller ponds that retain water for 2-4 months can be used for fish production with appropriate fish species and appropriate management practices. Over 80% of the hatcheries in West Bengal have shifted from breeding and rearing IMC to other species like, *Puntius javanicus* and *Clarius garipenias*, which was comparatively more adaptable to the drought conditions of enhanced temperature and less water in the ponds and have a market demand (Fig. 33).

An early warning system for weather events is needed to aid post cyclone management. Fishers in the cyclone prone South 24 Parganas district during post cyclone period are totally dependent on fishing and wild fish spawns collection from the estuary of River Ganga as the only source of income. Due to saline water incursions paddy fields get inundated and become unfit for agriculture. These areas may temporarily be converted into ponds for fish culture with saline tolerant fish species *viz Mugil parsia, M. tade and Lates calcarifer*. It is essential to optimally utilize the normal culture periods and maximize fish production and profit by selecting suitable fish species and appropriate cultural practices.

A seaward green belt should be created by planting of mangrove plants in the inundated areas. This will create in a few years time a widened mangrove fringe protecting the littoral zone of the Indian coastal states, where aquaculture is practiced from cyclonic storms.

In the future availability of water will be a major constraint for aquaculture considering its varied users. Integrating aquaculture with other practices, including agro-aquaculture and culture-based fisheries, will be useful. Short-cycle aquaculture may also be valuable, using new species or strains and new technologies or management practices to fit into seasonal opportunities.

In India, a sizeable fishermen population depends on freshwater ecosystems for their livelihood and sustenance. Water demands from the industrial, municipal and agricultural sectors will increase substantially with population growth in the coming years. Climate change will compound these problems as far as demand for water is concerned. In such a scenario, implementation of integrated water resource management involving different stake holders of fresh water would be the most effective management approach. It is obvious that the future of fisheries will be shaped by cross-sectoral solutions to the current problems.

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PLATE

Experimental netting

Selection of experimental IMC brooders

Experimental Indian major carp brooders

Dissection of experimental fishes

Dissected fish

Dissected mature ovary