"CLIMATE CHANGE AND INLAND AQUACULTURE: GLOBAL VS. SOUTH ASIAN PERSPECTIVE". In: "Perspectives on Inland Fisheries & Climate Change in India" Perspectives on Climate Change and Inl...

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Perspectives on Climate Change & Inland Fisheries in India

Edited by

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ICAR-CIFRI

Perspectives on Climate Change & Inland Fisheries in India

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National Innovations on Climate Resilient Agriculture, India

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FOREWORD

Indian fisheries has shown over sixteen folds growth during last seven decades, i.e. from 0.75 mmt in 1950-51 to 12.4 mmt in 2017-18, that has placed the country second position in global fish production. The sector provides livelihood to over 14 million people at primary level and earns more than Rs. 45,000 crores annually through exports. The multiple benefits that inland fisheries and aquaculture provide for poverty alleviation are now threatened by climate change. Climate variability manifested by sea level rise, increased incidence of flood, drought, tropical cyclones, and increasing water stress in several countries of the world have adversely impacted the aquatic ecosystems. Given likely climate warming scenarios, water problems in the river basin will increase and may be critical in terms of the ecosystem goods and services derived from the inland water bodies via fisheries. Impacts include alterations of the climate variables like air and water temperature, rainfall pattern and extreme events like drought and cyclones. It also includes effects on fish distribution, breeding, biodiversity, productivity of fishery resources and the physiological impact on fish. It is pertinent to highlight that there are very few comprehensive books available with us, which cover vulnerability of climate change on inland fisheries, its mitigation measures and adaptation strategies. I am happy to note that ICAR-Central Inland Fisheries Research Institute (CIFRI), Barrackpore is bringing out a comprehensive book on climate change and inland fisheries in India, with inclusion of experience from experts under the programme on NICRA. I complement ICAR-CIFRI for their contributions in the field of climate change and inland fisheries research and wish the Institute great success in future in all aspects of research that would enable in sustainable fisheries enhancement from inland open waters of the country. I am sure the book will be of great value to the students, researchers, planners and all associated stakeholders.

7th March, 2019

(J. K. Jena)

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FOREWORD

India is endowed with huge inland open water resources in form of rivers, reservoirs, wetlands and estuaries. These fisheries resources harbour rich fish diversity to the tune of 800 species. These fisheries resources not only cater to nutritional security of the population but also provides livelihood to over 14 million people in the country. The inland fish production is contributing around 1.4 million tons of fish to the national food basket. The production from these natural and manmade open water resources is increasing gradually and significantly over past few decades as result of adoption of improved management practices and unconventional production systems like cage and pen culture. Although these resources provide multiple benefits to various stakeholders, they are currently facing threat from the climate change impacts. Though studies on climate change impacts on inland open water fisheries in India are rare, in the past few years ICAR-CIFRI has emerged as a nodal organization conducting research in this area. The Institute has carried out a quantum of research pertaining to climate change in major river basins, impact on maturation, breeding and spawn availability in inland open waters, thermal tolerance of species, carbon sequestration and vulnerability assessment etc. The Institute has also published a number of quality research publications in the frontier areas besides policy papers. I am glad that team NICRA of ICAR-CIFRI is coming out with a book on "Perspectives on Climate Change and Inland Fisheries in India" covering diverse aspects with chapters contributed by experts. The book encompasses status of climate research, impact of climate change on inland fisheries, overview of achievements made under NICRA project, mitigation and adaptation strategies, application of GIS, importance of e-flow, carbon sequestration potential of wetlands, green house gas emission, impact of heatwave, vulnerability assessment etc. I am confident that the book will serve as a knowledge bank for stakeholders and will be of great use to researchers, planners and policy makers for strategizing mitigation and adaptation policies for climate change in inland fisheries sector.

7th March, 2019 **(B. K. Das)**

PREFACE

During the last few decades, climate change and associated stressors have been identified as a major threat to the inland fisheries, biodiversity and ecosystem. Major impacts on inland open waters include change in base flow, altered hydrology, thermal stress to aquatic flora and fauna, extended range and increased occurrence extreme events, habitat degradation, alteration in breeding and spawning behavior etc. leading to adverse consequence on aquatic biodiversity and fisheries. This may consequently will impact the recreational and subsistence fishers, their income and livelihood. In this connection, ICAR-CIFRI has undertaken research under NICRA project on the aspects of impact of climate change on inland open water fisheries, ecological and reproductive vulnerability assessment, estimation of thermal tolerance of fishes, e- atlas on fish hatcheries, carbon sequestration potentials of wetlands, climate smart fisheries in wetlands etc. Considering the lack of compiled comprehensive information on various aspects of climate change and inland fisheries, the institute has taken the lead in publishing the book titled ''Perspective on Climate Change and Inland Fisheries in India''. The researchers with vast experience in the relevant field have authored chapters for this book. The book focuses on status of climate research, impact of climate change on inland fisheries, overview of achievements made under NICRA project and development of mitigation and adaptation strategies besides identifying emerging issues and challenges for developing priority research areas. The present volume covers 27 well written chapters dealing with experiences from National Innovations in Climate Resilient Agriculture (NICRA) Project, technology prioritization for adoption in climate smart agriculture/fisheries, vulnerability assessment, role of IMD, CO_2 mitigation potentials of microalgae,impact of global warming on cold water fisheries, carbon sequestrations, assessment of Green House Gas (GHG) emission, impact of heatwave, environmental flow, thermal effect on physio-biochemical aspects, climate change impact on fisheries of coastal Sundarbans, advances in climato-ecological based models, predictive modelling etc. It is expected that the book chapters embodied in this volume will be useful in understanding the changing pattern of ecosystem and their implications on inland fisheries, possible adaptation and mitigation strategies which will be of immense help to researchers, students, fishers, planners and policy makers.

7th March, 2019 **(Editors)**

Chapter 1

CLIMATE CHANGE ADAPTATION IN INDIA: EXPERIENCES FROM NATIONAL INNOVATIONS IN CLIMATE RESILIENT AGRICULTURE (NICRA) PROJECT

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Introduction

Climate change projections suggest that an increase in temperature by 2 to 3.5°C would reduce net agricultural income by 25%. Although an increase in carbon dioxide is likely to be beneficial to several crops, associated increase in temperature and increased variability in rainfall would considerably affect food production. The AR-5 of IPCC indicates a probability of 10 to 40 percent loss in crop production by the year 2080-2100. It is also evident through modeling studies that loss of 4 to 5 million tons in wheat production in future with every 1°C rise in temperature. Climate change is likely to aggravate the heat stress in dairy animals and adversely affect their productive and reproductive capabilities. A preliminary estimate indicates that global warming is likely to reduce milk production in India to the tune of 1.6 million by 2020. Increasing sea and river water temperature is likely to affect fish breeding, migration and harvest. Indian coastline, which is about 7,517 km, is vulnerable to climate change impacts such as water intrusion and coastal salinity. A rise in temperature as low as 1°C could have a profound impact on survival and the geographical distribution of different fresh water &marine fish species. Therefore, it is very important for farmers and other stakeholders to adopt climate resilient technologies and reduce the losses. Simple adaptations such as change in planting dates and crop varieties could help reduce the adverse effects of climate change to some extent. In the recent past increased extreme weather events have been experienced in some or other parts of the country viz., droughts (2000-2004, 2006, 2009, 2011, 2012, 2014 & 2015), floods (2005, 2006, 2012, 2014 & 2015), cyclones (2012, 2015), heat wave (2003, 2004, 2005, 2007, 2010 & 2016), cold wave (2005, 2006, 2008, 2011, 2012, 2013 and 2017), hailstorm (2014, 2015). Increased number of mid-season droughts and high intensity rains that take away fertile soil leading to water stress reduced food production, stability and livelihoods of the farmers in the country. Small changes in temperature and rainfall would have significant effect on the quality of cereals, fruits, aromatic and medicinal plants.

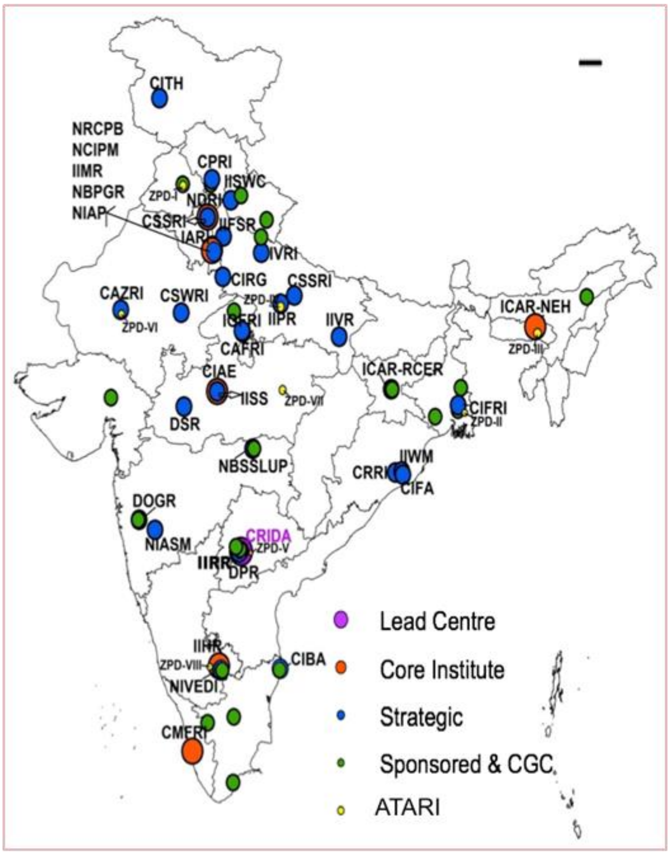

Fig.1. NICRA network

Pests and diseases are highly dependent upon temperature and humidity, and therefore will greatly be influenced by climate change. The recent outbreak of whitefly on cotton in northwest India and pink bollworm at several cotton growing areas of the country is attributed to aberrant changes in weather.

Therefore it is evident that climate change has become an important area of concern for India to ensure food and nutritional security for growing population. To meet the challenges of sustaining domestic food production in the face of changing climate and generate information on adaptation and mitigation in agriculture to contribute to global fora like UNFCC, it is important to have concerted research on this important subject. With this background, Indian Council of Agricultural Research (ICAR), under the Ministry of Agriculture and Farmers Welfare launched a network'*National Innovations in Climate Resilient Agriculture*' (NICRA) during the year 2011. NICRA aims to evolve crop varieties tolerant to climatic stresses like floods, droughts, frost, inundation due to cyclones and heat waves. Under this project about 41 Institutes of ICAR are conducting research under Strategic Research Component covering various theme areas viz., development of multiple stress tolerant crop genotypes, natural resource management, quantification of green house gas emissions in agriculture and the develop technologies for their reduction, climate resilient horticulture, marine, brackish and inland fisheries, heat tolerant livestock, mitigation and adaptation to changing climate in small ruminants and poultry.Sate of the art infrastructure required or climate change research such as high through-put phenotyping platforms, free air temperature elevation (FATE), carbon dioxide and temperature gradient tunnels (CTGC), high performance computers, automatic weather stations, growth chambers, rainout shelters, animal calorimeter, shipping vessel, flux towers and satellite receiving station were established in the research institutes across the country under NICRA project.

Technology Demonstration Component (TDC) under NICRA aims to demonstration of location specific practices and technologies to enable farmers cope with current climatic variability. Demonstration of available location-specific technologies related

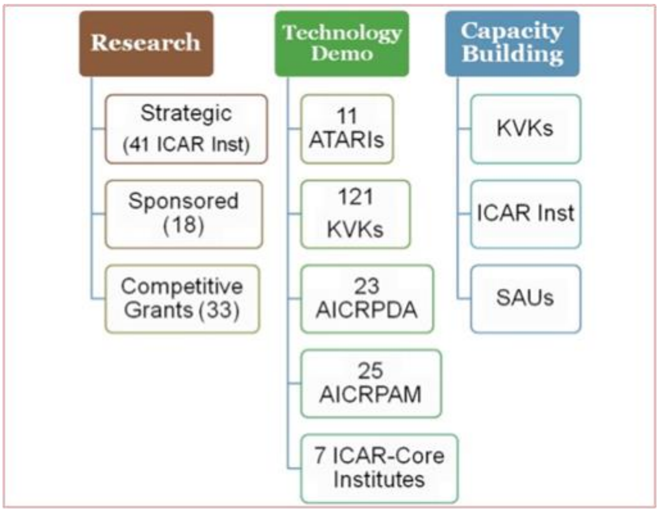

Fig. 2. Components of NICRA

to natural resource management, crop production, livestock and fisheries is being taken up in the climatically vulnerable districts for enhancing the adaptive capacity and resilience against climatic variability. Technologies with a potential to cope with climate variability are being demonstrated under Technology Demonstration Component (TDC) in 121 most vulnerable districts selected across the country through Krishi Vigyan Kendras (KVKs).

Institutional intervention Component under NICRA aims at creating enabling support system in the village comprising of strengthening of existing institutions or initiating new ones (Village Level Climate Risk Management Committees (VCRMC)), establishment and management of Custom Hiring Centers (CHCs) for farm implements, seed bank, fodder bank, creation of commodity groups, water sharing groups, community nursery and initiating collective marketing by tapping value chains.100 custom hiring centers (CHCs) for farm machinery were setup under NICRA project, which are being managed by Village Climate Risk Management Committee (VCRMC) comprising of villagers. Module on use of ICT for knowledge empowerment of the communities in terms of climate risk management is also being planned in select KVKs for generation of locally relevant content and its dissemination in text and voice enabled formats. 121 KVKs associated under NICRA projects have also taken initiatives such as participatory village level seed production of short duration, drought and flood tolerant varieties, establishment of seed banks involving these varieties were established in the KVKs, demonstration and of improved varieties of fodder seeds and establishment of fodder bank in NICRA villages. Details on the research under this project is as under.

Climate Smart Crop Varieties

Large number of germplasm screened for drought, heat, salinity, submergence tolerance etc. in different field and horticultural crops, for identifying donors for stress tolerance. Number of advance breeding materialswas generated and evaluated at multi-locations for developing new cultivars. Germplasm lines of rice and wheat tolerant to drought and heat stress have been collected from different climatic hot-spot regions of India. So far a total of 184 rice accessions were collected. Evaluation of wheat germplasm for drought tolerance with 1485 accessions was conducted to identify drought tolerance lines based on 22 morpho-physiological traits. Based on the drought susceptible index a reference set will be developed for allele mining using micro satellite markers. Marker assisted back cross breeding was carried out using molecular markers link to the QTL governing drought tolerance into Pusa Basmati-1. Rice varieties. Two rice genotypes for submergence tolerance were registered with National Bureau of Plant Genetic Resources (MBPGR), New Delhi. One salinity tolerant variety is in final year of All India Coordinated Research Project trials. Three superior heat tolerant hybrids were developed. Four drought tolerant rice varieties were released for Tripura. Two extra-early (50-55 days) green gram varieties were identified for summer cultivation (IPM 409-4, IPM 205-7) and one multiple stress tolerance redgram wild accession (*C. scarabaeoides*). A large number of soybean genotypes were evaluated for drought. Lines JS 97-52, EC 538828, EC 456548 and EC 602288 identified as relatively tolerant. These lines have been crossed among each other and with lines with superior agronomic background and are in $F_{2\text{-}3}$ generations. Five heat tolerant and 12 drought tolerant genotypes in tomato. Number of mapping population in rice, wheat, maize were developed for identifying QTL for various abiotic stresses in these crops for utilization in maker assisted selection (MAS) breeding.

Natural Resource Management

GHG emissions (CO_2, CH_4& N_2O) due to implementation of climate resilient interventions in various production systems (annual and/perennial crops, irrigated rice, inputs, livestock, forestry and land use change) were converted to an equivalent value (tonne CO_2 equivalent) in 7 villages of Gujarat and Rajasthan, which were found to be negative suggesting a sink in GHG emissions. Direct-seeded rice (DSR) with mungbean residue incorporation, brown manuring (BM) with *sesbania,* rice residue retention (RR) in zero till (ZT) wheat/rabi crops are important conservation agriculture (CA) practices. It was observed that mung bean residue (MBR) + DSR – ZTW – ZT summer mung bean (ZTSMB) gave highest system productivity, net return, water productivity and low GWP. In long term efforts to assess CA practices on productivity enhancement, nutrient use efficiency, soil health and quality, it was observed that seed (3.8 t ha^{-1}) and stover (5.6 t ha^{-1}) yields in maize in CA were on par with conventional system (CT). Also, significantly higher grain (5.3 t ha^{-1}), stover

(6.5 t ha^{-1}) yields and harvest index (0.44) were realized with balanced fertilization with NPKSZnB. Analysis of Resource Conservation Technologies (RCT) in NEH zone indicated that conventional Tillage (CT) has higher cumulative soil respiration (> 18%) compared to zero tillage. Agroforestry offset carbon dioxide from atmosphere is 0.77 tons of CO_2ha^{-1} $year^{-1}$and agroforestry system are estimated to mitigate 109.34 million tonnes CO_2 annually from 142.0 million ha of agriculture land. Further, it is estimated to offset 33 per cent of total GHGs emissions from agriculture sector annually at country level. The net eco-system methane exchange during rice growth period was the highest between active tillering to maximum tillering stage in rice. The diurnal variations in mean Net Eco-system Exchange (NEE) in submerged rice eco-system in both dry and wet seasons varied from + 0.2 to - 1.2 and + 0.4 to - 0.8 mg CO_2 m^{-2} s^{-1}. The cumulative seasonal methane emission was reduced by 75% in aerobic rice as compared to continuously flooded rice. The seasonal emissions were lower in slow release N fertilizer, especially, when applied on the basis of Customized Leaf Colour Chart (CLCC). Zero tillage in wheat lowered the GWP as compared to tilled wheat. Similarly, CO_2, CH_4 and N_2O fluxes were influenced by tillage / anchored residue and anchored residues of 10 and 30 cm in zero till reduced the N_2O emissions in rainfedpigeonpea-castor system. In efforts on mitigation strategies by reducing carbon foot prints through conservation agriculture in rainfed regions, carbon foot print from various practices like decomposition of crop residues, application of synthetic N fertilizers, field operations and input production indicated that there is a scope to reduce carbon foot prints by reducing one tillage operation with harvesting at 10 cm height with minimal impact on the crop yields. Long-term conservation horticultural practices in mango orchards improved the quality of soils through enhancing the organic carbon fraction and biological status, especially near the surface. Soil aggregates and water stability improved under conservation treatments. Cover crop, Mucuna, could conserve maximum moisture and reported higher Glomalin content in soil indicating the improvement in soil aggregation. Assessment of biochar on productivity, nutrient use efficiency and C sequestration potential of maize based cropping system in North-Eastern Hill region indicated a higher soil microbial biomass carbon (SMBC), dehydrogenase enzyme activity (DHA) and soil organic carbon (SOC) with application of biochar @ 5.0 t/ha along with 75% RDF + 4 t/ha FYM, while exchangeable aluminium and exchangeable acidity were reduced.GHG inventory for different cropping systems and production systems. GHG emissions quantified from Conservation Agriculture (CA) – 15 to 20% reduction, Resource conservation technologies (Biochar, zero tillage, reduced tillage, mulching etc.). C Sequestration in different agroforestry systems (16-22 t C ha^{-1})

Greenhouse Gas Emission from Agriculture and Allied Sector

Under NICRA, emphasis has been placed on the development of technologies, which can reduce the green house gas emissions without compromising on yield. As part of this initiative, various ICAR institutes such as Indian Agricultural Research Institute (IARI), New Delhi, Indian Institute of Farming Systems Research (IIFSR), Modipuram, Indian Institute Soil Science (IISS), Bhopal, Central Arid Zone Research Institute (CAZRI), Jodhpur, ICAR Research Complex for NEH Region (ICAR-NEH), Umiam are working on various themes related to the GHG emissions. Facilities like, Eddy Covariance towers are established at IARI, New Delhi and National Rice Research Institute (NRRI), Cuttack for continuously monitoring the GHG emissions from the crop fields during growing season so as to quantify precisely the extent of GHG emissions from the paddy systems. Research Facilities like Rainout shelter, Carbon dioxide Temperature Gradient Chamber (CTGC), Free Air Carbon dioxide Enrichment (FACE), Free Air Temperature Enrichment (FATE) etc. have been established to understand the impact of elevated carbon dioxide (eCO_2) and temperature and develop crop varieties that can withstand these stresses. Practices which can further reduce the GHG emissions such as improved systems of paddy cultivation, fertiliser management, improved fertiliser materials, crop diversification, etc. are explored for further reducing the GHG emissions from the paddy based systems.The proven mitigation practices, which can reduce the GHG emissions, are being demonstrated to farmers as part of the Technology Demonstration Component (TDC) of NICRA. The TDC of NICRA is being implemented in 121 climatically vulnerable districts of the country by taking one or cluster of villages in each of the vulnerable district.

Location specific, crop specific mitigation practices such as system of rice intensification, direct seeded rice cultivation (dry and wet methods of cultivation), soil test based fertiliser application, rational application of nitrogen, integration of trees especially fruit trees in the arable systems, efficient irrigation systems such as drip method and sprinkler method of application which can reduce the energy use while irrigating field crops, demonstration of zero tillage cultivation as an alternate to burning crop residues in rice-wheat systems of Punjab and Haryana where large quantities of rice residues are being burnt, integration of green manure crops in the existing cropping systems, promotion of green fodder crops and greater use of green fodder for livestock, etc. are being demonstrated as part of the technology demonstration component of NICRA in the 121 climatically vulnerable districts of the country. The proven resilient practices are being integrated in the development programs such as the Crop diversification in traditionally paddy growing regions as part of the National Food Security Mission (NFSM) wherein 1.02 lakh ha is being diversified from paddy to other less water consuming crops in the country during the year 2015-2016. Similarly the paddy systems of cultivation such as System of rice cultivation, direct seeded rice are being promoted by the development programs as part of the NFSM where in 1.63 lakh ha area was brought under these improved methods of paddy cultivation in the country during the year 2015-2016. Such kind of efforts would contribute to reduction of GHG emissions in the country.

Horticulture

Climate change impacts several horticultural crops in the country. Flooding for 24 hours severely affects tomato during flowering stage. Onion during blub stage is highly sensitive to flooding, where as warmer temperatures shorten the duration of onion bulb development leading to lower yields. Similarly, soil warming adversely affects several cucurbits. Reduction in chilling temperature in the recent years in Himachal Pradesh drastically affected apple production, and the farmers are shifting from apple to kiwi, pomegranate and other vegetables. More importantly, temperature and carbon dioxide are likely to alter the biology and forging behavior of pollinators that play key role in several horticulture crops. Under NICRA project research has been initiated at 5 ICAR Institutes viz., Indian Institute of Horticultural Research (IIHR), Bengaluru, Indian Institute of Vegetable Research (IIVR), Varanasi, Central Potato Research Institute (CPRI), Shimla, Central Institute of Temperate Horticulture (CITH), Srinagar and Directorate of Onion and Garlic Research (DOGR), Pune. High throughput screening of germplasm using plant Phenomics, Temperature Gradient Chambers, FATE Facility, Root imaging system, Environmental Chamber, TIR Facility, Photosynthetic System and Rainout shelter enabled to characterizes large number of germplasm lines and identify suitable donors for breeding against drought, heat stress and flooding in tomato, brinjal and onion. The technique for inter-specific grafting of tomato over brinjal has been standardized and large-scale demonstrations have been taken up to withstand drought and flooding in tomato. Environmentally safe protocol was developed for synchronizing flowering in mango, which is induced due to changing climate. A microbial inoculation with osmo tolerant bacterial strains have been developed to improve yield under limited moisture stress in tomato. Several resource conservation technologies viz., mulching, zero tillage, reduced tillage, biochar etc. have been demonstrated in climatically vulnerable districts across the country through KrishiVigyan Kendras (KVKs). Large-scale adoption of this climate resilient technologies enable to adopt the changes associated with global warming and also keeps pace with increasing demand for horticulture products in the country in the years to come.

Livestock

Under NICRA project climate change research facilities for livestock viz., CO_2 Environmental Chambers, Thermal Imaging System, Animal Calorimeter, Custom Designed Animal Shed etc. have been established at ICAR-National Dairy Research Institute (NDRI), Karnal and ICAR-Indian Veterinary Research Institute (IVRI), Izatnagar. Biochemical, morphological and physiological characterization of indigenous cattle breeds were carried out and compared with exotic breeds. The traits identified in indigenous breed viz., heat shock proteins, air coat colour, wooly hair etc. that impart tolerance to heat stress could be used in future animal breeding programs to develop breeds that can withstand high temperature. Different feed supplements have been identified and tested successfully to withstand heat stress in cattle. Studies on prilled feeding in cattle showed that they help lowering stress levels and methane emission. Custom designed shelters system and feed supplementation with chromium propionate, mineral supplements (Cu, Mg, Ca and Zn) both in feed and fodder significantly improved the ability to withstand heat stress. At ICAR-North Eastern Hill Region, Umiam, the local birds of Mizoram are predominantly black in colour, small size, crown appearance on head, light pink comb with black, poorly develop wattle, small ear lobe, shank is brown to black and elongated. The average annual egg production of local birds is 45-55 eggs. Local birds are more tolerant to common diseases of poultry. Innovative deep litter pig housing model was developed that offers the advantages of better micro-environment both summer and winter, better physiological adaptation, protecting animal welfare and behavior, faster growth rate of piglets and higher performance and productivity and low incidences of diseases/ conditions. The performance of Vanaraja poultry under backyard farming at different altitude under diversified agro-climatic condition was evaluated. Vanaraja birds have high tolerance to incidence of diseases and showed wide adaptability under different altitude. Many of these climate resilient technologies viz., feed supplement, shelter management, improved breeds, silage making, de-warming etc. have been demonstrated in the farmer’s field through KVKs in the 121 climatically vulnerable districts across the country. Up-scaling of these technologies through respective State Governments would enable the livestock farmers in the country cope with vagaries associated with climate change.

Fisheries

Under NICRA project climate change research facilities for Fisheries viz., Research Vessel, Green House Gases analyzer Agilent 7890A GC Customized, Fish Biology Lab, CHNS/O analyzer, Automatic Weather Station installed etc. have been established at ICAR- Central Marine Fisheries Research Institute (CMFRI), Kochi, ICAR- Central Inland Fisheries Research Institute (CIFRI), Barrackpore, ICAR- Central Institute of Brackish water Aquaculture (CIBA), Chennai and ICAR- Central Institute of Freshwater Aquaculture (CIFA), Bhubaneswar. Relationship of temperature and spawning in marine and freshwater fisheries sector is being elucidated so that fish catch in different regions can be predicted by temperature monitoring. A shift in the spawning season of oil sardine was observed off the Chennai coast from January-March season to June-July. Optimum temperature for highest hatching percentage was determined in Cobia. A closed poly house technology was standardized for enhancing the hatching rate of common carp during winter season. An e-Atlas of freshwater inland capture fisheries was prepared which helps in contingency planning during aberrant weather. For the first time a green house gas emission measurement system was standardized for brackish water aquaculture ponds. Cost effective adaptation strategies like aeration and addition of immuno-stimulant in the high energy floating feed helped freshwater fish to cope with salinity stress as a result of seawater inundation in Sundarban islands. Relationship was established between increase in Surface Sea Temperature (SST) and catch and spawning in major marine fish species. Simulation modeling was used to understand the climate change and impacts at regional/national level.

Micro Level Agro Advisory

Under ICAR-NICRA project a concept of micro level Agromet advisories at block level was developed and on a pilot basis with the help blocks level forecasts provided by IMD, Agrometeorologists of AICRPAM cooperating centers and KVK subject matter specialists initiated in 25 selected blocks in 25 selected districts. AICRPAM introduced a new concept "Field Information Facilitators (FIFs)" who acts as the interface between the farmer and AICRPAM & KVK for Crop data collection and dissemination of MAAS.

The Dissemination mechanism was strengthened with different methods used by the AICRPAM centers viz. Dandora, pasting posters at different important places where people frequently watch, through SMS to the mobile phones of the farmers who are registered with AICRPAM center and KVKs. Special mobile applications were also developed by AICRPAM centers for dissemination of AAS. The feedback obtained from the farmers stated that many of them were satisfied with the timely Agromet advisories which are benefitted them a lot. Some of the success stories presented below. In reality expansion of these services throughout the country will benefit of farming community and helps in doubling of their income.

Policy Support

Vulnerability assessment map prepared under NICRA is being used by different Ministries and several NGOs/CBOs.

- NICRA is also contributing to National missions like NMSA, Water mission, Green fund and INDC
- GHG inventory by NICRA partner institutes contributes to BUR reports
- Outcome of NICRA project supported some of the policy issues in Sates of Maharashtra (BBF Technology), Million farm ponds in the Sates of Andhra Pradesh and Telangana, ground water recharge initiatives (Southern states), drought proofing in Odisha, NABARD action plans, NICRA model village expansion in Assam etc.
- Contingency planning workshops organized every year in different States helps in preparedness to face weather aberrations.

Over all, NICRA project is contributing towards developing adaptation and mitigation strategies in the country and enabling to make Indian agriculture more resilient to climate change.

Conclusion

NICRA is a unique project, which brings all sectors of agriculture viz. crops, horticulture, livestock, fisheries, NRM and extension scientists on one platform for addressing climate concerns. It is very important to sustain the efforts made in the past few years and take forward the project for some more years. Over the past five years, the state of the art infrastructure facilities have been established, standardized and put in to function in core institutes of ICAR to undertake the climate change research. Manpower (Scientists, Research Associates, Research Fellows, Technical Officers etc.) have been trained to handle and operate these facilities. However, some of these precious research facilities are yet to be utilized to the full potential. In other words, a large platform related to climate change research has been created in the country. Crop improvement for multiple stresses takes several years of research and multi location testing. Efforts made under this project, in some cases resulted in development of varieties/hybrids ready for large-scale cultivation. Whereas, many are under different stages of development which may require few more years to be released as variety/hybrid/breed. Simulation modelling to assess the impact of climate change at regional level is still at initial stage. Standardization of minimum data sets and compilation of data from different sources have shown good progress. In the next phase, these data sets will be used for modelling. Capacity building for this activity will be emphasized and a dedicated group will be formulized. Research, essentially long term in nature, should continue further to achieve the intended outputs and outcomes.

Though there are some positive lessons and experiences emerging out of technology demonstration component, there is still considerable need to continue this activity to identify and demonstrate technologies that help deal with climate change. In fact, the technologies found to be performing well are getting fed into programs such as NMSA. There is still need to develop variety of adaptation options for different sub-sectors within agriculture, for different regions and for farmers with varying resource endowments. Such an effort is to be accompanied by identification of factors that help adopt technologies on a wider scale.

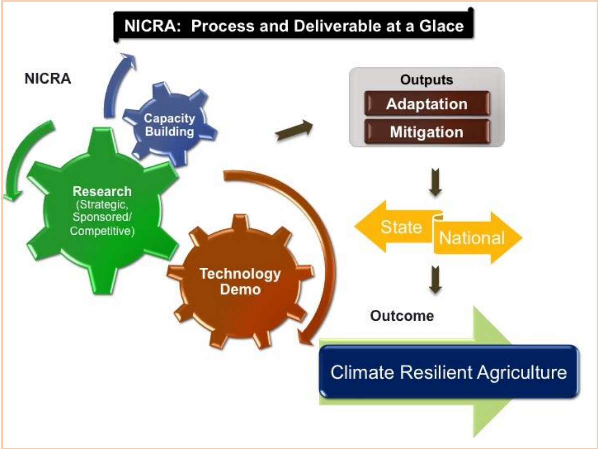

Fig. 3. NICRA: Process and Deliverable at a Glance

The commitments of the country to emission reductions require generate appropriate information and data on emissions as well as options that help reduce emissions. Techniques standardized so far under NICRA for estimation of GHG emissions from different management practices will be used for further reducing the carbon footprint of production systems in the country. Government of India has committed for the reduction of emission intensity of GDP by 32-35% by 2030 from 2005 levels, and the outputs of NICRA project contributing to several national project reports i.e., Intended Nationally Determined Contribution (INDC), Biennial Update Report (BUR), Nationally Appropriate Mitigation Action (NAMAs), National Mission on Sustainable Agriculture (NMSA) and several other Missions under National Action Plan on Climate Change. The system-wide impacts and responses to climate change need to be understood better and more comprehensively. The efforts in this direction, which have begun, recently have to be taken through their logical course for such an understanding is necessary to identify and prioritize various adaptation options. To sum up, the activities initiated few years back under NICRA should continue and expand in scope and content, and enable to develop multi location multi sector mitigation and adaptation strategies so that we combat major challenge posed due to climate change in Agriculture.

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Chapter 2

CLIMATE CHANGE AND INLAND OPEN WATER FISHERIES: ICAR-CIFRI INITIATIVES, PRIORITIES AND ACHIEVEMENTS

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Introduction

The fisheries and aquaculture sector contribute significantly to nutritional and livelihood security in developing countries. Over the three decades, global fish production has increased significantly to 167.2 million tonnes. Of this, aquaculture has significant contribution of 73.8 million tonnes (SOFIA, 2016). India is the second largest producer of fish contributing 11.4 million ton to the global fish production with a contribution of 7.7 and 3.64 million tonnes from inland and marine fisheries sectors, respectively. Fish products export fetched approximately Rs. 37870 crores in 2016-17 (DAHDF, 2017). The sector provides livelihood for more than 14 million people in the country. But in recent years, climate variability in form increased air and water temperatures, sea level rise, increased incidence of drought, flood, cyclones, and water have adversely affected the aquatic ecosystems, fisheries and fishers' livelihood (Badjeck et al, 2010). In Asia majority of fishery resources are anthropogenically disturbed and vulnerable to climate change (FAO, 2011). The multiple benefits that aquatic resources provide are now threatened by climate change (Das et al 2013).

As per IPCC's Assessment Report 5 (AR5), climate change is likely to reduce agricultural productivity in the tropics. Changing hydrological regimes due to erratic rainfall, melting glaciers will affect water resources, agriculture, coastal areas and resource dependent livelihoods. The increased occurrence of events such as summer thunderstorms, frequent intense drought of short duration, non-seasonal rains, prolonged monsoon and winter rains in Asia have been predicted (Sarkar et al., 2018). Specifically for the regions of South East Asia, of which India is a part, an accelerated hydro-cycle is anticipated which may result in frequent occurrence of high intensity short duration dry seasons followed by low intensity long duration wet seasons (IPCC, 2014). As per latest report of IPCC observed global mean surface temperature (GMST) for the decade 2006–2015 was 0.87°C 6 times higher than the average over the 1850–1900 period. Estimated anthropogenic global warming is currently increasing at 0.2°C per decade due to past and ongoing emissions. Climate models project increases in mean temperature in most land and ocean regions, hot extremes in most inhabited regions, heavy precipitation in several regions and the probability of drought and precipitation deficits in some regions (IPCC, 2018).

India has vast expanse of fresh water in the form of rivers, lakes, reservoirs and associated waters. The Gangetic river system, India's largest, harbours about 265 species of freshwater fish and supports a complex mix of artisanal, subsistence, traditional and semi-intensive culture fisheries based on the main river and adjoining water bodies of the Gangetic plains situated mainly in the three Indian states of Uttar Pradesh, Bihar and West Bengal (Vass et al., 2009). Given likely climate warming scenarios, water problems in the Ganga river basin will increase and may be critical in terms of the ecosystem goods and services derived from the inland water bodies via fisheries. Balancing the needs of the aquatic environment and other users may become difficult in many of India's aquatic ecosystems as population and associated demands increase (Das, 2009).

ICAR-Central Inland Fisheries Research Institute initiated research on climate change way back in 2004 under ICAR network project on "Impact, Adaptation and Vulnerability of Indian Agriculture to Climate Change in India" and later continued the climate change research under another ICAR network project on "National Innovations on Climate Resilient Agriculture (NICRA)". In the last one and a half decade, the institute has emerged as a nodal organisation conducting climate driven research in the field of inland open water fisheries. The work was carried out in 10 states in the eastern, central and northern parts of the country. A quantum of research pertaining to climate change in major river basins, impact of changing climate on gonadal maturation, breeding and spawn availability in inland open waters, assessment of thermal tolerance of species, carbon sequestration potential of wetlands and vulnerability assessment framework etc. has been carried out. This paper reviews knowledge generated by ICAR-CIFRI with regard to the exposure of inland fisheries to climatic changes in India.

Assessment of climate change impact on inland fisheries in Ganges

Climate change is evident in India as manifested by increased air temperatures, regional variation in the monsoon, frequent occurrence of droughts, and a regional increase in severe storm incidence in coastal states of India. The impact of climate change is being felt in the inland aquatic resources and their fisheries. Literature on the River Ganga and water bodies in its plains, indicate a 0.99°C increase in the minimum water temperature recorded in the upper stretch of River Ganga and 0.5 to 1.4°C in the aquaculture farms of West Bengal (Das et al., 2013). Increased post monsoon rains have contributed to breeding failure of the Indian Major Carps (IMC) and a consequent decline in fish spawn availability in river Ganga). A geographic shift of warm water fish species *Glossogobius gurius* and *Xenentodon cancila* to the colder stretch of the river Ganga has been reported. In last 30 years, the predator prey ratio in the middle stretch in the river Ganga has also declined drasatically. Fish production has shown a distinct change in the last two decades in the middle stretch of river Ganga where the contribution of IMC has decreased from 41.4% to 8.3% and that of miscellaneous and catfish species increased(Vass et al, 2009). Drought in West Bengal in 2009 caused rainfall deficits of 29% and 27% in the districts of North 24 Parganas and Bankura respectively; affecting 92% of hatcheriesand caused 61% to 73% of fish spawn compared to the previous years. A digital elevation model generated for coastal district of South 24 Parganas indicated the potential for 3% to 11% submergence of aquaculture areas in response to 1 to 2 meter rises due to sea water incursions (Das et al., 2013).

Impact of Climate Change on the Breeding of fishes

The aquaculture hatcheries in the state of West Bengal extensively breed the Indian major carps, which form the mainstay of Inland aquaculture in the country. These fishes breed during the monsoon season usually June to September. In recent years, the spawning of carps has been observed as early as March. Temperature along with rainfall and photoperiod stimulate the gonadal maturation of Indian major carp. Average minimum and maximum temperature throughout West Bengal has increased and rainfall pattern has changed, Analysis of the air temperature data from 1999-2009 from North 24 Parganas and Bankura, West Bengal, where aquaculture hatchery farms are located was recorded by IIMT Pune (Dey et al., 2006, Das et al., 2013). The data indicated mean maximum and mean minimum air and water temperature have increased and higher temperature was recorded during colder months. Data also indicated that during 1980 the breeding of Indian Major Carps started during the last week of May, whereas from 2005 it started during mid April. The breeding period of Indian major carps has extended by 40-60 days with breeding season extending from

110-120 days (Pre1980-85) to 160-165 days (2000-2008) in hatcheries in four districts of West Bengal, India (Dey et al. 2007).

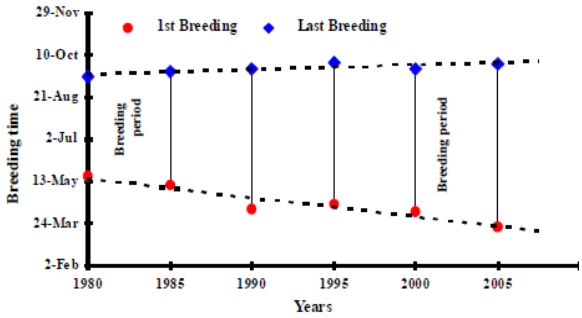


Fig. 1. Enhanced breeding periods in hatcheries of Bankura (a) and North 24 Parganas (reproduced from Day et al 2007)

Impact of climatic variables, *viz*. temperature and rainfall on the spawning of Indian Major Carps (IMC) was also studied in the river Mahanadi, in the fish hatcheries in its plains by das et al 2012. As per their study during 1981-2010 the average minimum and maximum temperature throughout the state has increased in the range of 0.1 °C to 0.9 ºC. The annual rainfall in districts of Cuttack and Puri have also increased while it has decreased in Angul, Balasore, Khurda, Sambalpur and Bolangir districts. They have reported declined fish spawn availability in river Mahanadi from 30-43 ml $net^{-1}day^{-1}$ to t of 6 ml $net^{-1}day^{-1}$. The study revealed that the onset of the breeding period of the Indian major carps has advanced by one month in the hatcheries in last decade. The advancement in breeding period was attributed primarily to the effect of increased water temperature and shifting of the rainfall pattern facilitating early maturation and spawning. The hatcheries surveyed also perceived temperature and rainfall as the most important factors responsible for advancement of the onset of breeding of IMC.

Mahseer is an important group of endemic game fish found in the Indian subcontinent inhabiting in streams, riverine pools and lakes. Reproductive biology of mahseer from

Himalayan region of Uttrakhand to study impact of climate change on its breeding phenology. The authors conclude that the "breeding phenology of golden mahseer may likely have gone through two distinct steps of transformation viz. shifting-prolongation (1911–1981) and reduction-stabilization (1981–present)". They predict that mahseer will continuously adapt to changing climate in lesser Himalayas.

Development of E-Atlas

The institute has developed standalone software in the form of E-atlas that integrates data on hatchery location, fish species cultivated, onset and period of breeding and spawn output of inland fishes over the years. The spatial differentiation visualized in the E-atlas will help planners in developing adaptation strategies for inland fisheries to climate related changes.

Impact of temperature change on growth of *Labeo rohita:* Development of a Growth Model

Temperature affects survival and growth of any species at a given location. Within suitable thermal range, increasing temperatures may favor faster growth rates and longer growing seasons. ICAR-CIFRI assessed the impact temperature on the growth of *Labeo rohita* fingerlings reared in simulated temperature for 35 days at water temperatures ranging from 29ºC to 35ºC. "Fish reared at 34ºC water temperature exhibited a significantly faster growth than other temperatures. The change in growth rates were insignificant between 29ºC, to 32ºC treatment groups but growth rates significantly increased in the temperatures ranging from 32ºC to 34ºC and decreased thereafter" (Das et al., 2013). As per this study, it would take about 54-55 days for a carp to double in weight at 30ºC - 33ºC but only 35-36 days at 34 ºC. According to the authors their growth model gives a reliable projection of growth with unit rise of temperature and may be useful for developing species-specific adaptation strategies under the climate warming scenarios.

A framework for assessing vulnerability of inland fisheries to impacts of climate variability in India

A composite vulnerability index (0.0–1.0) was innovated by Das et al., 2013 for assessment of fisheries vulnerability to climate variations in 14 districts of West Bengal state on basis of functional relationships amongst sensitivity, exposure and adaptive capacity using 19 indicators related to inland fisheries. The data obtained reflected different spatial combinations of climate exposure, sensitivity and adaptive capacity among the districts. Five districts were highly vulnerable which was attributable to low adaptive capacity of the fishers, which played an important role in altering the spatial pattern of vulnerability among the districts. This research provides an important basis for policy makers to develop appropriate adaptation strategies to minimize the risk of fisheries sector to climate variations (Das et al., 2013).

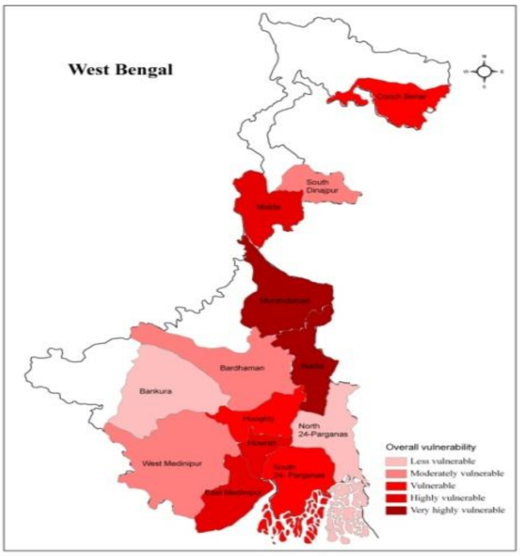
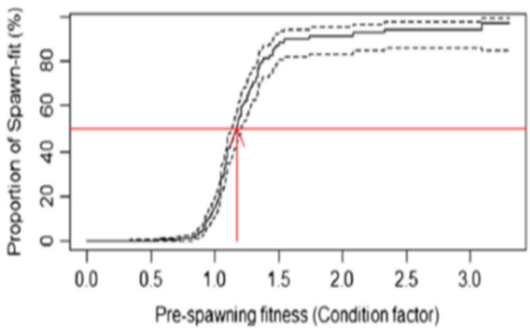


Fig. 2. Mapping of vulnerability index for West Bengal based on overall vulnerability (Reproduced from Das et al., 2013)

Conceptualization and parameterization of pre-spawning fitness and identification of climate preferendum through models

The concept of threshold condition factor (Fulton), beyond which more than 50% of the female fish population may attain readiness for spawning coined as pre-spawning fitness (Kspawn50), has been proposed by Sarkar et al, 2018. They strategized a two-step analysis. First, a parameter coined as pre-spawning fitness (Kspawn50) similar to length at 50% maturity (L50) was conceptualized and estimated by applying non-parametric Kaplan-Meier. Secondly, an attempt was made to identify the thermal and precipitation window (climate preferendum) in which the K spawn50 is attained by the fish. LOESS smoothing technique was applied to map the climate preferendum for attainment of estimated Kspawn50. Kspawn 50 was parameterized and benchmarked for *Mystus tengara*. *Mystus cavasius*, *Eutropiichthys vacha* and *Johnius coitor* from Ganga river basin.



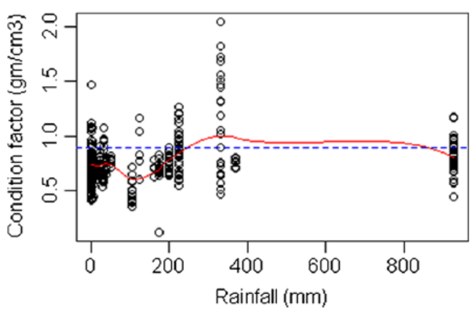


Fig. 3. Estimation of pre spawning fitness (PSF) coefficient and its precipitation (Reproduced from Sarkar et al, 2018)

The knowledge on the role of environmental variables in relation to gonadal maturation and breeding of commercially important fish species in inland open waters remain largely unexplored. Karnatak et al, 2018 made preliminary attempt to outline the relatively important environmental variables influencing maturation and spawning of *C. punctata* in a tropical floodplain wetland of West Bengal, India and estimated threshold values of GSI for successful spawning. The authors conceptualized 'Breeding Event' by binary coding and used Generalized Additive Model (GAM) to determine the threshold value of GSI for breeding. Among the climatic and water chemistry variables studied, seasonal variation in rainfall was found to have the most profound effect on gonadal maturation and breeding in *C. punctata*, followed by water temperature. The favourable range of rainfall and temperature varied between 800 mm to 1400 mm and 29 °C and 31 °C respectively. The authors conclude that rainfall being the major climatic factors influencing water chemistry in the wetlands, changes in rainfall pattern may influence breeding periodicity of *C. punctata* in wetlands in climate change scenario.

Sarkar et al, 2018 studied reproductive biology of female amphidromous croaker *Johnius coitor* for the first time from various freshwater stretches of Ganga river basin, India in relation to climatic variability. Water temperature was found to be the most crucial environmental parameter influencing gonadal maturation and breeding. Study revealed water temperature in the range of 23–25 °C and threshold GSI above 3 units as essential for breeding. Pre-spawning fitness (Kspawn50) and size at 50% maturity (LM50) were estimated in the range 1.27–1.37 units and 19–24.5 cm respectively. LOESS smoothing technique hinted water temperatures <20 °C and >32 °C to be detrimental for attainment of pre-spawning fitness while no dependence on rainfall was observed. Minimal climate driven changes were predicted in breeding of this fish species. The baseline information generated may act as benchmark for future studies assessing climate driven changes and evolutionary adaptations in croakers from river Ganga.

A stakeholder-driven approach for quantifying climate change induced threats to wetland fisheries

Floodplain wetlands of West Bengal, India, are important fisheries resources and provide tremendous economic and ecological services. There is lack of long-term quantified data to assess the impacts of climate change on floodplain wetlands fisheries in India. To overcome the issue of lack of long-term quantified data for assessing the impacts of climate change on floodplain wetlands fisheries in India, a stakeholder-driven approach has been developed by modifying Delphi method (Naskar et al, 2018). Involvement of all the stakeholders and consideration of farmer perceptions on climate resilience policies is essential to devise resource-specific, farmer-friendly and climate change resilient fisheries/aquaculture strategies. An effort was made to develop a methodology for ascertaining stakeholders' perceptions with an objective of enlisting, quantifying and prioritizing various threats on the wetland fishery due to climate change.

The study identified around seven potential climate change-induced threats on wetland fisheries among which water stress (95% consensus), wetland accretion/ sedimentation (85%), aquatic weed proliferation (70%) and loss of wetland connectivity (65%) were high-priority issues demanding immediate management action. The results obtained from stakeholders' perception were validated with findings of published literature, some of which are based on long-term data and complicated modeling approach. The methodology is alternative to data-driven approach for quantifying climate-induced threats to wetland fisheries. The assessment framework developed can easily be recalibrated and replicated in other areas, where long-term research data are not available.

Identification of Adaptation strategies for climate resilient wetland fisheries

Six adaptation strategies were identified, from beels of West Bengal by Sarkar et al, 2018 namely Temporary pre-summer enclosure, Submerged branch pile (Kata) refuge, Autumn stocking, Torch light fishing, Deep pool (Komor) refuge and Floating aquatic macrophyte refuge fishery (Pana chapa). These can serve as refuge during summer and help in maintaining base stocks in the wetlands for recruitment in the following monsoon season. Their study elaborates the climate smart nature of these pre-existing indigenous fishery strategies, emphasizes on their optimization and polarization for their large-scale adoption by wetland fishers.

Demonstration of Climate Resilient Pen System (CRPS) in floodplain wetlands of India

The institute has successfully demonstrated Climate resilient pen systems in wetlands of West Bengal, Assam and Kerala for farming of fish and shellfish and conservation of SIFs. The pen designated as CRPS has high tensile strength HDPE net material, provision to withstand flood, wind action and is used for culturing resilient indigenous species. Sufficiently reinforced and structurally superior net enclosures using the latest net fabric with highest available tensile strength in the market is employed for making the net wall. The net walls have minimal split bamboo and 'only net' composition to facilitate better water exchange. The height of the pen wall is kept more than highest water level encountered during peak monsoon. Excess net can be roll-down during lean season when the water depth inside pen recedes. The structure is constructed 5 m away from the bank/bundh of the wetland so that the effective water area inside the pen is not compromised during lean season. However, to counter the opposite effect during monsoon (i.e. marginal water is deep enough), provision is kept to fence the gaps with net material to prevent escape of stocked fishes. The institute has also released a short seven minute documentary on CRPS which has also been uploaded in Youtube (https://www.youtube.com/watch? v=IyYJka_ZHus).

Fish seed stocking in CRPS through community participation

Carbon sequestration studies

The C budgeting strategy developed by the Institute quantifies the total sequestered carbon per unit area per annum taking the major biotic and abiotic components of the system into consideration under the single experimental framework. This would help in explaining the differences in C sequestration potential of different type of wetlands and in quantifying the ‘commercial blue C’ in the form of fish crop harvested from the system as a spinoff of the C-cycle. The institute has generated information on carbon sequestration potential from different types of wetlands and from wetlands situated in different agro climatic zones across India. Assessment of carbon sequestration potential of different types of wetlands from Eastern and North Eastern India revealed higher sequestration potential in wetlands of Eastern India compared to reference upland sites.

Governance and Policy

The institute also developed a Developed a policy document on climate change and inland fisheries. The recommendations of the policy document have been well consulted and appreciated by states of Assam, Odisha and West Bengal through inclusion in their state action plans for fisheries development.

Future Research Thrust

Heat waves are expected to amplify in magnitude and frequency under anthropogenic climatic variation (IPCC 2012). According to latest report of IPCC, heat waves will "very likely" intensify over most land and aquatic areas in this century**.** India is also experiencing increased instances of intense heat waves, which are extreme in nature. The Institute is now set to initiate research on impact of heat waves on inland open water fisheries. The institute has also initiated work on green house gas emissions from different types of wetlands. Methane is the second most important greenhouse gas contributing to about 20% of global warming. Natural wetland accounts for 23% of the global methane budget where Methanogenic archaea are the exclusive producers, which accounts for major (75%) of the methane emitted to the atmosphere however, aerobic and anaerobic methanotrophic microorganisms mitigate majority of the methane emitted. Wetlands with varying environmental condition and anthropogenic activities may affect methanotroph and methanogen population. The institute has recently initiated studies on identification and quantification of these bacteria from different types of wetlands.

Conclusion

ICAR-CIFRI has been conducting important research on impact of climate change on inland fisheries, and has generated significant amount of knowledge, and has published a number of research articles, technical bulletins, leaflets, etc. which will be benefitting students, researchers and stakeholders. The huge quantum of research outputs emanated from the projects will serve as baseline to understand the climate change and associated impacts on inland fisheries and to develop mitigation and adaptation strategies benefitting fishers, researchers, planners and policy makers.

Acknowledgement

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Chapter 3

TECHNOLOGY PRIORITIZATION FOR ADOPTION IN CLIMATE SMART AGRICULTURE / FISHERIES

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Introduction

India is faced with the challenge of sustaining its rapid economic growth in the face of increasing threat of climate change. With an economy closely tied to its natural resource base and climate sensitive sectors, agriculture, forestry and fisheries the climate change impacts are likely to bring new challenges as well as exacerbate already existing ones, impacting livelihoods and food security (Das M.K., 2015). The climate issue has at present become a part of the larger challenge of sustainable development in India.

At present the climate change scenarios (IPCC, 2014 and IMD, 2017) reveal carbon dioxide concentration has crossed 410 ppm. The mean temperature has increased by approx. 1^{o}C.A seasonal shift indicated by winter shortening is evident. The rainfall variability and intensity has increased. There is evidence of the glaciers retreating and ice sheets melting and sea levels rising. The future climate scenarios clearly indicate frequency and intensity of climatic extremes viz., cyclones, heavy rains, heat waves, flood and drought increasing. Predictions show that without additional mitigation, global temperature is to increase by 3.7 to 4.8^{o}C. The sea level to rise by approx. 50 cm by 2100. Since rainfall distribution in India is crucial: even with normal monsoon in 2016 and 2017, 34 and 18 % area had deficit rainfall and 19 and 21% had excess respectively.

The latest (2018) IPCC special report “Global Warming of 1.5 °C” on the impacts of global warming of 1.5 °C above pre-industrial levels highlights a number of climate change impacts that could be avoided by limiting global warming to 1.5°C compared to 2°C, or more. According to the new report, technologies are in hand to keep global warming limited to 1.5°C, such as renewable forms of energy. The main challenge is in putting these to work quickly and massively, which in turn hinges on the desires of policymakers and the public

The key issues of climate change related to agriculture are i) effect on crops ii) implications on water availability iii) impacts on livestock and milk production iv) effect on freshwater and marine fisheries. Considering the above potential impacts an urgent need has been felt for developing climate smart sustainable agriculture (CSSA) in India. It essentially means an integrated approach to developing technical, policy and economic conditions to achieve sustainable agricultural development for food security under climate change. The three main aspects of CSSA are increasing productivity and means ii) building resilience to climate change iii) reducing/or removing carbon emissions.

It is pertinent at this point to delve into the major initiatives undertaken by of Govt. of India for developing climate resilient agriculture

1. National Mission on Sustainable Agriculture (NMSA): The NMSA is one of the eight missions under National Action Plan on Climate Change (NAPCC) to address adaptation and mitigation approaches on agriculture systems of India. The NMSA has identified 10 key dimensions for adaptation. These include improved crop seeds, livestock and fish culture; water use efficiency; pest management; improved farm practices; improved nutrient management; agricultural insurance; credit support; markets; access to information and livelihood diversification.

2. Rain fed Area Development (RAD): The RAD focuses on Integrated Farming System (IFS) for improving productivity and minimizing the risks associated with

climatic variability. Under this system, crops/cropping system is integrated with activities like horticulture, livestock, fishery, agro-forestry, apiculture etc. to enable farmers not only in enlarging farm returns for sustaining livelihood, but also to offset the negative impact of drought, flood or other extreme weather events on agriculture.
3. National Agro forestry Policy (NAP): The policy will provide a platform to stimulate the growth of agro forestry in India. Agro forestry is known to have the potential to mitigate the climate change effects through microclimate moderation and natural resources conservation in the short run and through carbon sequestration in the long run.

4.Pradhan Mantri Krishi SinchaiYojana (PMKSY)**:** The PMKSY not only focuses on creating sources for assured irrigation, but also creating protective irrigation by harnessing rain water at micro level through ‘Jal Sanchay’ and ‘Jal Sinchan’.

5. Agriculture Contingency Plan: Central Research Institute for Dry land Agriculture (CRIDA), ICAR has prepared district level Agriculture Contingency Plans in collaboration with state agricultural universities using a standard template to tackle aberrant monsoon situations leading to drought and floods, extreme events (heat waves, cold waves, frost, hailstorms, cyclone) adversely affecting crops, livestock and fisheries (including horticulture).

6. National Initiative for Climate Resilient Agriculture (NICRA): The NICRA is a network project of the Indian Council of Agricultural Research (ICAR) launched in February, 2011. The project aims to enhance resilience of Indian agriculture to climate change and climate vulnerability through strategic research and technology demonstration. The research on adaptation and mitigation covers crop, livestock, fisheries and natural resource management. The project consists of four components viz. Strategic research, Technology Demonstration, Capacity Building and Sponsored/Competitive grants.

7. State Action Plan on Climate Change (SAPCC): India‘s efforts in climate change mitigation and adaptation actions are commendable with several states seriously engaged to address the climate change induced risks.

One of the important principles of the National Action Plan calls for deploying and development of new technologies that fulfil the mitigation and adaptation needs of the country. A dire need was felt for scouting technologies for India that are clean and environment friendly, cost-effective and one that suits country-specific requirements. Keeping this aspect in view the National Mission on Sustainable Knowledge for Climate Change (NMSKCC) mission of Dept. of Science and Technology (DST), GOI entrusted Technology Information, Forecasting and Assessment Council (TIFAC) to prepare Global Technology Watch Group (GTWG) reports on sustainable agriculture. TIFAC formed the GTWG of experts for different sectors of agriculture, livestock and fisheries with the objective of **a)** To prepare a global technology database for climate-smart sustainable agriculture, **b)** to prioritize these technologies as per Indian context and, **c)** to prepare a Report for the Government and Industry for accelerating actionfor early adoption of the technologies.

Technology Scouting and Prioritization - Steps

Six steps were followed for scouting and prioritizing the technologies available globally and suitable for climate-smart sustainable agriculture in India.

1. Scouting of all the available technologies from literature, expert judgement, stakeholders’ feedback, etc.

2. Classification and rationalization of the scouted technologies to remove duplication, overlapping and double counting.

3. Identification of potential and relevant technologies based on expert judgement.

4. Prioritization of the technologies based on technological, economic and environmental parameters (Ranking 1).

5. Identification of top 10 technologies.

6. Prioritization of the top 10 technologies based on policy and socio-cultural parameters (Ranking 2).

7. Final ranking of the technologies with 75% weightage for technological, economic and environmental parameters and 25% weightage for policy and socio-cultural parameters.

Technology prioritization

It is imperative to prioritize the technologies identified through technology scouting process as per country needs because all the technologies may not be equally suitable and implementable for climate-smart sustainable agriculture. Therefore,. A Multi-Criteria Decision Analysis (MCDA) method was followed for prioritization of the scouted technologies in different sub-sectors of agriculture. Primarily, in the MCDA method, technologies are prioritized using five broad parameters viz. Social, Technological, Environmental, Economy and Policy (STEEP). Three steps were followed to prioritize technologies.

Firstly, for each parameter, few sub-parameters were identified based on discussion and consensus by GTWG. It was also felt that all the parameters do not have equal importance in achieving the climate resilient sustainable agriculture development. Accordingly, different weightages were assigned to each sub-parameter depending on their relative importance. Further, it was also observed that these parameters may not be uniformly applicable to all sub-sectors; hence different weightings were given to each sub-parameter in different sub-sectors.

Prioritization with Technological, Economic and Environmental Parameters (Ranking1)

For technological, economic and environmental parameters, a few sub-parameters were identified and each of these sub-parameters was given different weightage based on expert judgement as presented in Table 1.

Table 1. Sub-parameters of technological, economic and environmental parameters and the respective weightage.

Parameter	Sub-parameter	Weightage (%)*
A. Technological	1. Impact on production	20
	2. Ease of implementation	10
	3. Mechanization/ICT compatible	5
	4. Readiness level	10
B. Economic	1. Enhanced income of farmers	15
	2. Economic feasibility	15
C. Environmental	1. Energy efficiency/renewable energy	10
	2. Greenhouse gas mitigation	5
	3. Climate vulnerability/risk reduction	10
Total	9	100

*Weightage for sub-parameters used for fisheries sub-sector

Once the weightage was fixed, each technology was scored (out of 100) for different sub-parameters.Approximately700 technologies from various sub sectors of agriculture were scouted of which 17 were from the fisheries sub sector. Thetop 10 technologies were identified based the highest total scores for ranking 1. This exercise was done by 15-20 experts of the respective sub-sector, interaction meetings and stakeholders workshops.

Prioritization with Policy and Socio-cultural parameters (Ranking 2)

The next round of ranking of these 10 identified top technologies (ranking 2) was done using socio-cultural and policy parameters. For each of the parameter, few sub-parameters were identified and each of these sub-parameters was given different weightage based on expert judgement as presented in Table 2.

Table. 2. Sub-parameters of socio-cultural and policy parameters and the respective weightage

Parameter	Sub-parameter	Weightage (%)*	
		Very high	Very low
A. Socio-cultural	1. Socio-cultural complexity	100	0
	2. No-regret characteristics	100	0
B. Policy	1. Institutional complexity	100	0
	2. Urgency	100	0
	3. Small farmers friendly	100	0

*Weightage for sub-parameters.

Once the weightage was fixed, each technology was given score (out of 100) for different sub-parameters.

Final ranking of the technologies

Final ranking was given taking 75% weightage for the technological, economic and environmental parameters and 25% weightage for the socio-cultural and policyparameters. In the overall analysis, the weightage given to various parameters are given in Table 3.

Table 3. Overall weightage for various parameters

Parameter	Weightage (%)*
Technological	35
Economic	25
Environmental	15
Socio-cultural	10
Policy	15
Total	100

*The weightage varied for different sub-sectors

Technology Validation Workshop

To discuss and validate the technologies scouted by the GTWG Sustainable Agriculture group a validation workshop was organized in 2018 at National Academy of Agricultural Sciences (NAAS) .The workshopwas attended by President, NAAS, Chairman, National Steering Committee, GTWG project,DG ICAR and around 30 distinguished Fellows of NAAS.

Prioritization of technologies for the Fisheries sector

The fisheries and aquaculture sector has a significant contribution to food security and livelihood in India. The sector contributes 0.79 percent to the *Gross domestic product* (*GDP*)**.** Globally, India is the second largest producer of fish contributing 5.43 percent to the global fish production and is also the second major producer of fish through aquaculture. The total fish production in India is 8.23 million tonnes with a contribution of 4.98 million tonnes from inland fisheries and 3.25 million tonnes from marine fisheries. The volume of fish and fish products exported during 2010-11 was 813091 tonnes worth Rs. 13000 crores. The sector provides livelihood for 14 million people in the country (DAHDF, 2014). But in recent years, climate variability manifested by rise of sea level, increased incidence of flood, drought, tropical cyclones and increasing water stress in various countries including India have adversely affected the aquatic ecosystems, fisheries and fishers' livelihood (Cruz et al.,2007, Badjeck et al.,2010 and Das et al.,2013). The importance of these projections stems from the fact that a majority of the fishers in Asia live in anthropogenically disturbed areas and are sustained by aquatic resources vulnerable to climate variations (FAO, 2011). The multiple benefits that fisheries and aquaculture provide for alleviation of poverty in these countries are threatened by climate change.

Unlike the terrestrial environment where the impact of climate change is mainly felt directly by the agricultural crops or livestock, the impact on fisheries and aquaculture is mediated through the aquatic environment which serves as the habitat for fish. The main drivers of climate change related to fisheries viz., flood, drought, tropical cyclones and increasing water stress has the potential to alter the aquatic habitat characteristics impeding fish production. But, a major concern is the sectors vulnerability to a wide range of on-going threats, including overfishing, habitat loss, water abstraction, drainage of wetlands, pollution, and dam construction, making the impact of climate change difficult to segregate (IPCC, 2014 and IMD, 2017). While developing the adaptation strategies it is imperative to understand the links between fisheries and agriculture for the region. Productive agricultural areas in Asia are located around lakes, swamps, reservoirs, and river-floodplains. Fisheries very often provide capital to invest in agricultural inputs and livestock in these regions (Das et al., 2016). If the fishing system is under stress, the potential of the other components of the tri-economy is reduced (WFC, 2007). In the scenario of the climate change projections for the region which emphasise reduced rainfall and more water stress the demand of water from the common pool inland aquatic resources will increase among the competing users. Improper management of these valuable resources will increase their vulnerability and would affect poor people more (Beck and Nesmith, 2001).

The Ganga river basin area in India can be cited as an example to clarify the point. It is one of the hot spots susceptible to land/atmosphere interactions sustaining at present approximately 440 million people which is expected to rise to 634 million by 2025.The impacts occurring in the Ganga basin due to climate change cannot be looked at in isolation, it needs to be assessed together with other environmental changes. For example the hydrological impacts of two of the most important drivers of change in the Ganga basin viz., development of reservoirs and barrages and climate changes are largely opposite to each other. Significant change in climate related factors such as precipitation and sea level rise are estimated to occur over the time span of several decades and consequently, their impacts on the water resources, ecosystems, organisms and livelihoods are expected particularly in the longer term in the basin. On the other hand the changes caused by hydropower development in terms of increasing reservoir capacity or diversion of water and their consequent impact in the basin are going to be felt within a much shorter time scale possibly within 5-15 years. These factors have brought a level of uncertainty in dealing with the problem of climate change vulnerability and impact studies in India by the government and the stakeholders[1].

Considering the uncertainties of the climate change effect on fisheries it is felt judicious to introduce climate resilient development strategies particularly for fisheries of inland and near-shore waters so that these both support general development and climate change adaptation in the vulnerable region. This would in general enhance the adaptive capacity of the poorer section of the society. In this context following eight climate resilient technologies of the fisheries sector has been prioritizedusing the Multi-Criteria Decision Analysis (MCDA) method mentioned above in the GTWG project.

A) Brackish water aquaculture

Intensive storm surges and inundation of the coastal areas causes salinization due to mixing of saline water with fresh water in these areas. Brackish water aquaculture of some species extensively cultured in the coastal states of India viz., *Mugil cephalus, M. parsia*, *Lates calcarifer*, *Chanos chanos*, *Etroplus suratensis* forms a very useful option in such areas sustaining productivity and livelihood (Handbook of Fisheries and Aquaculture, 2011).

B) Periphyton based carp culture

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

Periphyton-based practices have developed independently and are used to catch fish in open waters in various parts of the world. In India (West Bengal) the practice is known as Komor or Huri, in Bangladesh it is called Katha, in West Africa Acadja, and in Cambodia Samarahand. In the eastern states of India the practice is essentially fixing vertically unused bamboo sticks, tree branches to act as substrates for colonization by the plankton, microbes, invertebrates and other organisms that make up periphyton, in the various household tanks so commonly found in the rural areas. The farmers in this part of India and Bangladesh traditionally believe that shaola (periphyton) growing on the substrate form food for the fish and serve as protection against poaching of fish. Indian major carps are grown in these ponds for fish culture to sustain the rural population. The technology seems to hold promise for the farming of any herbivorous fish, which is capable of harvesting periphyton from substrates (Das and Sharma, 2010).

C) Cage culture of fish

Fish culture in floating cages installed in wetlands, reservoir, river, or off shore seahas become an important option for the fisheries sector in the wake of limitation of land and water availability to enhance fish production and provide an important means of providing alternative livelihood for fishers. At present in India the fish species cultured in cages in marine and brackish waters are *Lates calcarifer,* Cobia (*Rachycentron canadum*), *Mugil cephalus, Etroplus suratensis* and in inland fresh waters are *Labeo rohita, Cirrhinus mrigala, Pangasius sp. Channa sp. and Heteropneustes fossilis* (Handbook of Fisheries and Aquaculture, 2011).

D) ***Fish cum paddy culture***

Agri-based systems include rice-fish integration, horticulture-fish system, mushroom-fish system, seri-fish system. In this system, fish culture is integrated with agricultural crops such as rice, banana and coconut, thereby producing fish and agricultural crops under one interlinked system. In India, though six million hectares are under rice cultivation, only 0.03 per cent of this is now used for rice-fish culture. This type of fish culture has several advantages such as (a) economical utilisation of land, (b) little extra labour, (c) savings on labour cost towards weeding and supplemental feeding, (d) enhanced rice yield, and (e) additional income and diversified harvest such as fish and rice from water, and onion, bean, and sweet potato through cultivation on bunds. This technology of fish culture can be expanded in the rice fields of our country (Handbook of Fisheries and Aquaculture, 2011).

E) Integrated fish livestock farming

Integration of livestock in fish culture is an old age system of practice. Ducks, poultry, pig, cattle, buffalo, sheep and goat are common in mixed farming. Nowadays rabbit also incorporated in integrated livestock cum fish culture. Due to progressive shrinking of farm holding to obtain maximum output adoption of mixed farming system with livestock and fish become very popular in wetland and water shed areas of the country. The by-product utilization of one sub-system e.g. excreta of livestock becomes an input to a second sub-system i.e. in fish culture (http://www.krishisewa.com/articles/livestock/402-livestock-fishery-integrated-farming.html).

F) Pen culture of fish

Pens can be constructed with frameworks of wood, bamboo, metal, etc, on which netting or other fencing material is stretched to form an enclosure. The netting is fixed to the bottom of the water to prevent fish from swimming under it. This can be done by using pegs or sand bags. The mesh of net used for the pen should be small enough to prevent the fingerlings from escaping through it. The major advantage of pen culture is i) Maximum use of available water bodies like wetlands, reservoirs ii) Reduce pressure on land use iii) Rapid ,easy and complete harvest of fish iv) Scope to raise different species and size of fish (https://youtu.be/byYLka_ZHus).

G) Waste water aquaculture

The production of fish in ponds fertilized with waste water is a common practice in many parts of Asia. Waste-water fed aquaculture is a well-established climate resilient practice that contributes substantially to inland fish production in India and elsewhere. The biodegradability of these wastes forms the basis for sewage treatment converting waste into economic resource for recycling. The sewage effluents in fish ponds mediated by microorganism act in the manner as organic fertilizers and liberate nitrogen, phosphorus and trace elements which stimulate the production of fish food organisms in the aquatic culture systems. It is estimated that at present there are more than 130 waste water aquaculture units in India covering above 10,000 ha. Normally, multiple stocking and multiple harvesting is adopted in these bheries, and fishes are reared for 3-5 months, depending on the growth of the fishes to reach marketable size. The average fish production ranges from 1,500 to 2,000 kg/ha (Handbook of Fisheries and Aquaculture, 2011).

H) Drought tolerant fish culture

The impact of climate variability on the aquaculture system will reflect in reduced water quality and limitations in the cultivable area and volume. As a result loss in fish production is expected. The technology essentially uses smaller ponds that retain water for 2-4 months. Fish species cultured are *Pangasius sp., Puntius javanicus, Pygocentrus mattereri, Oreochromis niloticus* (Handbook of Fisheries and Aquaculture, 2011).

The present initiative by TIFAC through Global Technology Watch Group (GTWG) under National Mission on Sustainable Knowledge for Climate Change (NMSKCC) mission of the Department of Science & Technology (DST), Government of India has resulted in scouting of about 778 technologies subdivided into 11 sub-categories following different foresight techniques with respect to agriculture and allied disciplines. The top ten technologies from each of the sub-category were shortlisted following a logically drawn quantitative Multi Criteria Decision Analysis (MCDA) technique. These technologies need immediate attention for validation in various agro-ecological regions and nurtured extensively for use by the concerned stakeholders.

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Chapter 4

CO_2 MITIGATION POTENTIALS OF MICROALGAE: A NEW PROPOSITION FOR CLOSING THE LOOP OF CARBON THROUGH FOOD CHAIN OF HERBIVOROUS FISH

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Introduction

Microalgae have been extensively researched for biofuel or biochar production through molecular and biotechnological interventions (Nogia et al., 2016); the less explored area is the use of microalgae for mitigation of global warming by trapping atmospheric carbon and production of microalgae that are preferred food items of herbivorous fish and zooplankton in open ponds or in wetlands. Herbivorous fishes are primary consumers with short food chain and hence energetically more efficient than the carnivorous fish having loner food chain or energy intensive. Another advantage of herbivorous fish culture is the biological clearance of aquatic weeds and algae in a pond without application of toxic chemicals. So it is a win-win strategy towards carbon mitigation of global warming and production of phytophagous fish concurrently clearing algal biomass from open ponds.

Microalgal photosynthesis

Photosynthesis is the conversion of photon energy into chemical energy to form glucose and water and oxygen is released as byproduct. The contributions of energy to chlorophyll are mainly from the violet-blue, reddish orange-red wavelengths of the spectrum. The chloroplast of the microalgae, similar to other plants, is the site of photosynthetic reactions carried out in two separate steps - the biophysical and biochemical reactions (Fig 1).

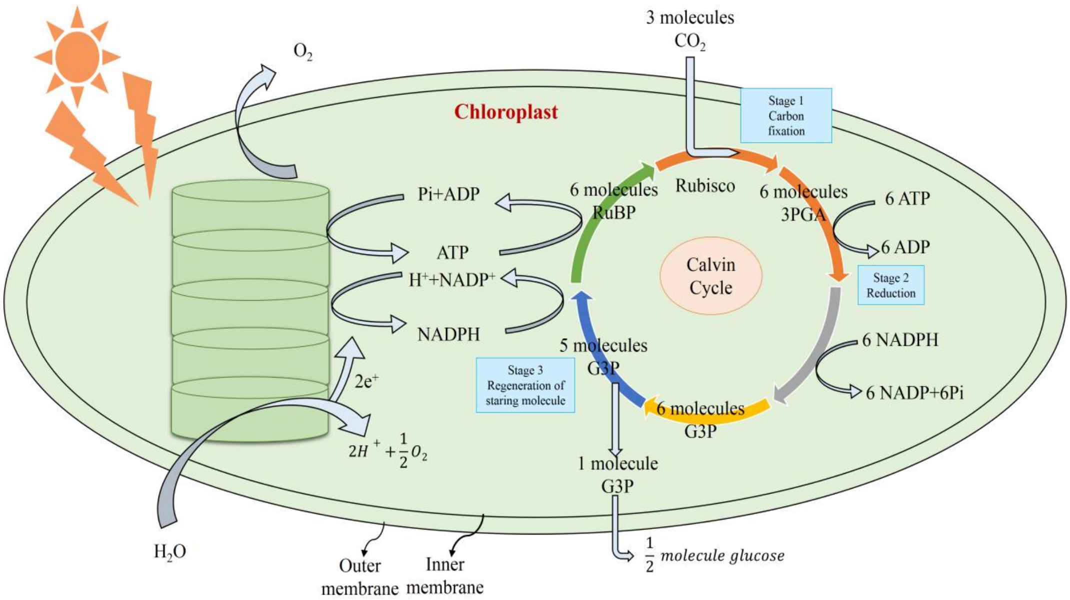

Fig. 1. An overview of the photosynthetic process in microalgae

The biophysical reactions take place in the thylakoid discs of the chloroplasts and water is oxidized with the production of oxygen. The energy produced in the form of ATP and NADPH is used to fix or assimilate CO_2 in the dark reactions. The biochemical reaction occurs in the stroma resulting in the formation of primarily sugar molecules with some other organic molecules required for cell function and metabolism of microalgae.

Advantage of carbon sequestration by microalgae in wetlands

Although the wetlands are hot spot of green biodiversity, they are underestimated in the context of carbon sequestration potentials and storage capacity of carbon (IPCC, 2014; Jana et al., 2015, 2019; Nandy et al., 2018). Wetlands contain about 35 per cent of global terrestrial carbon though they comprise only 6 - 9% of the Earth's surface.

The carbon flux in water bodies depends on surface area, water concentrations and gas transfer velocity. Sediments of aquaculture ponds play an important role in carbon sequestration. About 16.6 million tons of carbon is annually buried in aquaculture ponds of the world (Boyd and Wood, 2010) and maximum sequestration occurs in Asia and particularly in China (Verdegem and Bosma, 2009). In other words, carbon sequestration by aquaculture ponds is about 0.21% of the annual global C emissions. However, under unmanaged anaerobic conditions, wetlands can also emit some greenhouse gases such as methane, nitrous oxide and hydrogen sulphide though this is limited under saline conditions or swampy areas. Notwithstanding the manifold positive impacts of wetlands overweighed towards beneficial environmental impacts and led to argue that wetland should not be destroyed because of GHG emissions under limited conditions (Mitsch et al., 2012).

One of the major advantages of microalgae in aquatic environment is the 100% harvest of the production, and the carbon fixing rates of microalgae are much higher than terrestrial plants. It is known that 1.6 and 2 grams of captured CO_2 is used for every gram algal biomass. As CO_2 is present in atmosphere in concentration lower than nitrogen (N_2) and oxygen (O_2), this has created a thermodynamic barrier in CO_2 capture. Nevertheless, high coefficient solubility of CO_2 makes it far more soluble than atmospheric oxygen and nitrogen (Cole, 1983). Carbon dioxide reacts with water; the carbon atom of CO_2 is electron poor with an oxidation state of IV. The electron rich oxygen of water donates an electron pair to the carbon. After proton transfer from water to oxygen of the CO_2 unit, carbonic acid is formed and then into bicarbonate and hydrogen, resulting in lowering of the pH - a favourable condition when CO_2 gets dissolved in water.

One of the excellent abilities of aquatic cyanobacteria and eukaryotic algae is to use all forms of dissolved inorganic carbon (free CO2 - CO_3- HCO_3) at different pH conditions in aquatic environment. The CO_2- CO_3- HCO_3 system acts as a buffer as well as a source of carbon for the photosynthetic microalgae at different pH condition**s.** Among the three chemical species of carbon in water, bicarbonate (HCO_3) is most dominant (> 50%) at pH between 6.4 and 10.3, whereas carbonic acid (H_2CO_3) and carbonate (CO_3) are dominant at pH < 6.4 and > 8.3, respectively (Jana 1998; Wetzel, 2005).

Carbon capture potentials of microalgae

The microalgae are able to capture as high as 90% of carbon dioxide or bicarbonate in open ponds though the ability varies among species. *Scenedesmus* was better able to tolerate very high CO_2 concentrations than *Chlorella though* both algae had about the same growth rate when the CO_2 concentration remained in the range of 10 - 30%. About 20% CO_2 tolerant strains such as *Scenedesmus*, *Chlorococum* and *Ankistrodesmus* formed several separate branches suggesting that certain groups or genotypes of algae tend to perform better under high CO_2 level compared with other algal groups (Zheng et al., 2013). A microalgal consortium consisting of *Chlorella* sp., *Scenedesmus* sp., *Sphaerocystis* sp. and *Spirulina* sp. (Fig. 2) procured from wastewater ponds revealed quite high CO2 sequestration (53- 100%; 150- 291 mg/g) (Bhakta et al., 2015).

Three *ex situ* experiments were performed to examine the growth of microalgae at different N/P ratios (5, 20, 40, 50, 60, 70, 80, 90, 100) of water using urea and single super phosphate as sources of N and P in three separate trials. It becomes evident that the pattern of growth was almost similar in all the treatments used (Fig. 3). There was a gradual rise in population from day 1 to 13 followed by a decline. While no definitive peak was discernible in lower ratios of N/P, broad peak was exhibited extending from day 8 onwards in higher N/P ratios. For example, treatment with N/P ratio of 60 and 70 showed the peaks during later phase of growth cycle. Comparing the peaks among the higher ratios, the peak was highest in the treatment of 70, followed by 80 or 60.

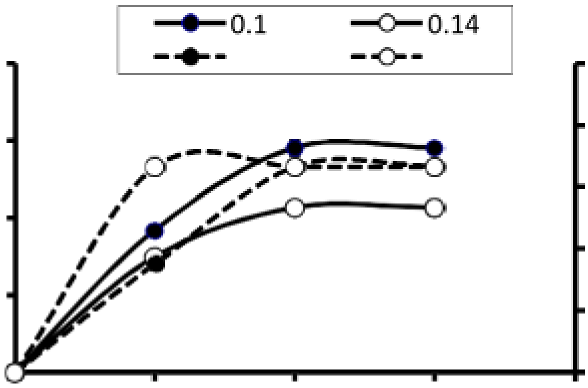

Fig. 2. CO_2 sequestration and mass balance of CMAC showed appreciable CO_2 sequestration percentage and capacity with remarkable growth performance in wastewater system

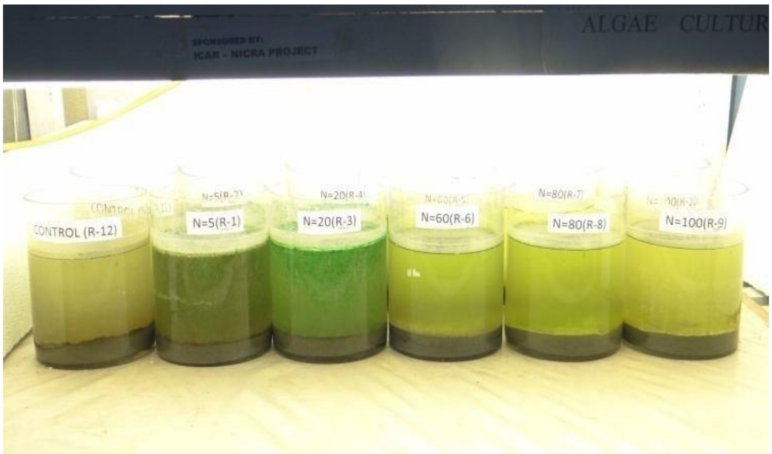

Fig. 3. Experimental setup showing the growth of microalgae in different N:P ratios maintained in the battery jars.

Microscopic examination of the microalgal population revealed the composition as *Chlorella, Scenedesmus, Ankistrodesmus, Crucigenia,Pediastrum*, etc. The counts of microalgal population was related with intensity of colour expressed on optical density.

This implied that input of N should be 60 - 80 times more than P for sustaining the greater growth of green algae. Trials were also conducted in open ponds using limnocorrals. The results implied that this optimal nutrient condition can be maintained in open ponds by manipulating pond fertilization schedule for selection of right algae that would capture atmospheric carbon and at the same time would serve as natural food for herbivorous fishes regarded as low carbon footprint and commercially important fishes. It is also known that carbon-dioxide capture efficiencies as high as 80 to 99% are achievable under optimal conditions and with gas residence times as short as two seconds (Keffer and Kleinheinz, 2002).

The mechanism of carbon capture

Photosynthesis by microalgae and aquatic plants occurs in two phases. The first reaction is light dependent where protein rich chlorophyll pigments are held in chloroplast. The second reaction or dark reaction or Blackman's reaction is slower than light reaction and takes place in the stroma of chloroplast that embedded in the plasma membrane of photoautotrophs. The black reaction also occur in the presence of light. There are two cyclic reactions in dark reaction –Calvin cycle or C-3 cycle and Hatch and Slack pathway or C4 cycle. The Calvin cycle or C3 cycle, first observed by Calvin in unicellular green alga *Chlorella*, is a cyclic reaction occurring in the dark phase of photosynthesis when energy poor CO_2 is converted into energy rich sugars during the process of carbon fixation or assimilation.

RuBisCO (Ribulose-1, 5-bisphosphate carboxylase/oxygenase) is an enzyme and is involved in the first major step of carbon fixation when carbon dioxide is converted to glucose (Fig. 4). In this pathway, it involves the carboxylation of ribulose bis-phosphate (RuBP) in presence of RuBisCO producing phosphoglycerate (PGA). The RuBisCO enzyme is capable of utilizing both CO_2 and O_2 leading to formation of carboxylation in presence of CO_2 and oxygenation of RuBP in presence of oxygen, respectively (Fig.4). When concentration of O_2 is high and CO_2 is low, RuBisCO acts as an oxygenase and further catalyzes the photorespiration reaction resulting in reduced carbon fixation due to production of 2-carbon molecule phosphogycolate (Peterhansel et al., 2010). Many aquatic plants using RUBISCO as their initial carboxylase counter the limitations on CO_2 supply via the operation of biophysical CO_2 concentrating mechanisms which are based on active transport of HCO^-_3, CO_2 or H^+ at the plasmalemma, and use bulk-phase HCO^-_3 or CO_2 as the C source (Raven et al., 1985).

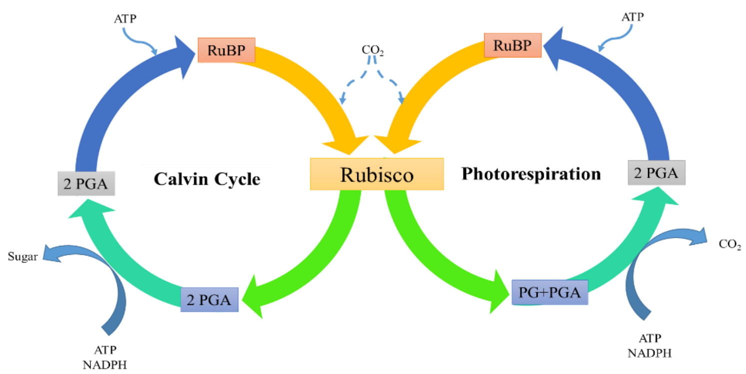

Fig. 4. A comparison of photorespiration and carbon fixation in C3 plants.

In aquatic environment, algae captures carbon is pumped into the cell by bicarbonate transporters present in both the plasma membrane and in the chloroplast envelope of eukaryotic algae (Spalding et al., 2008). Inside the chloroplast, bicarbonate is concentrated, dehydrated spontaneously or by carbonic anhydrase through Calvin-cycle activity, finally yielding algal biomass. Pyrenoids of chloroplast which are analogous to cyanobacterial carboxysomes (Moroney and Ynalvez, 2010) played a great role the inhibition of photorespiration process thus aiding in increasing carboxylase activity of RuBisCO helping in carbon fixation (Peterhansel et al., 2010). Although the structural configurations of pyrenoids may vary with species of algae, but in all cases, pyrenoids are present within the chloroplast embedded in plasma membrane of photoautotrophs, where RuBisCO molecules are found and help in concentrating CO_2 around RuBisCO (Peterhansel et al., 2010).

This loss of carbon reduces the Calvin cycle ability to regenerate the five-carbon sugar substrate ribulose bisphosphate which is essential for CO_2 fixation by RuBisco. The process of photorespiration in the presence of light reduces photosynthetic carbon fixation efficiency by 20% to 30% (Zhu et al., 2008). For reducing the competitive inhibition of oxygen on carbon fixation by rubisco, microalgae actively pump sufficient bicarbonate from water phase into cells and to increase the internal CO_2 concentrations to levels above those possible by equilibrium with air, and thus competitively inhibit photorespiration (Badger and Price, 1994). Other beneficial uses of algae are biochar and biofuel production.

Conclusion

Desired microalgae can be grown by manipulation the pond fertilization schedule in open ponds. This would help to grow selective microalgae which would capture atmospheric carbon and serve as food source for low carbon foot print fishes.

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Chapter 5

IMPACT OF GLOBAL WARMING ON COLDWATER FISHERIES

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Introduction

Climate change is emerging as the latest threat to the world's dwindling fish stocks. It is projected to impact broadly across ecosystems, increasing pressure on all livelihoods and food supplies, including fisheries and aquaculture sector. The impacts of climate change on fish and fisheries will result from changes in biological and abiotic components and anthropogenic changes. Changes in water temperature, water levels, extreme climatic events, diseases, and climate-driven shifts in predator and prey abundances will all impact fisheries. Fishes are poikilothermic and their metabolic and reproductive physiological processes and disease resistance is temperature dependent. Increased water temperature allows fish to increase their metabolism, which in turn increases their oxygen demand. However the oxygen carrying capacity of warm water is less than coldwater. This is especially important in freshwater river systems where temperature stress is likely to be more variable than in coastal systems (UNEP/ICIMOD, 2002; Muralidhar & Ponniah, 2009).

Coldwater fisheries have a great potential in generating rural income and providing food security to the economically poor population residing in Indian uplands. The country has suitable hatchery management techniques for the production of rainbow and brown trout fingerlings, farming technologies for Chinese carp and common carp. In mountain region where the water temperature ranges from 5-26°C, coldwater fishes are important ecological indicators for climate change as they are very sensitive to changes in water temperature and other environmental conditions.

Coldwater fish such as trout thrive in streams with temperatures of 10 to 18.3 degrees centigrade. In many areas, the fish are already living at the upper end of their thermal range, and even modest warming could render streams uninhabitable. Ecological models that relate climatic variables to fish growth and abundance show that both temperature and precipitation often have marked effects on many species of freshwater fish. The most noticeable would be the significant losses of coldwater fish species by the end of the next century as climate change leads to a reduction of coldwater fish habitat. Under the changing scenario, it is important to identify the potential impacts of climate change on coldwater fish and fisheries in streams and inland lakes and to develop adaptation management strategies in response to climate change impacts (UNEP/ICIMOD, 2002; Muralidhar & Ponniah, 2009).

Global warming and its Impact on Fisheries

Fisheries, due to their primitive nature, are among the human activities most exposed to climate changes. The output of fisheries, as well as their costs and benefits, are directly and strongly affected by variations in natural conditions. Habitat conditions, which are the main determinants of the productivity and location of fish stocks, are strongly affected by ocean and atmospheric temperatures. The current prospect of substantial global warming, therefore, will lead to concern about what this is likely to mean for the world's fisheries.

Fish are more sensitive to temperature than many animals because they are poikilothermic animals. When fish encounter colder temperature, their metabolism slows down and they become sluggish. As the surrounding water warms up, their metabolism speeds up, they digest food more rapidly, grow more quickly, and have more energy to reproduce. For example, rainbow trout grow significantly more slowly when their water temperature is raised only 2°C and food is limited, and fish such as salmon, whitefish, and perch are all expected to grow more slowly if food supply does not increase as temperatures rise. Declining numbers of fish could have a devastating impact on human populations that rely on fish for protein. Indigenous peoples in the arctic, where temperatures have risen dramatically, are already feeling the effects of global warming. Many communities have experienced recent changes in the distribution, abundance, and quality of fish they have historically relied upon (Ashlay, 2007; Magnuson and DeStatsio, 1996).

Water is a key player that integrates many geographic sub regions and economic/social/ ecological sectors. Changes in climate resulting from increasing atmospheric concentrations of greenhouse gases could have significant effects on water resources. The quantity and quality of water are likely to be directly affected by climate change. Changes in the hydrological cycle will cause changes in ecosystem, which in turn, affect human health (e.g., by altering the geographic distribution of infectious diseases) and biological productivity and diversity. The impacts of climate change on water resources are potentially large and could result from increases in temperature and from changes in mean annual values and variability of precipitation (Anderson et. al., 1999, Sarma et al., 2009).

Salmon, trout and other species of coldwater fish face an increasingly uncertain future in the streams and rivers due to the effects of global warming. Rising temperatures will likely impact these coldwater species of fish across the broad range of areas they inhabit. Trout and salmon are especially vulnerable to global warming because of their dependence on clear, cold water.

As coldwater habitats warm, the rising temperatures will have negative impacts on the entire life history of these iconic fish-from eggs to juveniles to adults. Climate change is not some uncertain future problem. It is happening right now, and evidence is seen in terms of reduced snow pack and earlier spring runoff. The global temperatures have already risen more than 1°F during the last century, and scientists project that temperatures will increase anywhere from 2 to 10 °F over the next 100 years. All of this will increase the vulnerability of coldwater fish, many of which are already imperiled by habitat degradation and other human-caused factors.

Global warming is likely to spur the disappearance of trout and salmon from as much as 18 to 38 percent of their current habitat by the year 2090. The study also found that habitat loss for individual species could be as high as 17 percent by 2030, 34 percent by 2060 and 42 percent by 2090, if emissions of heat trapping pollution such as carbon dioxide are not reduced. Coldwater fish such as trout and salmon thrive in streams with temperatures of 50 to 65°F.

In many areas, the fish are already living at the upper end of their thermal range; meaning even modest warming could render streams uninhabitable. In reality, habitat loss could be even more extensive than predicted. Regardless of location, the disappearance of coldwater fish will come at a significant cost -to jobs, recreation and regional culture. Global warming threatens to push already over-exploited and stressed fish populations and habitats over the brink (Ashlay, 2007; Frederick & Gleick, 1989).

Climate Change Projections in Himalaya

The Himalaya has the largest concentration of glaciers outside the polar caps. With glacier coverage of 33,000 km^2, it provides around 8.6 X 106 m3 of water annually (Dyurgerov and Maier, 1997). Various studies suggest that the warming in the

Himalayas has been greater than the global average. Glacier melt in the Himalayas is likely to increase intensity and frequency of various environmental risks, including floods and snow melting, soil erosion, avalanches and failure of moraine dammed lakes, and affect the water regime within the next couple of decades (Mahat and Bajracharya, 2007).

Atmospheric warming of 1°C observed in the Himalayas over the past thirty years (UNEP /ICIMOD, 2002) has led to a considerable reduction in glacier area. If current warming rates are maintained, Himalayan glaciers could decay at very rapid rates, shrinking from the present 500,000 square km to 100,000 square km by 2030s (IPCC, 2007). Continued glacial melt is expected to lead to increased river flow and floods over the next few decades, followed by reduced flows. Seasonal variation in runoff will likely be affected, causing water shortages during dry summer months. Glacial Lake Out-burst Floods (GLOF) are catastrophic discharges of water resulting primarily from melting glaciers and breach dams in glacial lakes.

Table 1: Different climate change drivers and possible impact of on sustainability of coldwater fisheries

Drivers	Risks	Implications
Water temperature	Increased temperature will bring about physiological changes in fish for thriving.	Critical to reproduce even though some adult fish may tolerate higher stream temperatures, microbial diseases, survival of fish will be adversely affected. Coldwater fish such as rainbow and brown trout may not be able to survive and cold water fishing may end or be greatly reduced (Studies at New Hampshire predicts loss of 50% and great

		reduction at New York) (NHES, 2008; http://www.dailygazette.com. 2008)
Precipitation	Fluctuations in stream flow affecting life cycle of fishes.	Food availability could be reduced and fish eggs could be destroyed. High water velocity could prevent warmer temperature species from colonizing previously cold-water fish habitats because cold-water fish often prefer faster moving streams.
Extreme climatic events		
Big storms and floods	Water too high and dirty will affect adversely affect fish and fishery.	Tend to wreck the fishing in the short term, killing trout and aquatic insects in the long-term. Implications for hatchery - damage to water intake infrastructure
Drought	Lower water level and reduced stream flows; Declining water levels and ice covers will affect adversely affect fish and fishery.	Reduced food availability, suffocate and desiccate fish eggs, coldwater fish are prevented from migrating to spawning grounds, decreased availability and quality of habitat areas for fish causing crowding, spread of disease, and stranding in isolated pools of water. Many small streams may dry up, negatively impact the natural environment and survival of fish in streams, wetland size and function could be diminished resulting changes in the habitat and species in lakes.
Reduction in snow pack	Adversely affect environmental flow of streams	Implications for hatchery - Decreased amount of water available for hatchery use; reduced production or increased cost due to use of

		expensive mechanical water chilling devices to produce high quality juveniles.

Issues Related to Climate Change in Himalayas

In the face of changing climate condition, it is important to assess the potential impacts to coldwater fish and fisheries and implement adaptive management plans to ameliorate climate change impact on coldwater streams and inland lakes and their fisheries.

Fish Diversity

The Gangetic drainage in the Himalaya is primarily restricted to the State of Uttarakhand in India and Nepal. Studies document 182 fish species from 92 genera under 31 families and 11 orders; however, recently 134 species have been enumerated from the entire state of Uttarakhand. The fish fauna comprises primarily cyprinids, cobitids, sisorids and other fish species. 42 fish spp. are known from the Alaknanda, 39 from the Bhagirathi and 56 spp from the Ganga (Gosain & Basuray, 2006).

Fish Community

The fish community in the upper and middle section of Himalaya comprises of *Schizothorax richardsonii, S. plagiostomus, Crossochelus latius latius, Garra gotyla gotyla, Glyptothorax pectinopterum, Glyptothorax* spp. and *Pseudecheneis sulcatus*. In the foothills the fish community in the Ganga includes *Tor putitora, Schizothorax* spp., *Labeo* spp., *Chagunius chagunio, Ompok* spp., *Danio devario, Brachydanio rerio, Esomus danricus, Bagarius* spp., *Aorichthys seenghala, Mystus* spp., *Clupisoma* and others (Bhatt et. al., 2000).

Fisheries

The fish fauna is dominated by cyprinids, especially snow trout spp. in the Alaknanda and Bhagirathi. Snow trout species attain good size (2-3 kg.). By virtue of their abundance snow trout dominate the fish catch and are hence commercially important. Though their fecundity (ca. 30,000 in 55 cm fish) is low compared to the Indian major carps, their abundance compared to *Crossocheilus latius latius* and *Garra gotyla gotyla* (which too have low fecundity ca. 10,000 in 20 cm fish), despite heavy fishing, may be attributed to the difficult terrain which restricts fishing to hospitable terrain only. The population can survive in such unapproachable safe zones. Also they appear to be abundant because it is a multispecies catch comprising *Schizothorax richardsonii*, *S. plagiostomus* and *S. sinuatus* and its other spp. In the foothill section Himalayan mahseer and other cyprinid (*Labeo* spp., *S. progastus*) and catfish form the backbone of riverine fishery. Fishery is limited to parts of the river flowing through the municipal areas. Since the rivers are under the jurisdiction of Forest Department, especially the upper and middle section where it flows through protected forests, fishery is legally prohibited. Yet lot of fishing activity (poaching in legal terms) exists. The snow trout form significant fishery (>90%) in the upper and middle sections while the golden mahseer (5-15%) in the foothill section.

Himalayan mahseer provides attractive fishery by virtue of its size (as high as 22 -25 Kg). Large size fetches more money in one kill. Hence, it is also fished during the migratory phase including the spawning season, as large brooders can be landed in this duration. Fishing of any kind is prohibited in the vicinity of Rishikesh to Haridwar owing to religious nature of these towns in the foothills. Between these towns the river falls under the jurisdiction of the Rajaji National Park. Instances of poaching are common in this Gujjar (nomadic tribes of India) inhabited stretch (Climate change, 2001; Krishnamoorti et al., 1999).

Coldwater streams

Coldwaters of India may be grouped into three (Mahanta & Sarma, 2010):

(a) **Snow fed streams:** These are found in the Greater Himalayas at about 1,470 m asl. These are in the form of streams which are small during winter and swell up and turbulent during summer.

(b) Spring fed streams: These are found in the Lesser Himalayas at about 875-1,470 m asl.

The streams are in the form of rapids and pools which maintain moderate throughout the year. The bottom is boulders and stones, covered with algae.

(c) Rain fed streams: These are found in the Siwaliks and Northeast India other than Brahmaputra basin and the Deccan. The streams are with great volume of water during monsoon, but most of them become lean or dried up during winter. The bottom is constituted by algae covered boulders and cobbles.

Coldwater Eco-system

The impacts affecting aquatic systems and fisheries, especially in hill areas, are increasing global temperature, and changing rainfall patterns. Increased river temperatures will change species distributions (food web dynamics), as poikilothermic fish and invertebrates attempt to behaviourally thermo-regulate by migrating to cooler water in geographically constrained rivers and lakes. Metabolic rates increase with the consequent need for more food to support this higher metabolism. Coldwater fish are very sensitive to changes in water temperature and other environmental conditions. They are important ecological indicators for climate change. Native coldwater fish form a core part of our culture and identity of the country's legacy. Anglers make significant contribution to the local and state economy in pursuit of their passion, however changes in the coldwater ecosystem will adversely affect angling activities.

In freshwater systems water temperature stress will be most market for stenothermal freshwater invertebrates and fish. This will especially impact the higher altitude and very economically valuable freshwater recreational fisheries, which are based on capture of introduced trout species (Vishwanath, 2009).

Mitigation approaches

Response to prevent climate driven changes or minimize their impacts might occur on two scales, first a global response that addresses the ongoing human-caused release of carbon and other gases into the atmosphere and second, region-specific and basin-specific responses that optimize the quality and extent of cold-water fisheries habitat. Fisheries related organizations will have to focus their efforts on the second of these responses while supporting efforts to address the global condition. In order to minimize habitat losses it will be necessary to priorities restoration and protection efforts to secure the best habitat m existence first, and to then work outward from that high quality habitat. It is also important to approach habitat restoration on a watershed basis rather than simply looking at habitat (UNEP/ ICIMOD, 2002).

Development of Adaptation Strategies

Adaptation strategies that will best protect and enhance coldwater resources confront by climate change should be identified. Such adaptation strategies may include the following:

- Most resilient coldwater streams may be protected from habitat degradation.

- Plan for extreme events- Restoration of degraded streams in order to best withstand extreme and damaging weather events, if large-scale flooding events may become more common.
- Recognize the importance of land management m the watershed
- Best management practices such as conservation tillage approaches to agriculture to protect the biological integrity of coldwater streams.
- Remove dams and culverts that prevent fish from migrating to more comfortable habitat.
- Take less water from streams for irrigation.
- Restore diverse habitat with things like boulders and woody debris.
- Floods in this region can be modified to a large extent by creating storage's and water harvesting structure in the upper reaches of the streams of the basins.
- Conserve water and open space.
- Reducing threats such as dams, deforestation, and pollution will go a long way in helping the sustainability of coldwater fisheries.
- Reducing the use of chemical pesticides and fertilizers, which often wind up in lakes and streams.
- Volunteer with organizations working to clean up local waterways.
- Observe fishing regulations and other measures to protect wild stocks.

Research requirements

Higher priority will be for more scientific objectivity focused work in diverse situations and in this context more scientific works and monitoring mechanisms are needed for effective planning. It is better to make use of existing information and propose new research where necessary to advance science-based management of coldwater fish and fisheries impacted by changes in climate. Adaptation focused research addressed to specific contexts should also get high priority. The major research requirements are grouped into two categories. The first on understanding the impact and developing physical mitigation measures as outline below (Murlidhar & Ponniah, 2009; Mahanta & Sarma, 2010).

- Data needs are required to address the identification of risks, vulnerabilities, and adaptation strategies are many and varied:

1. Climate change predictions for air temperature and precipitation
2. Hydrologic models linking changes in air temperature and precipitation to changes in water temperature and groundwater input to streams
3. Watershed-scale and reach-scale habitat data in response to climate change and influence on streams and fishes
4. Fish and habitat temporal trend data

- Classification of streams based on their potential to withstand climate change impacts.
- Current scientific understanding and research into GLOF, an issue that has come about as a result of recent changes to the global climate.
- Detailed satellite imagery processing techniques for monitoring of lakes that are known to be potentially impacted due to climate change.

The second category, relates to adaptive measures at the biological and biophysical level. Among the fish species the number of strains available in trout and common carp is more than any other fish species. These strains exhibit a wide variation in the adaptability to temperature and hence developing strains to meet changes in temperature would be relatively easier in these species. The other aspect relates to modifications in culture systems and practices to mitigate the impact of climate change.

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Chapter 6

AGRO-CLIMATIC ZONE SPECIFIC RAINFALL CHANGE SCENARIO OF WEST BENGAL USING CMIP5 GLOBAL CLIMATE MODELS (GCMS) SIMULATIONS

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Introduction

There is no doubt about climate change as IPCC's recent assessment report stated that climate change is an unequivocal phenomenon (IPCC, 2013). But how much climate has changed over different smaller scales like different agro-climatic zones may attract more attention to public and government agencies. Over the state of West Bengal there is no reliable past and future climate change information (except Das and Lohar, 2005) over each available agro-climatic zones using multi observational data sources including recent generation GCM simulations. In the state of West Bengal, there are six distinct climatic agro climatic zones. So creating zone specific past and future climate change scenario may provide some useful information for the multi-level stake holders, policy makers and local Government for implementing any developmental policy and mitigation and adaptation strategies towards combating climate change.

A clear picture of local scale (station level) climate change information using the combined approach of observed station data and GCMs simulations over the six agro-climatic zones of West Bengal are still missing. The present study aims to construct local scale climate scenarios from CMIP5 GCMs simulation along with IMD observational and gridded data as well as to construct a future rainfall projection using four RCPs simulation of CMIP5 GCMs.With this background information, the present study has been carried out for following objectives.

1) To quantify the historical rainfall change during 1901-2005 using multiple sources of data.
2) To evaluate IPCC's CMIP5 GCMs over the concerned agro-climatic zones towards selection of best performing models.
3) To construct ensemble based future rainfall change scenario.

Study area, Data and Methods

Study area

The present study has confined over the state of West Bengal. It is situated in the eastern part of the country between 21^{o}20' to 27^{o}32 AND latitude and 85^{o}50' and 89^{o}52' E longitude. On the basis of distribution of climate, soil and agricultural feasibility whole state of West Bengal is divided into 6 distinct agro-climatic zones (Fig. 1) which are: i) Hill Zone (HZ) ii) Terai Zone (TZ) iii) Old Alluvial Zone (OAZ) iv) New Alluvial Zone (NAZ) v) Red and Laterite zone (RLZ) and Coastal Saline Zone (CSZ).

Data

In this study, two types of long term data have been used. They are as follows:

Observational data

Monthly rainfall station data during the period of 1901-2017 and IMD's high resolution (0.25^{o} X 0.25^{o}) rainfall gridded data (Pai *et al.*, 2014) for 19 district headquarters of West Bengal has been procured from the India Meteorological Department (IMD), Pune, to check how much rainfall has change through different sources of data.

Model data

For past and future rainfall analysis, we have used 20 numbers of CMIP5 GCMs through the data portal of the Royal Netherlands Meteorological Institute (https://climexp.knmi.nl/selectfield_cmip5.cgi?id5someone@somewhere). List of 20 GCMs used in this study are given below in Table 1.

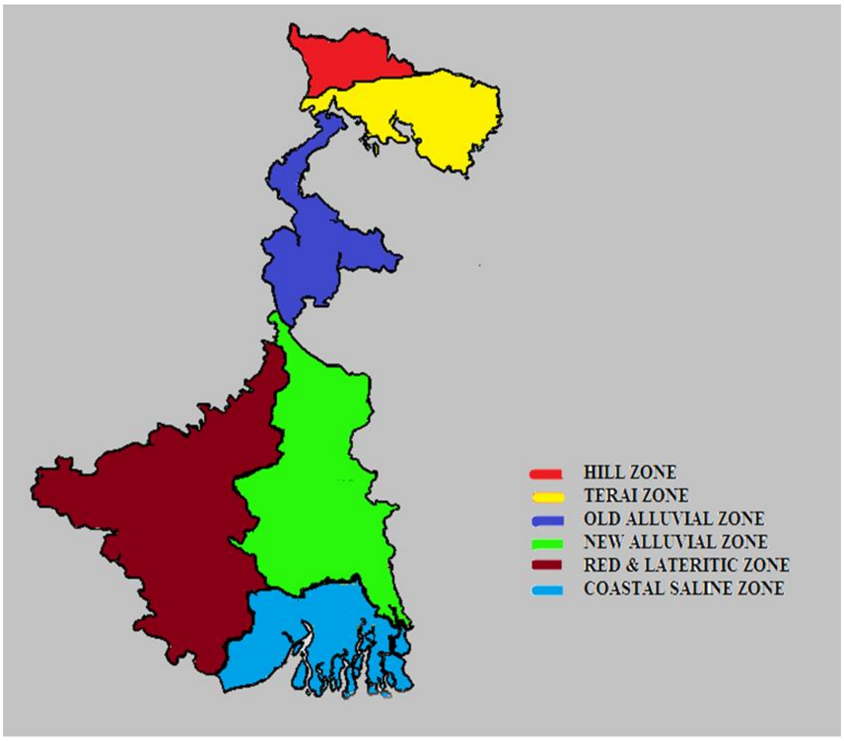

Fig. 1. Agro-climatic zones of West Bengal

Table 1. Description of the CMIP5 GCMs used in this study

Sl No.	Model	Horizontal resolution (latitude(°) x longitude(°))	Sl no.	Model	Horizontal resolution (latitude(°) x longitude(°))
1	bcc-csm1-1	2.8×2.8	11	GISS-E2-R	2×2.5
2	bcc-csm1-1-m	1.125×1.125	12	HadGEM2-AO	1.25×1.875
3	CCSM4	0.95×1.25	13	IPSL-CM5A-LR	1.875×3.75
4	CESM1-CAM5	0.95×1.25	14	IPSL-CM5A-MR	1.25×2.5
5	CSIRO-Mk3-6-0	1.875×1.875	15	MIROC5	1.4×1.4
6	FIO-ESM	2.8×2.8	16	MIROC-ESM-CHEM	2.8×2.8
7	GFDL-CM3	2×2.5	17	MIROC-ESM	2.8×2.8
8	GFDL-ESM2G	2×2.5	18	MRI-CGCM3	1.125×1.125
9	GFDL-ESM2M	2×2.5	19	NorESM1-ME	1.875×2.5
10	GISS-E2-H	2×2.5	20	NorESM1-M	1.875×2.5

Methodology

- ✓ Generated district-wise monthly rainfall time series during 1901-2005 for historical and 2006-2095 for future projection using bilinear interpolation techniques which takes weightage of four nearby grid points.

- ✓ Created historical rainfall change trends for each zone using linear regression for 1901-2005.

- ✓ Calculated the percentage change of rainfall during 2020s, 2050s, 2080s using four RCPs with respect to the base period of 1971-2000.

- ✓ Calculated the values of similarity indices like (correlation and d-index) and error statistics (NRMSE and Pbias) for evaluating the GCMs performance with the following expression defined in Table 2.

Table 2. Describes the description of statistical measures where M = Model output, $\overline{M}$ = Mean of model output, σ_M = standard deviation of model output, O = observations, $\overline{O}$ = mean of observations, σ_O= standard deviation of the observations and N= number of the year.

Name of similarity statistics	Equations	Reference/ studies that used this expression
Mean bias	$MB = \left[\frac{1}{N}\sum_{n=1}^{N}(M_n - O_n)\right]$	Willmott (1982)
Correlation	$R = \dfrac{\frac{1}{N}\sum_{n=1}^{N}(M_n - \overline{M})(O_n - \overline{O})}{\sigma_M \sigma_O}$	Taylor (2001)
Index of agreement (*d*-index)	$d - \text{index} = 1.0 - \left(\dfrac{\sum_{n=1}^{N}(O_n - M_n)^2}{\sum_{n=1}^{N}\left(\lvert M_n - \overline{O}\rvert + \lvert O_n - \overline{O}\rvert\right)^2}\right)$	Willmott (1981), Legates & McCabe (1999)
Normalised total RMSE	$NTRMSE = \frac{1}{\sigma_O}\left[\frac{1}{N}\sum_{n=1}^{N}(M_n - O_n)^2\right]^{1/2}$	Janssen & Heuberger (1995), Covey et al. (2002)

Results and discussion

The results of this work are described as follows:

Historical (1901-2005) rainfall change

- Historical rainfall change during 1901-2005 using 20 numbers of GCMs along with IMD station and gridded data reveals that mean winter rainfall was more ranging from 50-190 mm over hill and terai zone whereas it was slightly lesser in other zones. It also indicated that MME20 simulate more rain (54-102mm) compared to IMD station and gridded data (25-46mm).
- In case of pre-monsoon season similar pattern indicating more rain over hill and terai zone and less rain over other zones. The GCM CESM1_CAM5 simulated

excessive pre-monsoon rain (above 800 mm) in hill and terai zone along with HadGEM2_AO and MIROC5 simulate high pre-monsoon rainfall over almost all zones compared to other GCMs. MME20 simulate less rain compared to IMD grid and IMD station for all zones.

- As per expectation of common people the long term mean during 1901-2005 was estimated from 20GCMs along with two IMD data sources which revealed that MME20 and IMD station showed similar rainfall (1690-1793mm) over hill and terai zone but station rainfall was exceeding MME20 over other zones but IMD grid estimated high rainfall 2547-2562mm over HZ and TZ compared to MME20 and IMD station.
- In case of post monsoon season mean rainfall during 1901-2005 varies from 114-185mm irrespective to all zones where MME20 indicated more rainfall compared to station and gridded data over HZ and TZ. It also observed that all data showed a decreasing amount of post monsoon rainfall from north Bengal zones to south Bengal zones.
- Historical annual rainfall was also quantified from different models and station data. Models showed high variability of annual rainfall (1070mm in case of CSIRO_Mk3_6_0 to 5239mm for CESM1_CAM5) particularly over HZ TZ. Annual rainfall over RLZ was minimum viz. 986mm for MME20, 1386mm for IMD grid and 1411mm for IMD station respectively. While maximum annual rainfall was received almost more than double over HZ.
- Winter rain has shown increasing trend 0-6mm over HZ, TZ while it was decreased 0-8mm over other zones for two IMD data while MME20 showed nominal increasing trend for all zones.
- Monsoon rain has increased 0-150mm in case of IMD grid while MME20 showed it was decreased 0-15mm over all zones in the last century.

- In general annual rainfall has shown an increment of 0-200mm irrespective of all zones and data sources except HZ for MME20 and OAZ for IMD station showed decreasing trend.

Evaluation of CMIP5 GCMs

Model evaluation study over agro-climatic zones indicated that no models are able to capture historical rainfall over each zone indicating models have strong positive or negative bias. Zone wise GCM evaluation was carried out using comparison of seasonal cycle along with four conventional statistical measures (correlation, d-index, NRMSE and Pbias), which indicates that performance of GCM varies from zone to zone and index to index. Some models like CCSM4, HadGEM2_AO and NorESM1_ME showed comparatively better performance over most of the zones which obtain highest rank while GISS_E2_R, IPSL_CM5A_LR and MRI_CGCM3 performed poorly almost all zones and consider in the bottom level of the ranking system (Table 3). These better performing top ranked model can be used over any agro climatic zone for any impact study without any further evaluation while poor models need to be improved its simulation through different downscaling techniques like bias correction etc.

Table 3. Zone –wise ranking of CMIP5 GCMs based on their performance

Model	HZ	TZ	OAZ	NAZ	RLZ	CSZ	Overall rank
bcc-csm1-1	18	14	14	13	16	16	17
bcc-csm1-1-m	11	11	12	12	13	17	16
CCSM4	7	6	13	5	3	1	3
CESM1-CAM5	10	1	8	6	5	2	6
CSIRO-Mk3-6-0	19	20	16	4	4	6	13
FIO-ESM	9	10	6	14	15	15	11

GFDL-CM3	17	16	4	3	6	3	5
GFDL-ESM2G	1	8	17	16	10	10	4
GFDL-ESM2M	2	7	7	17	12	14	8
GISS-E2-H	3	5	2	9	17	13	9
GISS-E2-R	14	15	15	18	20	19	18
HadGEM2-AO	6	9	3	2	2	5	1
IPSL-CM5A-LR	20	17	18	19	19	18	19
IPSL-CM5A-MR	19	18	20	8	8	4	14
MIROC5	13	12	9	11	11	8	12
MIROC-ESM-CHEM	12	11	11	15	14	12	15
MIROC-ESM	8	2	1	1	1	9	10
MRI-CGCM3	18	19	19	20	18	20	20
NorESM1-ME	5	4	10	10	9	11	7
NorESM1-M	4	3	5	7	7	7	2

Multi-model ensemble based future rainfall change scenarios

The comparison of past rainfall pattern with its future projection with 4 RCPs indicated that model to model variation are more in the future time scale which implies models simulation with each agro-climatic zone has huge uncertainty which has been depicted through wide range of model spread both in past as well as in future.

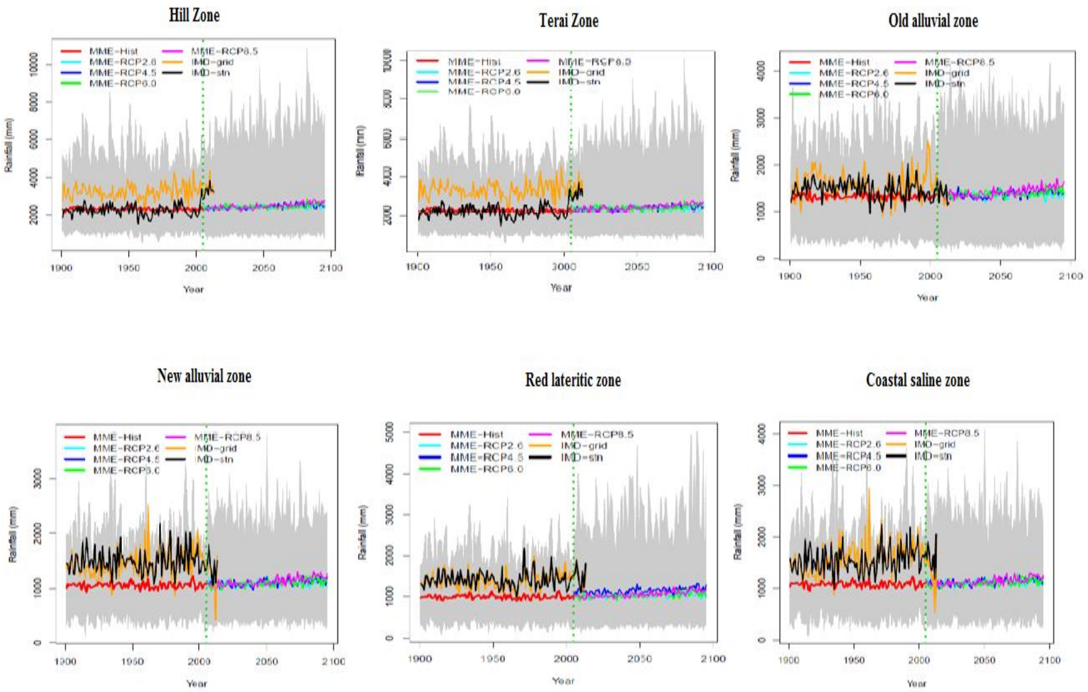

Fig. 2. Variation of annual past and future rainfall change using 20CMIP5 GCMs for four RCPs over six agro-climatic zones of West Bengal

Percentage future rainfall change

- Future rainfall for all six agro-climatic zones were calculated for 3 different times namely 2020s,2050s,2080s with respect to climatological base period of 1971-2000 reveal that percentage of decreasing rain 5-12 % is increasing from 2020s to 2080s in winter season over HZ. It is cleared that over HZ winter rain is going to be decreased at the end of 21st century while other seasons and annual showed an increasing trend (5-15%) of rainfall as per 4 RCPs over HZ.
- Similarly winter rain is going to be decreased according to all RCPs in three times while other seasons and annual rainfall is going to be increased 5-18% over TZ. In all cases rainfall change is low in 2020s and high in 2080s.

- Similar decreasing trend of winter rainfall over OAZ and NAZ is projected for all RCPs while other season and annual showing an increasing for all time period and RCPs. It is noticed that RCP4.5 indicates high increasing trend of future projection over RLZ compared to other RCPs in all season except winter.
- Over CSZ both winter and pre-monsoon season has increasing as well as decreasing trends as per different RCPs while monsoon and annual indicated an increasing rainfall upto 12%.

Conclusion

- Multi sources historical records (both model and observation data) indicates more rainfall over north Bengal agro-climatic zones compared to south Bengal zones.
- Annual rainfall has shown in increasing trends almost all zones (50-200mm) whereas winter rainfall has indicated a nominal decreasing trend by 5-7mm over NAZ, RLZ and CSZ during 1901-2005.
- In general models are unable to reproduce zone specific rainfall satisfactorily.
- However some models like HadGEM2_AO, NorESM1_ME, CCSM4 capture the observed rainfall over some zones quite accurately.
- Future projection using four RCPs reveals that model projection exhibits high uncertainty meaning lower radiative forcing (RCP2.6) simulated lower rainfall and extreme radiative forcing (RCP8.5) indicates higher rainfall change.
- Except winter, the rainfall over hill zone is going to be increased by 0-15% irrespective of all seasons and all future time period.

- Rainfall projection will be highest over red & Laterite zone (15-20%) and lowest 1-7% over coastal and saline zone.

- RCPs from the best performing models able to reproduce observed inter-annual variability during 2006-2017 adequately, indicating GCM projection during 2018-2100 will be more reliable over six agro climatic zones of West Bengal.

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Chapter 7

CLIMATE DATA COLLECTION, ANALYSIS AND INTERPRETATION

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Introduction

There is a disagreement among the scientists whether we are experiencing climate change or climate variability. To answer this question climatological data i.e. weather data for a long time is required. Almost every nation has its national meteorological organization which collects, transmits and archives meteorological data. This climate data is very useful to identify the deviation of the current weather from the normal, diagnose the behavior of extreme events, generate climate information for user sectors, detect any teleconnection among the climatological events etc. Analyzing climate data scientist can do climate projection. The anticipation of any climate change may help the policy makers to frame sustainable policy for the world and future generation.

Methodology

Data

It is the information which can be used for reference or analysis.

Weather and climate data

Weather is the present state of the atmosphere which is experienced at any moment and location whereas climate is the long term average of the weather condition of a region usually 30 years or more. Weather is basically described in terms of temperature, humidity, precipitation and wind. These parameters are recorded by meteorological organizations of a nation and become weather data whereas climate data not only consists of these over a long period of time but it also extends beyond that. Climate data includes

1. Global Climate Observing System (GCOS)
2. An expanded view of climate metadata that includes metadata on observations, discovery and data provenance
3. Standard WMO products
4. Derived observations and gridded data
5. Numerical model outputs
6. A range of ancillary data used to support climate data management system
7. Other important data such as logical data models

Climatological normal

According to the WMO climatological normal is “period averages computed for a uniform and long period comprising at least three consecutive 10-year periods”. Standard normals are computed every thirty years and the latest global standard normals are from 1981-2010. Tables of normal contains averages of pressure, temperature, relative humidity, clouds, vapour pressure, rainfall, wind speed, wind directions, visibility, extremes of maximum temperature, minimum temperature, rainfall and the frequencies of weather phenomena .

Data collection and data flow

IMD has a vast network of surface observatories at present there are 530 surface observatories which are located almost one in each district to meet the requirements of weather forecasting, agriculture and other operations of the country. In these surface observatories manual observations of air temperature, relative humidity, sunshine duration, solar radiation, wind speed and direction, precipitation, evaporation and cloud cover etc. are taken. These manually observed data in the synoptic hours is transmitted from observation sites to RMC/MC via e-mail or over telephone in the coded format as prescribed by WMO. These coded messages are sent through Global Telecommunication System (GTS) for operational use and real-time data processing, quality control and archival use. However, all meteorological observations recorded by observatories in IMD's network do not flow through GTS. Instead these observatories are manually scrutinized and keyed in RMC/MCs in delayed mode in standard formats supplied by National Data Center (NDC). These data files are then transferred to NDC for further processing and archival use. IMD has a vast network of Automatic Weather Stations (AWS). At present in India there are more than 650 AWSs and 1350 Automatic Rain Gauge (ARG) stations are there and the number is on the rise. The AWSs and ARG stations record air temperature, relative humidity, wind speed, barometric pressure, rainfall, soil temperature, leaf wetness and soil moisture. These data are recorded and transmitted to the data receiving center located at Pune at hourly basis. Data from AWSs are transmitted to NDC through Automatic Message Switching System (AMSS) and are archived in real time basis. These data are subject to minimum quality checks. Besides manual observatories, AWSs and ARG stations at present there are 44 Automatic Radiation Stations where reflected, global, diffuse, terrestrial, net and direct solar radiation are measured and transmitted to radiation lab Pune. There are also 10 air pollution monitoring observatories, 62 Pilot Balloon observatories, 39 Radio sonde and Radio wind observatories, 219 agro meteorological observatories and more than 700 hydro-meteorological observatories. In addition to this, 200 ships of the Indian Voluntary Observing Fleet (IVOF) record marine surface data and supply to IMD.

Data reception and Processing

Real-time data are transmitted instantaneously to a data collection center and delivered to the real time users, e.g. weather forecasters. Real-time data such as synoptic message and AWS/ARG data flowing through GTS are decoded to the proper variables of the CliSys data base and archived. These data consist of WMO standard coded messages viz. SYNOP, AWS, ARG, TEMP, METAR and SHIPS. Data values are checked for its global limits and internal consistency before ingestion into the database.

The real-time data reception in the database is visualized in near real time basis. A geographical data monitoring displays the IMDs observation network on map of India and related status of the incoming data from stations through color codes. Also a tabular form indicates the status (missing value rate) of a given parameter for a given period and for a given station, in accordance with the theoretical metadata frequency measurements. It displays the real/ expected time series in both tabular and graphical form.

The non-real time data are those from the manual stations which are sent in a delayed mode and received from the RMCs and MCs of IMD. These consist of surface, autographic, upper-air, radiation, rainfall, agro-meteorological data. All observatories send their observation records to their respective data-keying centers on monthly basis. The observations are firstly manually scrutinized by the technical sections of the RMCs and MCs and then keyed-in the predefined NDC supplied data formats. After receiving these keyed-in observations from the data keying centers, quality checks viz. valid character check for each field, duplicate checks, extreme value limit, internal consistency, hydrostatic checks for the upper air data are applied at NDC as per the guidelines of WMO for data processing (WMO 1992). These data in ASCII format are then converted into the CliSys format and are ingested into the database. The non-real time data acquisition processes use the same data loading procedures as used by real-time data.

Quality Control

The quality control process is designed to check the quality of the whole data-flow ensuring the data is error-free as far as possible. The main purpose of quality control is to check whether a reported data value is representative of a real phenomenon or is an outlier not consistent with present weather conditions. Data errors can enter the data set at many sources including the observation site, instrument/sensor, data transmission or data entry stages. All data quality checks and flagging system in the Climate Data Management System (CDMS) have been developed as per the WMO guidelines (WMO 1993). Quality controls for each data are mainly designed for hourly and daily meteorological data in the system. They make real-time checks at the data ingestion level through tolerance tests. After data loading, the data control process is run with the results stored in a doubt table and quality control flags are updated.

The quality controls pass through four levels which are syntax cum Tolerance tests, Priority test, Filter test and consistency controls. The "Meteorological" controls are performed once the data are in the database. There are Global limit checks, Related elements global limits, Internal consistency, Global rate of change and station record limits, Standard deviation check and Station rate of change check. Further spatial consistency checks can be applied by visualization of climate values spatially with direct link to data modification functionalities. Once data are in the database, non-real time tests consisting of internal consistency i.e. physical relationships among climatological elements and temporal consistency i.e. variation of a climatological element in time are applied.

Climate data analysis methodology

Climate data analysis is very useful for climate modeling, climate study, seasonal outlook forecast etc. There are many techniques to analysis climate data out of which statistical technique is most commonly used. The most common statistics are mean, median and mode of some variables. The standard deviation and correlation is also widely used. But the most frequently used statistical method is trend analysis. Trend is the rate at which a parameter changes over a time period. The trend may be linear or non-linear. However, generally, it is synonymous with the linear slope of the line fit to the time series. Simple linear regression is the most commonly used to estimate the linear trend (slope) and statistical significance (via a student-t test). The null hypothesis is no trend. The non-parametric (distribution free) Mann-Kendall (M-K) test can also be used to assess monotonic trend. The M-K test is often combined with the Theil-Sen robust estimate of linear trend.

Before applying any test, the user should be familiar with the underlying assumptions of both the technique used to generate the estimates of trend and the statistical methods used for testing. For example, the Student t-test assumes the residuals have zero mean and constant variance. Further, a time series of N values may have fewer than N independent values due to serial correlation or seasonal effects. The estimate of the number of independent values is sometimes called the *equivalent sample size*. There are methodologies to estimate the number of independent values which should be used in assessing the statistical significance in the (say) Student t-test. Alternatively, the series may be pre-whitened or deseasonalized *prior* to applying the regression or M-K test statistical tests.

Climatological trends of West Bengal (India)

Below trends in temperature for the time period 1901-2016 over West Bengal and India and rainfall over West Bengal is analyzed. It is seen that all India annual mean temperature anomaly shows an increasing trend of 0.64°C/100 year whereas the same for West Bengal is 0.31°C/100 year. The annual maximum and minimum temperature anomaly for the period over West Bengal are 0.43°C/100 year and 0.18°C/100 year respectively.

But when we compare the districts wise trend of annual mean temperature with that of normal over West Bengal. It is seen that except Purulia district all districts of West Bengal show increasing trend. Whereas in the case of annual maximum temperature except Purulia and West Midnapore all other districts show increasing trend. For annual minimum temperature except Purulia, Bankura, Jalpaiguri and Coochbehar all districts show increasing trend. Now when we analyze season wise temperature it is seen that in the case of minimum winter temperature except Purulia, Bankura, Burdwan, Darjeeling, Jalpaiguri and Coochbehar all districts show increasing trend. In the case of premonsoon maxima except Purulia, Bankura, Burdwan, East & West Midnapore, Howrah, Hooghly, Kolkata, North & South 24 Paragana all districts show increasing trend.

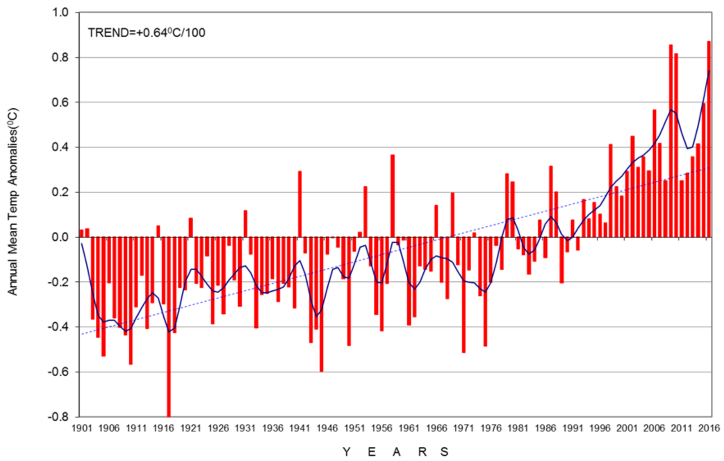

Fig.1. All India annual mean temperature anomalies

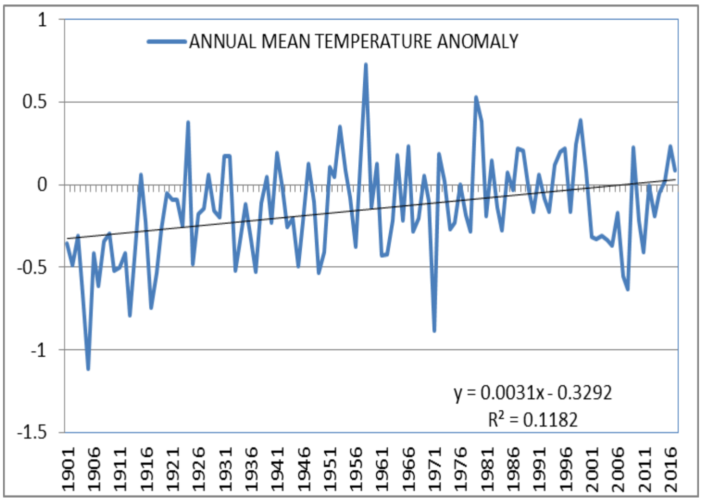

Fig.2. Annual mean temperature anomaly of West Bengal

Trend

Normal

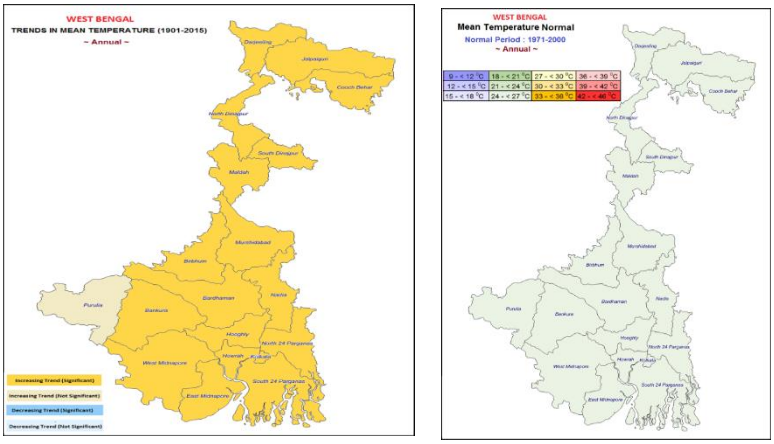

Fig.3. Annual mean temperature of West Bengal, trend vs normal

When we analyze the trends in rainfall it is seen that there is no significant trend in all India monsoon rainfall. However significant trends and major shifts in rainfall pattern are being noticed in smaller spatial scale.

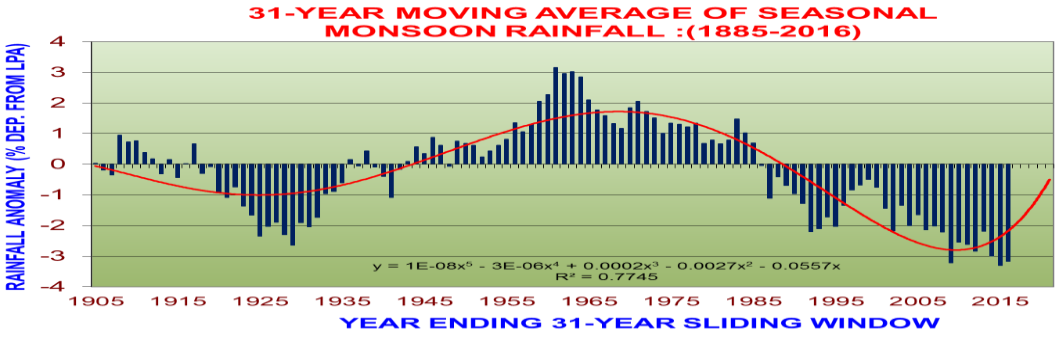

Fig. 4. 31-year moving average of seasonal monsoon rainfall

In case of West Bengal significant decreasing trend in annual rainfall has been observed over Jalpaiguri, North & South Dinajpur, Malda, Purulia, Burdwan, Nadia, Hooghly and Howrah and significant increasing trend in rainfall has been observed over Birbhum, Bankura, East &West Midnapore, Kolkata and South 24 Paragana.

But when we analyze season wise rainfall it is seen that in winter season, rainfall received more over northern and southern parts. Darjeeling, Purulia, West & East Midnapore, Hooghly and Howrah districts have the highest average rainfall received between 37-41 mm. Coochbehar, North & South Dinajpur and Malda districts have the lowest average rainfall between 22-26 mm. All districts except Uttar Dinajpur have significant decreasing trend in winter rainfall during the period 1901-2015. In the premonsoon season significant increasing trend in rainfall has been observed over Darjeeling and West Midnapore districts. Significant decreasing trend in rainfall has been observed over Burdwan, Nadia and Howrah districts. In the monsoon season significant increasing trend in rainfall has been observed Birbhum, Bankura, East & West Midnapore and South 24 Paragana. In the post monsoon season only Kolkata shows increasing trend in rainfall.

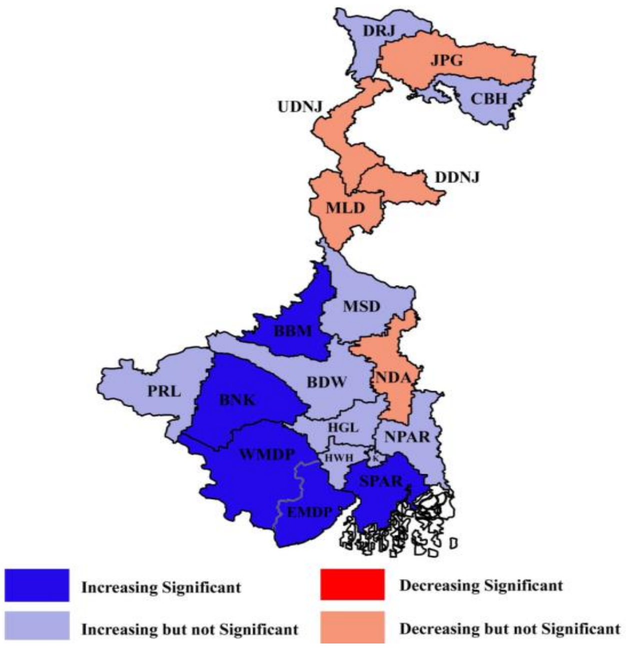

Fig.5. Trend in annual rainfall

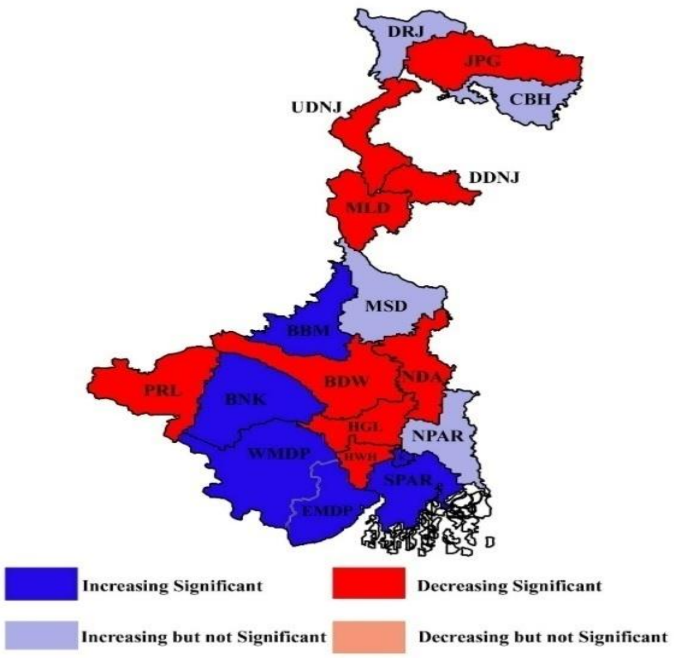

Fig.6. Trend in monsoon rainfall

Chapter 8

IMPACT OF FLOOD ON FISHERIES IN NORTH EAST INDIA: COPING UP AND MITIGATION STRATEGIES

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Introduction

Flood, defined as an overflow of large quantity of water that submerges a normally dry area, is one of the most common natural disasters of the world, having tremendous impact on the socio economic condition, life and livelihood of people. India is one of the worst flood affected countries of the globe. The Indian subcontinent has specific geographical structures which makes various parts of the country vulnerable to flood. The snow clad Himalayan range to the north, encompassing one of the largest glaciers of the world, is the origin of several perennial river systems flowing through the subcontinent. One of the major causes of flood in India is the swelling up of these river systems inundating vast areas of the flood plains inhabited by millions of people. The Vulnerability Atlas of flood zone of India published by Central water Commission (CWC) revealed that the flood prone areas of India are mainly distributed in the Indo-Ganga-Brahmaputra plains and in the eastern and western coastal regions. According to the report of the National Flood Commission (1980), 12% land of Indian subcontinent (nearly 40 million ha) is prone to flood. However the area affected by flood has been reported to be on an increasing trend as per database maintained by CWC during 1953-2010 (Report on Working Group on Flood Management and Region Specific Issues for XII Plan, 2011). Available data on flood related damage in India indicates that recurrence and intensity of flood has amplified to a great extent over the years making it one of the biggest disasters in the country taking lives of thousands of people, affecting millions of people, causing loss of crops, livestock and other property worth huge amount of money thus affecting the socio economic growth of the country (Tripathi, 2015). Among the regions of the Indian subcontinent that are most vulnerable to water induced disasters, the North East Region is the one that experiences devastating flood every year (Fig1).

The NE Region of India

Comprised of eight land locked states viz. Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Tripura and Sikkim, the NE region of India is situated in the eastern Himalayan Region between longitude 21º57′ to 29º30′ N and latitude 84º46′ to 97º30′ E. This region, covering a geographical area of 2.62 lakh sq.km (around 7.98% of the total geographical area of the country), differs significantly from other parts of the country in physiographic, agro-climatic, demographic and socio- economic features. Besides drastic variation in climatic condition representing tropical, sub tropical, temperate and alpine zones in different locations, the region is characterised by high rainfall, acidic soil and water (pH 4.0-6.0), spectacular variation in environmental temperature (sub zero to 39ºC) along with diverse topography ranging from vast plains of Assam and Tripura, upland flat valley of Manipur to predominantly hilly and mountainous regions of Arunachal Pradesh, Mizoram and Sikkim. The major occupation of the ethnic population of the region is agriculture and allied activities including fisheries.

The North East Region of India is blessed with diverse and rich flora and fauna, owing to which the Conservation International (USA), had included this region in two of the richest biodiversity hotspots of the world, the Indo Burma Hot spot and the Himalayan Hot spot. Being blessed with vast and varied freshwater resources and remarkably rich freshwater fish biodiversity comprising of 296 fish species belonging to 110 genera under 35 families (Sarkar *et* al, 2010), the region had been recognised as one of the Hot spots for freshwater fish bio diversity of the world (Kottelat and Whitten, 1996).

Fig.1. Flood map of India

The fishery resources of the region include 20050 km of rivers, 188760 ha reservoirs and 143740 ha of flood plain wetlands and lakes (Sugunan, 2003) in addition to 62289 ha ponds and mini-barrages. Other advantages like high demand for fish and fishery products, as majority of the population being fish eater (90-100% in different states), export potentiality and favourable agro-climatic condition offer tremendous scope for developing fisheries as a major sector for socio- economic growth of the region. However, the region depicts a poor picture amidst plenty of potential resources, ample scope for industrialization and plethora of agribusiness opportunities due to a number of inherent factors among which annual devastating flood is the one (Chetia Borah, 2018).

Flood in NE Region of India

Each and every state of the NE region is prone to flood with variable extent, frequency and intensity. Out of the different states, Assam is the highest flood affected followed by Manipur and Tripura and is one of the top five flood affected states of the country (fig 1). A perusal of available literature on flood intensity in the state indicates an increasing trend from the year 1950 to 2000 in terms of area affected (from 8.85% to 40%) with substantial increase in loss of crop and property due to flood (from Rs. 58.6 Million to 1451.7 Million) during this period (Bujarbaruah, 2013). From the available data, it has been observed that the state of Assam suffers from multiple instances of flood waves annually (2-5 waves) leading to huge loss of life and property and making coping and mitigation mechanism difficult. The recently updated flood hazard atlas for the state of Assam prepared by National Remote Sensing Centre (NRSC), ISRO, Hyderabad, on the basis of available flood data acquired through satellite images indicated that 28.75% (22.54 lakh ha) of land of the state was affected by flood during the period 1998-2015.

Factors Causing Flood in the NE Region of India

The region is blessed with two major rivers systems Brahmaputra and the Barak which along with their tributaries, rivulets/hill streams, flood plain wetlands and lakes constitute the major components of natural fishery resources of the region. The Brahmaputra is a trans boundary river flowing through different countries of Asia, viz. Tibet (China), Bhutan, India and Bangladesh. The Brahmaputra basin spreads over five different states in the NE Region viz. Assam, Arunachal Pradesh, Meghalaya, Sikkim and Nagaland. The Barak valley spreads over the states of Assam, Meghalaya, Manipur, Mizoram, Tripura and Nagaland. In addition to Brahmaputra and Barak river systems, a good number of minor rivers draining into Myanmar and Bangladesh extend over the states of Mizoram, Nagaland, Manipur and Tripura. Overflow of these river systems is the primary source of flood in the NE states causing loss of life, damage of agricultural and allied crops, infrastructure and other properties and is caused by a variety of natural and manmade reasons (Table 1). Some of the major reasons are discussed below:

Heavy rainfall

Heavy rainfall is one of the major reasons of overflowing of the river systems, followed by inadequate capacity of the river to hold the excess water within their banks (NIDM, 2015). According to National Institute of Disaster Management (NIDM), Govt. of India, most of the river flood in India occurs synchronously with major rainfall occurrence during the monsoon months (June to September) and are usually associated with tropical storms, active monsoon conditions etc. The average annual rainfall in India is 1150 mm with significant variations across the country. Besides heavy rainfall, cloud busting, outburst of glacial lakes, melting of glaciers, cyclone and tsunami are other causes of flood in different regions of India. Being situated in one of the highest precipitated zones of the planet, the states of the North East Region of the country receive a very high rainfall with annual precipitation ranging from 1577mm to 6002mm (average of 2068mm) in different places (Parthasarathy *et al*, 1995). The South West monsoon is responsible for major share of annual rainfall in the Region. Although trend analysis data of rainfall during 1871-2008 did not show any clear trend in the region as a whole (Jain *et al* 2013), very high rainfall during monsoon is recorded over the region (around 1513mm, much higher than all India average 865mm) (Parthasarathy, *et al*. 1995), which is one of the major reasons for flood during that season. The Brahmaputra valley receives as high as 3900 mm mean annual rainfall, 66-85% of which occurs in the monsoon period, inducing multiple flood peaks during the period (Gogoi Khonikar and Deka, 2013).Over the North East region as a whole, highest rainfall events has been recorded in the month of July followed by June and August (Mahanta *et al*, 2012). The Barak valley also receives 2000-3900 mm precipitation with maximum during monsoon which along with other factors resulting in high intensity flood during that period. Erratic rainfall during different seasons also gives rise to untimely and unprecedented flood creating havoc in different states of the region. An all time higher intensity flood has been recorded in different states like Assam, Manipur, Mizoram and Tripura in recent years as a result of heavy shower causing landslides, erosion and geo morphological changes in addition to impact on life and livelihood of people.

Geographical position

Geographical position of the states of the region is one of the major reasons for vulnerability to flood. Situated in the eastern Himalayan region, the physiology of the region is still young and is still in the process of forming, which along with other reasons like seismicity and heavy rainfall make the region more vulnerable to flood related consequences. The mayhem of devastating flood in Assam is not only due to high precipitation, but also due to the geographical position that allows the state to be influenced by the runoff from the plateaus and hills of the surrounding states (Bujarbaruah, 2013). The Brahmaputra valley covers about 56000 Sq km of alluvial plains and is fed by 34 tributaries of both the bank. The river Brahmaputra has the highest specific yield (with an annual runoff of 537.2cukm) in the world and that flows through a very narrow valley of hardly 40-50km width in Assam (Sharma, 2013).The breach in embankments along the mighty river Brahmaputra and its various tributaries crisscrossing the valley are the causes of increasing incidences of flooding in the region.

Climate Change

Climate change has been identified as one of the major reasons for increase in frequency and intensity of flood (Rosenzweig *et al*, 2011). Study on change in climatic factors indicates global warming to the range of 0.69 to 1.08°C over the period of 1901-2012, with a future projection of increase of global mean surface temperature by 0.3°C to 1.7°C (IPCC 2013). Since most of the climate change models predict increased frequency of extreme hydrologic events (Rosenzweig *et al*, 2011), a better understanding of the impact of flood related disturbances on the aquatic biota and habitat is the need of the hour for proper management of water resources as well as for developing coping up strategies and mitigation measures to combat impact of flood.

A study on the river Brahmaputra indicated that impact of climate change manifested by increased temperature may have profound impact, as the rising temperature trigger melting of glaciers in the Himalayas, which along with rising evapo-transpiration and erratic rainfall pattern may cause repercussions on the river hydrology leading to intense flood and draughts in Assam (Sharma, 2013). The state level climate change trends in India (Rathore *et al* 2013) indicated significant increase in Annual mean temperature in several states of NE India like Arunachal Pradesh, Assam, Manipur and Tripura as well as significant change in annual rainfall pattern in different seasons in recent years, which along with other reasons induce untimely, intense and unpredictable flood. The high vulnerability of the Himalayan Region to climate change effects is likely to exacerbate the hydrological regime of the Brahmaputra with resultant adverse impact on the Brahmaputra valley (Sharma, 2013).

Siltation

Siltation is another significant factor that leads to reduction in area and depth in most of the river systems as well as flood plain wetlands of NE India. This problem is registered to be particularly severe in the Brahmaputra basin. Because of its erosive nature and high voltage flowing force, the river Brahmaputra carry very high quantity of silt which is deposited in the river bed, wetlands and other areas during inundation by flood. Annual sediment volume carried by the river Brahmaputra is around 800 million tonnes which is one of the highest in the world (Sharma, 2013). Due to constant silt deposition process in the Brahmaputra and its tributaries, the sizes of the river channels are progressively getting reduced over the years making them inadequate to carry the huge flow volume (around 429.76cukm during four monsoon months) resulting in widespread flooding due to excess water spill from the siltation impaired river channels (Sharma, 2013).

Shrinkage of flood plain wetlands

Flood plain wetlands connected to a river system either directly or indirectly can hold huge amount of overflowing water, thereby reducing the intensity and spread of flood considerably. A case study on flood in the Brahmaputra valley indicated that loss and shrinkage of flood plain wetlands resulted in floods with higher intensity in recent years (Sharma, 2013).Absence of proper boundary demarcation in most of the flood plain wetlands leading to human encroachments, transformation of wetland and surrounding land for urban development are the major reasons which along with other factors like weed infestation, siltation and climate change related impacts have led to shrinkage of flood plain wetlands. As per report, over 4500 wetlands in the Brahmaputra valley are rapidly degrading resulting in decrease in flood absorption capacity (Sharma, 2013). As for example, there was an overall decline in the area of an important wetland, the Deepor Beel of Brahmaputra valley (Ramsar site of Assam declared in 2002), upto14.1% during the period from 1990 to 2007 (Sharma, 2013). The flood control measures like erection of embankment as well as sluice-gate near the feeding river or along the wetland area affect productivity of wetland by way of preventing or limiting auto-stocking and annual flushing. Rapid urbanization in the region has led to conversion of many wetlands inducing impending danger of unprecedented devastating flood in new and flood free areas (not declared as flood prone). Instances of draining out of wetlands and converting them for other purposes in several developed countries has led to undesirable consequences like loss of ground water level, unpredictable flash floods, erosion and draught like situations leading to ecological disasters (Matthew, 2013). Reclamation and restoration of the water holding capacity of the flood plain wetlands in the region therefore offers tremendous scope for reducing flood intensity and frequencies in the river valleys (Chetia Borah *et al* 2013a).

Release of water by Hydro electric Projects

Sudden release of huge volume of water without any precaution or warning from the Hydro electric power plants under the North Eastern Electric Power Corporation Limited (NEEPCO, a Central public Sector enterprise owned by the Government of India), situated in different parts of NE Region of India often results in devastating flood in the downstream areas. Huge volume of water released from the Ranganadi Hydro Electric Project under NEEPCO, situated in Arunachal Pradesh often creates havoc in the Dhemaji Lakhimpur area of Assam resulting in loss of life and livelihood of people (Gogoi *et al*, 2013). Likewise water rush from the Doyang Hydroelectric project under NEEPCO, situated in Nagaland has been the cause of intensive flood in Golaghat district of Assam in the downstream.

Table 1. Major causes of Flood in NE Region of India

Sl. No.	Natural	Anthropogenic
1.	Geology and geomorphology of the region	Drainage blockage due to construction of bridge, culverts, sluice gate etc. and congestion due to plastic pollution etc
2.	Siltation and rising of river bed	Human encroachment in riverine catchment area
3.	Seismic activity	Deforestation
4.	Excessive rainfall	Shrinkage of floodplain wetlands due to human encroachment and conversion
5.	Siltation & weed infestation/ shrinkage of flood plain wetlands	Unscientific construction of dams/bundhs in river
6.	Blockage in the drainage due to landslide, erosion	Sudden release of huge volume of water from dams of hydroelectric power projects

Impacts of Flood on Natural Fishery Resources

The impact of flood is mediated by the magnitude, frequency, duration, timing and rate of change of water levels (Richter *et al*, 1996). Depending on these factors, flood may have both negative and positive impacts on the inundated area. Regular annual flood rhythm is recognised as a natural phenomenon of a river ecosystem that maintains productivity and ecosystem harmony. In addition to the impact on the inundated areas, the inbuilt overflowing condition of the water body has a variety of effects on different components of the aquatic ecosystem either directly or indirectly. Although the impact of flood on the agriculture sector in North East India is assessed every year, similar assessment on the fishery sector is not carried out properly. It is obvious that flood related mayhem has tremendous impact on the life and livelihood of the fishers of the natural resources as well as on the socio economic condition of the fish farmers and other stake holders. The nature, extent and gravity of the mayhem of flood may vary according to the nature of the resources (culture or capture fisheries), intensity and duration of flood along with many other factors. Review of works done elsewhere indicated that flood has multifaceted impact on the natural fishery resources. Some of them are as follows:

1. Floods induce changes in aquatic environment in the form of widening / extension of habitat, fresh water influx and enhancement of resource availability that can stimulate fish productivity, increase species abundance, richness, diversity and evenness compared to an ecosystem with stable flow regime (Junk *et al*, 1989).

2. Flood has tremendous impact on the structure and abundance of resident fish population. It has been reported that although lotic fish communities have evolved with dynamic geo-morphological conditions and are relatively resilient to extreme hydrologic events (Lytle and Poff, 2004), high intensity flood may reduce fish density and biomass and influence community composition of the resident population (Warren *et al*, 2009, Milner *et al*, 2012). The magnitude of flood, availability of suitable refuge (floodplains and backwaters) and flood timings have tremendous impact on the resident fish population in relation to the life history of the species (Jowett and Richardson, 1989, Fausch et al, 2001). Kano et al. (2011) stated that the impact may vary according to the fish species, age, size, health, morphology, physiology (tolerance to turbidity, strength to swim in turbulence intensive water etc), behaviour (movement, habitat use) and community composition (species abundance, diversity etc.).

3. Seasonal fluctuation of water level, known as ‘flood pulse’ influence the population dynamics of river fisheries (Junk *et al*, 1989), but the extent and

mechanisms through which the flood pulses affect the productivity has not been established. Riverine flood generally creates connection of rivers with the flood plains and supply nutrients to aquatic terrestrial transition zones stimulating biological productivity and habitat heterogeneity vis a vis benefit the resident fish population by inducing breeding and enhancing recruitment (Tockner et al 2000, Stoffels et al 2014). Fresh water influx accompanied by rising water levels and current of water trigger fish reproduction in many fish species and they migrate to spawn naturally in freshly flooded floodplains when water level rises (Castello, 2008). However, the impact is species specific and varies according to the biological and physiological characteristics and maturity status of the fish species.

4. Earlier studies indicated that although flood have positive impact on population of some fish species through production enhancement and promoting recruitment, there is negative impact on some other species due to abrupt change in the habitat characteristics resulting in decline in population structure and size (Bice *et al*, 2014, Andrew *et al*, 2016).Direct effects involve displacement related mortality, destruction of incubating eggs, destruction of developing embryos and mortality of newly hatched out juveniles by the flood induced water current and turbulence and water quality fluctuation, while indirect effects may include reduction in carrying capacity and change in population composition due to habitat alteration that favours propagation of one species, while inhibiting other (Elwood and Waters, 1969). Study on impact of long term flooding on fishes and aquatic habitat in riverine deltas indicated overall decrease in species richness and diversity with decline in structural indices, while there was higher relative abundance of some species during post flood period (Andrew *et al*, 2016).

The natural fishery resources of the NE region of India are also susceptible to similar kind of impacts of flood. However there is need for location specific study and proper assessment of the impact, so as to draw a workable road map to cope up with the mayhem of flood and address necessary mitigation measures. Some impacts of flood on fishery sector are enlisted in Table 2.

Table 2. Impacts of flood on fisheries of NE Region

Sl. No.	Capture fishery	Culture fishery
1.	Impact on environmental parameters	Damage of pond infrastructure
2.	Changes in ecosystem balance	Changes of ecosystem balance
3.	Impacts of infrastructures (Dam, Bridge, Bundh etc.)	Pollution through flood
4.	Siltation and erosion	Weed infestation (specifically floating weeds)
5.	Pollution from catchment area	Impact on farming operation
6.	Impacts on fishing operation	Loss of fish through migration/mortality
7.	Impacts on fish assemblage	Water and soil quality deterioration
8.	Impact on fish population structure	Change in primary productivity/ food chain
9.	Enhancement of fish productivity by autostocking, recruitment.	Entry of alien/ wild carnivorous fish species
10	Loss of fish through destruction of eggs/juveniles, migration, mortality.	Disease outbreak
11.	Invasion of alien species.	Siltation/ sand deposit

Fig. 2. Flood disaster in Assam

Impact of flood on fisheries under protected areas of NE Region of India

The North East Region of the country is bestowed with a good number of forests designated as the National parks and Wild life sanctuaries for their importance as wild life habitats as well as biodiversity repository. Out of the total 103 National Parks of India, 16 nos are situated in the states of the North Eastern Region covering around 2.57% total geographical areas of the region. Majority of the protected forest areas of NE India encompass a variety of natural water bodies including parts of the major river systems of the region and their tributaries, flood plain wetlands, swamps etc. that are abode of indigenous as well as endemic fish fauna. Studies conducted on the fishery resources of the protected areas of the NE region (Dutta *et al*, 1998, Sen and Choudhury, 1977, Wakid and Biswas, 2005, Sarkar *et al*, 2008), indicated potentiality of these resources in protection and conservation of indigenous fish biodiversity**.** The Dibru Saikhowa National park of Assam, for example, is endowed with vast and varied water bodies that encompasses 51 sqkm of flood plain wetlands, several rivers, rivulets, swamps etc. harbouring rich aquatic biodiversity including 108 fish species representing 64 genera and 27 families (Bania, 2013). Wakid and Biswas (2002) reported a residential population of the freshwater River Dolphin, *Platanista gangetica* in the Dibru Saikhowa National park water resources, which reportedly was the most dense and prominent population in the entire North Brahmaputra Basin of Assam. The Kaziranga National Park, which hosts two thirds of world's one horned Rhinoceros, is a World Heritage Site, declared as a Tiger Reserve in 2006 for its unique Royal Bengal Tiger population and as an important Bird Area for conservation of avifaunal species by Bird life International. The Park is criss-crossed by four major rivers including the mighty river Brahmaputra and is endowed with myriads of flood plain wetlands, swamps, rivulets and canals that act as habitat and breeding ground for diverse indigenous and endemic fish fauna.

However, most of the National parks and Wild Life Sanctuaries of this region experiences flood every year causing threat to the wild life. For example, the Dibru Saikhowa National park of Assam has been under continuous threat of flood, as it is situated in the flood prone areas of the flood plains of the river Brahmaputra and rivulets Debang, Lohit, Dibru in the tropical monsoon belt with high annual rainfall. The park has been subjected to geo-morphological changes in recent years due to widening and changing of river courses and high amount of siltation during flood (Sharma and Phukan, 2003).This along with increasing anthropogenic pressure from the neighbouring areas has led to shrinkage of the ecosystem and depletion of the biodiversity (Wakid and Biswas, 2005). Likewise, the Kaziranga National Park situated in the flood plain of the mighty River Brahmaputra experiences devastating flood every year causing tremendous impact on the valuable wild life including the rich wild fish fauna.

Generally fish fauna of lotic environment are adapted to regular annual flood pulse that gives them ample opportunities for breeding and grazing in wider area in fresh flood water. It has been observed that along with overflowing of the water bodies during monsoon, the gravid and mature fishes use to come out from their natural habitats and escape to the adjoining areas filled with fresh rain water for foreplay and spawning. However, with the increasing intensity of flood they get dispersed to the neighbouring areas, where most of them are captured by the local population or fall prey to other untoward situations. Although the creation of Freshwater Aquatic Sanctuary (FAS) within protected forest area network has been recommended as one of the effective strategies for protecting freshwater biodiversity from different threats (Saunders *et al*, 2002, Sarkar *et al*, 2008), annual devastating flood prevalent in the region may stand as a hurdle towards achieving that goal.

Invasion of alien fish species in to the natural resources

Besides impact on the resident population, flood facilitates invasion of alien fish species in to the natural resources, creating another threat for the native fish biodiversity and natural habitat (Jain *et al.* 2007). Quite a few alien fishes were introduced to NE Region of India for improving local fishery potential and broadening species diversity in aquaculture programme. The Chinese carps Silver carp (*Hypophthalmichthys molitrix*), Grass carp (*Ctenopharyngodon idella*) and Common carp (*Cyprinus carpio*) are some of the species that were already established themselves in the culture fishery sector of the state. Some other species like *Clarias gariepinus* (Thiland magur), *Arichthys nobilis* (Big head), *Oreochromis nilotica*, etc. introduced to the state clandestinely have been causing severe problems in ecosystem balance. Recent introduction & popularization of other alien species like African Pangas (*Pangassius sutchi*) and Amazon Piranha (Pacu) locally called as Rupchanda (*Piaractus brachypomus*) as well as reporting of some of the species in natural waters like *beels* and rivers, has indicated an alarmingly grave situation of invasion and establishment of these alien species in natural resources. (Biswas & Das, 2013). Reported invasion of alien ornamental species like Sucker mouth armoured catfish of

Loricariidae family in natural water resources like flood plain wetland, rivers etc. has been creating havoc in the region (Singh and Lakra, 2011). There are reports that floods may exert differential effects on introduced and native species by increasing reproduction, recruitment and population growth to a greater extent than the native species (Scheerer 2002, Barko et al, 2006, Sommer et al, 2014). As such, there is need for immediate action to check culture of alien fish species, particularly in the flood affected areas of the region, where there is every risk of escaping of the alien species from the culture ponds along with flood water and invading the natural resources.

The Way Ahead

While flood affected resources need immediate restoration and redress measures, it is also necessary to develop a roadmap towards sustainable utilization of production potentiality of available water resources of flood prone areas for fish production.

Following strategies need to be taken up as coping up and mitigation of impact of flood on natural fishery resources (capture fishery sector) of NE Region:

1. Proper assessment of impact of flood including loss of fish stock, change in community size and structure, deterioration of ecosystem, change in water quality, pollution, damage of infrastructures and implements, disease outbreak, invasion of alien species and mortality of fish.
2. Revisiting and refinement of technologies for creation of bundh, dam, sluice gate, drainage system etc. befitting the specific environmental, geographical and hydrological conditions as well as biological need of the resident aquatic species at particular locations and water bodies.
3. Reclamation of flood plain wetlands that have been facing the problem of shrinkage to restore its original size and depth, so as to enhance their water holding capacity for retaining more flood water from the overflowing rivers

and thus reducing the intensity of flood considerably (Chetia Borah *et al* 2013a)

4. Integrated approach for sustainable and productive management of flood plain wetlands with community participation (Chetia Borah, 2014).
5. Creation of aquatic sanctuary in flood secured areas to conserve and restore the fish germplasm of the region.
6. Development of technology for breeding and creation of infrastructures like hatchery for fish seed production of desired species for ranching in the natural resources after flood to mitigate loss due to flood.
7. Awareness about preparedness to address the flood induced challenges, availability of day to day meteorological data,
8. Early warning system and coping up strategies among the aboriginal fisherman communities and other stakeholders, particularly before release of sudden flash of water from hydro electric project.
9. Suitable alternative livelihood option during the flood period along with specific skill development programme for the fishers and other stakeholders that depend on the flood affected water bodies for their livelihood.
10. Improvisation of fishing gears, crafts and tools for better efficiency and for proper harnessing of productivity of the flood prone natural resources
11. Strengthening transport and communication facility, power supply system, disaster management, health care and maintaining hygiene in the flood prone areas.
12. Provision for disease diagnosis and water quality monitoring for different location.
13. Provisioning specific policy support for coping up and mitigation strategies for the flood affected fisher population including insurance and financial support.

14. Specific policy support for conservation and restoration of biodiversity and productivity of the natural resources as well as addressing and mitigating the impact of flood on the natural fishery resources in eco friendly way.

The mayhem of flood has been an integral component in the lives of farming community of the flood prone areas. However, scientific intervention may help the farmers in utilizing the available resources in flood prone areas for productive purpose. Fish culture in flood prone areas is always risky and beset with lot of problems including destruction of pond infrastructure, deterioration of pond ecosystem, loss of fish through uncontrolled exit, invasion of alien and carnivorous species, weed infestation, fish mortality due to water pollution, disease infestation etc. Development of specific production and management technology suitable for flood prone areas is important for harnessing the production potentiality from such areas. However most of the package of practices for fish farming in the state are recommended as suitable for flood free situations only (Anon, 1997). Chetia Borah (2013) suggested a few suitable technologies for harnessing production potentialities of existing culture fisheries in flood prone areas of Assam, that included technology for integrated farming of fish with livestock and horticulture to mitigate loss and cope up with the impact of flood, composite culture of indigenous major and minor carps in flood prone areas excluding exotic species to avoid entry of the exotic species to natural resources through flood, short term fish culture of minor carps and small indigenous fish species avoiding the flood period of the year, mutiple stocking multiple harvesting to harness maximum production potentiality and cage culture to protect fish stock under adverse condition of flood. For flood prone areas, this system of cage culture can be used for raising fish fry to fingerling stage, storing fish seed as input for after flood redress and protecting table fish from washing away by flood water. Successful operation of cage culture system in different wetlands of flood prone areas has been successfully demonstrated in the region, particularly for the areas with low or medium intensity flood occurrence.

Table 3. Pre & post flood strategy to mitigate impact of flood on culture fishery

Sl. No.	Pre-flood	Post flood
1.	Strengthening & raising pond embankment around and above the highest flood level.	Assessment of loss due to flood impact
2.	Turfing of newly raised/constructed embankment to avoid top soil loss suring rain	Desilting of pond where siltation due to flood occurs
3.	Boulder pitching of the side and embankment.	Repairing/renovation of embankment.
4.	Preparedness including nylon nets erection with bamboo poles other imputs.	Dewatering of pond when necessary to eradicate weed fish/weeds/silt & debris
5.	Harvesting and shifting to safer place	Assessment of pond fish population/restocking where necessary.
6.	Storage of fish/fish seed in suitable cage to avoid loss.	Water quality assessment and redressial measures
7.	Fish aggregating/attraction measures.	Monitoring of fish health and disease/parasitic infestation etc.

Chetia Borah *et al* 2013b

Fig. 3. Turfing of pond embankment to avoid top soil loss

Fig. 4. Floating type cage culture in a flood plain wetland of Assam

Fig. 5. Erection of nylon net for protection of fish biomass during flood

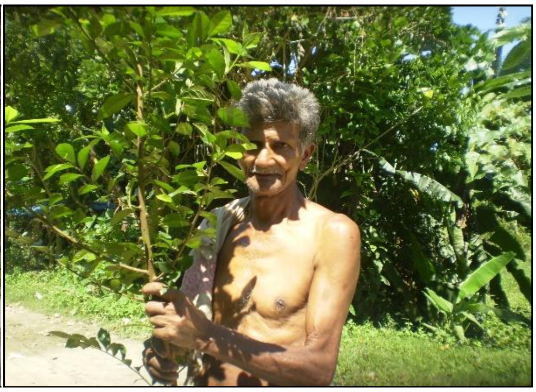

Fig. 6. Fisherman using *Soura* (*Grewia sapida* Roxb) for fish agregration

Conclusion

The extent of mayhem of flood in the life and livelihood of the people living in the flood prone areas and its impact on the development of agricultural and allied sector vis a vis on the economic growth of the NE Region calls for immediate action to frame specific policy for the issue at central government level by declaring it as a national calamity. Proper strategy need to be taken for controlling intensity of flood while securing the ecosystem health, for strengthening disaster management cell, for creating awareness on timely precautionary, mitigation and redress measures suitable for the region including alternative livelihood option. The high vulnerability of the Himalayan Region to climate change effects, impact of anthropogenic and inherent natural reasons indicate more intense hydrological disasters in near future, Most of the climate change models also predict higher intensity hydrological events that may have irreversible adverse impact on the fishery sector of the region. As such it is high time to act responsibly to restore the natural fishery resources, to conserve the rich fish biodiversity and to safe gourd the life and livelihood of the aboriginal fishers, fish farmers and other stakeholders from the mayhem of flood. Conjugated effort of fishery scientists, environmentalists, engineers, geologists, policymakers, government functionaries and NGOs working on the field will definitely infuse the desired strength to the sector to fight the flood related problems and prosper against all odds.

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Chapter 9

BRACKISH WATER FISH DIVERSITY IN INDIAN SUNDARBANS IN THE BACKDROP OF CLIMATE CHANGE INDUCED SALINITY ALTERATION

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Introduction

The neritic zone of the ocean is extremely important from the production point of view as it receives major nutrients (ammonia, nitrate, phosphate and silicate - the raw materials for primary production) from adjacent landmasses and sustains the foundation community of marine and estuarine biodiversity – the phytoplankton. This community comprises of diverse species of tiny free floating floral components like *Coscinodiscus* sp., *Chaetoceros* sp., *Fragilaria* sp., *Biddulphia* sp., etc. The upwelling areas of the marine environment support large population of several types of phytoplankton due to presence of nutrient rich water that are transported from the bottom of the ocean to the surface layer. Phytoplankton provide food to the zooplankton (the major groups include copepods, chaetognaths, harpacticoids etc.) of the pelagic zone, which are finally consumed by fishes (like herring, cod, flounder, bombay duck, hilsa etc.) that comprise the nekton community of the marine and estuarine ecosystems (Fig. 1). Any change in the lower tiers of food web due to sea level rise, saline water intrusion, ocean acidification (as a result of lowering of pH) or temperature rise is likely to be transmitted to the members of higher trophic level (nekton).

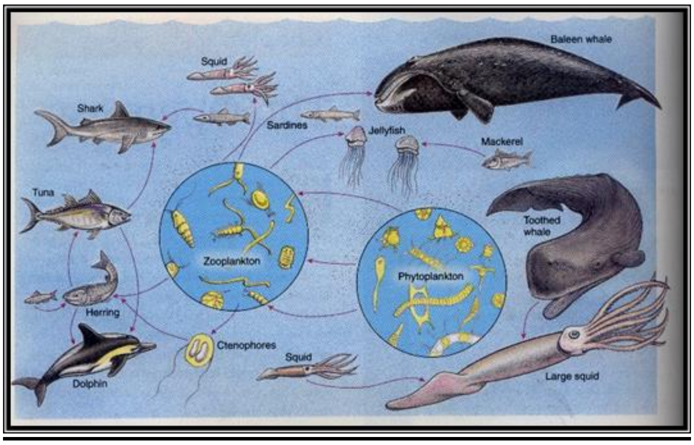

Fig. 1. Food web of marine ecosystem

By definition, pelagic animals that swim actively are known as nekton. Most of the animals under this category are vertebrates (animals with backbones such as fishes, reptiles, marine birds and marine mammals), but a few representatives are invertebrates (like squids and nautiluses and some species of shrimps-like arthropods). Marine and estuarine fishes are the dominant vertebrate nekton that live in salt water, brackish water or even migrate in the fresh water system for breeding purpose. Fishes may also live near the surface or at great depths both in extreme warm and cold conditions. Like other ectothermic (cold-blooded) organisms, fishes are incapable of generating and maintaining a steady internal temperature from metabolic heat; so the internal body temperature of a fish is usually the same as that of the surrounding environment. This is one of the reasons why fishes are highly vulnerable to oscillation of environmental parameters due to climate change. The degree of vulnerability is, however, functions of **exposure** of the fish species to a particular parameter (variable), the **sensitivity** of the species to the parameter and the adaptive capacity of the species to cope with the stress. Mathematically the concept may be expressed as:

Vulnerability = f (exposure, sensitivity, adaptive capacity)

Fishes are divided into two major groups based on the nature of their skeletons: the cartilagenous fishes (Chondrichthyes) and the bony fishes (Osteichthyes). Both bony (*e.g., Tenualosa ilisha*, *Scatophagus argus* etc.) and cartilaginous fishes (like whale shark, dog shark, sting rays, guitar fishes, etc.) are important components of the nekton community in the Bay of Bengal and adjacent estuaries, which is the case study region in the present dissertation.

Osteichthyes

Bony fishes are found at all depths and in all the oceans, but their distribution is determined directly or indirectly by the abundance and biomass of primary producers. This is the basis of evaluating Potential Fishing Zone (PFZ), which is detected from the satellites (Fig. 2, 3 and 4). It is very important to note in this context that satellites do not observe fish stocks directly, but measurements such as sea-surface temperature (SST), sea-surface height (SSH), ocean colour, ocean winds and sea ice, characterize critical habitat that influences marine resources including fish stocks. Most of the spatial features that are important to marine ecosystems like ocean fronts, eddies, convergence zones, river plumes and coastal processes, cannot be adequately resolved without satellite data. Chlorophyll, present in the phytoplankton is the only biological component of the marine ecosystem accessible to remote sensing (*via* ocean colour) and as such provides a key metric for evaluating the health and productivity of marine ecosystems on a global scale. Long-term ocean colour satellite monitoring provides an important tool for better understanding of the marine processes, ecology, fish stock and the coastal environmental changes (Tang and Kawamura, 2001). Modern oceanographic vessels are, therefore linked to satellites *via* computers allowing scientists to use immediate data to plan their sampling programmes while at sea.

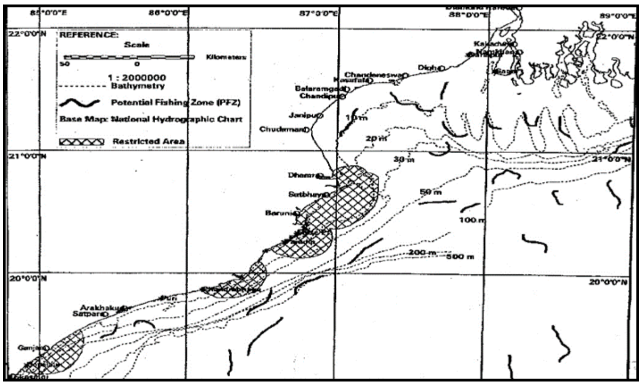

Fig. 2. Map showing potential fishing zone off Orissa and West Bengal coast; map based on SST/Chlorophyll composite of 08 – 09 November, 2003

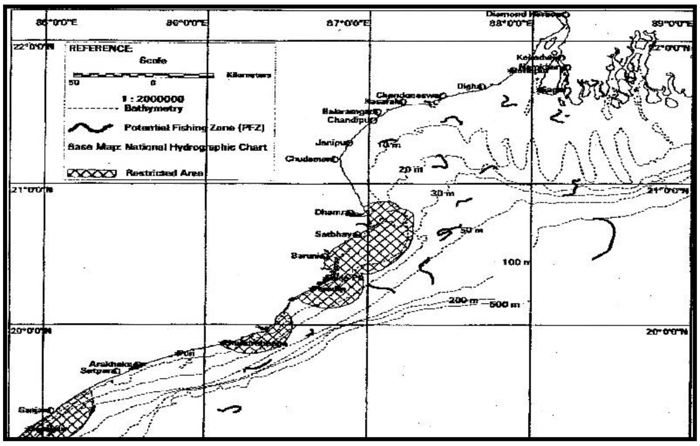

Fig. 3. Map showing potential fishing zone off Orissa and West Bengal coast; map based on SST/Chlorophyll composite of 23 – 24 November, 2003

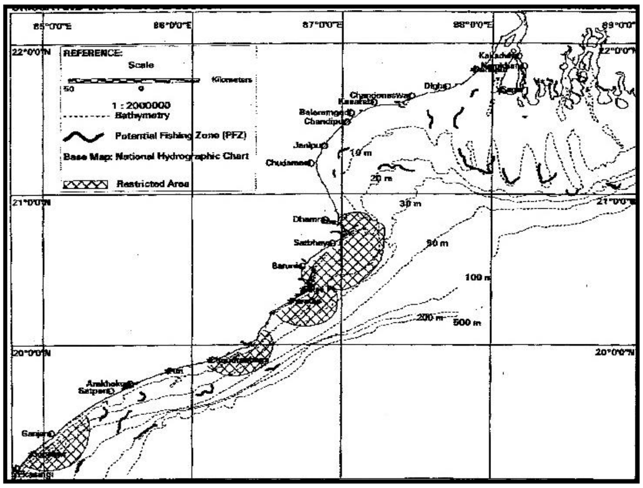

Fig. 4. Map showing potential fishing zone off Orissa and West Bengal coast; map based on SST/Chlorophyll composite of 07 – 08 December, 2003

Fishes are mostly concentrated in upwelling areas, shallow coastal zones and estuaries. The surface waters support much greater populations of fish per unit volume of water than the deeper zones, where food resources are very less in terms of quality (diversity) and quantity. The presence of mangroves and other associate floral species also regulate the distribution of fishes in the marine and estuarine compartments. The rich bony fish (osteichthyes) diversity in the waters of mangrove dominated Indian Sundarbans is a very relevant example in this context. The aquatic sub-system of deltaic Sundarbans is the dwelling spot, nursery and breeding ground of a wide variety of finfish and shellfish. Hamilton-Buchanan (1922) carried out an extensive survey in this Gangetic delta complex with respect to fish fauna. The works of Hora (1933, 1934, 1936, 1943), Perase (1932), Prashad *et al*. (1940), Koumans (1942), Gupta (1967a, 1967b), Talwar (1991) and Talwar *et al*. (1992) reveal valuable information on the fish resources of Indian Sundarbans. The catch composition of finfish in and around this tropical mangrove ecosystem usually exhibits the pattern: *Bombay duck* > *Cat fishes* > *Clupeids* > *Prawns* > *Croakers* > *Pomfret* > *Ribbon fish* > *Sardines*

> *Elasmobranchs* > *Eels*. The annual landing data of finfish from Indian Sundarbans region indicates an increasing trend (Table 7.1) in spite of the existence of several threats in this deltaic lobe.

Table 1: Mean annual landings of important fish species (in metric tonnes) from Indian Sundarbans estuarine system during 1964-65 to 1975-76 and 1987-88 to 1990-91

Fish Species	1964-65 to 1972-73	1973-74 to1975-76	1987-88 to 1990-91
Tenualosa ilisha	-	-	2679.45
Harpodon nehereus	1242.2	2579.8	4842.52
Pama pama	73	320.1	4547.47
Setipinna spp.	422.1	780.6	6221.4
Arius jella	5.3	23.3	915.9
Pampus spp.	5.7	9.8	902.77
Polynemus paradiseus	3.6	21.8	191.4
Coilia spp.	1.3	2.3	987.72
Ilisha elongata	26.9	102.2	674.3
Otolithoides biauritus	103.8	156.8	322.07
Polydactylus indicus	0.6	3	154.15
Polydactylus sp.	-	-	115.15
Trichiurus sp.	246.5	806.4	3026.97
O. militaris	5.3	44.7	-
Others	551.6	921.8	8699.42
Total	2622.2	5772.6	34280.88

Source: Jhingran (1992)

Several workers have depicted the taxonomic diversity of fish species in and around the aquatic sub-system of mangrove dominated Sundarbans deltaic complex. Pillay (1967) estimated the species number to be more than 120. Jhingran (1982) documented a total of 172 species and stated that the diversity is comparatively more in the high saline zone (lower estuarine stretch) of Indian Sundarbans. His estimate revealed 73 species of fresh water origin and 99 species of marine/higher salinity origin. Mandal and Nandi (1989) documented 141 species of finfish under 100 genera, while Chaudhuri and Choudhury (1994) recorded 250 species under 96 genera in the waters of Indian Sundarbans. Khan (2003) recorded 107 species from Sundarban Biosphere Reserve region, but this figure does not include the species restricted in the low saline upper zone of the Hugli-Matla estuarine complex.

With respect to ecological tolerance, a large fraction of the finfish species in the mangrove dominated estuarine complex is euryhaline in nature and move freely from the upper stretch of minimum salinity to lower stretch of maximum salinity. Such species will be affected at a smaller magnitude by climate change as they have a wide span of adaptation to salinity. However, species that are restricted only to lower stretch of the Hugli-Matla estuarine complex and adjacent Bay of Bengal region or in the upper freshwater dominated zone will be most affected on account of climate change due to their narrow range of ecological tolerance.

The fish fauna of the estuarine waters in and around Indian Sundarbans has been classified into residents and transients (migrants). The species whose individuals of different sizes are present during all the months of the year in any zone of the estuary are referred to as resident species. The important resident species of fish are *Mugil parsia, Mugil tade, Polynemus paradiseus, Polydactylus indicus, Otolithoides biauritus, Lates calcarifer, Hilsa toli, Arius jella, Harpodon nehereus, Setipinna taty, Ilisha elongata, Setipinna phasa, Coilia ramcarati, Pama pama* and *Sillaginopsis panijus*. The transient or migratory fishes enter and stay in the Bay of Bengal associated estuaries for a short period. Depending on their migratory pattern and direction, the migrants are divided into three categories (Jhingran, 1982).

(1) Marine forms that migrate upstream and spawn in freshwater areas of the estuary like *Tenualosa ilisha, Polynemus paradiseus, Sillaginopsis panijus and Pama pama*, (2) Freshwater species, which spawn in saline area of the estuary like *Pangasius pangasius*, and (3) Marine species, that spawn in less saline water of the estuary like *Arius jella*, *Osteogeneious militaris* and *Polydactylus indicus*.

Chondrichthyes

Elasmobranchs (chondrichthyes) constitute a vital segment of marine and estuarine nekton and are of great commercial importance all over the globe, apart from being a major component in marine food web. About 350 species of sharks and 320 species of rays are known to exist. Nearly all are marine, although a few species inhabit estuaries and a very few are permanent inhabitants of fresh water. It has been observed that sharks usually prefer swimming in open waters, whereas rays tend to be found on or near the bottom. The annual catch of elasmobranchs in India is around 70,000 tonnes, which is over 4% of total marine fish landings (http://www.mpeda.com /FisheryResources/Elasmobranchs/Elasmobranchs.htm).

According to MPEDA (1999) the annual average landings of elasmobranchs during 1995-1998 was 75,037 tonnes and the estimated potential of this group is 1,68,000 tonnes. The major elasmobranchs contributing to Indian fisheries are *Rhizoprionodon oligolinx, Isurus oxyrinchus, Sphyrna blochii, Sphyrna mokarran, Rhynchobatus djiddensis, Rhinobatus granulatus, Rhina ancyclostoma, Dasyatis sephen, Dasyatis uarnak, Dasyatis imbricatus, Dasyatis marginatus, Himantura alcockii, Aetobatus narinari, Aetomylaeus mehotii, Aetomylaeus maculatus, Rhinoptera javanica, Gymnura poecilura* and *Mobula diabola*. Sharks account for 60-70% of this total figure. Maritime states like Tamil Nadu, Gujarat, Maharashtra, Kerala, Karnataka and Andhra Pradesh contribute around 85% of shark landings in India. About 65 species of sharks that contribute to fishery stock are sighted in Indian waters and over 20 of them belong to Carcharhinidae and Sphyrnidae families (http://www.mpeda.com /FisheryResources/Elasmobranchs/Elasmobranchs.htm).

Sharks are thus dominant species of elasmobranchs and play a major role in both ecology and economics. The various direct and indirect products obtained from sharks are today used in food, tourism and pharmaceutical industries. Because of such multiple uses, the community is presently under threat due to overexploitation. Deterioration of water quality due to anthropogenic activities and industrial discharge has increased the magnitude of threat. Few species of sharks (particularly *Glyphis gangeticus*) are so sensitive in nature that they cannot withstand the alteration of water quality caused by rapid industrialization and urbanization. Such species are extremely vulnerable to oscillation of hydrological parameters often induced by climate change. The drastic reduction of *Glyphis gangeticus* population in recent times in the Ganga-Bhagirathi-Hugli riverine stretch is an indication of change in water quality, but how far it is related to climate change induced alteration needs to be critically investigated.

Physiography

The Indian Sundarbans at the apex of the Bay of Bengal (between $21^{0}40'$N to $22^{0}40'$ N latitude and $88^{0}03'$ to $89^{0}07'$E longitude) is located on the southern fringe of the state of West Bengal, covering the major portion of the North and South 24 Parganas districts. The region is bordered by Bangladesh in the East, the Hooghly River in the West, Dampier and Hodges line in the North and the Bay of Bengal in the South.

With a considerable degree of marine characteristics in major portion of the ecosystem, the important morphotypes of deltaic Sundarbans are beaches, mudflats, coastal dunes, sand flats, estuaries, creeks, inlets and mangrove swamps.

Spatially, the Indian Sundarbans may be broadly divided into three salinity regions (Table 2), out of which the high saline zone supports the oyster bed in the intertidal regions.

Table 2. Divisions of Indian Sundarbans on the basis of salinity

Zone	Areas included
High Saline	Partha Pratima, Namkhana, Sagar, Kultali, Gosaba & Basanti.
Medium Saline	Canning-I & II, Kakdwip, Mathurapur-II, Jainagar-II
Low Saline	Kulpi, Mathurapur-I

Source: A draft report on Indian Sundarbans (2003), Dept. of Fishery, Govt. of West Bengal.

The components of the aquatic sub-system in Indian Sundarbans, suffer characteristic seasonal changes due to factors like evaporation, precipitation, run-off etc. In the northwestern Bay of Bengal, the premonsoon period (summer) is usually characterized with high saline surface water and relatively high pH. The picture in monsoon period gets totally reversed. Due to increased precipitation and run-off from the adjacent land masses, the salinity of the surface water lowered along with pH, but the concentrations of the nutrients increase, which may be attributed to increased run-off from the adjacent agricultural fields, municipality, urban sectors, etc. (Mitra, 2000). The seasonal variation of some important hydrological parameters around the Indian Sundarbans ecosystem that is at the apex of the Bay of Bengal is shown in table 3.

Table 3. Seasonal variation of physico-chemical characteristics in three distinct salinity regimes in the Indian Sundarbans

Season	Dissolved Oxygen	Water temp (ºC)	Dilution factor	Salinity	pH	Nitrate (µg /l)	Phosphate (µg/l)	Silicate (µg/l)
Upper Stretch								
A	6.0	34.0	0.96	1.5	8.00	19.87	3.36	56.30
B	5.9	33.5	1.00	0.0	7.48	21.05	4.18	63.85
C	5.8	22.1	0.97	1.0	7.90	20.60	2.84	70.36
Middle Stretch								
A	6.3	33.5	0.70	10.5	8.30	17.80	1.37	79.84
B	6.2	33.0	1.00	0.0	7.89	18.55	2.08	91.28
C	5.9	25.1	0.90	3.3	8.20	20.29	2.37	101.20
Lower Stretch								
A	6.9	33.9	0.23	26.1	8.36	19.50	1.36	161.85
B	6.8	33.2	0.67	8.5	8.12	26.53	1.89	182.30
C	6.3	26.0	0.40	20.0	8.28	18.75	1.37	137.40

Source: Seas at the Millennium: An environmental Evaluation (2000).

Geologically, the Sundarbans delta is the largest prograding delta on the globe. Solely quaternary sediments carried and deposited by the river Ganges, Matla and Bidyadhari, cover the region. The present deposition of detritus has formed since last 6000 years of stable phase. In the recent past, the Bengal basin suffered some neotectonic movements. Between 12th & 16th century, there was an easterly tilt of Bengal basin, which resulted in shift of Ganges towards east, and river Padma became active. During this period, the Matla & Bidyadhari river systems formed innumerable network of creeks between Ganga & Padma. During the 16th century, the Ganges flow shifted almost totally eastwards into river Padma, and the Matla & Bidyadhari river system got completely cut off from sweet water source and is presently fed by the back water of sea. The main estuaries from west to east in Indian Sundarbans are Hooghly, Saptamikhi, Thakuran, Bidya, Bidyadhari, Gosaba Kalindi and Raimongal (Table 4). The average tidal amplitude in these estuaries ranges from 3.5 to 5.0m.

Although the region is situated south of the tropic of Cancer, the temperature is aquable due to its proximity to the sea. Average annual maximum temperature is around 35 degree C. the summer extends from middle of March to middle June and the winter from December to February. The monsoon usually sets in around middle of June and lasts up to middle of September. Rough weather lasts from 15th March to 15th September and the weather prevails between mid Septembers to mid March. Average annual rainfall is 1920 mm. Average humidity is about 82% and is more or less uniform throughout the year.

The rivers are the live matrix of deltaic complex, on which the unique spectrum of biological diversity is embedded. In Indian Sundarbans, approximately 2069 sq. km area is occupied by tidal river system. The main estuaries, from west to east are highlighted in table 4 along with their salient features.

Table 4. Important rivers of Indian Sundarbans

River	Description
Hooghly	➢ It forms the western border of Indian Sundarbans ➢ It is the main river of West Bengal and along with the Ganges and Bhagirathi rivers comprise a national waterway. ➢ Most of the coastal industries of West Bengal are concentrated along the western bank of this river.
Muriganga	➢ It is a branch of the Hooghly river. ➢ It flows along the east of Sagar Island. ➢ Unique mangrove vegetation is found along the bank of this river.
Saptamukhi	➢ It has its origin at Sultanpur. ➢ It is connected with the Muriganga (Bartala) branch of the Hooghly river through Hatania-Duania canal.
Thakuran	➢ It begins near Jayanagar in South 24 Parganas and has a number of connections with the Saptamukhi. ➢ It has perhaps earlier connected with the Calcutta canal through the Kultali and the Piyali rives, which exist today in a dying state.
Matla	➢ This river originates at the confluence of Bidyadhari, Khuratya and the Rampur Khal close to the town of Canning jn south 24 Parganas. ➢ Matla is connected to Bidya and ultimately flows to the Bay of Bengal. The fresh water connection and discharge to this river has been lost in the recent times.

	➢ Salinity of the river water is relatively high (in comparison to Hooghly and Muriganga) owing to fresh water cut-off from the upstream region.
Bidyadhari	➢ This was flourishing branch of the Bhagirathi during the 15th or 16th century, but now serves only as a sewage and excess rainwater outlet from the city of Kolkata. ➢ The river bed is completely silted and presently it is almost in dying condition.
Gosaba	➢ The waters of Matla and Harinbhanga (Raimangal) through a large number of canals from it. ➢ The river flows through the reserve forests.
Harinbhanga	➢ The river begins from Sahebkhali in North 24 Parganas and is connected with the Rampura khal by Barakalagachi river and with the Gosaba river through the river Terobhanki. ➢ The Harinbhanga (also known as Ichamati and Raimangal) forms a natural demarcation between India and Bangladesh.

Materials and Methods

Selection of the sampling stations

Two sampling zones were selected each in the western and central sectors of Indian Sundarbans, a Gangetic delta at the apex of the Bay of Bengal. The western sector of the deltaic lobe receives the snowmelt water of mighty Himalayan glaciers after being regulated through several barrages on the way. The central sector on the other hand, is fully deprived from such supply due to heavy siltation and clogging of the

Bidyadhari channel in the late 15th century. The western sector also receives wastes and effluents of complex nature from multifarious industries concentrated mainly in the upstream zone. On this background four sampling stations (two each in western and central sectors) were selected (Table 5) to analyze the brackish water fish diversity (catch and Bar H used to evaluate Shannon Weiner Species Diversity Index) in context to hydrological parameters (surface water temperature, salinity, pH and DO). The work was carried out during 7th to 10th March, 2017. Fish composition was documented from the 100 kg catch from the local market and counting the number of fishes in each species bar H was enumerated.

Table 5. Sampling stations with salient features

Station	Salient Features
Kachuberia (Stn.1)	It is located in the Hooghly estuary and is the northern tip of Sagar Island, the largest island in Indian Sundarbans
Sagar Island South (Stn.2)	Situated at the confluence of the River Hooghly and the Bay of Bengal on the western sector of Indian Sundarbans
Gosaba (Stn. 3)	Located in the Matla Riverine stretch in the central sector of Indian Sundarbans
Bali Island (Stn. 4)	Located in the central sector of Indian Sundarbans. Noted for its wilderness and mangrove diversity; selected as our control zone.

Analysis of Physico-chemical Variables of Water

- ✓ **Temperature:** Measured by direct dipping a 0^0-100^0C mercury thermometer during high tide period, preferably around 12:00 noon. The data were collected from CPCB.
- ✓ **Salinity:** The surface water salinity was recorded by means of an optical refractometer (Atago, Japan), and cross-checked in laboratory by employing Mohr- Kundson method (after Strickland and Parsons, 1968).
- ✓ **pH:** On spot measurement was done by using a portable pH meter (sensitivity $= \pm 0.02$). The data were collected from Dept. of Marine Science, University of Calcutta.
- ✓ **Dissolved oxygen (D.O):** Measured by DO meter after fixing them in the field with Winkler’s reagents.

Results and Discussions

The biogeographic distribution of fish species is very much influenced by salinity. An interesting example in this context is the extension of the spawning ground of *Tenualosa ilisha* in more upstream zone after the construction of the Farakka barrage on the Gangetic stretch of India. The studies conducted during 1982-1992 clearly reveal that the ecology of Hooghly estuary (downstream zone of Ganga-Bhagirathi system) has undergone a major change due to construction of the Farakka barrage in 1975. The increased freshwater discharge has resulted in considerable decrease in salinity throughout the estuary. The fresh water zone has extended toward the mouth of the estuary and the marine and estuarine zone has been pushed almost towards the end of the lower stretch of the estuary (Sinha *et al*., 1996). This has resulted in the expansion of the spawning ground of *Tenualosa ilisha* in the post Farakka barrage period (De and Saigal, 1989). Prior to 1975 (before the installation of the Farakka barrage), the spawning ground was restricted from Calcutta to Medgachi (Fig. 5), but survey conducted during 1987 to 1989 showed that the spawning ground has expanded more in the upstream zone almost towards Nabadwip (Fig. 6). This case study clearly confirms that biogeographic distribution of fish (preferably migratory fish) and even their spawning ground coordinates are regulated by aquatic salinity.

Alteration of aquatic salinity has profound influence on fish distribution and their migratory range, but the direction of salinity shift has a major role to play in determining extent and pattern of migration (Table 6).

Table 6. Pattern and extent of fish migration as function of aquatic salinity

<table>
<tr><td colspan="2">Fish type</td><td>Salinity
(High to low: an effect of deglaciation, barrage discharge, high precipitation etc.)</td><td>Salinity
(Low to high: an effect of seawater intrusion, sea level rise, high evaporation rate, minimum precipitation etc.)</td></tr>
<tr><td>Resident fish</td><td>Migration towards optimum salinity, preferably in the downstream zone</td><td colspan="2">Migration towards optimum salinity, preferably in the upstream region</td></tr>
<tr><td>Anadromous fish</td><td>Congenial condition for spawning resulting in the expansion of the spawning zone</td><td colspan="2">Difficult situation resulting in the shrinkage of spawning area</td></tr>
<tr><td>Catadromous fish</td><td>Difficult situation for spawning resulting in the shrinkage of spawning area; more migration towards the downstream zone</td><td colspan="2">Congenial condition for spawning resulting in the expansion of the spawning zone</td></tr>
</table>

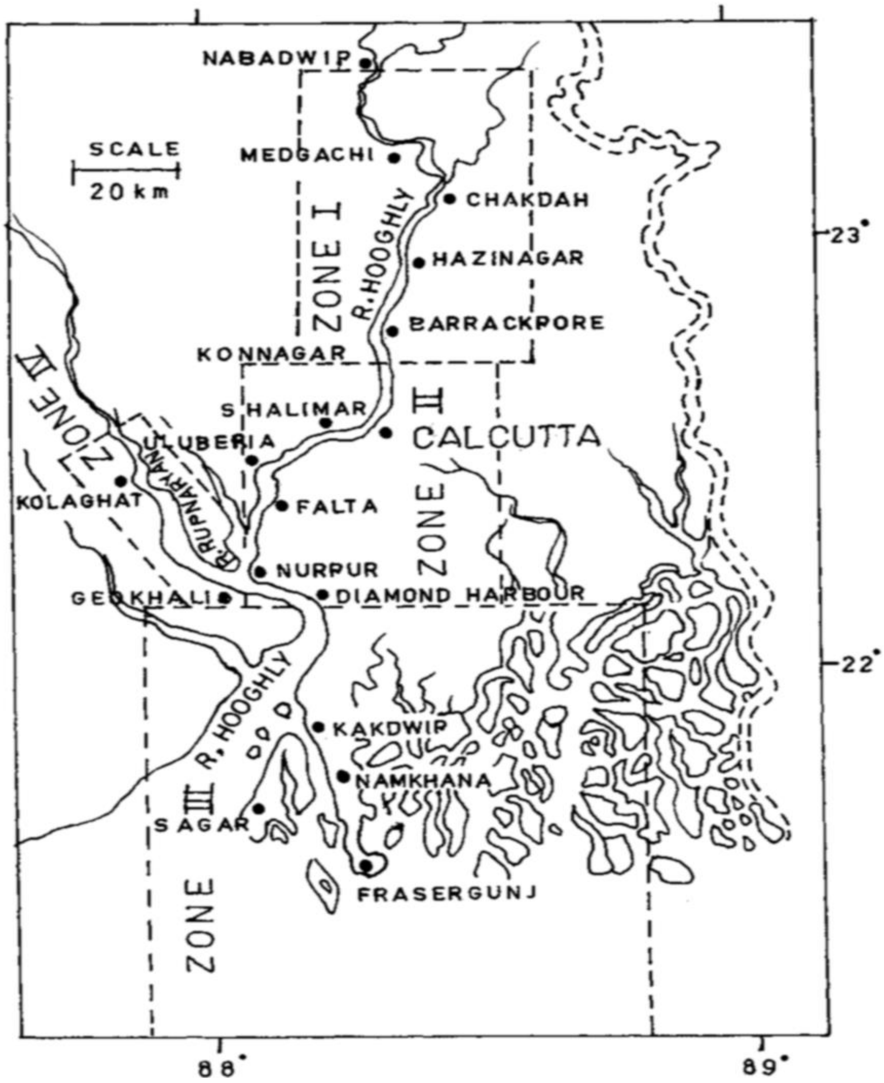

Fig. 5. Horizontal zonation of Hugli estuary before the construction of Farakka barrage; the marine and estuarine zone (ZONE III) was from Diamond Harbour to the mouth of the estuary and the spawning ground of *Tenualosa ilisha* was up to Medgachi (ZONE I)

The study conducted through the present work clearly indicates that salinity in the western sector is low (stations of western sector are Kachuberia and Sagar Island) in comparison to the central sector (Gosaba and Bali Island). Accordingly the pH also showed the same pattern. Due to high salinity and low dissolved oxygen (DO) in the stations of central sector in comparison to that of the western part (Table 7) profound influence has been posed on the fish community (Table 8). The availability of commercially important fishes like Hilsha (*Tenualosa ilisha*) was not there in the central sector probably due to higher salinity. Such situation may pose an adverse effect on the economic profile of the central Indian Sundarbans in near future as sea level rise (either due to global warming or sea bed rise or any other geophysical causes) may result in more intrusion of salt water in the Matla River.

Table 7. Physico-chemical variables in selected stations of Hugli-Matla estuarine complex

Station Parameter	Kachuberia (Stn. 1)	Sagar Island (Stn. 2)	Gosaba (Stn. 3)	Bali Island (Stn. 4)
Surface water temperature (^{O}C)	28.5	28.3	29.5	29.2
Surface water salinity (PSU)	9.95	22.15	23.19	24.50
Surface water pH	8.15	8.25	8.26	8.30
Dissolved oxygen (ppm)	*5.17*	*6.45*	*4.98*	4.66

Table 8A. Commonly available fishes in Kachuberia (in the western part)

Species name	Avg. body weight (gm)	Number	Total wt. in 100 kg.
Liza parsia	56	60	3360
Liza tade	102	71	2242
Tuna	597	46	15626

Scatophagous argus	277	41	11357
Pampus argentius	251	26	6526
Pampus niger	327	20	6540
Harpodon neherius	24	141	3384
Thryssa sp.	26	88	2288
Trichurus sp.	97	80	7760
Coilea sp.	8	65	520
Arius jella	601	14	8414
Polynemus paradesius	611	10	6110
Tenuolosa ilisha	614	34	20876
Total no. of Species	13		
Bar H	2.375		

Table 8B. Commonly available fishes in Sagar Island (in the western part)

Species name	Avg. body weight (gm)	Number	Total wt. in 100 kg.
Liza parsia	92	68	6256
Liza tade	95	71	6745
Tuna	505	34	17170
Scatophagous argus	210	90	18900
Pampus argentius	190	39	7410
Pampus niger	260	61	15860
Harpodon neherius	30	64	1920
Thryssa sp.	21	90	1890
Trichurus sp.	75	35	2625
Coilea sp.	5.8	100	574.2
Arius jella	300	22	6600

Polynemus paradesius	305	14	4270
Tenuolosa ilisha	575	17	9775
Total no. of Species	13		
Bar H	4.3009		

Table 8C. Commonly available fishes in Gosaba (in central sector)

Species name	Avg. body weight (gm)	Number	Total wt. in 100 kg.
Liza parsia	56	109	6104
Liza tade	102	113	12882
Tuna	601	26	15626
Scatophagus argus	284	31	8804
Pampus argentius	265	26	6890
Pampus niger	327	13	4251
Harpodon neherius	31	184	5704
Thryssa sp.	32	153	4896
Trichurus sp.	97	88	8536
Coilea sp.	11	39	429
Arius jella	639	29	18531
Polynemus paradesius	614	11	6754
Tenualosa ilisha	0	0	0
Total no. of Species	12		
Bar H	2.138		

Table 8D. Commonly available fishes in the Bali Island (in central sector)

Species name	Avg. body weight (gm)	Number	Total wt. in 100 kg.
Liza parsia	90	115	10350
Liza tade	115	127	14604
Tuna	595	29	17255
Scatophagus argus	290	29	8410
Pampus argentius	240	16	3840
Pampus niger	360	22	7920
Harpodon neherius	30	115	3450
Thryssa sp.	21	151	3171
Trichurus sp.	97	105	10185
Coilea sp.	7.8	117	913
Arius jella	415	18	7470
Polynemus paradesius	395	31	12245
Tenualosa ilisha	0	0	0
Total no. of Species	12		
Bar H	2.225		

The relatively higher Shannon Weiner Species Diversity Index (H) of commercially important fishes in the western sector of Indian Sundarbans clearly indicates a congenial environment for the survival of important fish species in this region. The presence of *Tenualosa ilisha* in the catch basket confirms the view. The low salinity, high DO may be the probable cause behind this. On contrary the less diversity of commercially important fish species and more diversity of trash varieties may be attributed to higher salinity and low DO in the Matla region. A long term study, however, is needed to justify this.

Conclusion

Climate change is not a myth, but a reality in the domain of the planet Earth. The alteration of salinity; acidification of oceans, seas, bays and estuaries; temperature rise; sea level fluctuation are the direct arms of climate change which has profound influence on the community structure of fishes. In the framework of Indian Sundarbans, the dominance of trash fishes in the catch basket of central region or the change of migratory pattern/route of several commercially important fishes are the visible outputs of the phenomenon of climate change. It is perhaps not an exaggeration to state that linking of the Hooghly and Matla estuaries may be a probable solution to bring down the significant variations of these two major estuaries in terms of salinity, which may be a roadmap for eco-restoration of the system. A comprehensive EIA with a backup EMP is, however, needed to carry out this vision.

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Chapter 10

CLIMATE RESILIENT AGRICULTURE THROUGH NATURAL RESOURCE MANAGEMENT IN EASTERN INDIA

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Introduction

The National Network Project of ICAR- National Innovations in Climate Resilient Agriculture (NICRA) focusing on to enhance the resilience of Indian agriculture to climate change and climate vulnerability through strategic research and technology demonstration. ICAR- Agricultural Technology Application Research Institute (ATARI) Kolkata is having seventeen NICRA implementing KVKs spreading across Bihar (7), Jharkhand (6), West Bengal (3) and Andaman & Nicobar Islands (1) which carried out different activities under Technology Demonstration Components (TDC) of NICRA Programme in different modules like Natural Resource Management (NRM), Crop Production, Livestock & Fisheries and Institutional Intervention through which 49962 farmers were benefited among which the value for NRM was 8173 during 2016-17.Natural Resource Management module covered improved drainage in flood prone areas, in-situ moisture conservation, construction/renovation of new water harvesting and recycling, structures/farm ponds/ checks dams/tank roof water harvesting tank, land shaping & rainwater harvesting structures, improved drainage in flood prone areas, conservation of tillage with appropriate, artificial ground water recharge and water saving irrigation methods, green manuring, 5% model of irrigation, crop residue management, bunding of field, Broad Bed Furrow, soil test based nutrient application, micro irrigation techniques, compost pits etc.The major interventions under site-specific rainwater harvesting strategies over 17.3 lakh cu m included in-situ moisture conservation; construction/renovation of new water harvesting and recycling structures/farm ponds/checks dams/tank roof water harvesting tank; land shaping and RWH structure; improved drainage in flood prone areas; conservation tillage where appropriate; artificial ground water recharge and water saving irrigation methods; green manuring; 5% model of irrigation; crop residue management; bunding of field; broad bed furrow; soil test based nutrient application; micro irrigation techniques; compost pits; participatory soil health management through identification and correction of major and micro nutrients. This led to increase cropping intensity by bringing around 1250 ha of area under protective irrigation regime since the inception of the project.

In-situ rainwater management (covering 412 farmers for an area of 66 ha during 2016-17) through ridge and furrow method and broad bed furrow practice conserves rainwater at field level, drains out excess water into community drainage channels, used to recharge ground water for supplemental irrigation to post-rainy season crops especially wheat and chickpea, maintains the balance of soil moisture by maximizing the use of rainfall through increased infiltration and moisture retention and reducing runoff and soil erosion. The outcome of different inventions is as follows: Summer ploughing in rice (var. *Lalat*) involved 62 farmers, covering 10 ha area with a yield of 39.7q/ha. Similarly, Green manuaring (dhaincha) in Rice (var. *Lalat)* involved 70 farmers covering 10.5 ha with yield of 39.6 q/ha. Brown manuaring in Rice (*var.Anjali*) involved 35 farmers covering 3.9 ha with yield of 29.8 q/ha. Azolla in Rice (var. *Lalat)* involved 9 farmers covering 3.5 ha with yield of 34.5q/ha. Zero Tillage in wheat yielded 35.9 q/ha while covering 10 ha area for 32 farmers. Zero Tillage in Maize yielded 31.8q/ha while covering 3 ha area for 10 farmers. Repair of bund accounted on 4 ha area with 27.5q/ha yield involving 14 farmers. Up gradation of monocropped land to multiple one with integration of fish involved 7 farmers covering 1.5 ha with yield of 168.2q/ha. Optimization of horticultural production through land embankment development involved 10 farmers covering 1.5 ha with yield of 168.2187q/ha. Optimization of horticultural crops through land embankment yielded 68.3 q/ha while covering 4.8 ha area for 32 farmers. For Organic mulching in vegetables (Tomato, brinjel) these figures were 258.5, 2 and 18 respectively while to that of Mulching were 206.3, 3 and 34 respectively. Plastic mulching of Okra and cucumber covered 1.3 ha with a yield of 32.8q/ha benefitting 22 farmers. For using plant leaf mulching in ginger these figures were 5.5 ha, 534q/ha and 33 respectively while to that of using Rice straw, forest leaves in elephant foot yam were 1.3 ha, 303q/ha and 24 farmers respectively.

Table 1. Performances of demonstration of in-situ moisture conservation technologies

Technology demonstrated	No. of farmers	Area (ha)	Yield (q/ha)	Economics of demonstration (Rs/ha)		
				Gross Cost	Net Return	BCR
Summer Ploughing in Rice (var. Lalat)	62	10.0	39.7	25480	23762	1.96
Green manuaring (dhaincha) in Rice (var. *Lalat)*	70	10.5	39.6	26900	26400	1.95
Azolla in Rice (*var. Lalat*)	9	3.5	34.5	23200	20220	1.99
Brown manuaring in Rice (*var.Anjali*)	35	3.9	29.8	18900	16320	1.91
Zero Tillage in Maize	10	3.0	31.8	11600	9800	1.73
Repair of bund	14	4.0	27.5	18500	12750	1.74
Up gradation of monocropped land to multiple one with integration of fish	7	1.5	168.2	31600	26340	1.85
Optimization of horticultural production through	10	1.5	187	23700	19825	1.85

land embankment development						
Optimization of horticultural crops through land embankment	32	4.8	68.3	55100	62670	2.17
Organic mulching in vegetables (Tomato, brinjel)	18	2.0	258.5	61550	74500	2.23
Mulching	34	3.0	206.3	70450	62680	1.88
Plastic mulching Okra, cucumber	22	1.3	32.8	5680	7750	2.54
Use plant leaf mulching in ginger	33	5.5	534	401000	989500	3.48
Use Rice straw, forest leaves in elephant foot yam	24	1.5	303	287000	328500	2.19
Total	412	66.0				

Land shaping with Ail cultivation check dam

Water harvesting through sand bag

LEWA in Pulse

Zero tilled wheat

Plastic mulching

Straw mulching in Okra

Water harvesting and recycling for supplemental irrigation were demonstrated in 17 NICRA adopted villages by the different KVKs involving 915 numbers of farmers. Under this head, Renovation of pond for fish production and irrigation involved 45 farmers covering 31 ha/unit with a yield of 53q/ha whereas, Renovation of canal covered 2.50 km involving 75 farmers. 5% Model involved 18 farmers covering an area of 6.8 ha/unit, finally yielding 41q/ha. Bora bandh yielded 44q/ha covering an area of 6.5 ha/unit involving 79 farmers. Renovation of Well for irrigation yielded 41q/ha covering an area of 25.4 ha/unit involving 73 farmers. Bund making leveling in Rice field yielded 37.5q/ha covering an area of 17.8 ha/unit involving 55 farmers. Natural mulching involved 15 farmers covering 4 ha/unit with a yield of 289.2q/ha. Digging of small pits in Diara land for cucubits involved 16 farmers covering 4.5 ha/unit with a yield of 81.5q/ha. New water harvesting structure in the Rice field yielded 35.6q/ha covering an area of 0.5 ha/unit involving 3 farmers, whereas, to that of New water harvesting structure in the wheat field were 36.5, 0.3 and 1. Renovation of old water harvesting structure in Rice field yielded 42.8q/ha covering an area of 28.7 ha/unit involving 109 farmers. Raising of land embankment yielded 204q/ha covering an area of 4 ha/unit involving 31 farmers. Ground water recharge covered 9.5 ha/unit involving 47 farmers. Construction of new pond for wheat involved 65 farmers covering an area of 7.5 ha/unit, finally yielding 34.9q/ha. Desiltation of defunct water harvesting structures covered 1 ha/unit involving 5 farmers. Renovation of *pyne* covered 4500(ft) involving 139 farmers; likewise to that of renovation of irrigation channel and renovation of common pond were 22 ha/unit, 13 farmers and 146'x146' ha/unit, 68 farmers respectively. Newly check dam yielded 39.1q/ha covering an area of 0.8 ha/unit involving 13 farmers. 10 bamboo boring covered 40.3 ha/unit involving 45 farmers.

Table 2. Performances of water harvesting and recycling for supplemental irrigation

Technology demonstrated	No. of farmers	Area (ha)/Unit	Output (q/ha)	Economics of demonstration (Rs/ha)		
				Gross Cost	Net Return	BCR
Renovation of pond for fish production and irrigation	45	31.0	53	75200	399500	6.4
Renovation of canal	75	2.5 km	-	-	-	-
5% Model	18	6.8	41	55800	71000	2.4
Bora bandh	79	6.5	44	37200	45600	2.3
Renovation of Well for irrigation	73	25.4	41	10900	4650	1.5
Bund making leveling in Rice field	55	17.8	37.5	30690	19180	1.68
Natural mulching	15	4.0	289.2	45970	138800	4.25
Digging of small pits in Diara land for cucubits	16	4.5	81.5	45890	130908	3.95
New water harvesting structure in the Rice field	3	0.5	35.6	35444	16156	1.49
New water harvesting	1	0.3	36.5	33480	19859	1.58

structure in the wheat field						
Renovation of old water harvesting structure in Rice field	109	28.7	42.8	116599	69550	1.58
Raising of land embankment	31	4.0	204	45291	153909	3.94
Ground water recharge	47	9.5	-	-	-	-
Construction of new pond for wheat	65	7.5	34.9	35000	22000	1.65
Desiltation of defunct water harvesting structures	5	1.0	-	-	-	-
Renovation of pyne	139	4500ft	-	56100	-	-
Renovation of irrigation channel	13	22.0				
Newly Check dam	13	0.8	39.1	32100	19500	1.58
Renovation of common pond	68	146'x146'		107385		
10 bamboo boring	45	40.3				
Total	915					




Borabandh   Renovation of canal   5% model   New Pond excavated

Sowing of *rabi*crops depends on the harvesting time of the preceding crop in *kharif*as well as the soil moisture status for land preparation for sowing. This variation in soil moisture content resulted delay in planting of *rabi* crops fetching vulnerable hightemperature stress during February/ March, thus incurring additional energy and cost. Zero till technology offers a viable and practical solution by avoidingrepeated tillage for land preparation and sowing, reducing cost of cultivation and alsopermits planting early by 10-15 days. Advancement in sowing date is an adaptation to avoidterminal heat stress. Zero-tillage refers to direct drilling of wheat in unploughedRicefields immediately after rice harvest using zero till drill or happy seeder. Moreover, Zero tillage technology showed very promising results in pulse and oilseed cultivation. Conservation tillage in wheat, Rice, lentil, pea and chickpea demonstrated in 15 NICRA adopted villages in an area of 217.3 ha of 375 numbers of farmers. The interventions under this head reflected that Sowing of wheat with ZTD yielded 43q/ha covering an area of 35.4 ha/unit involving 65 farmers. Likewise to that of Sowing of Rice, Sowing of lentil and Sowing of chick pea with ZTD machine were 44.5, 22.6, 48; 22.5, 43.8, 64 and 19.6, 43.7, 50 respectively. The values for Sowing of wheat (K-9107), Sowing of pea (Arkel) and Sowing of Maize with ZTD were 37.8, 20.8, 38; 26.4, 11.8, 33 and 34.5, 4.5, 19 respectively. Sowing of Rice with power tiller yielded 43.5q/ha covering an area of 34.7 ha/unit involving 58 farmers.

Table 3. Performance of ZTD in various crops

Technology demonstrated	No. of farmers	Area (ha)	Output (q/ha)	Economics of demonstration (Rs./ha)		
				Gross Cost	Net Return	BCR
Sowing of wheat with ZTD machine	65	35.4	43	73650	78600	2.56
Sowing of Rice with ZTD machine	48	22.6	44.5	68900	76100	2.31
Sowing of lentil with ZTD machine	64	43.8	22.5	60550	59300	2.07
Sowing of chick pea with ZTD machine	50	43.7	19.6	83650	145600	2.78
Sowing of Rice with power tiller	58	34.7	43.5	58580	54800	1.95
Sowing of wheat (K-9107) with ZTD	38	20.8	37.8	33900	29700	1.94
Sowing of pea(Arkel) with ZTD	33	11.8	26.4	43800	75100	2.79
Sowing of Maize with ZTD	19	4.5	34.5	15400	14600	1.95
Total	375	217.3				

Zero tillage

Artificial ground water recharge done by field bunding, water management and through SRI by sub soiler in Rice in 9 NICRA adopted villages covering 50.3 ha area in 90 farmers fields. Ground water recharge through SRI by sub-soiler recorded highest Rice yield (59.5 q/ha) and benefit: cost ratio (2.24). The interventions under this head during 2016-’17 were Field bunding for Rice which yielded 39.4q/ha covering an area of 12.6 ha involving 25 farmers. Water management through bunding of Rice fields (2.5 fit height and width 9 inch width) yielded 45.5q/ha covering an area of 28.4 ha involving 40 farmers. Ground water recharge through SRI by sub-soiler yielded 59.5q/ha covering an area of 9.3 ha involving 25 farmers.

Table 4. Performance of artificial ground water recharge technologies demonstrated

Technology demonstrated	No. of farmers	Area (ha)	Output (q/ha)	Economics of demonstration (Rs./ha)		
				Gross Cost	Net Return	BCR
Field bunding for Rice	25	12.6	39.4	25700	20222	1.78
Water management through bunding of Rice	40	28.4	45.5	24500	16700	1.71

fields (2.5 fit height and width 9 inch width)						
Ground water recharge through SRI by sub-soiler	25	9.3	59.5	39465	44918	2.24
Total	90	50.3				

Bunding in Rice field

Water saving irrigation methods like sprinkler irrigation, LEWA in rice, RBF in brinjal, micro-lift irrigation in Rice demonstrated in NICRA adopted villages covering an area of 76.0 ha in 347 farmers’ fields. The interventions were as follows: Irrigation system (micro lift Irrigation system) for Rice yielded 37.5q/ha covering an area of 14.8 ha involving 33 farmers. Application of biofertilizer in rice (var. MTU 7029) involved 77 farmers covering an area of 25.1 ha, finally yielding 71.5q/ha. Vermi-compost from biodegradable wastes yielded 17.8q/ha covering an area of 1.7 ha involving 77 farmers. Production of pigeon pea (var. PRG-158) on farm bund yielded 19.5q/ha covering an area of 1.8 ha involving 29 farmers. RBF in Brinjal involved 24 farmers covering an area of 3.5 ha, finally yielding 273q/ha. LEWA in rice (var. Rajendrasweta) involved 21 farmers covering an area of 4.9 ha, finally yielding 56.5q/ha. Sprinkler irrigation in rai (var. Bio-902) yielded 16.5q/ha covering an area of 5 ha involving 17 farmers. Sprinkler irrigation in green gram (Var. HUM-16) yielded 20.5q/ha covering an area of 3 ha involving 16 farmers. Sprinkler irrigation in lentil (Var. Arun) yielded 21.5q/ha covering an area of 6.9 ha involving 25 farmers, whereas to that of chickpea (Var. PG-186) were 16.8, 7.5 and 33. RBF in cucumber (Var. Malini) yielded 317q/ha covering an area of 1.8 ha involving 31 farmers.

Table 5. Performance of different water saving irrigation methods

Technology demonstrated	No. of farmers	Area (ha)	Output (q/ha)	Economics of demonstration (Rs./ha)		
				Gross Cost	Net Return	BCR
Irrigation system (micro lift Irrigation system) for Rice	33	14.8	37.5	26800	20800	1.79
Application of biofertilizer in rice (var. MTU 7029)	77	25.1	71.5	36240	60340	2.71
Vermi-compost from biodegradable wastes	41	1.7	17.8	4900	4200	1.88
Production of pigeon pea (var. PRG-158) on farm bund	29	1.8	19.5	27238	39970	2.49
RBF in Brinjal	24	3.5	273	62950	64850	2.33
LEWA in rice (var. Rajendrasweta)	21	4.9	56.5	32340	39100	2.29
Sprinkler irrigation in rai (var. Bio-902	17	5.0	16.5	18700	40100	3.49
Sprinkler irrigation in green gram(Var. HUM-16)	16	3.0	20.5	15100	36980	3.56

Sprinkler irrigation in lentil (Var. Arun)	25	6.9	21.5	18550	42775	3.44
Sprinkler irrigation in chickpea (Var. PG-186)	33	7.5	16.8	16250	23970	2.51
RBF in cucumber (Var. Malini)	31	1.8	317	93225	134155	2.51
Total	347	76.0				



Sprinkler and LEWA in field

Other demonstrations includes oyster mushroom cultivation, effective utilization moisture through seed production of blackgram, in-situ vermicomposting in orchards, soil test based nutrient application, cleaning and renovation of old farm pond, renovation of well, planting forest trees, plant for biodiversity, forestation, soil test based nutrient application, bio pesticides in tomato, dolomite in goraRice and cultivation of high yielding grass on farm bund were carried out in 1146 farmers' fields with an area of 323.5 ha of land. Out of these demonstrations on in-situ vermicomposting in orchards showed highest economic return. The interventions under this head during 2016-'17 were Effective utilization of moisture through seed production of blackgram after floodyielded 17.8q/ha covering an area of 20.1 ha involving 135 farmers. In-situ vermicomposting in orchards yielded 111.5q/ha covering an area of 7 ha involving 38 farmers.

Soil test based nutrient application involved 521 farmers covering an area of 230.8 ha, finally yielding 47.5q/ha. Cleaning & renovation of old farm pond involved 117 farmers covering an area of 5.8 ha, finally yielding 43.5q/ha. Renovation of old water harvesting structure (Well) yielded 38.5q/ha covering an area of 5.5 ha involving 35 farmers. Planting forest trees for biodiversity and forestation covered 8.8 ha area involving 49 farmers. Soil test based nutrient application (FYM/ inorganic fertilizer) involved 147 farmers covering an area of 19.4 ha, finally yielding 35.6q/ha. Application of Bio pesticides in tomato yielded 169.5q/ha covering an area of 6.6 ha involving 39 farmers, whereas to that of during application of Dolomite in goraRice were 27.8, 13.5 and 48 respectively. Cultivation of high yielding grass on farm bund involved 17 farmers covering an area of 6 ha, finally yielding 145.2q/ha.

Table 6. Performance of other demonstrations

Technology demonstrated	No. of farmers	Area (ha)	Output (q/ha)	Economics of demonstration (Rs./ha)		
				Gross Cost	Net Return	BCR
Effective utilization moisture through seed production of blackgram after flood	135	20.1	17.8	16100	46100	3.94
In-situ vermicomposting in orchards	38	7.0	111.5	32970	267400	7.46
Soil test based nutrient application	521	230.8	47.5	37978	30800	1.95

Cleaning & renovation of old farm pond	117	5.8	43.5	63850	164000	3.18
Renovation of old water harvesting structure (Well)	35	5.5	38.5	24100	39500	2.95
Planting forest trees for biodiversity, forestation	49	8.8		-	-	-
Soil test based nutrient application (FYM/ inorganic fertilizer)	147	19.4	35.6	9750	14980	2.96
Bio pesticides in tomato	39	6.6	169.5	53875	135240	3.75
Dolomite in goraRice	48	13.5	27.8	19910	15150	1.95
Cultivation of high yielding grass on farm bund	17	6.0	145.2	8570	16970	3.11
Total	1146	323.5				

Rainwater harvesting (*ex-situ*) and efficient use to enhance resilience of farms, farm ponds brought about a perceptible change in crop production during *Kharif and rabi* season. The harvested water was used for critical irrigations to wheat, vegetables, fodder etc that generates additional yield and income. This intervention increased the cropping intensity to the maximum extent up to 250% with an average cropping intensity of 98%. There were 121 number of rainwater harvesting structures have been developed which could store 524446.0 cu m of water. KVK wise rainwater harvesting structures developed during 2016-17 were tabulated.

Table 7. KVK wise rainwater harvesting structures developed during 2016-17

KVK	RWH structures	No. of unit	Storage capacity (cu. m)	No. of farmers	Protective irrigation potential (ha)	Increase in cropping intensity (%)
Port Blair	Desilting Pond	4	14500	20	2.5	50
	Rain shelter	3	3617.3	20	2	50
Aurangabad	Pond	1	4500	25	7	80
	Canal	3	20000	140	3.5	120
Buxar	Farm pond	1	25000	12	7.5	80
Jehanabad	Pond	6	18000	385	5.5	80
	Checkdam	2	8000	25	6.5	90
	5% model	3	12.5	6	2	50
Nawada	Pyne	2	16500	125	12	95
	Well	3	126.5	222	19	75
	Pond	5	3558.6	50	6.5	75
Saran	Pond	1	18500	110	15.5	75
	Inlet Channel	3	13580	35	1.5	90
	Inlet Channel	3	13210	38	2	100
Supaul	Desiliting drainage channel	2	300	65	1	100
Chatra	Well	2	1165.05	46	2	90
EastSinghbhum	5% Model	6	1200	42	5.5	90
	Pond Renovation	2	45500	45	7.5	250

Gumla	Renovation of Pond	1	20000	30	5	250
	Bora bandh	7	10000	65	15.5	50
	5% Model	2	2000	80	22	200
Koderma	Defunct pond	8	18500	20	15.5	90
	Repaired well	1	1665.05	18	6.5	80
	Jalkund	9	27000	20	8.5	70
Palamu	Well	2	6500	330	15.5	90
	Pond	2	21000	1745	15.5	90
	5% model	6	4000	80	2.5	100
Cooch Behar	Farm Ponds	3	35000	74	10.5	120
Malda	Small ditches for jute retting	10	20000	175	7	80
S. 24 Pgs.	Landshaping and rain water harvesting structure	5	10000	30	5	100
	Renovated defunct water bodies	6	25000	30	15.5	80
	Renovated 4 Km long canal	4	178000	715	45.5	100
Godda	Ring Well	5	12565	10	7.5	120
	Pond Renovation	3	25000	35	7	90
Banka	Pond Renovation	3	26500	20	5.5	80
Total		129	650000	4888	319	98



Renovated well | Renovated Pond



5% Model | Pond based IFS | Renovated Canal

Conclusion

It was evident from the present study that the natural resource management in terms of water conservation, water harvesting and recycling the drought prone/ affected study area was of immense importance to adapt to the recent climate change issues. New techniques were found to be effective for supplying water in the agriculture field. Under natural resource management, new construction irrigation channel, renovation of well and desiltation of ponds were demonstrated with highest benefit. Natural mulching and bund making leveling in paddy field were used for supplementary irrigation. Vermi-compost and bio-fertilizer were demonstrated for soil management and good crop production in the study area. Well management, soil moisture management, water quality and water conservation technologies were demonstrated with increased benefit to the farmers.

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Chapter 11

CLIMATE CHANGE AND INLAND AQUACULTURE: GLOBAL *VS.* SOUTH ASIAN PERSPECTIVE

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Introduction

Aquaculture has already been established itself as a top priority production system of living organisms continuously being diversified based on its management protocols and targeted species of culture governed by the agro-economical versatility and market oriented demand at different geo-climatic conditions of the globe. It is acting as a major food source through significant contribution of economically affordable good quality animal protein to human. Globally, fisheries and aquaculture make substantial contributions to the food security and livelihoods of millions of people. Excluding aquatic plants, total global production from the sector peaked at 171 million tonnes in 2016, with 53 percent of this total coming from capture fisheries and 47 percent from aquaculture (reaching 53 percent if non-food uses are excluded; FAO, 2018). The total landed value of the production in 2016 was estimated as US$ 362 billion, of which US$232 billion came from aquaculture production (FAO, 2018). During the year 1961 to 2016, aquaculture production growth has been largely responsible for the remarkable increase in global food fish consumption @ 3.2 percent per year, twice the human population growth rate. However, in recent years, this environmental production sector is profoundly being impacted by climatic variations particularly in the tropical and sub-tropical parts of the globe. Therefore, food fish is expected to be influenced and/ or impacted by climate change in different parts of the world (De Silva and Soto, 2009).

Climate change is an involuntary risk that creates vulnerability on the socio-economic development and raises stress especially on food demand and supply and also on the income level of the farmers (Thomas and Callan, 2007). The impacts of climate change on bio-physical and community livelihood have strong connection with each other, where they are known as the exposure unit to vulnerability of climate change. Climate change is a natural climatic event that influences the quality and quantity of aquaculture production (Beach and Viator, 2008). The impacts on aquaculture production due to this change differ depending on aspects such as its region, aquaculture practice systems, space, time, size, and changeability (De Silva and Soto, 2009). Climate variability affects the fluctuation of fish stocks that are important to the fishing community (Howden *et al*., 2007) as the biophysical factors like climatic change and extreme weather affects the sustainable growth of the aquaculture sector (De Silva, 2007).

Climate change is altering the physical, chemical, and biological characteristics of freshwater habitats (Hartmann *et al*., 2013), with concomitant effects on freshwater and diadromous fishes. Warmer air temperatures resulting from climate changes are expected to increase water temperatures, with effects on growth, reproduction, and survival of fishes and their prey (Hershkovitz *et al*. 2015). Moreover, climate change is predicted to alter species interactions, the timing of important life history events (e.g., migration, spawning), and the spatial distribution of fish populations (Lynch *et al*., 2016). On a physiological level, effects of climate change on individual fish include reduced immune function, decreased cardiovascular performance, and changes in reproductive investment (Whitney *et al*., 2016). Chemical characteristics of water bodies, such as dissolved oxygen (Ito and Momii, 2015), salinity (Bonte and Zwolsmen, 2010), and nutrient concentrations (Moss *et al*., 2011), are directly influenced by these climate induced changes in thermal and hydrologic regimes.

The issues of sustainability of aquaculture production with variable environmental externalities and consequences have risen due to the remarkable contribution towards economic growth (Tisdell and Leung, 1999). The productivity and profitability levels of aquaculture production depend on direct positive or indirect negative effects of climate change on aquaculture natural resources such as land, water, seeds, feeds, and energy (Oguntuga *et al*., 2009). Based on the social-ecology system concept, environment, aquaculture, and socio-economics interact and are dependent on each other. Thus, the risks of climate change ranged from exposure to people *vis-a-vis* property and vulnerability of physical, social, economic, and environmental factors or processes that grow in aquaculture community to the impact of hazards (Westlund *et al*., 2007).

The drivers of climate change that threatens aquaculture activities are temperature-pressure, oxygen demand and decreased pH, water supply variation and uncertainty, severe climatic events, regularity of disease, virus and toxic outbreaks, sea level rise, and the uncertainty of captured fish supply for aquaculture feeds (Ficke *et al*., 2007). Fluctuation of climate events such as changes in water temperature, annual precipitation, water stratification and the shift of raining and dry seasons all changes the physiological, ecological, and operational aspects of aquaculture activities (Handisyde *et al*., 2006). Changes in temperature and precipitation are the major causes of failure to pond aquaculture production and usually trailed with drought and flood seasons. These events have resulted in water stratification that harms cultured species especially in shrimp production. Moreover, climate change also causes disease outbreaks (Siwar *et al*., 2009) to fishes and shrimps in all stages of its growth. Though, Mackenzie and Mackenzie (1995) and UNEP (2002) have identified various factors responsible for climate change, threats of climate change to human society and its natural resources have been given top priority in the aftermath of the fourth assessment repot of IPCC (IPCC, 2007a). Anthropogenic activities like burning of fossil fuel, non-judicious land use practices, especially deforestation leads to the green house gas emission besides changes in technology with advancement of atomic, nuclear bombs and other industrial emissions along with natural emission of gases due to volcanic eruption leads to global warming and erosion of ozone layer, and, widening of the radiation budget of the earth.

Gradual rise of global mean temperature (Zwiers and Weaver, 2000) and atmospheric greenhouse gases (Brook *et al*., 1996) are already been documented (IPCC, 2007). Impacts of climate change on aquaculture could occur directly and or indirectly and not all facets of climate change will impact on aquaculture practices. The primary consequences of climate change that could potentially impact on aquaculture production are rising of sea level and surface temperature, change in monsoon season and precipitation patterns, extreme climatic events like occurrence of cyclones, hurricanes typhoons etc. and above all water stress. Increase in sea level rise and salinity intrusion in upstream water greatly affects freshwater culture practices, ecological and habitat changes basically in mangroves areas which act as nursery grounds for many euryhaline species. Furthermore, any increase and decrease in the temperature of the habitats can have a significant impact on general metabolism and hence the rate of growth, total production, reproductive efficacy (Wood and McDonald, 1997) and increased susceptibility to diseases and even to toxicants (Ficke *et al*., 2007).

The main impact of climate change on biodiversity has been noticed due to introduction of exotic species in various inland water bodies. This has resulted in competition for food and space with the indigenous species due to alteration of their habitats (Collares-Pereira and Cowx, 2004; Soto *et al*., 2006) besides transmission of pathogenic organisms and genetic interaction such as hybridization and introgression and other indirect genetic effects (Waples, 1991). Such incidents would tremendously impact the gene pool of the wild species. Moreover, the principal indirect impact of climate change on aquaculture is related to fishmeal and fish oil supplies and their concurrent usage not only in aquaculture but the whole animal husbandry sector as well.

Global perspective

Marine and brackish water finfish may be affected by changes in salinity, turbidity and temperature, which are considered as important factors for the development of larvae and juveniles. Saltwater intrusion in deltaic regions of inland areas could raise water tables, hamper drainage, and cause loss and damage of wetlands. Increase in run-off (10-40%) in some wet areas in East and South-East Asia, the Ganges and Nile river basins, and decreases (10-30%) per cent in other regions, including the Mediterranean, North and Southern Africa, the Mississippi, Amazon has been noticed (IAFAD, 2014). Decreased river flow causes increased erosion, sedimentation and irregularity of rain which threatens ecological production and freshwater fish populations in the affected rivers. Deltaic areas will be particularly vulnerable to the impacts of climate change as sea level rise can hamper deltaic regions of the Ganges-Brahmaputra, Nile and Mekong mega deltas as salinity intrusion and reduced river flow are expected to have an adverse impact on shrimp industry along the Ganges-Brahmaputra in India and Bangladesh, as well as in the Mekong Delta in Viet Nam.
Climate change is projected to result in a significant reduction in renewable surface water and groundwater resources in most of the dry subtropical regions, which can be expected to lead to greater competition between different types of agriculture and between agriculture and other sectors. As with inland fisheries, this expected trend, and other inter-sectoral interactions, means that focusing only on adaptation within

aquaculture is unlikely to be sufficient and effective reduction of vulnerability in the sector requires the integration of aquaculture into holistic, multi-sectoral watershed and coastal zone management and adaptive planning (Jimenez Cisneros *et al*., 2014).The most important inland fisheries are found in semi-arid regions of the globe. Production systems and livelihoods including fisheries in arid and semi-arid areas are at risk from future climate variability and change (Allison *et al*., 2007). Climate change affects the stratification of water bodies and circulation of water masses leading to changes in productivity that may cause eutrophication and shifts in relative abundance of species throughout the food chains (Ficke *et al*., 2007; Cheung *et al*., 2009). Stratification and eutrophication could occur more frequently due to climate change, causing a lack of oxygen and thus increasing the risk of crop mortality. Oxygen depletion may also result from upwelling events caused by extreme wind and rainfall occurrences (IAFAD, 2014). The long term consequences of such may results in decline in fisheries production and even disappearance of some vulnerable species. Though an increase in global air temperature may not always be necessarily reflected in corresponding increases in inland aquaculture ponds, increased eutrophication resulting in high diurnal fluctuation of dissolved oxygen may results in. Sudden changes in wind patterns and rainfall could result in upwelling of waters with its adverse effects on cultured stocks and naturally recruited fish stocks within the water body.

Climate changes and in particular global warming, could both directly and indirectly impact on mariculture in temperate regions. The salmon farming sector has already witnessed an increase in water temperature over the recent past and it is acknowledged that temperatures over 17 ºC would be detrimental, when feed intake drops and feed utilization efficacy is reduced. De Silva and Sotto (2009) reported that changes in salinity and temperature in brackish water habitats affects the biological processes of the organisms. In coastal zones, potential declines in mangrove forest habitat resulting from sea level rise, changes in sediment and pollutant loading from river and lake basins combined with land reclamation for agriculture or overexploitation could also impact fisheries by reducing or degrading critical coastal habitats. Mangrove forest loss for instance can negatively affect the diversity of benthic invertebrates such as tiger prawns or mud crabs, which are exploited or managed for profits exceeding US$ 4 billion per year (Ellison, 2008). The vulnerability of aquaculture-based communities is primarily a function of their exposure to extreme weather events, as well as the impact of climate change on the natural resources such as quality water, land, seed, feed and energy (Easterling *et al*., 2007; FAO, 2008). Climate change and extreme climatic events directly impact the inland and coastal capture fisheries resources which are also globally important sources of income and employment. An estimated 21 million fishers, equivalent to 36 percent of the global capture fishery workforce, and more than 36 million individuals in post-capture activities are employed in the sector (Lynch *et al.*, 2016) where, 90 percent of inland capture fishery catch is used for direct human consumption (Welcomme *et al.*, 2010).

Regional perspective

Latin America**:** Impact of climate change on aquaculture as predicted will have pronounced impacts in the most vulnerable countries like Belize, Honduras, Costa Rica and Ecuador. Increasing temperatures and extreme weather events are expected to result in widespread loss of marine species and reduced availability and quality of freshwater (IPCC, 2007 b) as well as damage to coral reefs and mangroves. Low lying areas will be affected by sea level rise and extreme weather events, particularly those associated with the El Niño-Southern Oscillation (ENSO) phenomenon, which will affect the La Plata estuary, coastal morphology, coral reefs, mangroves, location of fish stocks and availability of drinking water (IAFAD, 2014).

Africa: The fisheries sector plays an enormous role on the national economies of the region and constitutes the main livelihood for a majority of people living along the coasts and in riparian areas (Bene, 2006). Social, economical and ecological impacts due to climate change on fisheries and aquaculture are familiar scenario in African countries (World Fish Center, 2009) and Uganda, Nigeria and Egypt are particularly vulnerable. Moreover, most African communities are particularly vulnerable because of high poverty levels, reliance on rain-fed agriculture, lack of access to technology and improved culture practices (Anyanwu *et al*., 2014). Countries like Senegal, The Gambia, Sierra Leone and Ghana largely depend on fisheries (Bene, 2008). Palomares and Pauly (2004) has depicted that any decline in fisheries resources poses serious implications for food and internal security in the region. As deltas and estuaries of West Africa are rich in mangrove forests, any losses of mangroves in this region will negatively affect the diversity of fisheries resources. Munday *et al*. (2009) predicted that increased frequency of extreme winds, storm and high-tides, will mostly disrupt the lives of local coastal communities through disruption of fishing patterns and behavior, reduced safety at sea for fishers and others, disruption and damage to aquaculture installations such as fish farms, and damage and loss to property and boat. The inner delta of the Niger River in central Mali exemplifies the impacts of changes in rainfall attributed to climate change which might cause declines of fish production in coastal and inland fisheries of West Africa due to declining freshwater levels, and rising sea temperatures that could damage fish habitats (Allison *et al*., 2005). In Southern Africa, increasing frequencies of droughts are forecast, leading to greater variability in lake levels and river flows, affecting lakeshore and river floodplain livelihoods that incorporate fishing (Conway *et al*., 2005).

Asia: Southeast Asia is one of the world's most vulnerable regions to climate change because of its long coastlines, specific dependence on seasonal patterns of the monsoon, high concentration of population and economic activity in coastal areas, and heavy reliance on agriculture, fisheries, forestry and other natural resources (IPCC, 2007a,b). Asia-Pacific region is also the origin of two-thirds of global inland capture production (FAO, 2009) as more than 86% of the world's fishers and fish-farmers inhabit in this region. Likewise Latin America, Asia is also considered vulnerable towards impact of climate change on aquaculture and Viet Nam being the most vulnerable country in Asia, followed by Bangladesh, the Lao People's Democratic Republic (Laos) and China. Brackish aquaculture in Viet Nam, Egypt and Thailand emerged as having the highest vulnerabilities. Due to changing snowmelt and precipitation patterns, Bangladesh and Vietnam are severely threatened (Cruz *et al.*, 2007) in aquaculture production, wild stocks, and rice–fish systems.

Vietnam**:** The aquaculture industry in the delta is dominated by pond culture of shrimp (black tiger shrimp) and the striped catfish. The Mekong Delta has had a number of extreme climatic events in the past few years and is also subject to increasing saline water intrusion, for which there are already government operated barriers to regulate the saline water intrusion in some canals (Kam *et al*., 2012). The frequency of extreme weather events has increased dramatically over the last five decades (IPCC, 2007b) and the southern region will experience temperature increases of 0.4°C to 1.0°C from 2020–2050. Higher air and water temperatures may lead to higher organic decomposition rates, which may lead to fouling of the water, particularly in closed-culture systems such as ponds. Decreased dissolved oxygen may require more aeration, particularly in intensive culture of shrimp, which is more sensitive to reduced oxygenation than catfish. Disease outbreaks in catfish typically occur at the start of the rainy season and the end of the flood season (Poulsen *et al*., 2008) will be more widespread throughout the delta, compared with its effect on salinity intrusion.

Philippines**:** The United Nations Climate Summit in Copenhagen in 2009 declared the Philippines as the eighth among the top ten countries most vulnerable to climate change and the only country in Southeast Asia included in the top ten. Though Philippines is considered as the world's top biodiversity hotspot, the fishing communities and people dependent on fisheries and aquaculture would be vulnerable to the impacts of climate change in terms of dwindling stable livelihood, decreasing availability or quality of fish for food, and increasing safety risks from fishing operations during harsh weather conditions (FAO, 2008). In the Philippines, Ilolio province has been considered most vulnerable to climate change and accordingly selected as a case study area for the impacts and adaptation of small-scale aquaculture to climate change (NACA, 2012).

Sri Lanka**:** In Sri Lanka, culture based fisheries are primarily rain fed and insufficient rainfall coupled with shifting of inter-monsoonal rains due to climate change during the last decades (De Silva, 2006) resulted in conflict in water resource use from the reservoirs among the major stakeholders like paddy cultivators and aquaculture activists. Impact of climate change on water resources is expected to be borne by the northeastern and eastern dry zone of the country; they may become even drier by the 2050s (De Silva, 2006; De Silva *et al*. 2007). Moreover, frequent fluctuations of reservoir volume potentially create the stressful conditions to stocked fish species and may increase the mortality due to diseases, increased vulnerability to predators and even increase the susceptibility of stocked fish for poaching. Therefore, identification of strategies to improve the resilience of vulnerable fish farming communities to climate change impacts has given importance for the sustainability of culture based fisheries in seasonal reservoirs of Sri Lanka.

Bangladesh**:** Fisheries are the second largest revenue generator in Bangladesh that is experiencing scorching heat during summer and severe cold in winter as a result of climate change with an increase in the frequency and intensity of heavy rainfall during rainy season. Reduction in the number of native fish species is a common trend in Bangladesh due to anthropogenic impacts along with the adverse effects of climate change (Mohsin *et al*., 2013). Water salinity and its distribution in the coastal areas of Bangladesh are increasing with sea level rise (IPCC, 2001; World Bank, 2001). In Bangladesh, the 2004 floods caused damages to the aquaculture sector as fry and growing niches in 80% of water bodies in 45 flood-hit districts had been washed away where 13, 000 fish farms lost part of their stock in the Chandpur district alone resulting in economic losses of around 3.5 million US$ (Growfish, 2004a,b; Hague, 2004). Dey *et al*. (2013) reported declining trend of groundwater table over the last 30 years in the northwest Bangladesh and salinity emerged as the most significant climatic variable that affects prawn farming, followed by coastal flooding, cyclone, sea-level rise, water temperature, drought, and rainfall in Bangladesh. Increased salinity has had an adverse impact on the ecosystem of prawn farms, and thus, reduced the availability of aquatic flora and fauna, including crabs, fish, frogs, mollusks, snails, and turtles. The ecosystem of prawn farms is becoming increasingly threatened by loss of aquatic biodiversity which plays an important role in maintaining ecosystem services and resilience to climate change (Brander, 2007). Increased water salinity has also resulted in higher mortality of post larvae and increased the prevalence of diseases (Ahmed and Daina, 2015). Moreover, ecosystem functions of prawn farms may be severely affected by sea-level rise that increase CO_2 emission and decrease pH (Harley *et al*., 2006). However, salinity intrusion Bangladesh coastal area is important for *Penaeus monodon* production. Increase salinity increases the culture area for *P. monodon* whose growth reaches maximum at 5-25 ppt (Chanratchakool, 2003).

Sea-level appears to be rising by15.9–17.2 mm each year in coastal Bangladesh (Schiermeier, 2014), while global sea-level rises 2–3 mm each year (Pethick and Orford, 2013). Sea surface temperature in the Bay of Bengal is predicted to increase from 0.35 to 0.72^{0}C at day and 0.50 to 0.80^{0}C at night by 2050 (Chowdhury *et al*., 2012). Because of declining fish populations, increased sea surface temperature in the Bay of Bengal is likely to affect 3.5 million households of fishers (Chowdhury *et al*., 2012). In Bangladesh, expansion of shrimp farming into mangrove areas has reduced fish catches and the socio-economic condition of traditional coastal fishermen. The loss of life and structural damage caused by the 1991 cyclone in southeastern Bangladesh may have been made worse by the earlier loss of mangroves, and coastal shrimp ponds themselves suffered severe damage (Anonymous, 1991). The economic impacts of mangrove destruction ultimately can be very significant and may far outweigh the short-term benefits from conversion to shrimp ponds (Phillips, 1995).

India: The major impacts of climate changes on inland fisheries of India have been reviewed (Das *et al*., 2014; Mandal *et al.,* 20l3; Mohanty *et al*., 2018; Sharma et al., 2015). The major river systems of India will be impacted either with acute or regular water shortages or face excessive flood conditions (Vass *et al.,* 2009). The reproductive and spawning behaviour of the Indian major carps has been impacted and a consequent decline in fish spawn availability has been noticed in Ganges basin. Additionally, effect of drought revealed that rainfall deficits of 29% and 27% during breeding months affected 92% fish spawn hatcheries in two selected districts of West Bengal (Sarkar *et al*., 2017; Das et al., 2019).

Sea level rise over the next decades would increase salinity intrusion further upstream of rivers and consequently impact on fresh water culture practices (De Silva and Soto, 2009). Floods, droughts, and cyclones are the main extreme climatic events in tropical Asia and any increase in the intensity and/or frequency of these can damage brackishwater aquaculture (CIBA, 1991; 1992; Ponniah and Muralidhar, 2009; Muralidhar *et al*., 2009; Muralidhar and Vijayan, 2016; Zacharia *et al*., 2016). An increasing trend of tropical cyclonic storms (88–117 km h^{-1}) as well as formation of severe cyclonic storms (118–167 km h^{-1}) is evident in Bay of Bengal during the period of 1900–2008 (Das *et al*., 2014). In India, the east coast experienced a significant loss of mangroves due to large-scale conversion to aquaculture ponds, such as that experienced in the Godavari delta in Andhra Pradesh and the Sundarbans in West Bengal (Ramasubramanian *et al*., 2006, Chaudhuri *et al*., 2015, Krishnan and Birthal, 2002). In the changed situation, the salination of lands and water in the inhabited areas of Sundarban may bring more areas under brackish water aquaculture, given the decreasing viability of freshwater aquaculture and agriculture sectors, thus presenting an opportunity for this sector to capitalize on the changes posed by climate change (Chand *et al.*, 2012).

Climate change and shrimp farming

Impact of climate changes can be either direct or indirect on shrimp farming sector. Thus, water salinity may affect both physical and biological environment of shrimp farms, thereby reducing the availability of aquatic flora and fauna (Ahmed and Diana, 2015), ultimately affecting the biodiversity of the coastal ecosystem. Degradation of biodiversity in the coastal ecosystem makes it more vulnerable to climate change (Brander, 2007). Heavy rainfall may cause flooding, thereby resulting in physical damage of pond-dike and escaping of shrimp and post larvae. Moreover, it increases the acidity of water, which may increase the mortality of post larvae (Allan and Maguire, 1992 a, b). Heavy rainfall causes turbidity of water, which ultimately affects the ecosystem of the farm and reduces growth of shrimp by prohibiting sunlight penetration and hampering oxygen production (Ahmed and Diana, 2015). Oxygen depletion may cause disease of black tiger shrimp (Direkbusarakom and Danayadol, 1998). Lower water temperature due to heavy rainfall also makes an unsuitable condition for post larvae (Kumlu and Kir, 2005). Drought can also pose irreversible alteration of the farm by increasing the concentration of waste metabolites, including ammonia, carbon dioxide and nitrites (Ahmed and Diana, 2015). Prolonged and heavy rainfall during monsoon and resulting upstream flow are mainly responsible for coastal flooding. It damages the earthen dike of shrimp farm and let shrimp and post larvae escape by overflow of water. Flood also brings harmful substances and increases turbidity of water. Changes in water quality due to toxic material cause a threat for the survival of post larvae. Moreover, flood brings predatory fishes in the shrimp farm, which ultimately reduces shrimp production (Islam, 2008).

Conclusion

Proper understanding of vulnerabilities due to impact of climate change and recognition of opportunities of adaptive strategies through management approach and recommended policies will be the major breakthrough to mitigate the hazards of climate changes. As the global perspective is highly variable, impact of climate change will definitely be heterogeneous depending upon the capacity to withstand and strategies being adopted based on the socio-economic bearings of the populations involved. Nonetheless, environmental impact assessment and code of conduct for responsible fisheries should be taken as major consideration to minimize climate change impacts on inland fisheries. Public awareness and capacity building programme should get proper initiation for effective implementation of the policies and to respond effectively to the threats or opportunities posed by climate change. Above all, the stakeholders should have a commitment to implement the adaptive measures at the farm level and both the GOs and NGOs should be amalgamated with the stakeholders so as to achieve meaningful output of the mitigating strategies to be adopted.

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Chapter 12

IMPACT OF HEAT WAVE ON AQUATIC ECOLOGY AND FISHERIES: AN OVERVIEW

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Introduction

Heat waves (HWs) have been observed globally and are expected to amplify in magnitude and frequency under anthropogenic climatic variation (IPCC 2012). According to the Fourth Assessment of the Intergovernmental Panel on Climate Change (IPCC), heat waves will "very likely" intensify over most land and aquatic areas in this century. A prolonged period of heat waves where temperatures are considerably warmer than the normal can have a variety of detrimental impacts on aquatic ecosystems such as sudden habitat modification, drastic reduction in species diversity and depletion of important commercial fishery resources with significant socio-economic impacts. Prediction of biological responses from living aquatic resources to these short-term extreme events and developing adaptation strategies to cope up with the menace are becoming significant, although event-based research still lags behind trend-based works (Jentsch et al. 2007). The occurrence of intense heat waves is frequent globally due to climatic variability. India is also experiencing the impact of climate change in terms of increased instances of heat waves which are more extreme in nature with each passing year and have a devastating impact on both terrestrial and aquatic ecosystems thereby enhancing the number of heat wave casualties.

In India, no systematic studies have been attempted on heat wave and its impact on inland fisheries. The chapter reviews the research carried out across the globe on heat wave impacts, methods of analysis, synthesis of information and discuss on potential impact on aquatic ecology and fisheries in India.

Criteria of 'Heat Waves' by IMD

According to various agencies and institutions, the phenomenon of heat wave is defined as an extended period of time, especially forty-eight to seventy-two hours and longer with tremendous heat and humidity. Intolerable heat appearance differs regionally so that a precise definition of a heat wave includes sustained maximum temperature in excess of average temperature in a particular area. Heat waves typically occur between March and June, and in some rare cases even extend till July. According to Indian Meteorological Department (IMD), the criteria of 'Heat Waves' are as follows;

- The phenomenon of heat wave should not be considered until maximum temperature of a station reaches at least 40°C for plain lands and at least 30°C for hilly regions.
- During heat wave, temperature departure from normal is 5°C to 6°C. In severe cases, departure from normal is 7°C or more.
- When actual maximum temperature attains 45°C or more irrespective of normal maximum temperature, heat waves should be declared.

Methodology for estimation of heat waves

In general, a 'heat index' has been put in use to quantify the excess heat taking into account both temperature and humidity. Sophisticated analysis that expands beyond just measuring temperature and humidity incorporating types of air masses that surround specific geographic regions is used to scientifically predict the fatality of heat waves (Kalkstein and Greene, 1990). The studies performed on various aspects of heat wave phenomena and consequent adverse impacts on aquatic ecosystems have been tabulated as follows:

Table 1. Methodologies adopted for estimation of heat wave impacts

S. No.	Location	References	Specific area	Methodologies adopted
1.	Germany	Huber et al. 2010	Impact of heat wave on crustacean zooplankton in a freshwater lake	Weekly water temperature measurements during summer months were carried out by taking average between the surface and the mean depth of the water body (about 5 m) to get time-series of mean water column temperature (T, °C). As a measure of light availability in the water column, a light index (LI, dimensionless) was put in use incorporating day length and transparency of water (Sommer, 1993): LI = ¼ 2Zs(D/Dmax)1/Zm where Zs denotes Secchi depth (m), D is day length (h), Dmax is 24 h and Zm is mixing depth which was set to the mean depth of the water body (Wilhelm & Adrian, 2008). Conversion of Plankton abundances to biomass ($mgFWL^{-1}$) using species-specific individual body weight (BW) for zooplankton (Bottrell et al. 1976) and measured biovolumes ($mm^{-3}L^{-1}$) for phytoplankton. A conversion factor of 0.12 $mgCmm^{-3}$ (Rocha & Duncan, 1985) was used to estimate the carbon content of phytoplankton biovolume. Statistical analysis: Adopted linear regressions of moving averages (cf.

				fixed-period regression method; Livingstone, 1999) to assess the impact of specific seasonal warming patterns on summer populations of cyclopoid copepods and bosminids.
2.	Switzerland	Jankowski et al. 2006	Impact of summer heat wave on temperature profile and oxygen condition of two freshwater lakes situated in Central Europe	Summer water temperatures of the lakes were measured. Mean summer water temperature was calculated as an arithmetic mean of daily values from 1st June to 31st August. Mean summer air temperature was calculated as an arithmetic mean of daily values from 1st June to 31st August. Similarly, oxygen concentrations were measured from each standard depth of the lake. Statistical analysis: Mean summer water temperature and oxygen concentration (DO) in 2003 with the corresponding long-term means and with the predictions of relevant simulation models (for temperate lakes) selected for average wintery conditions followed by the 2003 summer heat wave menace.
3.	Russia	Kangur et al. 2013	Long-term effects of weather extremity and eutrophication on the fish community of a shallow eutrophic lake	Collection of data on the surface water temperature (SWT) of the lake Chronological data on limnological parameters like transparency of water as Secchi depth, DO and water pH were available from 1950s. Data on Total Phosphorus (TP) and chlorophyll-a concentration in various parts of the water body were available from 1980s. Published data from previous studies on cyanobacterial blooms (Laugasteet

				al., 2001) and fish kills (Semenova, 1960; Kanguret al., 2005). Hydrochemical analysis described by Starastet al. (2001) and Kangur and Mols (2008). Experimental fish samples were collected using bottom trawl at multiple locations. Statistical analysis: Analysis of Long-term changes in water temperature was performed using the 'GLM procedure' in SAS with a 'cubic polynomial model' at 95% confidence level. To estimate the long-periodical alteration in water pH and transparency, a larger linear model using 'SAS/STAT package' had been put.
4.	Portugal	Vinagre et al. 2012	Impact of differential temperature and heat waves on juvenile Europian seabass, *Dicentrarchus labrax*	Juvenile fishes were systematically acclimatised in three indoor recirculating 70L water tanks filled with oxygenated sea water for 3 weeks at a temperature of 16°C The fishes were gradually subjected to the experimental temperatures by altering the temperature of the water tanks @ 1°C/2 hr. till the target temperatures of 18°C, 24°C and 28°C were attained. Tagged and kept in this elevated temperature regime for another 60 days An increment in growth was registered and daily growth rate was calculated by dividing it with 60. At the end of the experiment, the weight measurement was also taken to estimate Fulton's Condition Factor, 'K'

				Prior to the assessment of the condition, a closed respirometry was carried out in shaded daylight (15L:09D) individually by allowing each candidate to exhaust available oxygen in a sealed respirometer containing filtered seawater incorporated with 50ppm streptomycin (Rosa and Seibel, 2008). The measurement of Routine Metabolic Rate (RMR) in the resting animal (Randall et al., 1997) was carried out and thermal sensitivity ('Q_{10} value') (Randall et al., 1997) was calculated in between above experimental temperatures.
5.	Central Europe	Huber et al. 2012	Contrasting responses of cyanobacteria to recent heat waves (2003 and 2006) explained by critical thresholds of abiotic drivers in a shallow, eutrophic lake	Weekly profile measurements (0–5 m depth at 0.5 m intervals) of water temperature(°C) were performed to calculate the 'Schmidt stability index' (g-cmcm-2) according to Soranno (1997), which assesses the intensity of thermal stratification of the water column Nutrient concentration, e.g. Total Nitrogen (TN, ppm), Total phosphate(TP, ppm), Dissolved Inorganic Nitrogen (DIN, ppm), Soluble Reactive Phosphate (SRP, μgL^{-1}), Dissolved Silicate (DSI, ppm), molar ratios of N to P (TN:TP and NO_3:TP) and planktonic abundance were determined from volumetrically weighed mixed samples Estimation of Algal biovolumes was done using standard limnological methods based on microscopic count and individually measured cell

				volumes (Driescher et al., 1993). Data regarding the availability of phytoplankton species were summed to yield biovolume of total phytoplankton, total cyanobacteria, and the dominant cyanobacterial genera The construction of time-series of major zooplankton groups like cladocerans, all freshwater copepods, rotifers, and ciliates) was done with the help of the available data on zooplankton abundance (ind. L^{-1}) Mean weekly measurement of meteorological variables was conducted by the nearby climatological station for 1993-2006. Statistical analysis: Extraction of critical thresholds of abiotic drivers from the long term (1993-2007) data set of the studied lake was performed using nonparametric CTA (Classification Tree Analysis) test.

Changes in fish species distribution and phenology

A considerable number of commercially valuable marine species of N-W Atlantic, e.g. silver hake, red hake, yellow-tail flounder and winter flounder responded to warmer temperatures and ocean heat wave by shifting their geographic distribution and seasonal cycles which affected marine fisheries through redistribution of resources available to fishermen at different locations (Pinsky and Fogarty 2012; Mills et al. 2013). The phenomenon of heat wave caused significant phenological changes in commercial lobster fishery in the north eastern United States by increasing molting rate and the abundance of legal-sized lobsters thereby extending the fishing season and supporting the record landings mainly during the period of high temperature regime.

Habitat modification and mass mortality

Extreme marine heat wave has affected 2000 km of Midwest coast of Australia in 2010-11 with an anomaly in SST (2-5°C above normal climatology) which led to changes in the habitat of sea-grass, coral and algae as well as huge mortality of marine invertebrates (crustaceans and molluscs) e.g. Shark Bay crab (*Portunus armatus*), Roei abalone (*Haliotis roei*) and major reductions in recruitment of scallops (*Amusium balloti*), king (*Penaeus latisulcatus*) and tiger (*P. esculentus*) prawns (Caputi et al. 2016).

Restructuring of species community

Synergistic interaction of extreme weather events (hypoxia and elevated water temperatures) with intense eutrophication resulted in radical restructuring of local fish community, e.g. Lake Smelt *Osmerus eperlanus eperlanus*, *Coregonus albula*

(Vendace) and *Gymnocephalus cernuus* (Ruffe) inhabiting Lake Peipsi (Russia/Estonia) (Kangur et al. 2013).

Extreme thermal stress and growth inhibition

Impact of differential temperature and heat wave on juvenile seabass, *Dicentrarchus labrax* reported that the estuarine water temperature attained during the period of intense heat wave (28°C) had resulted in increased rate of mortality, stunted growth, low condition factor and steep elevation in metabolism indicating that the species was probably under thermal stress at 28°C (Vinagre et al. 2012).

Impact on other aquatic organisms

The phenomenon of heat wave not only affected the fisheries (both freshwater and marine) but also caused enormous damage to other aquatic organisms in different parts of the world.

Impact on freshwater zooplankton populations

The recent climatological changes especially heat waves have adversely affected the zooplankton biology and their abundance in different freshwater ecosystems. Huber et al. 2010 reported that the response of summer zooplankton populations mainly cyclopoid copepods and cladoceran bosminids to heat wave events was found to be critically dependent on the temporal pattern of elevated temperatures. These thermophilic zooplankton species reacted to the incidence of warming in relation to annual plankton cycle (such as Clear Water Phase) rather than to warming during a fixed time period of the season.

Growth of harmful algal population

High temperature effects of summer heat wave in combination with reduced wind speed and cloudiness promoted favored growth of harmful cyanobacteria rather than diatoms and green algae indicating that recent climatic warming can favorably pose increased threat of detrimental cyanobacterial bloom in eutrophic freshwater ecosystems (Johnk et al. 2008).

Studies on impacts of Heat Wave in India

Heat wave has significantly extended its deleterious impact on Indian agricultural sector which has been described various researchers. Kumar and Gautam (2014) in their study reported that throughout 21st century, India is predicted to experience warming above global level. According to the authors, the average temperature shift is predicted to be 2.33°C-4.78°C with a doubling in CO_2 concentrations. These elevated temperatures and changing precipitation patterns along with higher evapo-transpiration rate (ET) and increased CO_2 level in the atmosphere have been predicted to severely affect the agricultural productivity of India. In another study, Murari et al. (2014) documented and warned that a sizeable portion of India including southern regions, west and east coasts which are presently unaffected would be badly affected by severe heat waves in near future. The authors further added that this intensification of heat wave and heat stress conditions would lead to increased mortality of all sorts of living organisms throughout India.

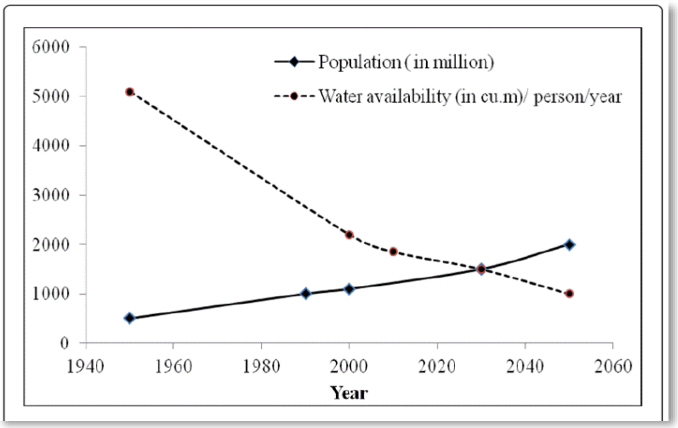

Fig. 1. Graphical representation of observed and projected decline in per capita average annual freshwater availability and growth of population from 1951-2050 (Source: Kumar and Gautam, 2014)

Innovative GIS (Geographical Information Systems) analysis

A direct relationship between rainfall deficit and heat wave and the impact of these climatological anomalies on development of drought and its further intensification in the state of Gujarat was studied. It was mentioned that in certain years, local factors had been more influential than global events such as 'El Nino' and the Southern Oscillation (ENSO) for occurrence and non-occurrence of drought in Gujarat (Bandyopadhyay et al. 2016). Pai et al. (2003) noticed a gradual increasing trend in frequency, persistency and spatial coverage of high frequency temperature extreme events (heat wave and cold wave) during the decade (1991-2000) in India.

Possible adaptation and mitigation strategies

Impact of heat wave on fisheries and other ecosystems	Potential adaptation measures
Habitat destruction and modification, changes in distribution and restructuring of community	Private research, development and investments in technologies to predict migration routes and availability of commercial fish stocks Prevention of overfishing in both freshwater and marine ecosystems
Reduced fisheries productivity and yields	Diversification of livelihood portfolio and provision of insurance schemes Sustainable management of resilient ecosystems Implementation of integrated adaptive management system
Reduced profitability, trade and market shocks	Reduction of costs to increase efficiency Diversification of markets and products Information services for anticipation of price and market shocks

Conclusion

In the recent scenario of global climate change, the phenomena of heat waves are frequent and risk not only the terrestrial ecosystems but also the aquatic ecosystems. Therefore development of management and adaptation and mitigation strategies is the need of the hour which will help to sustain freshwater and marine ecosystems and fisheries in the context of climatic variability. Recent global compilations of ecosystem relevant parameters, as well as concepts and empirical models dealing with functioning and responses of organisms to environmental alterations will provide the opportunity to assess and quantify risks of extreme weather events for aquatic ecosystems in novel ways. However retrospective studies, research priorities and constant research activities to comprehend the impact of heat wave on fisheries and other ecosystems and proper implementation of need-based adaptation and mitigation measures are extremely significant to avert deadly consequences of heat wave.

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Chapter 13

ENVIRONMENTAL FLOW AS AN EFFECTIVE MEANS TOWARDS MITIGATING CLIMATE CHANGE IMPACT ON RIVERS

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Introduction

Rivers constitute one of the most fundamental life-support systems that have sustained civilizations right from time immemorial and hold special cultural, spiritual as well as religious significance. Rivers are being utilized and harnessed by humans in a variety of ways such as agriculture and inland transport since the time human civilizations first emerged. In the present era it diversified and rivers are now source for domestic and industrial water supply, generation of hydro-electricity, inland fishing etc. Rivers are also responsible for deposition of fertile soil in the plains as well as formation of deltas and thereby contribute to natural processes. Rivers provide food and livelihood support to millions of people across the globe both directly and indirectly. But in the last few decades it has been observed that riverine resources are threatened by anthropogenic stresses resulting from water abstraction, discharge of industrial and domestic effluents, fragmentation of rivers owing to construction of cross river obstacles, accidental or deliberate introduction of exotic species and climate change (Vaas et al., 2011; Das et al., 2012).

As per National Academic Press (2007), three critical areas in river science and research viz. environmental flows and river restoration, sediment transport and geomorphology, and groundwater-surface water interactions has been identified which need to be given special attention and emphasis on a global scale. There is no denying to the fact that human actions in the form of construction of dams and obstacles etc. and natural actions in the form of climate change, disasters etc. have caused loss or degradation of riverine habitat. It is beyond doubt that the construction of dams and other interventions on several large rivers across the world resulted in short-term benefits, but in return the large sums of money has to be spent on restoration of river so as to improve water quality, protect riparian zones, improve riverine habitat, and stabilize streambanks far exceeded the benefits gained (Sinha et al., 2012a).

In the 20th century alone, world population has grown rapidly from 1.65 billion to 6 billion. At a time when we have witnessed a near doubling of human population over the past 50 years and when our world is expected to be impacted by an unprecedented degree of alteration, one major area for emphasis is formulation of vibrant strategies for the management of natural freshwater ecosystems in order to promote sustenance of such key resources.

Despite several decades of continued efforts, riverine water quality and its habitat remains at risk in most of the important rivers in the country owing to severe anthropogenic pressure. River Ganga seems to be most severely affected by very high pollution loading – both industrial as well as domestic and is listed as one of the most polluted river systems in the world. In order to tackle such challenges towards river management in India, scientific approach on a highly multi-disciplinary setup, which must be process-based andat the same time predictive is the need of the hour (Sinha et al., 2012a).

Indian River Systems

The Indian sub-continent is host to several large, medium and small rivers, having a distinct hydrological and sediment transport pattern influenced by monsoonal climate and tectonic setting. Many of these rivers have attracted international attention owing to a variety of reasons including flood, hydropower potential, transboundary disputes in terms of water sharing etc. for the last several decades (Sinha et al., 2012b). India is bestowed with rivers and tributaries which run into a combined length of 45,000 km. The country is drained by 15 major, 45 medium and 102 minor rivers along with a number of small streams (Vaasand Moza, 2011). Indian rivers can be categorized into i) Himalayan rivers and ii) Peninsular rivers based on their origin. The major Himalayan rivers which are perennial and snow fed which drain the Indian mainland include the Indus, Ganga and Brahmaputra together with their numerous tributaries. Their basins cover nearly two-thirds of the Indian sub-continent and are shared by China, Nepal, Pakistan, Bangladesh and Bhutan (Vaas et al., 2011). Besides the composite the Ganga–Brahmaputra–Meghna basin which comprise of Ganga, Brahmaputra and the Barak sub-basins covers nearly one-third of the land area of Indian Union. The rain fed Peninsular rivers include the west flowing Narmada, Tapti and the east flowing Mahanadi, Godavari, Krishna, Cauvery and their tributaries which drains the Deccan region. Besides few river originating in the arid regions of the West, such as Luni.

River Ganges with a total length of 2525 km is the largest river system in India and fifth largest in the world (Welcomme, 1985) draining the fertile Indo-Gangetic plains. It occupies a unique position in the history, culture and civilization of the Indian subcontinent and has been given the status of a national river owing to its significance (MOEF, 2009).Ganga supports a rich diversity of commercially valuable fish and harbours a total of 265 fish species (Vaas and Moza, 2011) at the same time providing food and sustaining over 7 million people along the Gangetic plains involved in subsistence, traditional and artisanal fisheries (Sinha and Khan, 2001).

Brahmaputra is a transboundary river originating from Kailash ranges of Himalayas in Tibet at an elevation of about 5150 m above MSL and flows for a length of about

2900 km through Tibet (China), India and Bangladesh. A total number of 141 finfish species has been reported from this river in Assam (Bhattacharjya et al., 2017).

Indus river and its five tributaries Jhelum, Chenab, Beas, Ravi and Sutlej drains the northern most part of India including Jammu and Kashmir, Himachal Pradesh and Punjab. Major part of this river flows through Pakistan. Narmada river has its origin near Amarkantak in Madhya Pradesh at an elevation of about 900 m above MSL and flows for about 1312 km before draining into the Arabian Sea through the Gulf of Cambay in Gujarat. With regard to its fisheries resources, 84 fish species has been reported from the western part of the river along the 150 km stretch from Punasa to Barwani (Vaas and Moza, 2011). Tapi one of the major rivers in peninsular India with a total length of around 724 km. The river originates near Multai in Betul district of Madhya Pradesh at an elevation of about 752 m above MSL and ultimately drains into Arabian Sea through the Gulf of Cambay. It is one of only three rivers in peninsular India that run from East to West - the other two being Narmada and Mahi. Tapi is the second largest Westward draining inter-state river basin covering the states of Maharashtra, Madhya Pradesh and Gujarat with 80% of the total basin area in Maharashtra. 52 fin fish species has been reported from this river (Vass and Moza, 2011).

Mahanadi river originates in Raipur district of Chhatisgarh and flows for about 851 km before draining into the Bay of Bengal. It flows through the states of Chattisgarh and Odisha. A recent study by the authors in river Mahanadi in the stretch of Hirakud to Paradip indicated a total of 156 fish species belonging to 60 families and of which, 15 species were recorded for the first time from the system which included *Anguilla bengalensis* (catadromous freshwater eel), *Congresox talabonoides*, *Ilisha elongata*, *Hilsa kelee*, *Securicula gora*, *Arius arius*, *Epinephelus coioides* (Orange spotted grouper), *Terapon puta*, *Gerres oyena*, *Acanthopagrus berda* (Picnic sea-bream), *Otolithes ruber* (Tiger-tooth croaker), *Upeneus sulphureus*, *Awaous grammepomus*, *Eupleurogrammus muticus* and *Lepturacanthus savala* (Roshith et al., 2017). Including the species recorded from previous studies on Mahanadi river, the total recorded fish diversity at Mahanadi river system comprises of 288 species belonging to 71 families and 17 orders. Cyprinidae was the most speciose family with 49 species, followed by Gobiidae (24 species), Engraulidae (11 species), Clupeidae (11 species) and Mugilidae with 10 species.

Godavari river also known as 'Ganges of the South' has its origin near Nasik in Maharashtra at an elevation of about 1067 m above MSL and drains into the bay of Bengal after flowing for a length of about 1465 km through the states of Maharastra, Telangana and Andhra Pradesh. Survey carried out by ICAR-CIFRI along the 189 km penultimate stretch of the river from Dowlaiswaram to Dummagudem anicuts revealed 83 fish species (Vaas and Moza, 2011).

Krishna river rises in the Western Ghats at an elevation of about 1337 m above MSL to the north of Mahabaleswar. The river flows eastward for about 1400 km and falls into the Bay of Bengal. The Krishna basin covers the states of Maharashtra, Karnataka and Andhra Pradesh.

Cauvery River is one of the important east flowing rivers of Karnataka. It has its origin near Talakaveri in Kodagu District at an elevation of 1341m in Brahmagiri Range of hills in the Western Ghats. The river flows through Kodagu, Mysore and Mandya districts of Karnataka State and enters Tamilnadu State near Hogenakal and thereafter flows through the plains of Tamilnadu and joins the Bay of Bengal near Karaikal. The important tributaries of Cauvery River in Karnataka are Hemavathy, Harangi, Shimsha and Arkavathi. The river Cauvery lies between East longitudes $75^0$30' and 79^0 45' and North latitudes 10^0 05' and 13^0 30' and is the third largest perennial river flowing in Southern India. The Cauvery basin is bounded by Tungabhadra sub-basin of Krishna basin on the Northern side and Palar basin on the Southern side. The Nilgiris, an offshoot of Western Ghats, extend Eastwards to the Eastern Ghats and divide the basin into two natural and political regions i.e, Karnataka plateau in the North and Tamilnadu plateau in the South. The total catchment area of the entire Cauvery basin is 81,155 sq. km and the total yield is of the order of 22,375 Mcum. Out of the total catchment of 81,155 sq.kms, 34,273 sq.kms lies in Karnataka, 43868 sq.kms in Tamil Nadu, 2866 sq.kms in Kerala and 148 sq.km in Pondicherry.A total of 80 fin fish species has been reported from this river (Vaas and Moza, 2011). A recent study by the authors in the stretch of Shivasamudram of river Cauvery indicated the fish fauna comprises of 65 species belonging to 7 orders and 13 families (CIFRI Report 2018). Among different groups of fish, Cyprinidae comprising of 38 species includes commercially important carps as food fish such as *Barbodes carnaticus, Cirrhinus. reba*, *Labeo calbasu*, *L. kontius, L. porcellus*, *L. boggut*, *Hypselobarbus dubius, H. micropogon, Osteochielus thomassi*, *Schismatorhynchos nukta and Tor khudree*, among others. Silurids include commercially important catfish such as *Sperata aor*, *S. seengala* and *Wallago attu* under large category, *Mystus cavasius* and *Ompok bimaculatus* under medium category. Commercially important species from other groups *are* - Channidae (*Channa marulius* and *C. striatus)*, Clariidae (*Clarias batrachus)* and Heteropneustidae *(Heteropneustes fossilis)*, among others.

Indian rivers criss-crossing the entire country has been the life line of the people since time immemorial and has supported livelihood and developmental activities in the form of agriculture, fisheries, development of industries, transportation and source of water for irrigation, drinking etc.

Impact of Climate Change on Rivers

Some of the most commonly used indicators for assessing impact of climate change on rivers include changes in mean annual discharge, seasonal discharge (based on four seasons), monthly discharge, Q95 and mean annual flooding pattern. However, studies and research on the impact of climate change on river flow regimes on a global-scale are quite rare (e.g. Milly *et al.*, 2002; Hirabayashi *et al.*, 2008; Doll and Zhang, 2010).One of the possible impact of climate change on water resources more importantly freshwaters is the change in mean annual runoff (MAR), which is the difference between the long-term averages of annual precipitation and evapo-transpiration (Bates *et al*., 2008). Climate change impact studies for individual drainage basins mostly focus on changes of river discharge and aspects of its temporal variability (Kundzewicz *et al*., 2007). Changes in evapo-transpiration owing to increasing temperature and modifications in precipitation pattern in a particular area as a result of climate change can lead to alterations in discharge and flow regime of rivers across temporal and spatial scales.

Fig.1 depicts the changes in MAR, on mean annual river discharges with and without water withdrawals and on low flows by 2050 by applying climate change scenarios computed by the climate models ECHAM4 and HadCM3. In case of 1(a) areas in green indicate increase in future run-offs (or less negative difference between precipitation and actual evapo-transpiration) and those in pink indicates decreasing future run-offs (more negative) while those in light yellow indicate no change. In case of 1(b), 1(c) and 1(d) increasing future discharge is indicated by green, pink indicates decreasing future discharge while no change is represented by light yellow.

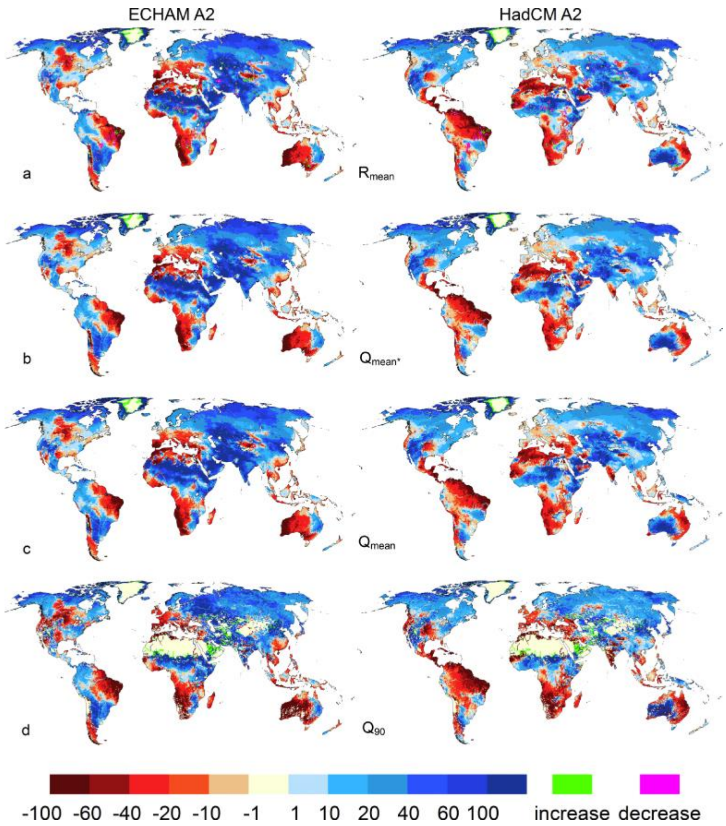

Fig. 1. Impact of climate change on MAR R_{mean} (a), on mean annual river discharge Q_{mean*} that would occur without water withdrawals (b), on mean annual river discharge Q_{mean} (with water withdrawals) (c) and on low flows Q_{90} (with water withdrawals) (d) by the 2050s (Adopted from Doll and Schmied, 2012).

River discharge varies across time and space. River flow regimes describe the temporal patterns of flow variability and climate change can induce changes in river flow regimes. Changes in seasonality, inter-annual variability, statistical low and high flows, and floods and droughts are perceived and probable impact of climate change on riverine ecosystems (Doll and Schmied, 2012). All the elements of a flow regime, such as high, medium and low flows, are important from the ecosystem point of view

(Richter et al.,1997) as they carries out specific functions. High flows help in channel flushing, maintaining lateral and longitudinal connectivity; medium flows facilitate fish growth and migration and low flows plays a key role in river connectivity (Acremanet al.,2009) and as such changes in the pattern of high, medium and low flows owing to climate change can alter riverine ecology.

Such modifications in flow regime of rivers do affect humans with respect to water supply, navigation, hydropower generation and flooding, and they create an adverse impact on habitat suitability of riverine biota (Poff and Zimmerman, 2010). Of particular relevance for freshwater ecosystems is the shifts from perennial to intermittent flow regimes or vice versa owing to climate change, as they seem to have a strong impact on inherent biota of the river (Bond *et al*., 2010) as well as on surrounding riparian vegetation (Stromberg *et al.*,2005). Changes in flow regime seem to affect the life-history characteristics of riverine biota more importantly fishes. Important life history traits such as breeding, migration for feeding in case of juveniles and breeding in case of adults and migration as a means to adapt to changing seasons is directly related to flow regime of rivers. Under altered conditions fragile organisms may find it hard to adapt and to survive and in extreme cases the whole ecosystem may collapse altogether.

Stagl and Hattermann (2016) studied the impact of climate change on ecological river flow alterations in Danube river and its major tributaries, wherein they presented projected changes for eight environmental flow indicators under three climate warming scenarios, pointing to a global temperature increase by the end of the 21st century of ~2 °C, ~3 °C or ~4 °C compared to pre-industrial times. As revealed by the results climate change is projected to significantly modify the recent environmental flow regime in Danube river basin, especially in the tributaries along Middle and Lower Danube basin. The impacts strongly accelerate with increasing global temperature. Increase in temperature by 2 °C, projected environmental flow alterations might still be moderate for most of the rivers. However, the results show very distinct changes for most of the eco-hydrological indicators when temperature will increase by 3 °C. Finally, increase in temperature by 4°C will highly alter the flow regime, especially in all tributaries of the Middle and Lower Danube basin. The greatest changes are associated with a discharge reduction in the warmer season of the year, including a very critical decrease in low flow magnitudes in Sava, Drava, and Tisza rivers and all tributaries of the Lower Danube basin. While Velika Morava river in particular is affected by a very strong decrease in low flow magnitudes and a strong decrease in winter flow.

With regard to the Murray Darling basin in Australia, Cai and Cowan (2008) after consideration of interdependencies, including the effect of rainfall and clouds on minimum temperatures, concluded that increase in maximum temperature by 1^0C has resulted in almost 15% decrease in flow of the rivers.

Changes in flow pattern and discharge as a result of changing evapo-transpiration and precipitation coupled with increased water abstraction for other uses can leave our rivers with very low water levels not sufficient to flush out or dilute the pollutants which increase their concentration factor and result in poor water quality. When such situation reaches critical levels it may even render the river not suitable for sustaining aquatic life. Climate change induced poor water quality in the form of rising turbidity levels either due to frequent high floods during monsoon causing erosion of river banks or due to lack of water sufficient enough to dilute the suspended solids during dry season is seen many rivers across Asian region (Table 1).

Table 1: Impact of climate change in some specific aquatic ecosystems of Asian region

River/Lake	Country	Impact of climate change
Paldanglake	S. Korea	Earlier ice break-up and shorter time period of ice-cover, increased concentration of suspended solids
Yuanjiang Red river basin	China	Increase in suspended sediment loads
Tarim river basin	China	Significant increase in evaporation
Yellow river	China	Severe low-flow events causing disrupting pollutant dispersal and self-cleaning
Ili river basin	China	Sudden changes of precipitation and temperature affecting flow patterns
Ganges river	India	Increased nitrogen and phosphorus loading in river
Indian Sunderbans	India	Increase in downstream salinity, decrease in phytoplankton and fish density and diversity
Yamuna river	India	Enhanced chemical weathering rates under high water temperatures
Spiti river	India	Various impacts of temperature and precipitation on snow water equivalent, snowmelt runoff, glacier melt runoff, total streamflow and their distribution
Cauvery river basin	India	Increasing trend for maximum temperature, minimum temperature and rainfall over the basin has impacted rice productivity in a great deal
Mahanadi	India	Observed changes in river flows
Subaranrekha river basin	India	Abrupt rainfall pattern and flooding

Indus river system	Indian subcontinent	Change in rainfall pattern, reduced winter rains
Lower Brahmaputra	Bangladesh	Abrupt changes in mean low and high flow conditions, destructive flood events
Mahaweliriver basin	Sri Lanka	Spatial and temporal changes in climate systems

*Adopted from: Tripathi et al., 2017.

Another cause of concern to riverine ecosystems is the changes in water quality owing to climate change. Sufficient discharge helps in maintaining water quality standards in riverine ecosystems, although control of pollution by dilution is not seen as a good strategy (Jain, 2015).Indian rivers are experiencing severe anthropogenic stress and are mostly pollutant laden.

Climate change induced natural calamities in the form of extreme floods, droughts and earthquakes can result in destruction of many sensitive, valuable and fragile riverine habitats. Earthquakes in particular can altogether alter the course of a river or modify its characteristics such as decrease in depth of river bed. This will result in increasing incidences of flood in the surrounding areas. On the other hand extreme floods and droughts which are results of climate change can lead riparian vegetation to disappear along with severe impacts on other riverine habitats and is likely to create a high degree of stress on the aquatic biodiversity.

Other impact of climate change on rivers include rise in mean water temperature, eutrophication leading to alga blooms, increase in frequency of floods during monsoon and very low water table during dry season leading to loss of suitable habitats and subsequent stress upon aquatic biodiversity of rivers. The impact of climate change on some specific riverine and other aquatic ecosystems across Asia are given in Table 1.

With respect to climate change impact on Indian rivers, studies in this line are quite limited (e.g. Gosain et al., 2006; Tripathi et al., 2017). Gosain et al. (2006) studied the impact of climate change on Krishna and Mahanadi basin through simulation of the hydrological conditions that shall prevail under the projected weather conditions in an area using the Soil and Water Assessment Tool (SWAT) model. The model has then been run on each of the basins using GHG climate scenario data (obtained based on predicted weather data for 2041–2060 period) but without changing the land use. The annual average precipitation, actual evapotranspiration and water yield was simulated by the SWAT model over Mahanadi basin and found that this river basin is expected to receive comparatively higher level of precipitation in future and a corresponding increase in evapotranspiration and water yield is also predicted. This will lead to severe flood conditions across the Mahanadi basin. On the contrary Krishna basin is expected to receive reduced precipitation in future with reduced evapotranspiration and reduced water yield. This basin is expected to experience severe drought conditions in the years to come. In case of Ganges, climate change induced erratic rainfall creating high and low flow conditions may lead to increase in organic matter content and nutrient load in the river and subsequent eutrophication which may interact with several environmental factors thereby changing its physiological properties (Vaas et al., 2010). Climate changed induced pollution (heavy metal, organic, radioactive etc.) in Ganga is a threat to the entire river ecosystem. It is seen that monsoonal discharge in Ganga contains elevated levels of some radioactive elements such as Ba, Ra and Sr which is due to increased rate of chemical weathering in Himalayas region and subsequent changes during transportation and deposition which might have link with increase in temperature around the region (Singh et al., 2010). Similarly reportedly higher levels of As and F in Ganges is a matter of great concern (Raha et al., 2012) and increase in water temperature might have accelerated its weathering process from where they are mainly derived.

In case of Narmada and Tapti basin, a decrease in precipitation is projected owing to climate change, however the total run-off in both the rivers is predicted to increase owing to reduction in evapotranspiration. With regard to Mahanadi, Brahmani, Ganga, Godavari and Cauvery basin an increase in precipitation is projected. This increase in precipitation does not result in increase in total run-off for Cauvery and Ganga river, which may be due to increased rates of evapo-transpiration. In case of Cauvery river basin an increase in rainfall by 2.7% is projected. However the run-off is expected to reduce by 2% as the evapotranspiration rate is set to increase by further 2% owing to increased temperature at the same time. In case of Sabarmati and Luni river basins the run-off is expected to decrease to the tune of two-third of the prevailing run-off, which will result in severe drought conditions. This severe condition is due to climate induced changes in precipitation and increasing temperature in the region (Vivekanandan and Das, 2011).

Impact of Climate Change on Aquatic Biodiversity in Rivers

Freshwater fishes particularly in rivers undergo a seasonal reproductive migration tightly linked to flow with early spring “freshers,” which acts as a cue to initiate movement (Pen et al., 1991). Besides reproductive migration, fishes also migrate to adapt to the changing temperatures across seasons as seen in the case of mahseers and snow trouts which migrate downstream of rivers during winter as water temperature upstream falls far below their tolerance limits and also migrates for feeding. Any such reduction in flows or alterations to the seasonality, frequency and timing of flows may therefore result in the loss of migratory triggers. Besides unusual low flows can expose in-stream barriers thereby hindering migration of fishes (Walker, 1985).Thus departures from natural flow pattern, either through man-made regulation and/or induced by climate change, may impact a wide range of aquatic species and associated ecosystem processes (Davies, 2010).

Increasing water temperature owing to climate change can impact freshwater riverine ecosystems by reducing the concentration of dissolved oxygen and at the same time increasing benthic respiration (Bunn et al., 1999). These two typical processes act in combination to drive river pools anoxic and can ultimately lead to mortality of aquatic organisms (Bunn & Davies, 1992).Rise in temperature can also lead to increase in rate of disease incidences in aquatic organisms, particularly parasitic infections. The severe disease outbreaks in fishes and shellfishes which occurred throughout India during the 1990s coincide with one of the warmest decades of the century (Vivekanandan and Das, 2011).

Another phenomena associated with climate change is lapse rate. In the Northern Hemisphere, climate change has resulted in distributional shift of key biota (Root et al., 2003) which is either towards the poles or to higher altitudes. In circumstances where movement has not been possible due to obstacles, there are instances where some species have become locally extinct (McCarty, 2001). Lapse rates refer to the average reduction in air temperature with increasing movement toward the poles or with increasing altitude. According to Allaby (2004) an environmental lapse rate with increasing altitude is about 6.5°C/km which tend to vary with region. Toward the poles, a lapse rate of 1°C/145 km is the accepted norm (Trapasso, 2005).

Climate change has resulted in shift in geographical distribution of fishes and other aquatic organisms along rivers. As per reports of ICAR-CIFRI, warm water fish species like *Glossogobius giuris*, *Pethia ticto*, *Xenentodon cancila* and *Mystus vittatus* which were earlier available in the lower and middle stretch of river Ganga are now available along the colder stretch around Haridwar (Vivekanandan and Das, 2011) and in extreme cases may lead to fragmentation of population as well.

Climate change induced temperature rise might have positive impact on growth of aquatic organisms, more particularly fishes. However rise in temperature induced poor water quality and poor habitat and in cases when temperature rise exceeds the thermal tolerance limit of the species, it will have negative impact upon the aquatic organisms. Besides temperature rise may lead to faster rate of nutrient enrichment leading to eutrophic condition in rivers and subsequent algal blooms. Such a situation is undesirable for survival and growth of aquatic organisms.

Environmental Flows (E-Flows)

The science of environmental flows is relatively young in India. Environmental flows (EFs) generally mean the amount of flow, which is either left in or released into a river system for protecting the riverine biota. The basic objective is to achieve certain specific targets such as maintaining a healthy ecosystem, meeting the water requirements for survival of aquatic organism present etc. Environmental flows could also target the main river channel and its surface waters along with fulfilling other requirements such as groundwater recharge, meeting the discharge requirements along the estuarine zones of the river, maintaining connectivity of associated wetlands or floodplains, maintaining riparian zone or any plant and animal species associated with these ecosystems (King et al., 2000).EFs does not merely indicate the overall flow in a river but also include detailed aspects of quantity, timing, duration, frequency, and quality of flows required to sustain freshwater, estuarine and near shore ecosystems along with the dependent human livelihoods (Acreman and Ferguson, 2010). Krchnaket al. (2009) defined the term environmental flows as a water flow regime that has been designed and implemented through release of water from an impoundment into the immediate downstream of a river with the basic objective of achieving desired ecological conditions and ecosystem services in the target stretch. Environmental flows requirement in a river system is dependent on a number of factors such as, the size of river, desired or targeted state to be achieved, sensitivity of river ecosystem, societal preference and uses of river water. Besides the trade-offs in environmental cost and economic benefit resulting out of water abstraction from the river and subsequent diversion for use in developmental activities and other purposes is also to be duly considered in estimating environmental flows (Jain, 2012). Hydrological data, information pertaining to river cross sections and channel morphology, in addition to data on quantitative needs of water for sustaining biotic life and its sensitivity to reductions in river flow, combined with knowledge on the preferences of all stakeholders are essential in estimating the environmental flow requirements (Acreman and Dunbar, 2004). However, Mohile and Gupta (2005) suggested that water requirements for drinking, fisheries, livelihood, navigation and dilution of effluents should not be included as part of environmental flows and instead should be consideredas water for people, livelihoodand industries and can be estimated separately. At the same time environmental flows requirements should consider the water requirements for sustenance of associated ecosystems.

E-Flows Vs Climate Change

Environmental flow can be an effective strategy towards maintenance of important ecosystem processes and biodiversity in rivers which have been impacted by climate change. Environmental flows, such as reservoir releases, could be used to re-establish important components of the historic flow regime and thereby sustain the riverine and associated ecosystems (Davies, 2010).Large number of important functions in rivers is regulated by magnitude, frequency, and seasonality of flows (Poff et al., 1997).Possible consequences of climate change on riverine ecosystems, ecological responses and restoration activities that needs to be undertaken are given in Table 2. From the table it is seen that e-flows maintenance is an effective tool in mitigating the impact of climate change on rivers and associated ecosystems.

Table 2: Possible impact of climate change on riverine ecosystems and activities for restoration

Impact of climate change on rivers	Possible consequence	Ecological Response	Restoration Actions
Decrease in autumn rainfall	Pool anoxia	Fish kills, release of metals and nutrients from river sediments	E-flows, fencing, and riparian re-vegetation
	Loss of longitudinal hydrological connectivity	Loss of upstream carbon subsidy	Removal of artificial barriers and e-flows
Decrease in winter rainfall	Loss of reproductive triggers	Local extirpation of fish	E-flows
	Loss of variability encouraging invasive species	Increased populations of competitive dominants	E-flows
	Exposing barriers to fish migration	Local extirpation of fish	Removal of artificial barriers, weed management and e-flows
Decrease in winter Stream-flow	Reduced pool scouring	Loss of pool habitat	E-flows and pool dredging
	Build-up of organic material	Increased BOD, fish kills (during summer)	E-flows
	Reduced riparian inundation and subsequent seed-set	Longer-term degradation of riparian vegetation	E-flows, fencing and riparianre-vegetation
Escalating	Exceedance thermal limits of sensitive	Local extirpation of fauna	Fencing, e-flows and riparian

Atmospheric warming	fauna		re-vegetation
	Increased benthic respiration	Increased BOD, anoxia	E-flows, fencing and riparianre-vegetation
	Decreased dissolved oxygen levels	Fish kills	E-flows, fencing and riparianre-vegetation
Increased evapotranspiration rates	Reduced stream-flow; shift to a temporary system	Loss of permanent river fauna	E-flows
	Loss of hydrological connectivity	Loss of upstream carbon subsidy	E-flows
Increased fire hazard	Loss of riparian vegetation leading to increased water temperature	Loss of sensitive species	Fencing, e-flows and riparianre-vegetation
	Exceedance of thermal limits	Loss of sensitive species	Fencing, e-flows and riparian re-vegetation
	Liberation of phosphorus and increased likelihood of algal blooms	Deterioration of water quality	Fencing and riparian re-vegetation, fire management and e-flows
Decrease in the intensity of winter flood flows	Reduced pool scouring; Increased pool aggradation	Loss of pool habitat	E-flows and pool dredging
	Loss of longitudinal hydrological	Loss upstream carbon subsidy	E-flows

	connectivity		
	Weed encroachment into channels	Loss of habitat and reduced high flow conveyance	Weed control and e-flows
	Increased invasive species	Increased competitive dominants	E-flows and weed control
Increased frequency of drought	Shift to temporary systems	Loss permanent river fauna	E-flows
	Loss of refugia (poor pool water quality)	Local extirpation of fauna	Fencing (pools), e-flowsand riparian re-vegetation
Increased sea and estuary levels	Loss of floodplain habitat	Reduced fish recruitment	Reserve design, e-flows and removal of artificial barriers
Increased frequency of warm spells/ heat waves	Pool anoxia	Local loss of pool fauna	Fencing, e-flows and riparianre-vegetation
	Exceedance thermal limits	Local extirpation of sensitive species	Fencing, riparian re-vegetation ande-flows

*Adopted from: Davies, 2010.

Conclusion

Changes in pattern of precipitation increase in temperature, increases in the frequency and intensity of extreme climatic events like floods and droughts, melting of glaciers and reduced snow cover in mountains are some of the hydrologic changes induced by climate change. In case of rivers climate change might impact the flow regime and it will have its bearing on riverine habitat and biodiversity. E-flows Under such circumstances maintaining e-flows keeping in mind the timing, frequency, magnitude and other critical aspects of flows can help to a great extent in sustaining our riverine ecosystems which are under tremendous stress both anthropogenic and climate induced.As water is the fundamental medium and vehicle for climate change impact, strategies to protect or restore environmental flows regimes in free flowing and highly regulated rivers need an urgent attention for Indian rivers.

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Chapter 14

VULNERABILITY ASSESSMENT OF INLAND FISHERIES TO CLIMATE CHANGE THROUGH VARIOUS TOOLS AND METHODS: AN INTEGRATED APPROACH

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Introduction

In the past few decades, various changes in climatic parameters have become pronounced globally. Climate change directly and/or indirectly has negatively impacted on livelihood and nutritional security in the fisheries sector, thus modifying the fish habitat and production on a large scale. India is very fortunate to have large fish genetic diversity of freshwater species (33000). Due to several stresses many species are in verge of extinction and became a part of threat status as per IUCN Red list. Climatic variabilities along with anthropogenic activities are creating threat to biological mechanism (recruitment process) and ecological profileof inland and marine fisheries. Although several experimental studies were being carried out in inland waters, but very few had been conducted to predict the degree of vulnerability on species-specific habitat distribution and ecological parameters. Thus, we need to predict the reproductive behavioral response associated with climatic and ecological variabilities of large number of freshwater fish species to conserve them in nature.

Since 2004, ICAR-Central Inland Fisheries Research Institute started research onclimate change under theICAR research project 'Impact, Adaptationand Vulnerability of Indian Agriculture toClimate Change' and is being continued as 'National Innovations on Climate Resilient Agriculture' (NICRA) from 2012 onwards under the ICAR Project.The Institute got recognition as nodal organization forclimatechange research with respect toInland Fisheries in India in the past several years. Hence, ICAR-CIFRI (NICRA) has taken the initiative to develop several tools and models to manage the natural germ plasm resources and change the near future of the fish species. The present paper discussed on various tools and methods used by different authors at global level for vulnerability assessment of aquatic ecosystem in the context of climatic variability.

Different tools to assess vulnerability of various aquatic systems with respect to climate change

Vulnerability assessments (VAs) can be used for improving adaptation development (designing of policies and interventions), raising awareness of threats and opportunities, and progressing scientific research (Patt et al., 2009).

Importance of this study is to assessthe climatic and ecological variables influencing seasonal variations, hence, different approaches to vulnerability assessment of aquatic systems along with its resources can be portrayed.

Many countries have already initiated different assessment protocol to study the vulnerability. Various works on vulnerability has been carried out at different levels like- species reproductive vulnerability, Ecological based vulnerability, and satellite based vulnerability assessment and stake-holder driven approach vulnerability assessment.

Importance of various approaches to assess vulnerability is as follows-

- ***Reproductive vulnerability***- This assessment approach is being used to determine changes in reproductive phenology of aquatic species due to variability in climatic and environmental parameters. Different reproductive parameters, life history traits of particular species, regular climatic data and environmental variables are used to determine breeding periodicity and spawning success in species. Thus, help us to understand the complexities of environmental and climatic insinuations on breeding strategy of species at ecosystem echelon.

- ***Ecological based vulnerability assessment***- This assessment signifies the wetland productivity status with changes in climatic variability; hence, strategic management planning and techniques can be framed to conserve the ecosystem.
- ***Vulnerability assessment through stake-holder approach-***Scarcity of long-term quantified data on adverse effects of climate change on flora and fauna (fishes) diversity in aquatic systems leads to acquire information regarding the current status of the productivity of the water bodies as well as problems faced by the farmers.

GIS based vulnerability assessment-Compilation and compare of present and previous status of aquatic ecosystems through remote sensing and GIS mapping help to verify the accuracy of survey data (through interaction with the interviewee and scientific approach). The information of different aquatic systems locatedin remote areas can be gathered and represented through remote sensing and GIS mapping.

Table 1. Models and tools to predict the reproductive vulnerability of fishes

Sl.No.	Place	Target Species	Parameters	Models/Tools	Explanation	Inference	Reference
1	Ames, Iowa	*Chrysemy spicta*	Recorded temperature during first embryonic stage, rate of change in temperature from embryonic development to spawning stage, rate of increasing in development of hatchling	Constant temperature equivalent (CTE) model	This model is used to predict the effect of climate change in terms of seasonal thermal pattern on rate of embryonic development, phenomenon of atresia, hatchling size and morphology, colour pattern, post hatchling behaviour and growth rate, offspring sex ratio and sexual dimorphism of matured individuals	Nest formation by females was negatively impacted by Climate change.	Telemeco *et al.* 2013

2	USA	(MMS) Marine Migratory Species (whales, turtles, Pacific salmon, Atlantic bluefin tuna, North Sea plaice, Halibut, hammerhead sharks, elephant seals)	Philopatry, breeding habitats, impact of climate change on phenology, timing of migration and reproduction, genetic adaptation, phenotypic plasticity, survival rate and fecundity.	Individual-based modeling framework	This model determines the impact of climatic variability on the migration timing between feeding and breeding habitats along with their condition, survival rate and fecundity.	Exceeding in climate change pattern affects the temporal size of migration along with inherent capacity of MMS for climatic variability and determination of threshold level of population extinction.	Anderson *et al.* 2013

3	Tibetan plateau	*Gymnocypris selincuoensis*	Radius of the first annulus of otolith, air and water temperature with respect to time series.	Long axis length of the first annulus (LAFA)	This approach is used to estimate Growth Season Extension (GSE) and Reproduction Advancement (RA).	By using this approach it was observed that reproductive phenology got advanced during spring season and increase in growth was found due to delay of winter season.	Tao *et al*.2017
4	India	*Channa puncata*	Daily rainfall andair temperature data,envionmental parameters,	GAM Model (Generalized Additive Model)	This model was used to predict the threshold Value of GSI for determining the onset of breeding phenology.	They standardize the optimum threshold value of GSI for	Karnatak *et al*.2018

			GSI (Gonado-somatic index), maturity stages, growth of fish, spawning season, Oocyte diameter.			*Channapuncata* was 4.14.	
5	India	*Mystus tengara*, *M. cavasius* and *Eutropiichthsvacha*	Daily air temperature and rainfall data, envionmental parameters, Fulton's condition factor, gonadal development stages and fecundity.	Kaplan-Meier method	This method was used to estimate pre-spawning fitness (Kspawn50).	Kspawn50 value of *Mystustengara*, *M. cavasius* and *Eutropiichthys vacha* was generated.	Sarkar *et al*.2017

Table 2. Models and Tools to predict the Ecological Vulnerability of aquatic systems

Sl. No.	Place	Index	Parameters	Explanation	Inference	Reference`
1	Brazil	Carlson's model based Trophic State Index	Secchi disk transparency, chlorophyll and total phosphorus	Based on this approach, the productivity of lake had been categorized into six categories viz, ultraolig-otrophic (U), oligotrophic (O), mesotrophic (M), eutrophic (E), supereutrophic (S) and hypereutrophic (H).	The work suggested that a criterion available for trophic state limits of temperate aquatic systems is not suitable to categorize the tropical or subtropical aquatic systems.	Cunha *et al.*, 2013
2	Kabar wetland in Bihar, India	Carlson's model based Trophic State Index	Secchi disk transparency, chlorophyll and total phosphorus	The three parameters were fitted in Carlson's formula and the state of productivity of the wetland was measured. TSI (SD) = 10*{6-[(ln(SD)/ln2)]} TSI (Chl-a) = 10*{6-[(2.04-0.68 ln Chl)/ln2]}	All the three parameters indicated the productivity of the studied wetland is mesotrophic in nature.	Sharma and Shardendu, 2012

				TSI (TP) = 10*{6-[(ln^{48}$_{TP}$)/ln2]}		
3	Xixi National Wetland Park, China	(Cai*et al.*, 2002, Jin, 1990) Comprehensive assessment model using analytic hierarchy process (AHP)	secchi depth, total nitrogen, total phosphorus, chlorophyll a and permanganate index	The trophic states was inferred by using the following formulae- TSI(Chl-a, mg/m^3)=10*(2.46+ln(Chl-a)/ln2.5) TSI(SD,m)=10*(2.46+(3.69-1.53*ln(SD))/ln2.5) TSI(TP,mg/L)=10*(2.46+(6.71+1.15*ln(TP))/ln2.5) TSI(TN,mg/L)=10*(2.46+(3.93+1.35*ln(TN))/ln2.5) TSI(COD$_{Mn}$,mg/L)=10*(2.46+(1.50+1.36*ln(COD$_{Mn}$)))	All the water bodies covered in this wetland and adjoining areas showed exceeded eutrophic level	Li *et al.*, 2010
4	Sri Lanka	Carlson and Simpson,1996 model based Trophic State Index	Secchi disk transparency, chlorophyll and total phosphorus	The productivity status of the 45 studied reservoirs were being calculated by using the formulae- TSI (SDD)= 60-14.41 ln SDD (metres)	Their study revealed that algal bloom was not a dominating criterion in the studied reservoirs and positively correlated to culture based fisheries yield.	Jayasinghe*et al.*, 2005

				TSI (Chl-a)= 9.81 ln Chlorophyll a (mg/m^3)+ 30.6 TSI (TP)= 14.42 ln total *P* (mg/m^3)+4.15		
5	River Mandakini, Madhya Pradesh, India	Carlson's model based Trophic State Index	Secchi disk transparency, chlorophyll and total phosphorus	This index was used to identify and categorize the productivity of lake as well as for lake management. Carlson's Trophic State Index (CTSI)= [TSI (SDT)+TSI (Chl-a)+TSI(TP)]/3	All the sampling site were in mesotrophic except for one site in oligotrophic	Chaurasia and Gupta, 2016
6	Mysore, India	Carlson and Simpson,1977 model based Trophic State Index	Secchi disk transparency, chlorophyll and total phosphorus	The productivity status of the studied lakes of Mysore was calculated by using Carson and Simpson formula	The studied lakes of Mysore revealed that they are in eutrophic condition and are in need for conservation	Murthy *et al*., 2008

Table 3. Vulnerability assessment associated with aquatic ecosystem through stake holder approach

Sl. No.	Place	Method	Inference	Reference
1	Kerala, India	PARS (parameter, attribute, resilient indicator and score) methodology to identify and rank different impact faced by fishermen community on environment, fishery and socio-economic parameters	Based on fishermen’s perception, fishery sector was mostly impacted by the consequences of climate change, followed by economic and environmental sector.	Salim et al., 2014
2	Tamil Nadu, India	Patnaik and Narayan model (2005) to assess vulnerability index of different coastal districts and PARS (parameter, attribute, resilient indicator and score) methodology.	There is a positive correlation with climate change and fishery sector of Tamil Nadu and Ramnathpuram district had the highest vulnerability followed by Kanyakumai and Nagapattinum district.	Johnson *et al*.,2016

3	Bangaldesh	Vulnerability assessment through stake holder approach based on ranking of indicators of exposure, sensitivity, and adaptive capacity.	Fishery based community of Bangladesh were highly sensitive to climate-related Stresses, especially floods and cyclones. This study also helped to reduce coastal livelihood vulnerability.	Islam *et al*.,2014
4	West Bengal, India	Vulnerability assessment through stake holder approach based on Modified Delphi method	seven potential climate change-induced threats on wetland fisheries such as water stress (95% consensus), sedimentation (85%), aquatic weed proliferation (70%) and loss of wetland connectivity (65%) were identified.	Naskar *et al*.,2017

Table 4. Models and Tools to predict Vulnerability of aquatic systems through GIS mapping

Sl.No.	Place	Models	Parameters	Explanation	Inference	Reference
1	Mulroy Bay, Ireland	(Navas *et al*., 2011) Combining GIS with neuro-fuzzy modeling	Bathymetry, Mean current velocity, Quiescence time, Granulometry, Oxygen depletion index and Stratification index	This model is used to classify the vulnerability of coastal areas appropriately to predict the suitability for aquaculture site selection.	Through sensitivity analysis along with GIS mapping and Neuro-fuzzy systems an approach to predict the protected and vulnerable areas was done, through which a positive correlation between vulnerability scores and	Navas *et al*., 2011

					ecological parameters (nitrogen concentrations) was established.	
2	East Coast of England	Risk Assessment Model using Arc-Info GIS package	Oceanographic and climatic parameters, data on sea defenses, elevation values and patterns of landuse.	This model was used to assess the insinuation of sea level rise along the east coast of England and also to estimate flood arrival periods with respect to climate change for upcoming years 2050 and 2100.	The results of the study indicated considerable vagueness coupled with sea level rise predictions.	Thumerer *et al*., 2000
3	Korea (Ocean)	GIS mapping	Exposure (Water temperature, Salinity, Dissolved oxygen),	With the help of GIS mapping assessment of vulnerability in	The vulnerability assessment indicated that	Park *et al*., 2011

			Sensitivity (Population of the Fishing Industry, Fishery Yield, Coastal area) and Adaptive capacity (Reliance Ratio of Local Finance, Gross Regional Domestic Product (GRDP)per person, A per capitanumber of civilservants)	relation to climate change of oceans was determined.	southwestern oceanwas more sensitiveand vulnerable than other part of the ocean.	
4	Atlantic ocean (Pará, Brazil)	(Szlafsztein and Sterr, 2007) Geographical Information Systems (GIS)-based composite	Coastline Length (km), Continentality, Coastline complexity, Coastal features, Coastal protectionmeasures,	Using ESRI's Arcview 3.2 program along with 16 separate natural and socio-economic variables were being used to	Three maps namely- Natural, Socio-economic and Total Vulnerability were presented and the	Szlafsztein and Sterr, 2007

		coastal vulnerability index (CVI)	Emergency relief – historic cases, Fluvial drainage and Flooding areas	create a single indicator that denotes the possible hazards occurred among regions and communities. Total Vulnerability Index = (Natural Vuln. Index + Socioeconomic Vuln. Index) / 2	confidence level associated with the results of the map was updated time-to-time for further analysis in the long run.	
5	Sukhna Lake, Chandigarh, India	(Dhillon and Mishra, 2013) GIS mapping using Landsat 7 ETM+	pH, DO (Dissolved oxygen) and Transparency using Sechhi Disk and Landsat 7 ETM+	The Trophic State Index had been recorded to estimate the present vulnerability fate of the studied lake.	The lake is in Hypereutrophic condition.	Dhillon and Mishra, 2013

Table 5. Description of ICAR-CIFRI research work with reference to vulnerability

Sl No.	Research Topic	Model/Index	Explanation
1	Adaptive climate change resilient indigenous fisheries strategies in the floodplain wetlands of West Bengal, India	Stakeholder approach through Delphi Method.	Some climate smart adaptive strategies had been identified such as Temporary pre-summer enclosure, Submerged branchpile (Kata) refuge, Deep pool (Komor) refuge and Floatingaquatic macrophyte refuge fishery (Pana chapa) can be used for sustainable fisheries management (Sarkar *et al*.,2018)
2	Pattern of reproductive biology of the endangered golden mahseer*Tor putitora*(Hamilton 1822) with special reference to regional climate changeimplications on breeding phenology from lesserHimalayan region, India	Gonado-somatic index (GSI) and fecundity	Mahseer is an important endemic fish found in Himalayan rivers and is part of lucrative sport fishery. From the study, the breeding phenology of golden mahseer was observed which stated reduction in duration of breeding season due to change in climatic scenario in lesser Himalayas (Joshi *et al*., 2018)
3	Baseline information of reproduction parameters of	Generalized additive model (GAM)	From the study, the benchmarked value had been inferred that Pre-spawning fitness (Kspawn50) and

	anamphidromous croaker *Johniuscoitor* (Hamilton, 1822) fromGanga river basin, India with special reference to potentialinfluence of climatic variability		length at 50% maturity (LM50) were 1.27–1.37 units and 19–24.5 cm respectively (Sarkar *et al*., 2017)
4	Understanding the role of climatic and environmentalvariables in gonadal maturation and spawning periodicityof spotted snakehead, *Channapunctata*(Bloch, 1793)in a tropical floodplain wetland, India	Generalized additive model (GAM)	The suitable range of rainfall and temperature obtained ranged between 800 mm to 1400 mm, and 29 °C and 31 °C respectively. The threshold GSI value was 4.14. Thus, the major climatic factors influenced reproductive behaviour of *Channapunctata* (Karnatak*et al*.,2018)
5	Quantifying climate change induced threats to wetland fisheries: a stakeholder-driven approach	Stakeholder approach through modified Delphi Method	seven potential climate change-inducedthreats on wetland fisheries such as water stress (95% consensus), sedimentation (85%), aquatic weed proliferation (70%) and loss of wetland connectivity(65%) were identified (Naskar*et al*.,2017)

Conclusion

Climate variability along with anthropogenic stresses on the environment produces potential negative impacts on various aquatic ecosystems. These impacts prompt efforts of mitigation or adaptation to nullify the impacts. Climate change generally will worsen existing tribulations including flooding and degradation of ecosystems.To adapt with the adverse consequences of climate change, the fisheries sector needs scientific information about important aquatic ecosystems and their resources in relation to climate change for structuring effective conservation and management action plan. Different tools and approaches for vulnerability assessment are considered as a crucial step to identify the present status of aquatic ecosystems and their resources with changing climate and environmental conditions, so as to implement actions that increase the resiliency of aquatic resources.

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Chapter 15

THERMAL EFFECT ON PHYSIO-BIOCHEMICAL ASPECTS OF FISHES AND THERMAL TOLERANCE UNDER CHANGING CLIMATIC SCENARIO

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Introduction

India is fortunate to be bestowed with inland open-water resources like rivers, estuaries, wetland, reservoirs, lakes and lagoons etc. (Sugunan et al., 1980) that are playing a vital role in the fish production, environment stabilization, livelihood of fishers' and rural economy. 'These resources are important natural resources playing a vital role in the fish production, rural economy and environment stabilization. Inland fisheries are important for maintenance of nature biodiversity as well as providing low cost protein, vital nutrients and livelihood to millions of people. In view of the above, understanding thermal tolerance of fish is important in relation to climate change situation.

Climate change' is the result of changes in natural internal processes, external forces or persistent anthropogenic changes in the composition of the atmosphere and land and regarded as matter of concern in global perspective. Climate change is also impacting the ecosystem in form of changes in rainfall pattern, sea level rise, shifting of season, acidification of water bodies, landscapes, loss in biodiversity and wildlife, extreme events, drought, forest fire, disease outbreaks etc. (Houghton et al., 2007). This is one of the biggest threats to both terrestrial and aquatic ecosystems including its biotic components. One of the impacts of climate change is increment of global surface temperature (1.4°F over the past century) known as 'global warming' (Anon, 2011). Increment in air temperature in future may induce rise in water temperature that may impact directly or indirectly various facets of aquatic ecosystem and fisheries as follows **(**Keith, 2010; Muhammad, 2010).

Table 1. Impact of climate change on aquatic ecosystem

Changes	Causes	Impacts
Increment of inland water temperature	Increments in air temperature	• Reduced dissolved oxygen (hypoxia/ anoxia) • More anaerobic bacterial growth and events of diseases and parasitic attack • Increased primary productivity of phytoplankton, periphyton and submerged macrophytes (eutrophication) • Reduced water quality and volume (water stress) • Limited food availability for fishes during summer • Changes in salinity and pH • Metabolites deposition • No water situation (drought)
Floods	Change in precipitation intensity, frequency, seasonality and variability	• Salinity change • Structural damage of small water bodies/habitat • Changes in flow rate, pH and turbidity

		• Introduction of disease causing agents and predator
Sea level rise	Higher temperature causing more glaciers melting	• Increase in salinity of coastal inland water bodies and undersea area • Structural damage of coastal area/ habitat
Ocean acidification	More CO_2 dissolve in water	• Shift of pH on acidic side directly impact some of phytoplankton and coral reefs and other aquatic animals

Fishes are poikilothermic animals and responds quickly to any increment in temperature change in their habitat. The habitat temperature may directly affect metabolic processes, oxygen demand, behavior, migration, growth, reproduction, and survival (Fry, 1971; Portner, 2001). The fishes from larger water bodies like ocean and in river will be able to migrate towards more suitable zone but it is not possible in ponds and wetlands putting them in more challenging situation to sustain in future climatic scenario (Ryan and Anthony, 2012). Some of the negative impacts such as reduction of fish size (Cheung et al., 2013), death due to hypoxia and immune suppression (Ouellet et al., 2013) already been documented in parts of the globe. Survival of fish in higher temperature depends on long-term of acclimation fish to gradually increasing temperature habitat with change of temperature in fish within physiological limit. This will induce in fish some mechanism that can cope the gradual change in temperature. The present article describes the effect of temperature increase in physiological limit, mechanism of thermal tolerance, methods of measuring thermal tolerance and application of measuring thermal tolerance of fish in Indian perspective.

Temperature increment in fishes and their effect

Due to global climate change future temperature of aquatic environment will increase that will potentially affect freshwater fisheries. Fishes are poikilotherms so any increment in temperature in their habitat will influence their activity of proteins and other tissue biochemical parameter related to metabolic processes, behaviour, oxygen demand, pathophysiological disturbances, migration, growth, reproduction, and survival. The fishes from larger water bodies like ocean and river will be able to migrate towards more suitable zone, which is not feasible in ponds and wetlands.

Effect on physiological aspects of growth and reproduction

Temperature or heat may affect the fish in positive manner upto certain optimal level beyond which it hampers the growth of fish. Reduction of growth due to extreme temperature can be matter of economical concern for fish farmers. Differentmethods or tools are available to monitor growth of fish in nature and long term experiments. Some of them are as follows:

- Condition factor (CF) = 100 x (weight (g)/length^3 (cm))
- Specific growth rate (SGR) = 100 × [ln final weight (g) - ln initial weight (g)] /time (days)),
- Feed conversion ratio (FCR) = feed intake/weight gain
- Weight gain percentage (WGP) = 100 X [final weight (g) - initial weight (g)] / initial weight (g))
- Critical oxygen tension (Pcrit) is defined as the oxygen pressure (PO2) below which an animal can no longer maintain a given rate of oxygen consumption and is known to increase with increase in temperature (Ultsch et al., 1978). Critical O_2 tension is an indicator of shifting metabolism from oxygen independent to oxygen dependent one.

Similarly, stressful temperature may also affect reproductive performance which may some situation may lead to extinction of some fish species in future.

Monitoring of reproductive success of fish species in such situations may involve the following methods:

- Gonadosomatic index (GSI)= (gonad weight (gm) / body weight (g)) x 100)
- Ova diameter and fecundity.

Effect of thermal increment at biochemical and molecular level

Long term exposure to higher thermal environment although showed some tangible expression in physiological level like somatic and reproductive growth , however these parameters are unable to provide sufficient information particularly for short span laboratory experiments under controlled conditions for which biochemical parameters are required to be monitored. "Fight or flight or" is the common response under stress for all kind of species including fish. Under 'fight' stress, animals try to alter its biochemical mechanism to cope the situation either in short term basis for survival or for long-term basis for adaptation. Survival and adaptation is the reflection of one's altered gene expression pattern in cellular signaling system, metabolites, and enzyme activity to maintain performance and survival.

Metabolisms: Most of the experiments are set for very short time periods like 1 to 2 months during which change in growth parameter occur. Blood glucose and cortisol are general stress markers of species. In stress, fish try to increase glucose in blood to provide energy to vital organs like brain. Cortisol activates the entire enzyme system required for new glucose synthesis (gluconeogenesis) in liver and stop glycolysis in all of the tissue except some vital organs. The conversion of protein to glucose also increased at stress situation. Being a steroids hormones cortisol is able to control expression of some protein in transcription level. Glucose, triglycerides and protein are the main energy sources of foodstuffs, provided to a species. Glucose is the immediate energy source while protein provides energy during

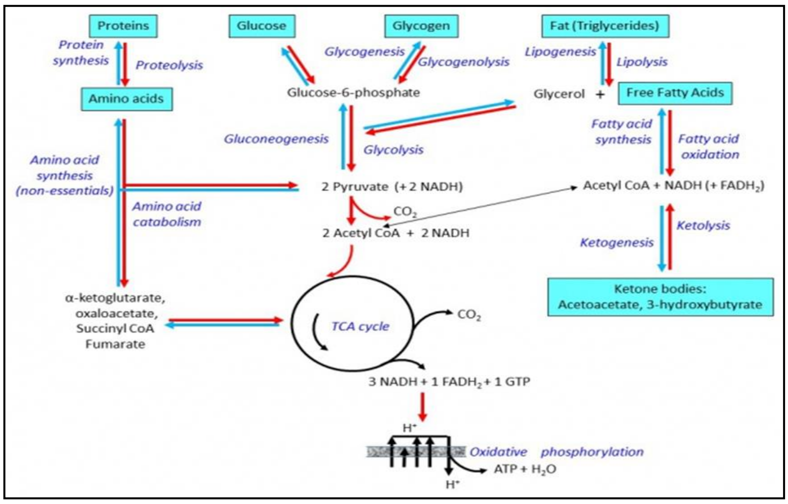

Fig.1. Overall glucose metabolisms (Adapted from Ward, 2016)

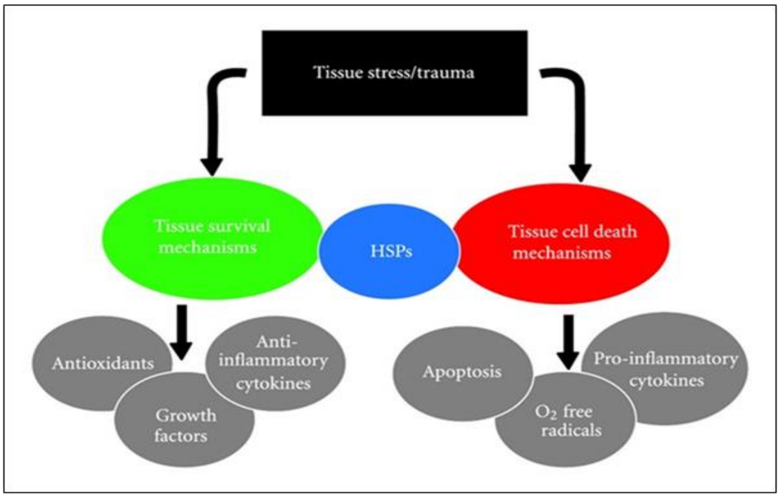

Fig. 2. Role of heat shock proteins (Adapted from Millar and Murrell, 2012)

prolonged hunger and in certain physiological disorders. Triglycerides act as energy source in case of higher energy demand. Stress indicates higher energy demand for which some researchers searched concentration of energy rich molecule like ATP, phosphocreatine, liver succinate etc. (Dijk et al, 1999) as possible marker for thermal stress (Dijk et al., 1999). As metabolisms of bimolecular are under hormonal control, hormones like cortisol, T3, T4, epinephrine and norepinephrine are important during stress. Every enzyme has an optimum temperature and pH which known to be changed during heat stress. Enzymes of carbohydrates metabolism (hexokinase, phosphofructokinase1, glucose 6 phosphatase, fructose -1,6 bis-phosphatase etc), protein metabolism (transaminase) and lipids metabolism (lipase) are the most important in this respect (Naga and Bernard, 2012; Ton et al., 2003). Realtime PCR data of hsp70 expression pattern showed higher expression in slower process than faster process (unpublished data).

Heat shock responses: Function of protein depends on its native 3D structure which may be denatured due to rise in temperature causing disturbance in the weak interaction. Heat shock proteins (HSPs) are the molecular chaperon required for proper folding of protein and also involve in protein transport to cellular compartments. Elevated temperature induces heat shock response and induced expression of various HSPs (Wu, 1995) like HSP10, HSPB, HSPA group, HSPC group, HSP40, HSP60, HSP104, HSP110. (Li and Srivastava, 2004; Schlesinger, 1990; Antonova et al., 2007; McLemore et al., 2005; Salinthone et al., 2008), HSP30, HSP70, HSP90 beta, HSP27, HSP47 and HSP60 (Wang et al., 2007), HSP78 (Norris et al., 1995) and warm acclimation protein (Kikuchi and Watabe, 1997). Hspeat shock protein is involved in different biochemical processes inside cell (Fig 2.)

Oxidative damage: Reactive oxygen species and reactive nitrogen species are the main defense mechanism for innate immunity that destroys microbes using free radical as oxidizing agents. Both of them are very toxic to cellular molecules like DNA and membrane unsaturated fatty acids which are protected by system of compartmentalization and protective mechanisms like reduced glutathione (GSH), catalase, peroxidase etc. Higher temperature induces oxidative stress through production of reactive oxygen species (ROS) causes cellular aging and death (Katja et al., 2006). In this regards, lipid peroxidation (Madeira et al., 2013), antioxidant enzymes (catalase, glutathione peroxidase, superoxide dismutase, glutathione –s-transferase) and non-enzymatic molecules (GSH, pyruvate, albumin, transferring etc.) (Naglaa, 2012; Jorge and María, 2009*)* indicates temperature induced oxidative stress and protective mechanisms to provide thermal tolerance. In our study fish were exposed to thermal stress in two different rates and their biochemical response were monitored.

Metabolites: Metabolic end products like ammonia, urea (Mommsen and Walsh, 1992) may create stress in on some harmful microbes and toxic effects for fishes of species which are unable to dilute the metabolites during water scarcity related temperature induction. Glutamine synthetase and carbamoyl phosphate synthetase are the enzymes involved in catabolism of nitrogenous substances and can be used as markers.

Biomolecules associated with growth and reproduction: The effect of thermal events in fish is reflected in different level of organization of fish staring from increase in size and weight of fish to biochemical and molecular events that specify the growth in long term. Due to increase in temperature the protein synthetic machinery involve in protection for thermal strees will be induced lerading to higher transcriptional and translation activity. In this regard, RNA- DNA and protein- DNA ratio in tissue can be used as good indicator of growth and metabolic state (Tomas et al., 2009; Buckley and Caldarone, 1999). Similarly, in case of short term temperature stress, blood hormones (estradiol, progesterone), ovarian protein (vitellogenin), enzymes (cathepsins), and serum calcium (Lee et al., 2008) can be used to monitor impacts of heat on reproductive success.

Immunity: Changes in water temperature, dissolved oxygen, eutrophication and metabolite load may lead to alteration in quality of habitat environment that may entertain pathological microbes. Impact of thermal stress on immune system can be monitored by measuring complement 3, macrophage activity, toll like receptors (adaptive immunity) and IgM (acquired immunity) etc **(**Nikolaus et al., 2004; Elisa et al., 2008).

Impact of thermal stress on other environmental parameters and associated health impacts

Heat stress is also known to induce other types of stresses, the impacts of which are cumulative.

Hypoxia: For maintenance of life of fishes, dissolved oxygen (DO) is one of the vital requirements, although not extreme for air breathing one. Higher temperature causes oxygenic stress and induces hypoxic/anoxic condition in fishes by decreasing the water solubility of gas and eutrophication. Hypoxia caused gill remodeling (Andy et al., 2012), , increased packed cell volume, hematocrit, lactate, alanine (Jimmy et al., 2006), expression of hypoxia-inducible factors (HIFs) (Semenza et al., 2004), hemopexin, heme oxygenase 1, ferritin (Gracey et al., 2001), genes of glycolysis (phosphoglycerate mutase, enolase, aldolase and lactate dehydrogenase), lactate dehydrogenase, prolyl hydroxylase domain containing protein 2 (PHD2) (Beers and

Sidel, 2011), CYTO1, NAD4L, erythropoietin**,** myosin light chain 3 (MYLZ3) (Gracey et al., 2001; Naga and Bernard, 2012; Ton et al., 2003), hemoglobin specificity (Bohr's effect) or switching expression to other isoforms (Rutjes et al., 2007) and decreased TCA cycle enzymes (succinate dehydrogenase, malate dehydrogenase) (Naga and Bernard, 2012; Ton et al., 2003).

Acidic pH and carbon dioxide stress: One of the impacts of global warming is higher amount of carbon dioxide (CO_2) in air that when dissolves in water form carbonic acids and thereby reduces the pH of the water bodies. Fish are known to tolerate pH in the range of 4-10 beyond which it experience stress and may die. Changes in the function of Cl^-/$HCO3^-$ exchanger, Na^+/H^+ exchanger, V type H^+- ATPase and Na^+, K^+- ATPase and increased cellular turnover and apoptosis signaling (annexin 5, eukaryotic translation elongation factor 1γ, receptor for protein kinase C and putative ribosomal protein S27 in fish gills) were observed in some fish species.

Water stress: Water stress may be defined as shortage of required water due to reduction in volume, depth as well in quality. As higher water temperature causes reduction in volume, water parameters, water quality, eutrophication, most of physiological and biochemical alteration effected by water stress are similar to other stresses.

Thermal tolerance

Effect of temperature on water bodies vis-a vis fishes need to be studied to understand the changes in fish physiology and behavior that may add knowledge to understand mechanisms of thermal tolerance of different fish species. Impacts differ from species to species, micro climatic zone of their habitat and rate of temperature increase.

Increment of temperature will be beneficial for some species but temperature beyond certain limit act as stressor. The fish that are unable to migrate survive by compromising their performances in terms of growth, immunity and reproduction; while in extreme temperature may lead to death. The range of temperatures at which a species will sustain is matter of concern in future temperature regime. Proper documentation and scientific knowledge for quantification of extent of thermal stress of a species either in field level or in laboratory is very essential to ascertain survival. Integration of both the data will help to predict thermal stress response of fishes followed by survival in future scenario. A fish species is said to be tolerant to a particular temperature when it will survive at that temperature. Sub lethal thermal stress may induce heat shock protein to maintain their homeostasis and survival by cross protection at higher acclimation temperatures. Higher acclimation temperature induces gluconeogenesis for

maintenance of energy level using lactate and amino acids as a substrate and glycogenolysis in *L. rohita* (Das et al. 2006).The mechanism of tolerance depends on exposure to temperature of acute, sub-acute or chronic in nature. Chronic slow exposure to higher temperature gradually helps fish to reorganize its molecular, biochemical and physiological and anatomical adaptation to changed habitat.

Variations of climatic variables especially temperature in future will be threat for several fish species and there is need for identifying alternative species for sustainable production and livelihood of fisherman communities. Therefore, identification of tolerant species is essential and in this context CT_{max} of 14 fish species of different sizes from natural resources (river Ganga, wetlands) and culture systems (ponds) were assessed (Fig. 3). Some biochemical data were also generated to study thermal stress. Preliminary establishment of relation of blood biochemical changes with reproductive maturity stages of *Labeo rohita* was also determined.

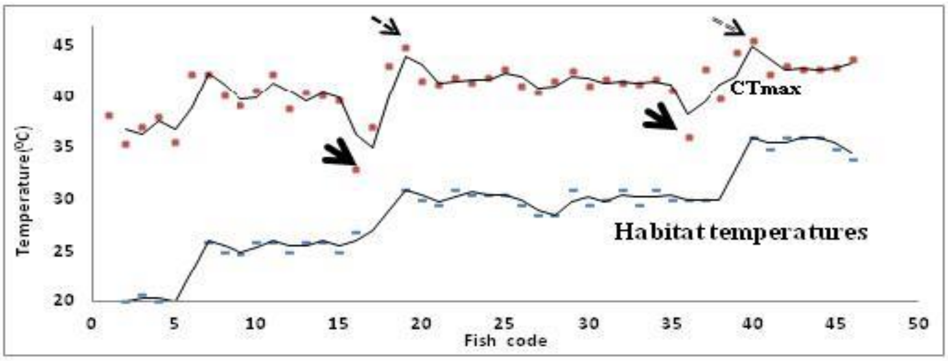

Fig. 3. CTmax and habitat temperatures of some fishes (Adapted from Aftabuddin et al. 2017)

CTmax values of important fish generated in our laboratory and that collected from literature showed fishes as more tolerant by dotted arrow and that as species that are more sensitive by bold arrow. (Fig. 3).

Assessment of Thermal tolerance in fishes

Effect of temperature or thermal increase in water bodies vis-a vis fishes need to be studied to understand the changes in fish physiology and behavior that may add knowledge of thermal tolerance of various fish species of aquaculture importance. Thermal tolerance as well stress of a fish species can be ascertained by following methods:

Lethal temperature is the temperature limit upto which fishes are documented to live and maximum point is called LTmax (Lethal temperature maximum).

Critical thermal maximum (CT max) may be defined as the temperature where fishes losses it's balance/equilibrium (LOE) due to increase in temperature at a constant rate from ambient temperature but become normal within few minutes after immediately transferring them to ambient temperature before the death point (Bennett and Beitinger, 1997; Majhi and Das, 2013). Thermal tolerance may be measured through several techniques, with CTMax being preferred for comparing the relative thermal tolerance of different groups as it is non-lethal, reflects a fish's ability to tolerate thermal stress, and can be measured precisely using readily available equipment (Beitinger et al., 2000). In our lab experiments, we determined CTmax of some of importance Indian carp species of different sizes collected during different seasons (unpublished data).

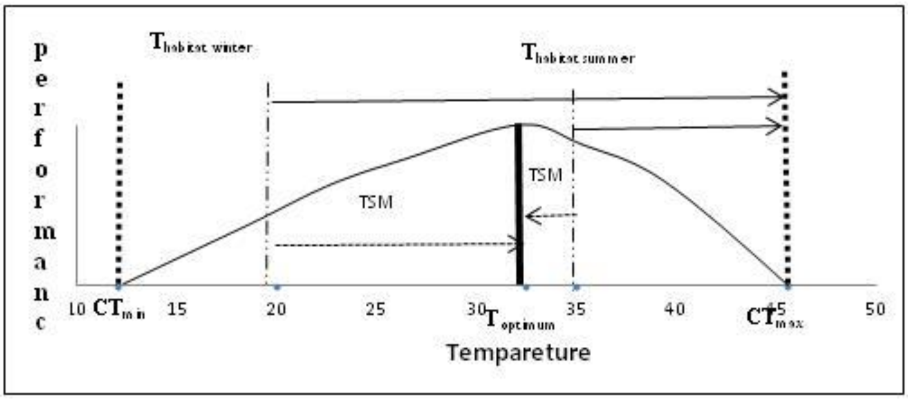

Fig. 4. WT and TSM of fish during winter and summer

Warming temperature (WT) is the measure of organism's thermal buffer or elasticity and defined by CTmax - T_{habit} (Jennifer et al., 2014). Higher the value of CT_{max} of a species, higher will be WT if they are from same environment. Comparison of species WT allow to choose species that are more tolerant.

Thermal Safety margin (TSM) is the difference of optimum and available habitat temperature and expressed as $T_{optimum} - T_{habit}$ (Jennifer et al., 2014). TSM help to predict performance of a fish in changed scenario. In order to generate information on TSM and WT, understanding of $T_{habitat}$ and $T_{optimum}$ is essential. $T_{habitat}$ (temperature of habitat) is the temperature of the environment where fish species generally live. Habitat temperature of species varies throughout the globe with different climatic zone. $T_{optimum}$ is the temperature of optimum performances of species and performances are measured by locomotion, growth, metabolism and reproduction.

There were some other methods to study thermal tolerance like acclimated chronic exposure (ACE), chronic lethal method (CLM), ACE with dial temperature fluctuation, LD50, Initial loss of equilibrium (ILOE), final loss of equilibrium (FLOE), flaring opercula and death (Bennett and Beitinger, 1997; Becker et al., 1979; Corissa et al., 2007).

Factors affecting thermal tolerance of fish

Most fishes are ectotherms and the effects of environmental temperature acting on the energy allocation at the organism direct their tolerance to extreme temperatures level such that the energy is re-directed to meet metabolic demands at high temperatures (Portner, 2002). Tolerance of a particular fish species depends on various factors relating to fish itself and its habitat. Fish species inhabiting in the same aquatic environment may vary with respect to temperature tolerance.

Factors like fish species, sizes, life stages (Recsetar et al 2012) and habitat condition (thermal history and dissolved oxygen), rate of temperature increase (Mora and Maya, 2006) and acclimation temperature (Fangue and Bennett, 2003) affect CT_{max} values of fish species influencing their survivability and tolerance. Portner and Farrell (2008) proposed that thermal tolerance should be narrower for larval fish and spawners and widest in juveniles. The narrower range of temperature tolerance in larval fishes may be explained by their lower energy reserves despite their high mass-specific metabolic rates, whereas in reproductive adults it is likely to be attributable to the increased oxygen demand to supply gonads (Portner and Farrell, 2008). Fish body size is another factor likely to affect oxygen-limited thermal tolerance, given strong relationships between oxygen consumption and body size and metabolic costs associated with growth and reproduction (Chretien et al, 2016). Larger fishes consume more oxygen per unit time, but less oxygen per unit mass per unit time.

Thermal tolerance range was increased with increasing acclimation temperatures in *L. rohita* which may be due to the increasing levels of heat shock proteins (Das et al., 2006). Tropical species have a lower acclimation capacity than their temperate counterparts indicating more vulnerability of tropical species to even small increases in habitat temperature (Leal, 2014).

Aquatic hypoxia is another potential stressor affecting the tolerance of fish to thermal stress.Toxic chemicals can affect the temperature responses of fish by exhibiting a preference for or avoidance of a particular temperature or they may undergo changes in thermal tolerance. The reduction in thermal tolerance of fish in the presence of endosulfan and chlorpyrifos suggest that, not only does temperature influence the sensitivity of fish to a toxic chemical but chemical exposure also affects the temperature tolerance of fishes (Patra et al, 2007).

Conclusion

Thermal tolerance of documented riverine fish species can be compared to prioritize the species having better potential to breed in captivity so that they can be cultured in higher temperature environment. Available information on thermal tolerance and their mechanism would provide sufficient information in better understanding of heat stress, thermal tolerance and adaptation mechanisms of species for identifying more tolerant species in suitable situations. Future migration of a species and related change in community composition can be predicted. Information on warming

temperature (WT) of fishes indicates survivability without considering performance while TSM considers performance. Both the parameters are essential to prioritize fishes in terms of thermal elasticity (survivability and performance) and can help in selecting the tolerant species in a given temperature. Wide thermal elasticity and beneficial growth performance can be predicted during winter in future warming regime considering available information. Reduction of growth due to higher temperature is the matter of concern on economic ground of fisheries and aquaculture, while alterations in reproductive performance due to higher habitat temperature may lead newer breeding strategy or extinction of some fish species. Compromise in growth and reproduction due to thermal effect allows quantifying extent of thermal stress to be tolerated by a species and developing type of mitigation strategies to save the species.

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Chapter 16

CLIMATE CHANGE ADAPTATION OPTIONS IN INLAND WATERS

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Introduction

Vulnerability of inland fisheries has been universally and unanimously recognized by fisheries experts all over the world. Before some 20-30 years, experts in the field were probably not bothered about sustainability and vulnerability. The sector at present is facing various man-induced and natural problems which are being assessed either qualitatively or quantitatively employing theoretical and/ or experimental methods. Majority of the man-induced problems are due to increase in the fishers' population, increased dependency on natural fisheries, increasing fishing efforts, capture of juveniles and brooders from the waterbody etc. Majority of the natural problems are due to abnormal floods, siltation leading to reduced water depths, closure of connecting channels of rivers to the wetlands, abnormal drought-like (dry) situations affecting natural fisheries, etc. The present situation in most of the inland water resources can be termed as highly vulnerable both in the resources and fishers points of view. Research efforts are now directed towards developing/ documenting adaptation strategies so that inland fisheries and fishers dependent on such fisheries can cope with ever-increasing climatic vagaries that are facing the entire system. In this chapter, an account of practical, proven and suggestive technologies or practices is presented as adaptation options in inland fisheries vis-à-vis climate change.

Adaptation option for altered temperature regime

Reports of abnormally high or low temperature events are publishedin newspapers on a regular basis not only from India but also from various places in Europe and Americas. The temperature data of thirty years (1980-2010) in and around Guwahati, Assam, India showed the annual mean maximum temperature fluctuated from 28.5^{o}C (1983) to 31.2^{o}C (2009) during 1980 to 2010 showing a variability of 3.7^{o}C over a 30 years period. Similarly annual mean minimum temperature increased from 19.6^{o}C in 1980 to 20.3^{o}C in 2010 thereby showing an increase in 0.7^{o}C over the same period (Saud et al., 2012). Water temperature determines most of the other water quality parameters like dissolved oxygen, pH, nutrient concentration and toxicity of natural and anthropogenic pollutants. Now, temperature of water is determined by the air temperature and other natural causes, which cannot be controlled, in general, by fishermen. We also know that relatively little water temperature change can alter fish metabolism and physiology, with consequences for growth, fecundity, feeding behavior, distribution, migration and abundance (Marcogliese, 2008).

Fish being poikilothermic, within a certain limit, increase in water temperature will enhance the metabolic rate and hence growth of fish provided sufficient food is available. There is a probability that increased temperature will lead to rapid growth and maturation of fish, which can be beneficial in situations wherein the target fish is a slow grower and having delayed maturation in normal condition. Sharma et al., (2015) suggested that temperature change will have impact on the suitability of species for a given location. For example, the Indian Major Carps (*Labeo catla*, *Labeo rohita* and *Cirrhinus mrigala*) will grow faster up to a water temperature of 33ºC but from 34ºC and above feeding is reduced and growth reduces (Sharma et al., 2015). Another positive aspect of increased temperature (along with increased pre-monsoon rainfall) is an extended breeding period of Indian major carps, which is about 40-60 days more than what it was 30 years back. In India, the inland aquaculture is centred around culture of Indian major carps, and their spawning occurs during the monsoon (June-July) and extends till September. In recent years, the phenomenon of IMC maturing and spawning as early as March is observed from this agro-climatic condition of North-eastern region, making it possible to breed them till the end of August of a year. Thus, there is an extended breeding activity as compared to a couple of decades ago (Dey et al., 2007).

Some of the options hatchery operators, fish farmers and fishermen can take up to cope with altered temperature regime or use the climatic event for their own benefit are:

(i) Selection of temperature-resilient fish species. Exotic carps such as *Ctenopharyngodon idella* (grass carp), *Hypophthalmichthys molitrix* (silver carp) and *Cyprinus carpio* (common carp) seem to perform well in cold temperatures compared to Indian major carps *Labeo catla* (catla), *Labeo rohita* (rohu) and *Cirrhinus mrigala* (mrigal).

(ii) Minor carps such as *Labeo bata* and *L. gonius* seem to perform better in colder temperatures.

(iii) Hatchery operators can opt for a large number of species for induced breeding and seed production because majority of IMCs, ECs, minor carps and catfishes attain early maturity (starting February-March).

(iv) Sanitation of the waterbody (with regular liming, removal of excess bottom mud etc.) should be maintained during cold winter months to avoid incidence of disease conditions, because 'winter syndrome' is a very common phenomenon in fish farms and floodplain wetlands of North-eastern India.

(v) To avoid 'heat kills' of fish during warmer days, provision of shades (with banana leaves, *Eichhornia* aggregates etc.), maintenance of a few deeper areas for the fish to take shelter etc.

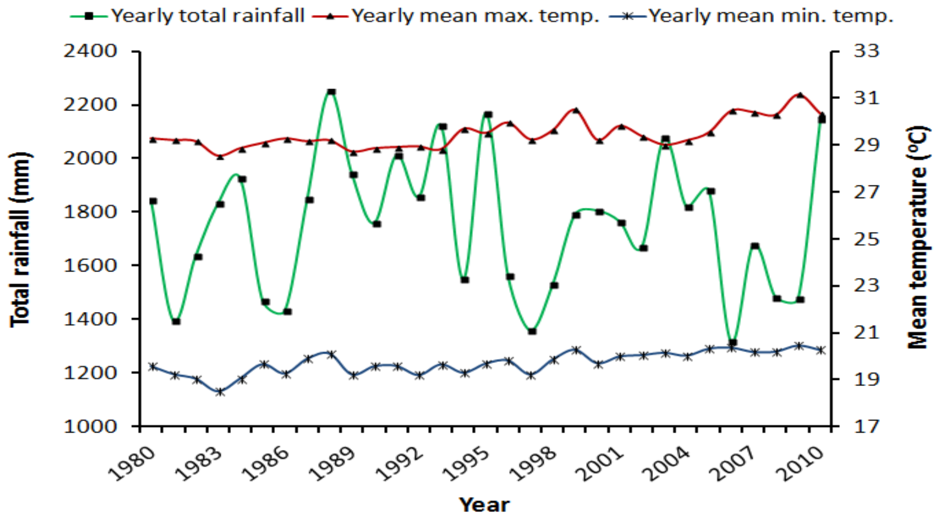

Fig.1. Annual mean rainfall, mean maximum and minimum temperature fluctuation pattern in and around Guwahati, Assam over the last 30 years (1980-2010). [Source: IMD, Pune] (Reproduced from Saud et al., 2012 with permission).

Adaptation option for altered rainfall regime

Rainfall seasonality, frequency and intensity have shown unexpected and abnormal patterns throughout India and elsewhere. Analysis of rainfall data of West Bengal for the period 1999-2009 indicated a drought year, i.e., 2009. A comparison was made between the average monthly rainfall of 1999-2009 with that of average monthly rainfall of only 2009. It showed that the amount of rainfall in the year 2009 during March was 20.6mm (-25%), April 2.0 (96%), May 229.2 (+146%), June 69.6 (-71%), July 278.7 (-11%), August 329.6 (+6%) and September 293.9 mm (+9%) in comparison to average of 1999-2009 (Sharma et al., 2015). In the districts of North

24 Parganas and Bankura of West Bengal, rainfall during the fish breeding months (March to September) was deficient by 29% and 27%, respectively during 2009 in comparison to the time period 1999-2008 (Sharma et al., 2015).

The rainfall data of thirty years (1980-2010) in and around Guwahati, Assam, India also showed considerable climatic variability (Fig.1). Yearly mean rainfall showed considerable year to year fluctuation during the period showing ten peaks and troughs. The amount of rainfall experienced by the region during the study period ranged from 1314.8 mm in 2008 to 2250.2 mm in 1988 showing wide variation of 947.4 mm. No definite trend of variation was observed in the rainfall pattern in the region apparently because rainfall is influenced by a complex set meteorological parameters/factors like atmospheric temperature, atmospheric and oceanographic events (including south west monsoon cycle) etc. (Saud et al., 2012).

Some of the options hatchery operators, fish farmers and fishermen can take up to cope with altered rainfall regime or use the climatic event for their own benefit are:

(i) Readiness to take prompt action either to pump out excess monsoon water or pump in river or ground water while water table of the farm goes down. The same can be practiced in case of smaller floodplain wetlands or reservoirs also.

(ii) Hatchery operators should be rainfall-ready for seed production once their brood fish is getting matured. Because of the uncertainty in monsoon rainfall patterns, a hatchery owner should be always ready in such a way as to operate whenever there is sufficient rainfall.

(iii) Wetland and reservoir fishers should be ready with their fishing tools and as soon as they anticipate a heavy rainfall and consequent flooding, majority of the stock should be harvested without much delay.

(iv) Creation of sluice gates and maintenance of inflow and outflow should be regularized to minimize the effect of water flow inside the waterbody and out from it.

Pen culture as adaptation option in wetlands

Pen culture experiments were initiated by ICAR-CIFRI, Barrackpore in 1989 in Dighali beel, Kamrup, Assam wherein common carp (*Cyprinis carpio*) seed was successfully raised. Another set of experiments on pen culture was conducted in Bagheswari beel, Mandira, Kamrup district in 1996-97. This was followed by large-scale demonstration of the technology in over 10 beels of Assam under the NATP (Jai Vigyan) sub-project during 1999-2003. The Institute continues to refine the technology of pen culture in selected wetlands of Assam, Manipur, West Bengal, Bihar, Uttar Pradesh. CIFRI has developed/ refined low-cost and simple technologies for fish culture in pens erected in shallow areas (water depth up to 2 m) of wetlands. The previous field experiments/ demonstrations have shown that fingerlings raised in enclosures are well adapted to the wetland environment and, therefore, survive and grow well when they are released in the wetland proper. Further, pens can also be used to raise table fish, which is especially suitable for weed-choked wetlands, where recapture of stocked fingerlings is difficult.

Site for pen installation should have a gentle slope and have water depth of less than 2 m during the rearing season. A mild water flow is desirable. However, the area should not experience strong wind and wave action. Proposed site should not have dense aquatic and terrestrial vegetation. Easy availability of required construction materials at reasonable rates, cheap labour, good communication and social environment are other important considerations in site selection.

Pen culture can be carried out throughout the year. However, the pens may be submerged by flood/ surface run-off waters during the peak rainy moths (June to August) especially in seasonally open wetlands. Similarly growth of most native candidate species is slowed down during the peak winter months (December-January). Therefore, the periods that are ideal for undertaking pen culture in most wetlands of the region are September to December and February to May.Small pens are easier to manage, and require less cost. However, construction of bigger pens facilitates better fish growth and is more economical. Past studies conducted by the Institute have shown that pens measuring 500-2500 $m^2$are found to be both economical and manageable.

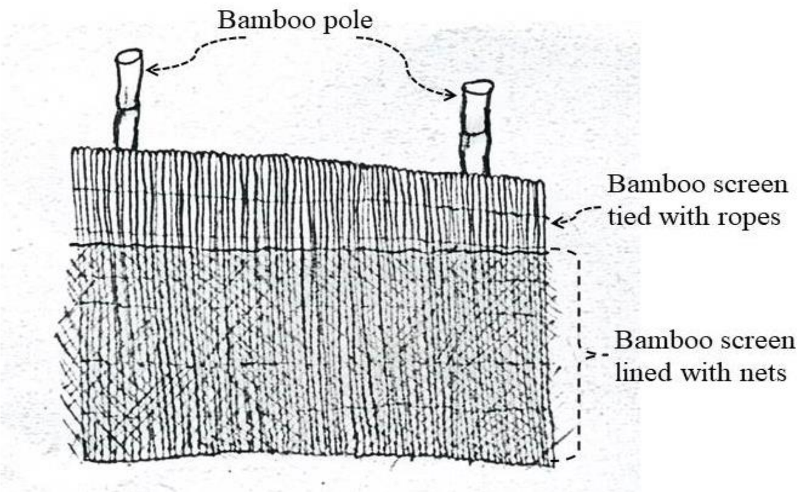

Fig. 2. Schematic diagram of bamboo screen (*bana*) lined with nets and supported by bamboo poles for constructing pens in a wetland/ lake/ pat.

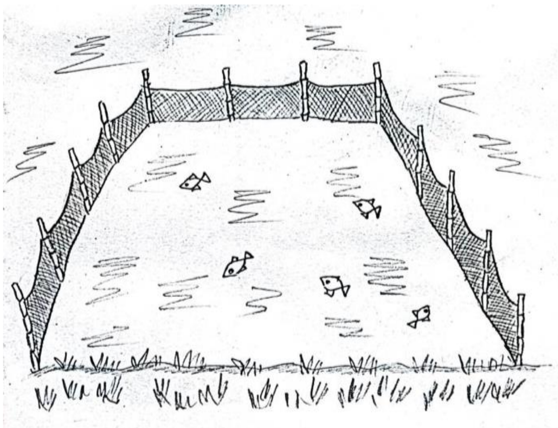

Fig. 3. Schematic diagram of a pen constructed using bamboo screen (*bana*) lined with nets and installed in the shallow marginal areas of a wetland/ lake/ pat

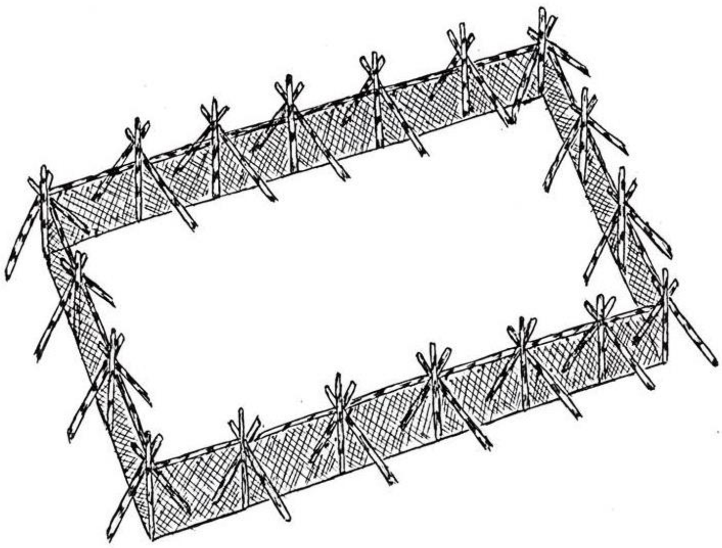

Fig. 4. Schematic diagram of a pen constructed using nets (nylon or HDPE) supported by bamboo poles and installed in a wetland/ lake/ pat

Cage culture as adaptation option in inland waters

Cage culture in inland open waters is proven to be a successful technology providing economic benefits of producing high biomass per unit area. This technology can be adopted under various agro-climatic conditions. Cages are used for rearing aquatic organisms in a volume of water enclosed on all sides with cage netting materials including bottom, while permitting the free circulation of water through the mesh of cages.Cage aquaculture has become a common technology in Central and South-east Asian countries such as China, Philippines, Indonesia and Thailand (Beveridge 1996, Beveridge and Stewart 1998). A wide range of marine and freshwater species are cultured in cages including seabass (*Lates calcarifer*) (Rimmer and Russel 1998), grouper and snapper (Subfamily: Epinephelinae) (Seng, 1998), tilapia (*Oreochromis* spp.), milkfish (*Chanos chanos*) (Bagarinao 1998), *Pangassius*, Grass carp (*Ctenopharyngodon idella*) and many others. ‘Traditional’ small-scale cage culture activities may be distinguished from the intensive cage production systems by their reliance on natural construction materials and low levels of feed inputs. ‘Modern’, intensive cage aquaculture typified by the use of synthetic, manufactured materials and commercial feed inputs first appeared in Japan with the culture of yellowtail (*Seriolaquinquer adiata*) in the 1950s. Atlantic salmon (*Salmo salar*) was first cultured in Norway a decade later while tilapia cage culture originated in the USA during the late 1960s (Beveridge, 1996).

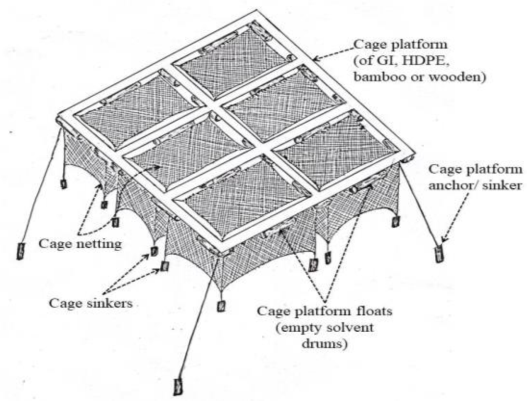

Fig. 5. Schematic diagram of a set of floating cages showing its platform, floats, sinkers and nettings

In India, cage culture was attempted for the first time in case of air breathing fishes like *Heteroneustes fossilis*, *Anabas testudineus* in swamps (Dehadraiet al., 1974).There were several attempts for replacing the ground nurseries with hapas/ cages. Studies conducted by Natarajan et al., (1979) and Menon (1983) showed thathigh survival rate ranging from 25-85% while raising carp fry in floating cages. Among carnivorous fishes, the giant murrel, *Channa marulius* cultured at density of 40 fish/m^3 in cages fed with trash fish, grew to an average size of 200 g in 6 months, recoding a net production of 0.8 kg/m^3/month. Further, trials on cage culture carried out at Darbhanga (Bihar) and Guwahati (Assam) under Coordinated Research Project on Air Breathing Fish Culture demonstrated production level of 0.3, 0.7, 1.0, 1.7, 1.5 and 1.3 kg/m^3/month for *Anabas testudineus*, *Heteropneustes fossilis*, *Clarias batrachus*, *Channa striatus*, *Channa punctatus*, respectively (Dehadrai, 1972).Fish production levels from cages used for growing marketable fish vary greatly depending on the type of management of inputs. Further, the number of fish that can be stocked in the cages depends on the carrying capacity, water exchange, species of fish, and quality and quantity of supplemental feed input.

Rearing and raising of fishes in cages is gaining importance all over the world because of its increasing technical, ecological, social and economic advantages over capture fisheries and conventional aquaculture. Cage fish culture technology is (i) compatible, non-competitive and complementary to other systems, (ii) applicable to almost all aquaculture species, (iii) idealfor open waters with low fish yield such as inland reservoirs, large rivers, coastal estuaries and other waterbodies relatively protected from turbulent waves and storms, and (iv) technologically simple, not-much capital intensive. It has social advantages in that landless people can find habitation and employment in cage aquaculture (Costa Pierce, 2002).

Small-scale cage aquaculture has been shown to be a flexible technology adaptable to the needs of poor people. By providingthe cages under the ownership of the landless farmers promoted the use of otherwise 'fallow' waterbodies (Hambreyet al., 2001). Operations carried out over shorter periods, such as fish overwintering, nursing, and fattening in small cages, fit well with the income-generating strategies of the poor by providing them with a potential source of income in periods of hardship and shortage (McAndrew et al., 2000). When integrated in ponds, cage culture allows the simultaneous farming of fish species at different tropic levels (caged fish are fed high-protein diets, while pond filter feeding species depend on caged fish wastes), enabling incremental production of biomass per unit of water while recycling nutrients (Yang and Lin, 2000).

Floodplains wetlands in India are an important resource for livelihood both for rural and urban communities. These wetlands are widely distributed throughout the Eastern and North-eastern part of India under the river Ganga and the Brahmaputra basins. They form the prime fishery resource in the state of Uttar Pradesh, Bihar, West Bengal, Assam, Manipur, Tripura, Arunachal Pradesh and Meghalaya, where they are commonly known as beel, moan, tal, jheel, pat, boar, chaur, etc. (Jha, 1989). These wetlands are one of the most productive aquatic environments of the world, as they can produce benefits eight times more than those of a paddy field of an equivalent area (Jhingran, 1989).As most of the beels have lost their riverine connections, the main source for auto-stocking of fish seed have been blocked, particularly those infested with weeds (Sugunan, 2000). In such a scenario rearing and culture of fishes in cages is advocated as a potential tool for beel fisheries enhancement especially in situations where the beel is heavily weed-choked.

Deep pools as adaptation options

Deep pools naturally exist in waterbodies such as rivers, floodplain wetlands and lakes. As the name suggests, these are areas where sufficient level of water remains accumulated even when there is drought-like situation in the waterbody. Some of the floodplain wetlands located in Lakhimpur and Nagaon districts of Assam get almost dried up during winter season, but there are some places in the waterbody where there are some deep pools. Fishes accumulate in those deeper areas for their survival. Creation of deep pools in shallower wetlands can be an adaptation strategy that can be used by beel fishers to overcome many problems. Following are some of the advantages that can be accrued by creation or making judicious use of such deep pools: (i) distress harvest and sale of fish can be prevented even if water level of the beel gets reduced because of drought; (ii) occasional harvest and sale of fish can be easily done from the deep pools; (iii) deeper areas can be used as breeding grounds for self-replenishing small indigenous fishes.

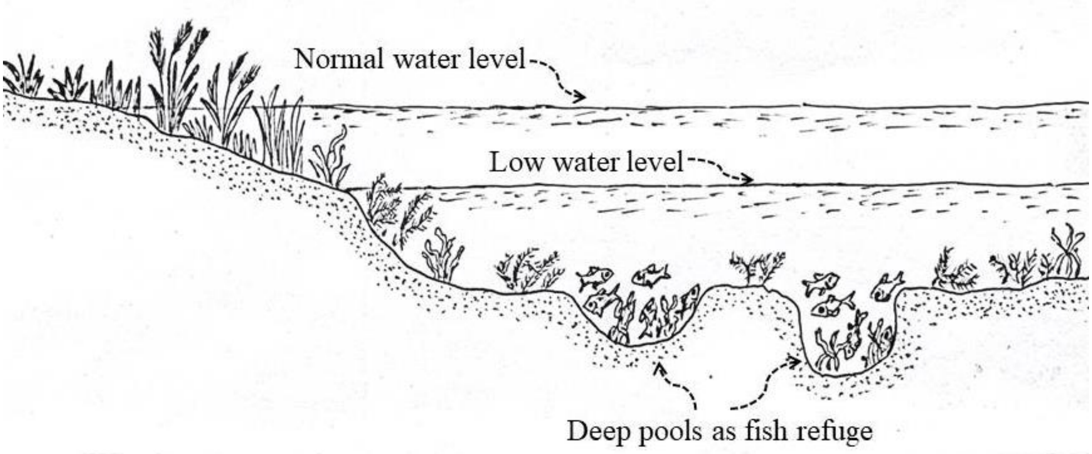

Fig. 6. Schematic diagram of deep pool in an aquatic ecosystem

Erection of fences/ screens on the embankments during high floods

Erection of fences or screens around the waterbody to protect fish stock from escapement during floods is comparable to bamboo-screen or net fencing of agricultural or horticultural areas to protect crops or vegetables from animal grazing. Majority of the districts of Assam is flood-prone and usually flooded every monsoon. Crop losses during monsoon season are a very common phenomenon in entire state of Assam. Fish farmers and fishers of flood-prone areas can adapt fencing technique to safeguard fish stocks or prevent crop losses.

Low-lying fish farms are at greater risks of crop loss during heavy rainfall-induced floods. In such farms, a fine-meshed net may be erected on the bundh or embankment of the farm with the help of bamboo support. Alternatively, farms can erect a bamboo screen, which may or may not be lined with nets. The strength of the bamboo support will depend on the expected force of water flow through the screen and also duration of such floods. The height of the fencing will depend on the anticipated height of flood waters.

Majority of the floodplain wetlands (beels) of Assam is flood-prone. During monsoon, heavy ingress of water into the beel takes place through connecting river channels and also from catchment areas. Normally the bundh or embankment of the beels is not capable of holding that much water and hence water flows out from the beel taking away stocked and natural fishes. This economic loss due to fish escapement from beels is a matter of concern for most of the fishers and lessees. The estimated economic loss due to fish escapement is not available, but reports of partial or total crop loss arenot uncommon in Assam. Hence, fencing, either of nets made of nylon, HDPE etc. or bamboo-screen can be erected around the beel to prevent such escapement of natural and stocked fish from the beel leading to huge economic loss adversely affecting livelihoods of fishers.

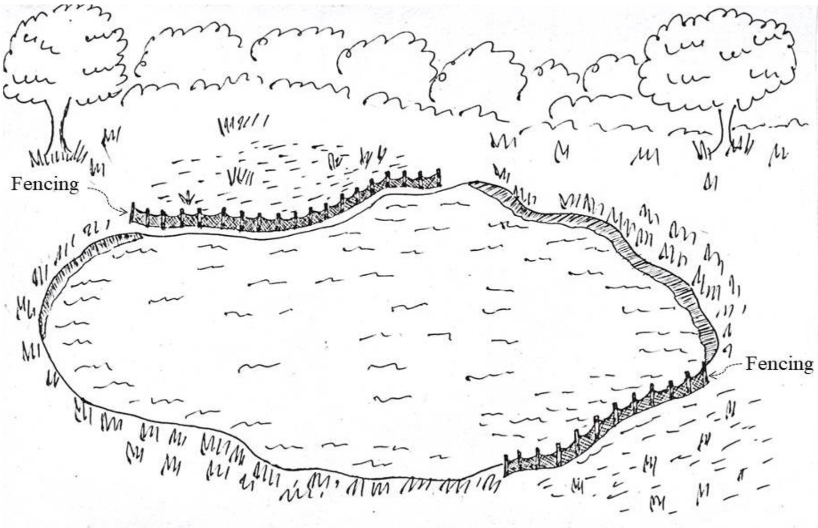

Fig. 7. Erection of fencing on the embankments

Responsible fishing methods for sustainable inland fisheries

Inland fisheries, throughout the world in general and India in particular, is under tremendous fishing pressure. This is the reason the natural fisheries is unsustainable. Adoption of responsible fishing methods is essential for very sustainability of the system. Fishers dependent on such fisheries should (i) adopt fishing methods that are non-destructive, (ii) not operate fishing gears during monsoon or breeding season, (iii) maintain certain areas as fish sanctuaries for sheltering, feeding and breeding, and (iv) not catch young ones and juveniles.

Katal fishing or ‘*Katalmara*’ or *Jeng*is a method which is popularlypracticed in the beels of Assam. Katals are small areas within the beel to entice fishes in accumulated mass of bushes, weeds and tree branches for a period of 2-3 months. Usually, masses of water hyacinth, bushes and tree branches are dumped together and a circle made by fixing tree stumps or bamboos around these vegetation mass to avoid scattering.

Installation of katalcan be done during September-October, when flood water starts receding. A few days prior to harvest, katalscan be encircled by 'katalmarajal' (encircling net) and 'banas' (closely-woven bamboo mats). The circle is gradually reduced by setting aside the vegetation, and fishes are caught by cast net or the encircling gear. The responsible beel fisher should release back the small and juvenile fishes that are entrapped in the *jeng*.

Small indigenous fish-based fishery in inland waters

Small indigenous fishes (abbreviated as SIFs), many of whom were known as 'weed fishes' earlier, are getting much more research attention throughout the world basically because of their nutritional significance in providing high quality proteins, fats, vitamins and minerals at higher concentrations at lower prices in human diet. The main characteristic of most of the SIFs is that they are climate-resilient species and naturally breeds in inland waters at relatively short time intervals. Most of the SIFs are tolerant of relatively poorer water qualities compared to major carps and catfishes. These are small in size, naturally found in open waters and ponds, and also they breed naturally without any artificial inducement. Mola (*Amblypharyngodon mola*), Puti (*Puntius sophore*, *P. chola*, *Pethia ticto*), Darkina (*Esomus danricus*), Chanda (*Parambassis ranga*, *Pseudambassis baculis*, *Chanda nama*), Goroi or spotted snakehead (*Channa punctatus*), Spiny eel (*Macrognathus pancalus*, *M. aral*, *Mastacembelus armatus*), Chela (*Chela cachius*), Chapra (*Gudusia chapra*), Gourami (*Colisa fasciatus*, *C. lalia*, *C. sota*) are some of the small nutritious self-recruiting fishes that need to be popularized as a complementary or supplementary species in carp polyculture in ponds and tanks or stock enhancement in open waters (beels) of NE region.

Culturing small fish punti (*Puntius sophore*) and/ or mola (*Amblypharyngodon mola*) in pond polyculture systems with large carps (rohu *Labeo rohita*, catla *Labeo catla* and mirror carp *Cyprinus carpio*) in Bangladesh was a success story (Wahab, Alim and Milstein, 2003). They demonstrated that the polyculture system was viable, as addition of these two SIFs did not reduce the production of large carps. In that experiment, large carps were stocked at 10000 no./ ha at a species ratio 1:1:1. Small fishes were stocked at three different stocking densities – 0, 25000 or 50000 no./ ha. While analysing the effect of stocking mola and/or punti on large carps and on each other, they found that catla production was not affected by the addition of the small fish. However, the growth of rohu was significantly (30-40% reduction) affected by mola, not by punti. On the other hand, mola had positive effect on growth rate and harvest weight (25-30% increase) of mirror carp. The addition of small fish did not significantly affect total yield and food conversion ratio.

Table 1. An example of compatible fish species for polyculture in ponds or stock enhancement in beels with their spatio-trophic habits

Species	Spatio-trophic habits	Stocking density (no./ha)
Catla (*Labeo catla*)	Surface feeder, zooplankton forms the major diet.	3300
Rohu (*Labeo rohita*)	Column feeder, plankton/ periphyton and organic debris forms the major diet.	3300
Common carp (*Cyprinus carpio*)	Bottom feeder, omnivorous (including detritus).	3400
Punti (*Puntius sophore*)	Surface feeder, omnivorous (small insects, algae, plankton)	25000
Mola (*Amblypharyngodon mola*)	Surface feeder, omnivorous (unicellular algae, protozoa, rotifer, small crustaceans)	25000

Creation and maintenance of macrophyte-based fishery

Fig. 8. Schematic diagram of aquatic macrophyte (*Eichhornia*) acting as shelter, feeding and breeding grounds of small indigenous fishes.

Fig. 9. Macrophyte management by barricading certain portions of a wetland/ beel/ pat for maintaining a clear fishing area

Climate-resilient hatchery practices

Fish hatchery practices followed by farmers have undergone modifications over time, mostly in response to climatic variabilities leading to changes in spawning behaviour of majority of fishes.Studies in different states of India have shown that the breeding season of Indian major carps (IMC) started in the month of April and ended in July during 1990s. However, during the past one and half decade (2001-16), the breeding season was observed to advance by nearly one month (i.e. it started in March) and extend by one month (up to August). Hence, the hatchery owners/ operators should initiate their hatchery operation as soon as their brood is mature and as early as monsoon arrives. They can extend the hatchery operation till the monsoon/ rainfall lasts. The study also revealed that the variety (number) of species used in the breeding programmes by hatchery operators could be changedto suitmarket demand and price. It is time that operators think of going beyond Indian major carps (*Labeo rohita, Cirrhinus mrigala* and *Labeo catla*) and try other species such as *L. calbasu, L. bata, L. gonius, Ctenopharyngodon idella, Hypophthalmichthys molitrix, Puntius javanicus* (*Barbonymus gonionotus*), *Hypophthalmichthys nobilis* (Big head carp), *Pangasius pangasius* (Pangas catfish) and *Ompok pabda* in their breeding programmes. Certain issues with regard to survival, growth and general health of brooders and offspring were reportedly from several hatcheries of late. For example, fecundity, quantity of milt produced and spawn survival were observed to be very low compared to earlier records. Post-spawning mortality of brooders was reported to be higher now compared to the earlier records.Under these circumstances, hatchery operators can (i) maintain superior water quality in tanks and ponds, (ii) feed the brood fish with fortified nutritionally balanced diets, (iii) select only fully matured brood fish for hypophysation and (iv) take utmost care of spawn and fry in respect to water quality in tanks/ nurseries and natural/ artificial feeds.

Climate-resilient fish species

Resident fish populations of any inland waterbody are naturally resilient to the micro-climate of that waterbody. This may not be the case with the fish stocked or ranched from outside. Hence, fishers should identify those species that are naturally present and conserve them. The small indigenous fishes (SIFs) are normally the resident populations that are resilient to their environment. For example, Mola (*A. mola*), Puti (*P. sophore*, *P. chola*, *P. ticto*), Darkina (*E. danricus*), Chanda (*P. ranga*, *Pseudambassis baculis*, *Chanda nama*), Goroi or spotted snakehead (*Channa punctatus*), Spiny eel (*Macrognathus pancalus*, *M. aral*, *Mastacembelus armatus*), Chela (*Chela cachius*), Chapra (*Gudusia chapra*), Gourami (*Colisa fasciatus*, *C. lalia*, *C. sota*) etc. In addition to these fishes, the exotic carps (*C. idella*, *H. molitrix*, *C. carpio*) are also more resilient compared to the major carps. Catfishes namely *Clarias magur* and *Heteropneustes fossilis* are highly valued and resilient species that can be cultured at very high stocking densities. Minor carps namely *Labeo bata* and *L. gonius* have shown to be winter tolerant species in enclosure culture demonstrations in Assam, India.

Fisheries enhancement in floodplain wetlands (beels) as adaptation option

The process by which qualitative and quantitative improvement is achieved in inland waters through exercising specific management options and fish stock enhancement (i.e., augmenting the stock of desirable fish species) is known as fisheries enhancement. This can be a very effective management measure that can be followed in the beels of Assam. Species enhancement refers to introduction of species, new to a particular ecosystem, to exploit or utilize the underutilized parts of the food chain and habitats not colonized by resident fauna or to compensate for loss of species due to environmental disturbance.It comprises one time or repeated stocking of a species deliberately with the objective of establishing its naturalized populations.

Supplementary stocking in selected beels of Assam was shown to enhance productivity of such waterbodies. There are only a few fish species including the Indian major carps (*Labeo catla*, *Labeo rohita* and *Cirrhinus mrigala*), exotic carps (silver carp, grass carp and common carp), minor carps (*L. gonius*, *L. bata* and *C. Reba*) and clown knife-fish (*Chitala chitala*) are stocked in the beels for stock enhancement. As a result of continuous supplementary stocking with these species the stocks of many small indigenous fish species might decline in course of time unless they receive new recruits from the parent/adjoining rivers during floods.

Success of stock enhancement programme depends on scientific stocking year after year, which needs matching fund availability and, therefore, may not be sustainable in case of beels managed by resource-poor fisher’s co-operative societies. In such situations, species enhancement appears to be a more sustainable fishery enhancement option. Species enhancement in beels with indigenous fishes having high market value, better consumer preference and faster growth rate seems to be a viable option. *Amblypharyngodon mola*, a small cyprinid fish (Family: Cyprinidae), locally known as *moa*, *mola* or *moka*, distributed in India, Pakistan, Burma and Bangladesh, can be a potential candidate for species enhancement in beels of Assam. Other than *A. mola*, small fishes like *Puntius* spp., *Colisa* spp. and *Gudusia chapra* are known to be very profitable for species enhancement in open waters of Northeast.

Conclusion

Climate change and its impacts are inevitable. Population explosion, consumerism, urbanization, industrialization and overall development of human societies have put overwhelming pressure on natural resources. Inland fisheries resources are not immune to the effect of climate change, which is manifested in the form of events such as erratic flood, drought, storm, hailstorm etc. Adapting to the changed climatic scenario is the only option left with fishers dependent on such resources. Fish farmers and fishers are required to understand that (i) changes in the temperature and rainfall (two very crucial climatic parameters for inland fisheries) can be appropriately utilized through proper planning and execution of seed production and farming activities, (ii) resident and dominant fish species in open waters are the ones that are climate-resilient and climate-tolerant, (iii) enclosure culture technologies are simple but useful tools for producing stocking material (advanced fingerlings) and table fish providing economic and social benefits, (iv) deeper areas of natural waterbodies can serve as critical habitats for fish stocks, (v) low-cost fencing around flood-prone wetlands/ beels can protect their stock from escapement, (vi) responsible fishing methods/ gears must be adopted for sustainable fisheries, (vii) small indigenous fishes should be conserved and/or transplantedbecause they can provide nutritional and income security, and (viii) scientific fisheries management of inland waters including enhancement with regard to fish stock, fish species and environment is crucial for securing livelihoods in the face of more severe and impending risks of climate change.

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Chapter 17

ECONOMIC VULNERABILITY OF THE FISHERMEN HOUSEHOLDS OF FLOODPLAIN WETLANDS

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Introduction

Traditionally fishermen in India, especially the inland fishermen are extremely poor with very low economic base. The fishermen communities are the marginalized group of people and vulnerable to external shocks. Vulnerability of a community is a reflection of risk exposure and coping capacity of its individual households. IPCC (2001) defined vulnerability to climate change as the degree to which a system is susceptible, or unable to cope with adverse effects of climate change, including climate variability and extremes. According to them the vulnerability is a function of the character, magnitude and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity. Mathematically vulnerability is expressed as the function of exposure, sensitivity, adaptive capacity (Brenkert and Malone, 2005). Exposure refers to the nature and degree to which a system is exposed to climatic variations, while the sensitivity is the degree to which a system is affected, by climatic variations. Adaptive capacity is defined as the ability of a system to adjust to climate change, to take advantage of opportunities or to cope with the consequences (IPCC, 2001). The climate change is an added threat to existing vulnerabilities (UNPEI, 2003).

The extent of impact of any external shock including climate change on any community will necessarily depend on the degree of vulnerability. Studies have shown that the vulnerability is the central element of poverty (Chambers, 1989; Khan, 1998; Narayan et al., 2000; World Bank, 2000; Prowse, 2003). It is also true for the other way round; poverty is a factor for vulnerability. Various studies have been conducted on vulnerability of ecosystem like reservoir (Chang et al., 2008); river basin (Palaniasamy et al., 2010), beach tourism (Sabine, 2010) and vulnerability to specific threat like HIV-AIDS (Nagoli et al., 2010), epidemic malaria (Wandiga et al., 2010). However, few studies (like Bene, 2009) have been conducted on assessment of fishermen’s economic vulnerability. Economic vulnerability study helps the researchers and policy makers to identify the household having high degree of vulnerability, which need immediate attention, for implementing the adaptation programmes.

Why are beel fishermen economically vulnerable?

Wetlands are natural resources having immense ecological and economic importance. They play a vital role in groundwater recharging, flood control, shoreline stabilization, sediment retention, retention of nutrients, biodiversity conservation, biomass export etc. The wetland ecosystem is rich in fish biodiversity. Wetlands are home to 40% (approximately 8500 species) of fish species live in fresh water in the world (Parish & Looi, 1999). However, due to siltation, loss of river connectivity, conversion to arable land, dumping of refuse, nutrient enrichment through sewage effluents and agricultural fertilizers wetlands are degrading day by day which leads to destruction of aquatic resources (fisheries resources in particular). As a result, it becomes more difficult for fishes to find the habitats they need. Consequently, the fishermen dependent on this ecosystem are finding it difficult to sustain their livelihood. Fisheries alone are not sufficient to maintain their families. They are compelled to search for different income sources other than fishers. However, due to lack of sufficient education, expertise and trainings the contribution of non-fisheries sources of income is not significant. Hence, the beel fishermen households are economically vulnerable.

Measuring economic vulnerability

The model developed by Bene (2009) is very simple and useful for assessing the economic vulnerability. Moreover, the model uses cross section data, which is very useful in Indian context as primary data on socio-economic variables are rarely available.

The model is as follows:

$$V_{ig} = CV_g Dep_{ia} \frac{1}{Div_i} Pov_i \qquad \ldots (1)$$

Where,

$$Div_i = A_i(1 - Dep_{ia}) + \sqrt{Sub_i + 1} \qquad \ldots. (2)$$

$$Pov_i = \sqrt{\frac{\bar{Z}}{Z_i}} \qquad \ldots (3)$$

And where V_{ig} is the vulnerability index, CV_g is the coefficient of variation (CV) of household’s income belonging to the same group g and Dep_{ia} is the proportion of total cash income of the household i derived from the main activity a. A_i is the total number of activities in which the household i is engaged, Sub_i is the number of subsistence activities amongst this total number. $\bar{Z}$ is the poverty line and Z_i is the daily cash income of the household i.

CIFRI Case studies on economic vulnerability

CIFRI conducted case studies on economic vulnerabilities in two beels of West Bengal, namely Kholsi and Akaipur and one beel of Assam, namely Deepor. Kholsi is a seasonally open beel and where as the Akaipur is a closed beel. The Kholsi beel is in Nadia district whereas the Akaipur is in North 24 Parganas district of West Bengal state. The fisheries of the two beels were managed by *Kholsi Udbastu Matsajibi Samabay Samiti Ltd*. (KUMSSL) and *Akaipur Dwarbasini Matsajibi Samabay Samiti Ltd*. (ADMSSL), respectively. On the other hand, the Deepor beel is the only Ramsar site in Assam. It is located to the south-west of the Guwahati city. The fishermen organized themselves as *Deepor Beel Panchpara Coop. Society Ltd.* (1976-77).

By employing the modified Bene (2009) methodology, the study showed that the average vulnerability scores were 0.21, 0.14 and 0.33 for Kholsi, Akaipur and Deepor beel, respectively. The scale of vulnerability is 0 to 1, 1 being extremely vulnerable. In Akaipur the vulnerability is lowest and in Deepor beel it was highest. Vulnerability of majority of the households in Akaipur was less than 0.30. The fisheries were well managed by the Society of this beel, which contributed to lower vulnerability. In Kholsi the majority of the households were in 0.10 to 0.40 categories. In Deepor the sizeable households are in >0.50 category, but in Akaipur no household was found to be in 0.50 category. In general, fishermen earned higher income than the state poverty line in Akaipur which reduces the vulnerability. The study further showed that income diversification is the negative factor for economic vulnerability.

The detailed study in Akaipur beel showed that the Cooperative Society in Akaipur is well managed and the management is more 'participatory'. Moreover, optimum and scientific stocking was done in this beel. Fishermen of this beel earned higher income than their counterpart of Kholsi or Deepor beel. Moreover, the Akaipur fishermen had more income diversification. Together, all these factors lower the economic vulnerability index. Further analyzing the factors affecting the vulnerability indices shows that the operational holding and the number of subsistence activities have highly significantly negative impact on economic vulnerability. Operation holding provides the fishers opportunity to grow crops or vegetables which provide food and some extra income to the family. Subsistence activities are also extremely important to lower the vulnerability. More subsistence activities means if one activity fails some other are there to compensate the loss. Through simulation study Bene (2009) also showed that complementary activities together with subsistence activities are extremely important for lowering economic vulnerability.

Conclusion

To reduce vulnerability of a community, attention needs to be given to improve coping capacity and resilience of the relatively more vulnerable households. The above discussion shows that in flood plain wetlands well managed cooperative society, optimum and scientific stocking, income diversification, participatory management, operational holding have negative impact on economic vulnerability of the fishermen households. Therefore, Government may facilitate the supplementary income generating opportunities. The Govt. Fisheries Dept may impress upon the fishermen to go for integrated agricultural activities in the vicinity of the wetlands. The Deepor beel is a perennial freshwater lake, located in the vicinity of Guwahati city. The beel harbours one of the largest concentrations of aquatic birds in Assam. The neighboring hills and forests are the home of many endangered and rare species of animals and insects. The eco-tourism may be developed in the beel with suitable infrastructure where the fishermen may get supplementary income and employment.

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Chapter 14

CLIMATE CHANGE IMPACT ON FISHERIES OF COASTAL SUNDARBANS, INDIA

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Introduction

Sundarbans is a dynamic and vibrating ecosystem formed by interactions between land and water, and is considered as one of the most productive wetlands on earth. It is one of the major global estuaries, which are likely to be badly affected by the accelerated rate of sea-level rise, as a direct consequence of climate change. Climate change is one of the greatest threats of the new millennium as it alters the function, diversity and productivity of the ecosystem. In fact, a study conducted by the Tata Energy Research Institute and the ministry of Environment and Forests in 1995, said that one meter sea level rise could displace 7.1 million people-including all coastal fishing communities. In a recent study (Hazra *et al*, 2002) it has been estimated that he Sundarbans will lose further 14% of its land area by 2020 due to relative sea level rise, storm surges and coastal flooding making more than 70,000 people homeless.

Fig.1. Map portraying the Indian Sundarbans Delta

Yet climate change does not seem a priority research area in this country. The Indian Sundarbans along with Bangladesh forms the largest Mangrove forest in the World. The Indian Sundarbans Delta is comprised of 9,630 sq. km. of land, of which 4,260sq. km. is reserved forest. The area is well known for multiple identities as Sundarbans Tiger Reserve (estd 1973), Sundarbans Biosphere Reserve, Sundarbans National Park and World Heritage site (estd 1987).The vast delta region with 102 islands are inhabited by a rich faunal assemblage, besides the floral diversity in the mangrove and terrestrial ecosystem; about 4.5 million people live in 52 islands of the region.

Fig.2. Ganga-Brahmaputra River System

The huge sediment load carried by Ganga-Bramhaputra river system to Sundarbans causes constant delta subsidence and many ascribe this is as the primary reason for considering rate of sea level rise in Sundarbans as higher than the global average rate of rise (2mm per year). In the Indian Sundarbans the rate of sea-level rise is 3.14mm/y at Sagar and 5 mm/y at Pakhiralay. As a result of this increased vulnerability of this unique ecosystem, the level of salinity in both surface waters as well as within ground water system is likely to increase (Nath *et.al.*, 1999). This increased salinity could have multiple impacts on socio-economic development potential of the islands, including, impacts on agriculture and fisheries etc. A changing salinity in the ecosystem could also impact both structure and distributional relationships of flora and fauna and thereby having implications for conservation of biodiversity in the mangrove ecosystem. During last century important mammal species like Javan Rhinoceros, Great Indian one Horned Rhinoceros, Soft ground Barasinga Deer, Wild Buffalo, Gharial, got extinct from Sundarban. The Barking Deer population became restricted to Halide Island till eighties which now became extinct. Many families of already drowned Islands of Lohachara, Supuribhanga have become climate refugees. The inhabited Ghoramara Island also is more than 80% drowned and the remaining people are all under threat of losing their homeland. Some 7500 Climate refugee families have settled on Sagar Island.

Fig.3

Fig.4

Fig.3 & 4. Impact of climate change on marine fisheries

Effect climate change on fishery of Sundarbans

The impact of climate change on marine fisheries stems from the fact that global warming may change the salinity level of the estuarine water that fish inhabit, the amount of oxygen in the water, pollution level and turbidity levels due to increased frequency of erosion caused by increased tidal amplitude. Direct effects act on physiology and behaviour and alter growth, reproductive capacity, mortality and distribution of fishes. Indirect effects alter the productivity, structure and composition of the marine ecosystem on which fish depend for food. In mangrove dominated deltaic complex of Indian Sunderbans, the aquatic subsystem has significantly altered in terms of salinity, nutrient load, productivity, planktonic composition and heavy metal concentration over a period of 30 years (Mitra *et al*. 2009a, b; Mitra and Banerjee 2011). The present study clearly indicates distinct dissimilarity between the western and central sectors in terms of fish diversity. The diversity of commercially important fish species has not altered significantly over years in western Indian Sunderbans, but in the central sector the diversity has reduced due to hyper saline condition. The trash fish diversity, however, has increased which are opportunistic in nature and can adapt even in stressed condition.

Table1. Effect of climate change on fisheries of Sundarbans

Climate change predictions	Impact on fisheries
Surface air temperature Rainfall Extreme weather events Rise in Sea level Impact of Himalyayn Glacier	Effect on habitat availability and fish richness Effect on fish growth and health Effect on fish reproductive integrity Environmental problem by lowering water quality and enhancing pollutants Adverse impact on fish seed production Geographic shift of species

Climate change impact on fish culture in Sundarbans

Global-mean sea-level rise occurred through the 20th Century, and continued rise is one of the more certain impacts of global warming (Douglas, 1991). This is resulting in a range of impacts including increased flood risk and submergence, salinisation of surface and ground waters, and morphological change, such as erosion and wetland loss. The potential human and ecosystem impacts in the 21st Century are significant but uncertain. Actual impacts will depend on a range of change factors in addition to the amount of sea level rise and climate change, including a number of factors which are human-controlled such as coastal land use and management approaches. Islands of Sundarbans are vulnerable to climate change impacts like sea level rise, soil erosion, saline water inundation as well as extreme climatic events like cyclones, storm and tidal surges (Sinha and Roychoudhry, 2004). These are bound to bring changes in aquaculture scenario of the region. In changing climatic scenario, fish will be subjected to hazard of temperature and salinity changes which will put them to various physiological stresses. These effects would also often become synergistic with other adverse like low pH, oxygen shortfall etc. Breach of pond dyke due to storm /tidal surge will cause ingression of saline water into the freshwater ponds, thus affecting the productivity of the region. Aquaculture operations will have to also cope with changed health related risks as a result of climate change. Potential shifts in tidal patterns and salinity regimes will have implications for aquaculture prevailing in this region

Status of fish culture in Sundarbans

Fisheries, next to agriculture, offer a major source of employment generation and poverty alleviation among the poor section of the backward communities in Sundarbans. Majority are marginal and small-scale farmers having perennial fish ponds and practise traditional farming. Brackish water aquaculture is prevalent only in peripheral areas which are adjacent to river or creek and tide-fed. On the contrary, freshwater aquaculture is vast, wide spread and rain-fed. In freshwater, composite carp culture is popular, though in some cases farmers culture high value Scampi (*Macrobrachium rosenbergii*) with the carps. Farmers often culture tilapia (*Oreochromis mossambicus* and *O. niloticus*) in fresh and brackish water with other fish /prawn for better production. In brackishwater, farmers mostly culture tiger shrimp (*Penaeus monodon*) with the fishes like *Lates calcerifer, Liza tade, Liza parsia, Mugil cephalus, Etroplus suratensis, Scatophagus argus etc.*

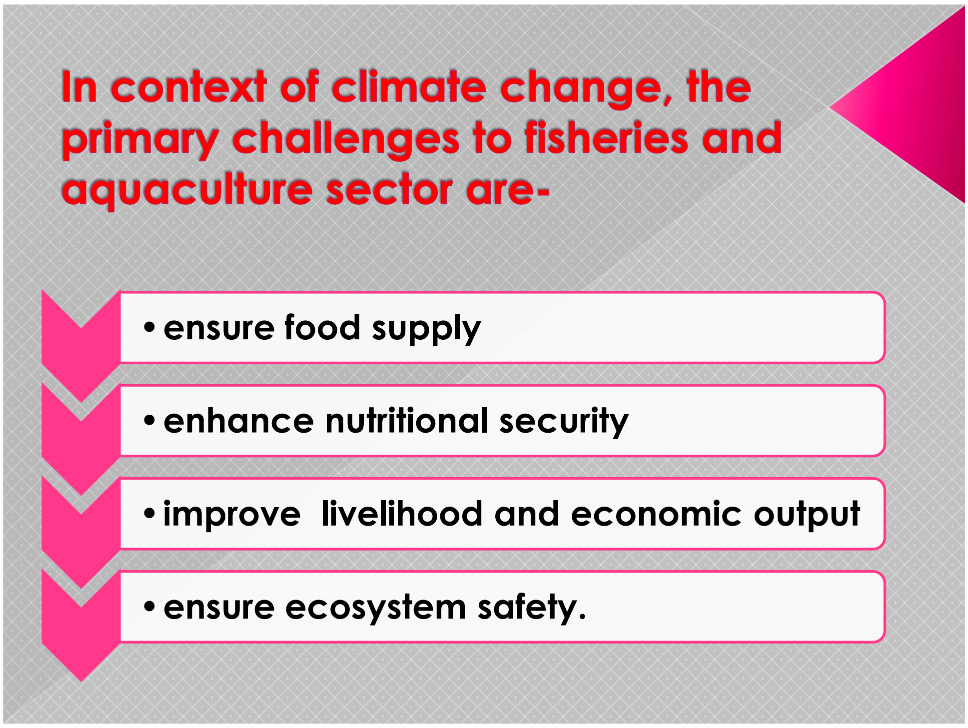

Fig.5. Primary challenges faced by fisheries and aquaculture sectors due to climate change

Captured fishery has been estimated around 50,000 tons per year, but this is also going down due to increase in salinity of surface waters. On the other hand, due to low salinity of estuarine water not exceeding 30 ppt, the Tiger Prawn hatchery has not been possible. However, if the water bodies for minor irrigation are constructed maintaining proper shape, slope and design; it can not only support the ecosystem, but also increase the maximum water retaining capacity than any other design of use. It will also help in utilisation of whole water body layer wise, bottom, slope and embankment round the year and the life of water body become double than any other activities. Silt deposition may be avoided through required periodical netting and raking. Minor irrigation deserves to be clubbed with aquaculture by keeping minimum water level (1.5 m) round the year for an all-round utilisation of the resources from the economic point of view and ecology. The The water bodies for minor irrigation are constructed maintaining proper shape, slope and design; it can not only support the ecosystem, but also increase the maximum water retaining capacity than any other design of use. It will also help in utilisation of whole water body layer wise, bottom, slope and embankment round the year and the life of water body become double than any other activities. Silt deposition may be avoided through required periodical netting and raking. Minor irrigation deserves to be clubbed with aquaculture by keeping minimum water level (1.5 m) round the year for an all-round utilisation of the resources from the economic point of view and ecology. The Irrigation ponds / tanks/ dighi, dead river bed and tributaries, Irrigation canals/ beels/ baors water bodies may be linked up for aquaculture and minor irrigation purpose. As climate shifts, certain species are forced to abandon their native habitats and invade a different site and adapt to that specific environment. Some fish from its original habitat will be lost forever, while some can be found in new places where they are not supposed to be.

Mitigation strategies

Sundarbans act as a great protector of environment, yet it is a great victim of climate change. Sundarbans reclamation started little early (1771) and the North-western part near Hingalganj was the earliest one. Next was the Gosaba Island and last was Sagar Islands and around. Vulnerability is a function of the character, magnitude and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity” (Watson, 2001). Vulnerability to climate change is considered to be high in coastal zone due to social, economic and environmental conditions that amplify susceptibility to negative impacts and contribute to low capacity to cope with and adapt to climate hazards (Fankhauser *et.al*., 1999). The analysis of available records of cyclones over the Bay of Bengal adjoining the Sundarbans, exhibits an increasing trend in the degree of their intensity while showing a decrease in the frequency of occurrence. This is a striking phenomenon in the perspective of warming trend discussed earlier and has significant bearing on the extent of coastal flooding, erosion and saline water intrusion due to storm surges. The rise in salinity in the Sundarbans has been exacerbated by rise in sea levels and deep ingress by saline water. However, a primary cause for rise in salinity and resultant change in the ecological patterns is because of increased consumption of upstream freshwater and release for very little freshwater into the Sundarbans. The lack of freshwater has caused several creeks to turn completely saline, with only the monsoons providing freshwater supply. The Government will be required to increase the supply of freshwater into the Sundarbans to ensure the existence of the area as an estuarine delta. Construction of embankments was the primary measure to prevent tidal inundation (Sharma, 1994). Due to gradual siltation of rivers and due to accelerated sea level rise toppling of embankments by tidal waters became more frequent now days. During *Aila* the embankments not protected with toe line mangroves mostly succumbed to tidal surges. Agricultural fields got inundated with saline waters, ponds were salinated. These are common in Sundarbans, therefore people cope up with innovation as follow-

1. Planting mangroves along the toe-line of embankments.
2. Massive mangrove plantation on the new charlands in order to make up for the lost tiger habitat.

3. Several Embankment Management Committee should be formed with the inhabitants of vicinity, so that at the first report of cracks in the embankment the forthwith repairs can be undertake by participatory concerted efforts of the affected villagers.
4. Indigenous saline paddy eg. Nonabokhra, Talmogar varieties cultivation are encouraged.
5. Massive rainwater harvesting plan through pond and canal excavations make for winter irrigation.
6. Shallow ground water aquifer should be recharged with rain water and pond water so that the diluted water can be used throughout the year for potable purposes.
7. Ecotourism up to the level of “Carrying Capacity” must be encouraged.

The danger is greatest where natural systems are severely degraded and human systems are failing and therefore incapable of effective response. Also, a household’s access to water, land and other resources are important determinants of its susceptibility. Moreover, land degradation and desertification may also be exacerbated in these areas, posing additional threats to human well-being and development, added by intensified human pressures on lands and poor management. The livelihoods and food security of the rural poor are threatened by climate change with all its impacts, and the vulnerability to adverse health impacts is greater where health care systems are weak and programs for disease surveillance and prevention are lacking Roy *et. al*., 2016). In addition to multiple factors converging to make the people inhabiting coastal zones and small islands highly endangered. *Liza parsia* and *Scatophagus argus can be* adapted well in freshwater and low salinity with no mortality. Under field demonstration (in farmer’s pond), the high value Tiger Prawn (*Penaeus monodon*) when stocked with Indian Major Carps in freshwater pond, exhibited satisfactory growth and survival. It indicates that some of the brackish water species can also be taken up as candidate species for freshwater aquaculture. This will help in resilient aquaculture against climate change induced saline water inundation in Sundarban islands.

Conclusion

The Sundarbans is endowed with enormous inland and marine waters, which provide immense livelihood and employment opportunities. Surface air temperature over this part of the Bay of Bengal is rising @ .019^{o}C/year which is correlated with the rate of relative sea level rise@ 3.14mm/ year, near Sagar Island. Rate of coastal erosion and land loss in the Sundarbans is fairly correlated with the rate of sea level rise. Though the frequency of high intensity events like hurricane and cyclonic storms is likely to reduce, the intensity along with surge height may increase in future. This implies threat to the coastal population with increased risk of coastal erosion and destruction of life and property. Due to coastal erosion and flooding, around 30,000 people are feared to be rendered homeless from Sagar Island alone, turning in to a kind of environmental refugees. Considering the whole of Sundarbans with the existing trend of population rise and reclamation, this number may touch 0.1 million mark by 2030. Alternate income generation and livelihood support for the masses forced to trigger climate change because of acute poverty. Agriculture and fish production may face a serious threat making livelihood and sustenance of the ecological community of Sundarbans difficult. New technologies and adaptive tools are required to mitigate the effect of climate change. Necessary technological interventions coupled with policy support in canal fish culture, pen culture crab culture can lead to substantial increase in inland fish production.

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Chapter 19

IMPLICATIONS OF CHANGING CLIMATE SCENARIO ON FISHES OF RIVER CAUVERY

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Introduction

Freshwater ecosystems and particularly rivers are among the most intensively impacted aquatic habitats on Earth (Dudgeon et al. 2006). The major rivers of the world are facing problems of ecosystem degradation due to changing climate and the pollution affecting the river biota and in turn human beings as well.

The gradual decline of global fish production in are widely documented as fishing down the food web or overfishing, together with climate change, which may lead to further decline of fisheries production and food insecurity. The direct effects on distribution and availability of fish, are not the only ways in which change in climate will affect freshwater fish and eventually their abundance. The indirect effects of climate change may also include geomorphological alterations of river systems due to nutrient run off that lead to eutrophication, acidification, chemical pollutants and biological invasions (Liu et al 2015).

Xenopoulos et al. (2005) have applied climate change scenarios to 325 river drainage basins world-wide using relationships between fish species richness and river discharge. Results project 4–22% (quartile range) fish species 'committed to extinction' by 2070 in about 30% of the rivers analysed, due to reductions in river discharge from climate change. The magnitude of the impacts of climate change vary among species and eco-regions.The amount of habitat available for freshwater fish species may also be reduced if increasing temperatures shrinks their thermal distributional limits, or if species are unable to adjust their distribution range to the new conditions. Climate change could also affect frequency, duration and magnitude of hydrological events, potentially damaging species adapted to present flow regimes (e.g. Doll & Zhang 2010).

River Cauvery

The Cauvery River is one of the major rivers of the Peninsula. It rises at an elevation of 1,341 m at Talakaveri on the Brahmagiri range of Kodagu district of Karnataka. It lies between 75°27' to 79°54' E longitudes and 10°9' to 13°30' N latitudes. After traversing over 850 km of a tortuous, twisting course of about 840 km through the states of Karnataka, Tamil Nadu, Kerala and a Union Territory of Pondicherry before falling into the Bay of Bengal at Kaveripatnam in Tamil Nadu. The Cauvery has a total drainage area of 81,155 sq km (2.5% of the total geographical area of the country). A peculiar feature of this river is that for irrigation purposes it is more intensively dammed than any other river in India. Millions of people depend on its water but a large group of fishermen depend on it for their livelihood.

Significant variations in climate on inter-annual and decadal changes of time scales can cause notable changes in distribution of fish, mediate their reproduction success, recruitment, survival and growth (Deepananda and Macusi 2012). In the rivers may experience reduction in biodiversity of its fish population due to eutrophic conditions. These effects can alter availability of fish which can negatively impact millions of people engaged directly with fishing and would significantly limit the availability of fish for food and income.

Variations in rainfall, rainy days and temperature in the Cauvery basin

The analysis of time series rainfall data from 1830 to 2005 based on trend line reveals that the onset of South West monsoon has advanced by 6 days. The date of end of monsoon is delayed by 8 days. Increasing trend observed in year wise seasonal rainfall and duration of monsoon. The seasonal pattern of rainfall during the period from 1830 to 2005 has shown that the average rainfall has been increased by 80 mm in the monsoon period and the duration of monsoon (number of days) has increased by 10 days. Nearly 70 percent of the annual rainfall has occurred during NEM and 20 percent in SWM.

Table 1. Magnitude of trend in annual and seasonal rainfall and rainy days (1901-2013)

Annual		Pre-monsoon		Monsoon		Post-monsoon	
Rainfall (mm/yr)	Rainy days (days/yr)	Rainfall (mm/yr)	Rainy days (days/yr)	Rainfall (mm/yr)	Rainy days (days/yr)	Rainfall (mm/yr)	Rainy days (days/yr)
0.879	0.000	–0.563	0.000	0.075	0.028	1.748*	0.050

*Indicate statistical significance at 95% confidence level according to the Mann–Kendall test.

The annual trend of rainy days was increasing. The seasonal trend showed a decrease in the number of rainy days during SWM and an increase during the NEM. The mean rainy days was 53.61 days.

The annual trend of minimum temperature was marginally declining (-0.01). The minimum temperature showed an increasing trend during SWM and NEM periods. The annual trend of maximum temperature was increasing (0.022^{0}C). While the mean was high during the SWM (0.019^0C) period, and0.022^0C during NEM. The maximum temperature trend was increasing in each season.

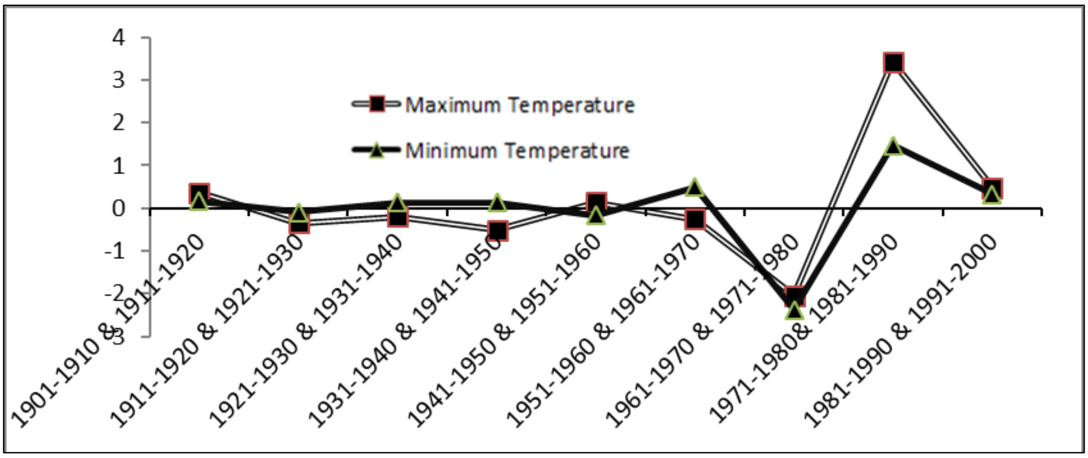

Fig.1. Decadal difference in mean maximum and mean minimum air temperature during monsoon months (peak breeding period) for Cauvery River basin

Figure shows deviations from the mean of annual precipitation in the Cauvery basin during the period 1971 to 2005. It is clear that there is significant spatial variability. There was consistent drought across the basin the early 2000, followed by an extremely wet year at a number of locations in 2005.

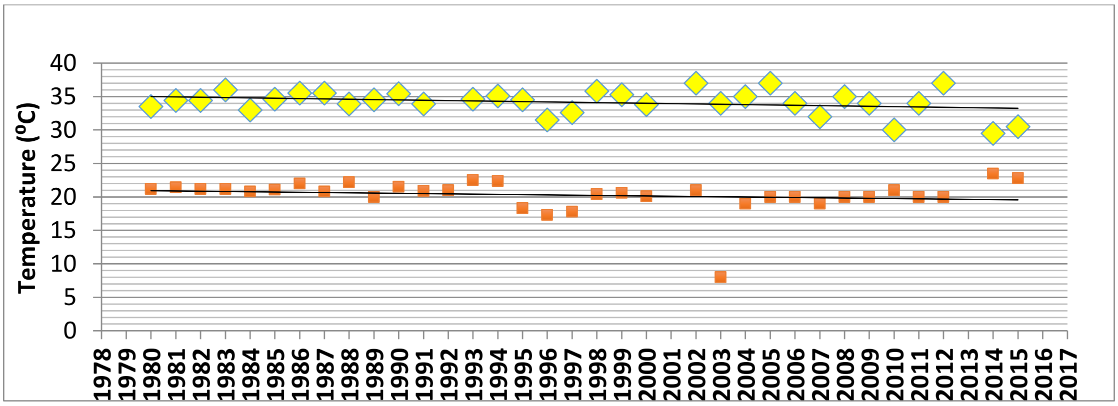

Fig.2. Temperature range (°C) over the Cauvery Basin (1980-2015)

Changes in species composition in River Cauvery

The river Cauvery has a rich indigenous fishery of *Cirrhinus cirrhosa, C. reba, Labeo kontius, L. fimbriatus, Puntius carnaticus, Pangasius pangasius, Mystus aor, Silonia silondia, Wallago attu*, etc. *Puntius dubius* disappeared after the river was dammed at Mettur but the introduced Gangetic carps like *Labeo catla, Labeo rohita, C. mrigala, L. calbastu*, etc., have established themselves in the river and contribute a sizable number of fingerling and marketable fish. It was noted that, even though the monsoon period is shorter than the non-monsoon period, about 62.3% of the total fish catch from the river takes place during monsoon.

The investigations conducted by ICAR-CIFRI showed that the change in climate factors has resulted in a perceptible change in the geographic distribution of fish fauna in River Cauvery. The fish catch composition study shows that the transplanted fish *Labeo catla* successfully established in the river. *Mystus punctatus (Hemibagrus punctatus)* recorded in Cauvery at Tamil Nadu in 1931. The overall populations in the native range were, therefore, thought to have declined in the last decade. *Puntius carnaticus* were abundant in the upper stretch of the river in 1960 but very scanty in numbers in the landings during 2013-14. *Gonoproktopterus dubius*, 28 % of catch in 1943-44 disappeared in 1955 and reappeared from 1977. *Hilsa ilisha* was recorded in 1940 but disappeared since 1955. *Mystus aor* and *Wallago attu* were more than 35% of catch in 1964-65 but reduced to less than 10% since 1992-93. Exotic fishes like *Cyprinus carpio* encountered in the fishery since 2000. *O. Mossambicus* and *O. Niloticus* reported in the river since 2004. Panikkar et al 2015 reported the first record of the Sucker mouth armoured catfish *Pterygoplichthys disjunctivus*, belonging to the family Loricariidae, from river Cauvery. The fish was collected at Sathegala stretch of river Cauvery (120 15' 13"N and 770 09'38"S). The establishment and invasion of *P. disjunctivus* may be a threat to freshwater faunal diversity of river Cauvery, if preventive measures are not immediately put in place.

Climate factors cause fluctuations in the haematological parameters of the fishes in a changing climate scenario. Assessment of haematological parameters provides an integrated measure of fish health status. Panikkar et al 2018 reported the impact of the seasonal variations on the haematological parameters of an important commercial freshwater fish, *Barbodes carnaticus* during three major tropical seasons; pre-monsoon, monsoon and post-monsoon.

Climate change, through direct habitat loss will not severely affect freshwater fish species richness in the near future. This result implies that there still is a chance to counteract current and future fish species loss by preferentially focusing conservation actions on the other important anthropogenic threats generating ongoing extinctions in rivers (habitat degradation and fragmentation, overexploitation, eutrophication and introduction of non-native species (Nilsson et al. 2005; Dudgeon et al. 2006; Giam et al. 2012).

Maturation and spawning in fishes from River Cauvery in Karnataka

Temperature is a physical regulatory factor which control all reproductive processes from maturation, spawning, and hatching in fishes. The effects of climate change on aquatic species will vary with latitude and habitat. Riverine habitats are likely to experience elevated temperatures in association with decreased flow rates and increasing incidence of hypoxic conditions, but with quite marked regional differences in effect.

Any changes in thermal regime caused by climate change will have major impact on the spawning of fishes these effects will be pronounced during all stages of the reproductive process (Pankhurst and King 2010). The extent of these effects will be determined by its thermal tolerance, capacity for adaptation, capacity to extend or shift ranges, and the timing of thermal challenges with respect to the reproductive cycle. The possible outcomes range from extremes of complete reproductive and recruitment failure to changes in seasonal shifts of reproduction.

Certain environmental variables may act as cues for reproduction and changes in these may affect seasonality and success of reproduction, as fishes are known to integrate their physiological functions with environmental cycles. Studies of reproduction and growth of many species indicated that the reproductive cycle of fishes are closely tied to the environmental changes particularly temperature and rainfall as well.

In South India, the temperatures are steady throughout the year, ranging between 24 to 34°C. The variations in biannual monsoon have changed the reproductive pattern of Indian major carps and they attain gonadal maturity, twice a year facilitating induces breeding of the IMC throughout the year as reported by Das, 2009.

Studies of reproduction and growth of many fish species from Cauvery River system indicated that the reproductive cycle of fishes are closely tied to the environmental changes particularly temperature and light. Maturing and mature fishes were observed during the period. Mature specimens of *S. nukta* were observed from June to Sept, *P. sarana* from June to November and *Mystus punctatus* during April to September. Matured specimens of *P. carnaticus* were obtained in the fishery during January and June. Immature *Channa marulius* was encountered in May whereas matured specimens were obtained from June to Sept. Matured *Tor khudree* was present in the fishery in June. Matured specimens of *M. armatus* encountered in the catch during May to July.

Spawning attributes in *Mastacembelus armatus*

Studies on *Mastacembelus armatus* by different workers indicate temperature is a primary environmental cue that regulates gonadal recrudescence and spawning (Narejo et al., 2002, Uthayakumar et al., 2013, Mahmud *et al*., 2015, Gupta and Banerjee, 2016)

- Absolute fecundity varied between 927-7409 egg cm^{-1} in *M. armatus* ranging from 12-48.2 cm in size. An average of 29 egg g^{-1} of the body weight of the fish. The ova diameter ranged between 0.4-1.45 mm in the ripe stage (March-May). Fully developed and ripe eggs (diameter 1.46-2.1mm) were encountered during June-July.

- Cyclic changes in the maturation, depletion of gonads intra -ovarian oocytes and GSI in *M. armatus* clearly indicated the breeding season synchronized with the onset of monsoon and the fish spawn only once in a year which extended from late June to early September. Fecundity was found to be low in *M. armatus* due to large size of the eggs.

- In the earlier studies conducted during 2001-2002(Narejo et al., 2002), the breeding season was during April to July which further advanced to June - September during our investigation in 2014-16. The slight shift in spawning season could be attributed to slight increase in duration of high temperature regime.

Perception of fishing community about climate change

A very high perception exists in fishing community about climate change observed in the last ten years. 95% understand temperature and sea level is changing. 91% say rainfall is changing and salinity also is increasing, 86% think extreme rainfall is affecting productivity and ground water level is changing as well. Surface water salinity increase is reported by 73% households.

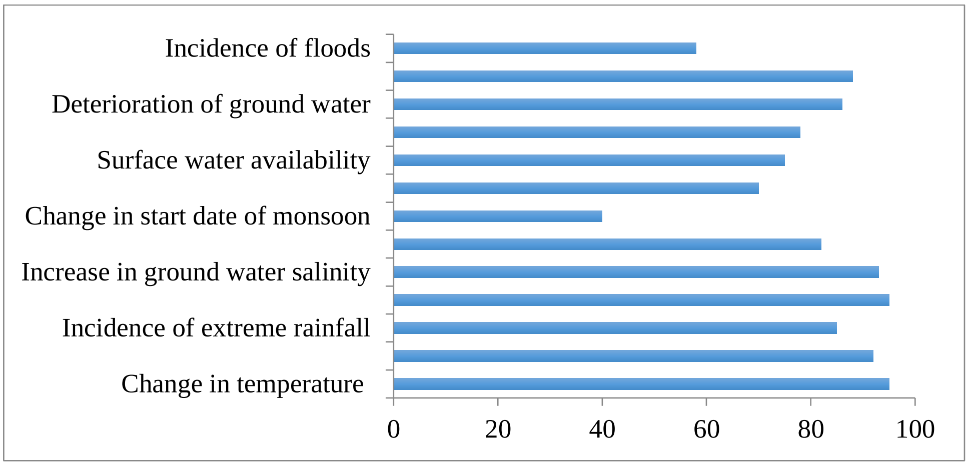

Fig. 3. Climate Change Issues Observed by the Fishing Community in Cauvery Basin, Tamil Nadu

Inland fisheries, which forms an integral part of many rural livelihood systems will be severely impacted by changes in precipitation, drought, changing water levels and flooding events. These changes need focused strategies to mitigate and cushion the impending impacts of a climate change. A general strategy in conservation efforts would be enhanced protection of watershed areas, a combination of government and community-based partnerships in implementing protection measures of natural habitats as mitigation measures on possible impacts of climate change.

Conclusion

Inland fisheries, which forms an integral part of many rural livelihood systems will be severely impacted by changes in precipitation, drought, changing water levels and flooding events. These changes need focused strategies to mitigate and cushion the impending impacts of a climate change. A general strategy in conservation efforts would be enhanced protection of watershed areas, a combination of government and community-based partnerships in implementing protection measures of natural habitats as mitigation measures on possible impacts of climate change

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Chapter 20

IMPACT OF CLIMATE VARIABILITY ON AQUACULTURE AND FISHERIES OF NORTHEAST INDIA

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Introduction

The Northeast region of India comprising the states of Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim and Tripura are blessed with rich biodiversity and fisheries resources. The NER of India covers an area of 2.62 lakh sq. km. It accounts for 7.9% of total geographical area of the country. The region can be physiographically categorized into the Eastern Himalaya, the Pataki and the Brahmaputra and the Barak valley plains. The region, with mighty Brahmaputra-Barak river systems and their tributaries has predominantly humid sub-tropical climate with hot, humid summers, severe monsoons, and mild winters. Geographically, apart from the Brahmaputra, Barak and Imphal valleys and some flat lands in between the hills of Meghalaya and Tripura, the remaining two-thirds of the area is hilly terrain interspersed with valleys and plains; the altitude varies from almost sea-level to over 7,000 meters (23,000 ft) above MSL. In the mountainous areas of Arunachal Pradesh, the Himalayan ranges in the northern border with India and China experience the lowest temperatures with heavy snow during winter and temperatures that drop below freezing point. Areas with altitudes exceeding 2,000 metres (6,562 ft) receive snowfall during winters and have cool summers. Below 2,000 metres (6,562 ft) above sea level, winter temperatures reach up to 15°C (59 °F) during the day with nights dropping to zero while summers are cool, with a mean maximum of 25°C (77°F) and a mean minimum of 15°C (59°F)

(Dikshit and Dikshit,2014). Climatic variability refers to sudden and discontinuous seasonal or monthly or periodic changes in climate or its components without showing any specific trend of temporal change. Researchers have predicted an increase in temperature by 2 to 4.5^{0}C by the end of the century; best estimate at 3^{0}C and very unlikely to be less than 1.5^{0}C.

Analysis made by the ICAR Research complex for NEH Region under the NICRA project (first phase) revealed that 2001-2010 has been the warmest decade. The year 2010 was the warmest year since 1901 with temperature being 1.8^{0}C above normal. In the year 2009, NE India observed one of the biggest droughts while in 2012, NE Indian states of Assam, Meghalaya, Arunachal Pradesh and Mizoram faced severe floods which didn't occur before. All the 27 districts of Assam were under the grip of devastating flood for the entire month of June. Again, flood reappeared in the month of September in the same year. Heavy intensity rainfall events have been increasing every year whereas; the distribution is getting more and more erratic. The mean maximum temperature of NE region is reported to be increasing @ +0.11^{0}C per decade. The climate models project 2.0-3.5^{0}C increase in temperature and 250-500 mm increase in precipitation in the NE region by 2050.

The forecast of climate change in the country viz. increasing trends in annual mean temperature, frequency of hot days and multiple day heat wave, more warming during post monsoon and winter, increase in extreme rains in northwest during summer monsoon in recent decades, consequent drought, and extreme climatic events are likely to be the most significant drivers that has greater impact on aquaculture and fisheries. The most notable and significant changes associated with global warming are gradual increase in atmospheric green house gases and the gradual rise of global mean temperatures. Some of the developing world's largest rivers are drying up because of climate change, threatening water supplies in some of the most populous places on the earth. The livelihood of wet lands completely drying out more in dry seasons is due to changes in temperature and precipitation. Aquaculture contributes about 35% to global fish supplies and is on the increase. Variability in the amount of precipitation under different scenarios of monsoon can negatively impact aquaculture and fish diversity.

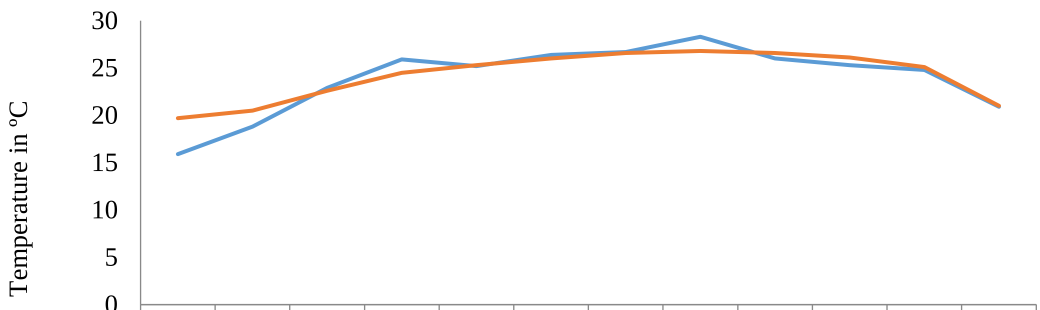
The impact on fisheries resources

The fishery resources of the North eastern region fall within all three types of climate i.e. Tropical, Sub-tropical and Temperate and represent an enriched biodiversity. Two principal rivers Brahmaputra and Barak and their numerous tributaries harbour varieties of fish species. The region harbour several important fish species of both food and ornamental value. In fact the North East India is considered as one of the hot spots of fresh water fish biodiversity in the world (Kottelat and Whitten, 1996). The North Eastern Region shares its fish fauna predominantly with that of the Indo-Gangetic fauna and to a small extent with the Burmese and South China fish fauna (Yadav and Chandra 1994). Although, Sen (2000) described 266 species, Goswami *et al.* (2012) listed 422 fish species from northeast India, belonging to 133 genera and 38 families.

The region is endowed with a large number of flood plain wetlands (Beel) and swamps (1.12 lakh ha.). In addition to cold water streams there are flood-locked plain wetland, reservoirs, lakes, ponds, paddy fields, mini barrages to support large scale aquaculture activities. Climate change will affect wetlands and their species e.g. through biological responses to changes in temperature, rainfall, water regimes, salinity etc. Wetlands play important roles in the global cycling of water, and the storage and cycling of carbon gases – these cycles will be affected by climate change.

However, changes in climate have already begun to affect the wetland biodiversity. The wetlands/rivers are in faster decline than rainforests. The potential impact is on spawning migrations of fish. Major changes in wetland water regimes such as flooding/drying may lead to loss of ecosystem services and livelihoods.

Temperature plays an important role in fish growth. The region in recent past has suffered from climatic variability which refers to sudden and discontinuous seasonal or monthly or periodic changes in climate or its components without showing any specific trend of temporal change. An instance of *water temperature variability during the years 2016 and 2017 in farm ponds located at 900 m above MSl has been presented in Fig.1.* The mean monthly water temperature of pond dropped down to 15.9^{0}C degree centigrade in 2016, while in 2017, it increased to 19.7^{0}C for the month of January (Das, 2018a unpublished).



	January	February	March	April	May	June	July	August	September	October	November	December
2016	15.9	18.8	22.9	25.9	25.2	26.4	26.7	28.3	26	25.3	24.8	20.9
2017	19.7	20.5	22.6	24.5	25.3	26	26.6	26.8	26.6	26.1	25.1	21

Fig.1. Graphical presentation of month-wise average temperature in farm ponds located at 900m above MSL during 2016 and 2017

Impact on aquaculture

There are direct and indirect impact on Fisheries and aquaculture. All cultured aquatic organisms are poikilotherms. Hence, any temperature change impacts on production. The temperate species are mostly affected due to rise in temperature. In tropics**,** impacts are positive; higher growth & production; but will need more feed inputs.

In general, fishes cannot maintain a constant body temperature like the mammals do. Their body is exactly the same temperature as the water they are living in. Fishes can live in very cold or very hot water, but each species has a specific range of preferred temperatures. Most fishes cannot survive in temperatures too far out of this range. When fishes encounter water that is too cold for them, their metabolic activities slow down and become lethargic. On the contrary, as the surrounding water warms up, metabolic activities are accelerated; they digest food more rapidly, grow more quickly, and eventually require more energy for reproduction. However, fishes need more feed and more oxygen to support this higher metabolism. On the contrary, when the water temperature in the pond/ mini-barrage falls below the optimal range during winter months, the rate of application of artificial feed and fertilizers /manures should be reduced.

Generally, the rate of all the biochemical reactions in aquatic organisms doubles with every 10°C rise in water temperature. Higher water temperature adversely influences solubility of oxygen in water. As a result, fish growth depends on water temperature to a large extent. For the Indian major carps fish species (Rohu, Catla & Mrigal) 25°C to 32°C has been found to be optimal for their growth and reproduction in the plains.

Since water temperature in the hills is usually less than 20°C even during warmer months, the exotic carps (common, grass and silver carps), mahseers and other such coldwater fishes that can grow and survive at lesser temperature than IMCs are more suitable for use in hill aquaculture. In recent years, the introduction of genetically improved fast growing Amur common carp (a Hungarian strain) in the Northeast by the ICAR NEH Region has yielded fruitful results in enhancing fish production from farmers ponds in the changing climate (Das, 2017). In addition, minor carps, *Labeo gonius*, *Labeo bata* and *Puntius javanicus* have also been successfully reared and induced bred for promotion of these species in mid-hill aquaculture successfully (Das, 2018).

The water temperature beyond tolerable limits adversely affects the growth and reproductive competence of teleost fish. The effect of such temperature rise will be more prominent in hill stream fishes like Chocolate mahseer *Neolissochilus hexagonolepis* because of their evolution in hilly environments and adaptation to low temperature. Majhi *et al*. (2013) examined the thermal tolerance, oxygen consumption and stress response in this fish species acclimatized at three different temperatures (24℃, 27℃ and 30℃) for 45 days. The study revealed that CTmax and LTmax increased significantly (P<0.05) with increasing acclimation temperature. Similarly, oxygen consumption rate at 24℃, 27℃ and 30℃ was 74.61 2.11, 94.32 2.33 and 122.54 2.01 $mgO_2kg^{-1}h^{-1}$ respectively. Further, among the three acclimated temperatures tested, fishes reared at 24℃ when subjected to thermal tolerance test encountered more stress (glucose level: 11.6± 1.14 mmol/l) than other groups (27℃: 9.22±0.22 mmol/l; 30℃: 7.4±0.89 mmol/l). The results suggested that water temperature of 31℃ and beyond in natural water bodies of Meghalaya might create physiological stress in Chocolate mahseer, which in the long run may affect its reproductive performance. Therefore, proven *in situ* and *ex situ* conservation approaches are recommended to conserve this species.

The climatic variability may affect several indigenous fish species especially in the Northeast hill streams. In the first phase of NICRA (National Innovations on Climate Resilient Agriculture) project, we studied two such potential ornamental fish species of hill streams in Meghalaya viz. *Danio dangila* and *Brachydanio rerio* (Hamilton, 1822). We determined critical (CTMax) and lethal (LTMax) thermal tolerance, acclimation response ration (ARR), rate of oxygen consumption and stress. The results of our study indicated significant increase ($p<0.05$) in CTMax (36.2±0.02, 37.7±0.31, 39.6±0.07, 40.9±0.10) and LTMax (38.1±0.08, 39.8±0.06, 40.0±0.07, 41.1±0.04) in *D. dangila* with increasing acclimation temperatures of 20°C, 25°C, 30°C and 35°C, respectively. Similarly, CTMax (36.4±0.05, 37.2±0.04, 38.7±0.03, 39.8±0.01) and LTMax (39.8±0.03, 40.4±0.02, 41.2±0.06, 42.2±0.03) increased significantly ($p<0.05$) in *B. rerio* with increasing acclimation temperatures. Inter-species variation was evident between the temperatures. Oxygen consumption rate increased ($p<0.05$) with increasing temperature in both the species. Overall, our results suggest that *B. rerio* is more thermal tolerant and show better adaptation in comparison to *D. dangila* (Majhi and Das, 2013).

In another study (Das and Majhi, 2014), low water temperature was found to induce stress and affect somatic growth in teleost *Channa stewartii.* The study demonstrated that elevated water temperature seems to be effective in minimizing stress and augmenting somatic growth in *C. stewartii.* It was observed that, like many other fish species from eastern Himalayan region (Majhi *et al* 2013), *C. stewartii* also encounters the environmental stress induced by low water temperature, particularly during the winter months. Probably this might be the reason that, fishes from the region invariably depict poor growth rate as most parts of the available energy is diverted towards stress mitigation than somatic growth. Thus, to commercially propagate the important fish species and/or to increase the fish production in the region, the farmers of the region should explore the beneficial effects of greenhouse pond.

Further, the ice melting and sea level rise will result in saline water intrusion and increased acidification. There may be overall decline in ocean productivity, change in monsoonal patterns & extreme weather events. The freshwater fishes could be moved further upstream due to sea level rise. However, rising sea levels lead to expansion of areas suitable for brackish water or salt water aquaculture such as shrimps and mud crab (Muralidhar and Vijayan, 2015). In future there may be greater demand for euryhaline fish species for aquaculture due to seal level rise. Some areas may become unsuitable for terrestrial agriculture, thus aquaculture may provide alternative livelihoods.

Due to global warming, there may be eutrophication and increased stratification in inland waters. Fish may die during dawn hours. The number of small scale farmers is more in hilly region which is often family owned and family run. Therefore impacts on many households; livelihoods are expected due to change in weather patterns and extreme events. Not many adaptive measures are available, however cluster insurance is encouraged. This will enable a resurrection of the businesses. The impacts on production may be temporary. Fish can adapt to climate change through integration of aquaculture with agriculture and Livestocks - which can help farmers to cope up with drought while boosting profits and household nutrition. Short-term culture of alternate species such as medium and minor carps could be another option to mitigate water stress condition during drought (Das, 2010). Further, need-based research and mass-awareness are earnestly needed to build capacity to adapt and respond to climate change.

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Chapter 21

ASSESSING VULNERABILITY FOR INLAND OPEN WATER FISHERIES: AN OVERVIEW

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Introduction

Fifth assessment report of Intergovernmental Panel on Climate Change (IPCC 2013) has indicated multiple lines of evidence for climate change. Though it has dispelled many uncertainties about climate change, warming of climate system has now been univocal. Scientists have claimed increasing trend of global mean surface temperatures over land and oceans, and discerned the fastest warming trend in the history of earth. Among others, changes in the likelihood of occurrence or strength of extreme weather events (e.g. flood, cyclone, drought, heavy rainfall etc.) are some of the indicators of climate change (IPCC 2013, AR5).

Evidences of climate change have also been observed in Asia, the largest continent on Earth. There are evidences of prominent increases in the likelihood of occurrence and intensity of extreme weather events such as heat waves, tropical cyclones, prolonged dry spells, snow avalanches, thunder storms etc. in the region (Cruz et al., 2007). For example, the region has experienced extreme events, such Tsunami in 2004; earthquake of Pakistan in 2005; devastating Aila over India and Bangladesh etc. in 2009.

Climate change is expected to affect many sectors: water resources; agriculture and food security; ecosystem and biodiversity; human health; and coastal zone. Fisheries associated with freshwater as well as seawater aquatic ecosystem will also be affected. For instance, fisheries at higher elevations are likely to be adversely affected by lower availability of oxygen due to a rise in air temperatures. In the plains, on the other hand, the timing and amount of precipitation may influence the spawning migration, dispersal, and growth of fish. Sea level rise and changes in sea surface temperature, salinity, wind speed and direction, strength of upwelling have the potential to substantially alter fish breeding habitats and food supply for fish, which ultimately affect the abundance of fish populations in Asian waters with associated effects on coastal economies (Cruz et al., 2007).

For development purpose, adaptation strategies have to be formulated within the uncertainty about the extent of climate change; and adjustments and changes at every level starting from community to national and to international level must be accounted for. Communities must build their resilience adopting appropriate technologies while diversifying their livelihoods to cope with current and future climate stress. Four purposes have been identified for vulnerability assessment: (i) to improve adaptation planning, (ii) to frame climate change mitigation as an urgent problem; (iii) to address social injustice, by exposing the differential burden of vulnerability borne by the socially disadvantaged; and (iv) to improve basic scientific understanding of vulnerability and improve the methods and tools used in its evaluation (Patt et al., 2009). Thus, to formulate proper adaptation strategies for a system, it is of significant importance to assess vulnerability that entails identification, quantification, and prioritization of the risk involved due to climate change.

The present article provides critical insight into conceptualizing and measuring vulnerability, aiming to consolidate the state-of-the-art for assessment of vulnerability to climatic change at and to provide directions for future research.

General concept of vulnerability assessment

Generally, vulnerability conceptualizes as the risk that a system, such as households, region or country, would be negatively affected by specific perturbation that impinge on the system. Probabilistically it is the probability of a system undergoing a negative change due to a perturbation (Gollopin, 2006). Different scientific disciplines have different specific definitions of vulnerability because they focus on different component of risks (Alwang et al., 2001). But it is clear that vulnerability relates to an undesirable outcome (e.g. vulnerability to poverty, vulnerability to natural hazard, vulnerability to environmental changes such as climate change etc.) and that such vulnerability is due to exposure to hazards which causes perturbation (Alwanng et al., 2001). The system can imply spatial scale that exhibit vulnerability, from micro (household), to meso (regional), macro (countries, continent, the Globe) levels.

Thus vulnerability assessment is the process of identifying, quantifying, and prioritizing (or ranking) the vulnerabilities in a system. Given that vulnerability can exist in different spatial scales, there are several approaches to assess vulnerability of a system. In most of the cases assessment framework is based upon suitable measures of vulnerability. There may exist number of vulnerability measures that may multiply in the future. It may be useful to point out some essential criteria that a sound vulnerability measure should ideally satisfy. First, vulnerability is an ex ant noton; so any measure of vulnerability should have a predictive quality (Cannon et al., 2003).

Second, measures of vulnerability should account socially acceptable level of outcome (Alwang et al., 2001, p. 33). Third, vulnerability indicators should contain information on the causes of vulnerability and the relative importance of covariate risk (Gunther & Harttgen, 2006). Fourth, a good measure of vulnerability should refer to a particular hazard (Cannon, 2007). Fifth, to measure vulnerability appropriately, one needs to consider the dynamics of vulnerability not only before a hazard occurs, but also during and after (Birkmann, 2007). Finally, vulnerability cannot be properly assessed without assessing a system's ways and means of coping with risk (See Naudé et al, 2009).

Assessment of vulnerability to climate change

Vulnerability to climate change is mainly conceptualized as the extent of damage of a region that is expected to be affected by various factors influenced by climate change. There are several definitions, which vary according to the application areas and sectors, of vulnerability to climate change. Interested readers are directed to consult further literature (Adger, 1999, Watson et al., 1996, Chris Easter, 2000; Dolan and Walker, 2003; Moss et al., 2001 and references therein) for detail definitions and conceptualizing vulnerability to climate change in different systems. The IPCC report has defined vulnerability as "*the degree to which a system is susceptible to or unable to cope with the adverse effect of climate change including climatic variability and extreme events. It is a function of character, magnitude and rate of climate variation to which a system is exposed, its sensitivity and its adaptive capacity*" (McCarthy et al., 2001) that is widely used in different system.

Quantitative vulnerability assessment

The quantitative vulnerability assessment is data driven approach. This approach, however, is useful for the community or region where quantitative data is available.

It essentially entails identification of indicators of vulnerability, defining measures of vulnerability and choice of suitable vulnerability indices. Measures of vulnerability to climate change typically function of three components: (1) exposure to climate change, which normally considered as direct danger (i.e. the stressor) and the nature and extent of changes to climate variables (temperature, precipitation, extreme weather events) of the region of interests; (2) sensitivity to its effects that describes the human-environmental conditions that can worsen the hazards, ameliorate the hazard or trigger an impact; and (3) adaptive capacity defined as the potential to implement adaptation measures that help to avert potential impact of climate change. Typically, vulnerability assessments quantify these components by identifying appropriate indicators to develop indices for components and subsequently combine those indices into an integrated index of vulnerability. Some of the indicators (primarily of exposure and sensitivity) are from the biophysical realm; others (mainly describing adaptive capacity) are drawn from socio-economic data. The usefulness of vulnerability indicators highly depends on the concept they express. Any information conveyed by the indicators should have relevance to stakeholders, while selecting indicators of vulnerability.

Method of construction of vulnerability index

The key component of quantitative vulnerability assessment is to construct a “vulnerability index” that is derived on the basis of several sets of indicators relevant to stakeholders of the study area. A single number evolve from the method of construction of vulnerability index, and it can be compared over spatial scales. Construction of vulnerability index consists of several steps: (a) selection of study area (State level, national level), in which vulnerability is supposed to be exists and varies over region (districts, zones etc.); (b) selection of indicators (on three components e.g., Exposure, Sensitivity and Adaptive Capacity.), which are selected on the basis of experts' judgment and results of previous research or both; (c) selection of specific time frame (normally for a year), as vulnerability changes over time; and (d) choosing suitable measure of vulnerability. Finally, a composite index is developed on the basis of weighted mean of three components. Thereafter following computational procedures can be followed to obtain the value of vulnerability index.

NORMALIZATION OF INDICATORS

Consider the data on each component of vulnerability is collected for K indicators for M region (districts) and X_{ij} denotes the value of the indicator j of the i^{th} region. The indicators' values will be in different units and scales. In order to obtain unit free values to compare, the indicators variables are normalized within 0 to 1 range. Before doing this, it is important to identify the functional relationship between the indicators and vulnerability. Two types of functional relationship are possible: (i) vulnerability increases with increase in the value of the indicator; and (ii) vulnerability increases with the decrease in the value of the indicator. Assume that higher the value of the indicator the more is the vulnerability. For example, suppose we have collected information on change in maximum temperature or change in annual rainfall or diurnal variation in temperature. It is clear that the higher the values of these indicators the more will be the vulnerability of the region to climate change as variation in climate variables increase the vulnerability. In this case we say that the variables have increasing functional relationship with vulnerability and the normalization for the j^{th} indicator of i^{th} region is done using the formula

$$x_{ij} = \frac{X_{ij} - Min(X_{ij})}{Max(X_{ij}) - Min(X_{ij})}$$

, where maximization and minimization was done over all $i = 1,2, \ldots,M$. It is clear that all these scores will lie between 0 and 1. The value 1 will correspond to the region with maximum value and 0 will correspond to the region with minimum value. For the case of decreasing functional relationship the normalizing formula becomes

$$x_{ij} = \frac{Max(X_{ij}) - X_{ij}}{Max(X_{ij}) - Min(X_{ij})}$$

For example, consider the case of adult literacy rate. It can be well contemplated that vulnerability will decrease with the increase of adult literacy rate because high adult literacy rate is indicative towards more awareness to cope with climate change.

COMPUTATION OF VULNERABILITY INDEX

After computing normalized scores of each of the indicators, the vulnerability index value is computed by taking average over the indicators. Simple average can be used if equal importance is given to each of the indicators. Thus the vulnerability index for i^{th} region (VI_i) giving equal weights to the indicators can be written as

$$VI_i = \frac{1}{K}\sum_{j=1}^{K} x_{ij} \quad \ldots\ (1).$$

The method of simple average as mentioned above is not realistic in real life situation because the concept of equal importance for each indicator hardly holds true. Method of weighted average has become very popular for this reason. In this method the weighted vulnerability index denoted as WVI_i can be written as

$$WVI_i = \sum_{j=1}^{k} w_j x_{ij} \quad \ldots\ (2)$$

, where w_j is the weight corresponding to the j^{th} indicator subject to the condition

$$0 < w_j < 1; \sum_{j=1}^{K} w_j = 1.$$

This method is quite general and simple average is a particular case of weighted average method when weights are set to ‘1’. The main challenge in the weighted average method is the choice of weights. Expert judgment to assign weight can be used, for simplicity. However, this is sometimes avoided as selection of experts and subsequent assignment of weight may lead to subjective bias. Iyenger and Sudarsan (1982) developed an objective approach to eliminate such subject bias. They proposed a method of composite index from multivariate data and it was used to rank the region (e.g, district) in terms of their economic performances. This method is statistically sound and can easily be calibrated for computing vulnerability index to climate change. The key assumption in this method is that w_j is inversely proportional to the standard deviation of the j^{th} indicator. Mathematically it can be written as

$$w_j = \frac{c}{\sqrt{var_i(x_{ij})}}$$

Where, c is the normalizing constant such that and $\sum_{j=1}^{K} w_j = 1$ the formula for computing c is written as

$$c = \left[\sum_{j=1}^{K} \frac{1}{\sqrt{var(x_{ij})}}\right]^{-1}$$

The choice of the weights in this manner would ensure that large variation in any one of the indicators would not unduly dominate the contribution to the rest of the indicators and distort inter regional comparisons. The vulnerability index computed by using above method also lies between 0 and 1, with 1 indicating maximum vulnerability and 0 indicating no vulnerability at all.

For classification purposes, a simple ranking of the regions based on the indices WVI_i would be enough. However for a meaningful characterization of the different stages of vulnerability, probabilistic classification is the more sensible approach. This is accomplished by assuming a probability distribution of weights. Following Iyengar and Sudarshan (1982), beta distribution is assumed due to its flexibility by choice of parameters for this purpose. Moreover, the value generated from this distribution lie in the interval (0,1) and can be used directly as weights. The probability density function of beta distribution is given by

$$f(z) = \frac{z^{a-1}(1-z)^{b-1}}{B(a,b)}$$

Where, $B\ (a,b)$ is the complete beta function denoted by

$$B(a,b) = \int_0^1 x^{a-1}(1-x)^{b-1}dx.$$

The beta distribution is skewed depending upon the choice of the parameter *a* and *b*. When a=*b* then the distribution becomes symmetric about 0.5. The two parameters *a* and*b* of the distribution can be estimated either by using the method described in Iyengar and Sudharshan (1982) or by using software packages. Let $(0, z\ 1), (z1, z2\ ),$ $(z2, z3\ ), (z3\ , z4\ )$ and $(z4\ ,1)$ be the linear intervals such that each interval has the same probability weight of 20 per cent. These intervals can then be used to characterize the various stages of vulnerability. For example, the following characterization of vulnerability can be done based on the WVI_i

Table 1. Characeterization of vulnerability based on WVI_i value

Category	Extent of Vulnerability	*WVI* value
1	Less Vulnerable	$0 < WVI_i < z_1$
2	Moderately Vulnerable	$z_1 < WVI_i < z_2$
3	Vulnerable	$z_2 < WVI_i < z_3$
4	Highly Vulnerable	$z_3 < WVI_i < z_4$
5	Very Highly Vulnerable	$z_4 < WVI_i < 1$

Multivariate statistical techniques

Since data for the construction of vulnerability indices are multivariate in nature, it is possible to apply multivariate statistical analysis tools to obtain weights for the indicators and subsequent classification of regions. Two classical multivariate tools are briefly outlined in the present context.

PRINCIPAL COMPONENTS

PCA is a multivariate technique for finding patterns in data of high dimension and produces same number of synthesized variables (usually called components), which are linear combination of original indicators. The number of components retained is based on the variance explained by the retained components (normally > 90 %). Another rule of thumb is to retain all the components with eigen value greater than 1 . Thereafter the components explaining maximum variation can be used as the vulnerability index. Weighted average of components with weight corresponding to percentage of variance explained can also be used for the same purpose. Gberibouo, G.A. and Ringler (2009) have applied this method to construct the vulnerability of South African farming sector. They identified a total of 19 indicators, 4 for exposure component, 6 for sensitivity component and 9 for adaptive capacity component. They retained the first principal component which explained about 33% of the variation and based on over all vulnerability index they classified the 9 farming provinces into 4 categories in terms of vulnerability as 'high', 'medium', 'low-medium' and 'low'.

CLUSTER ANALYSIS

The index approach is very easy to compute and intuitively clear. However, it leads to loss of information when aggregating different types of data. Further the interaction between the factors that were used for construction for the composite index is also masked. To address this problem some authors (for example, Sharma,U. and Patwardhan, A (2007) applied cluster analysis technique to identify vulnerability hotspots to tropical cyclone hazard in India.

Stakeholder-driven vulnerability assessment

This an alternative approach to quantitative vulnerability assessment. This is normally applied to the region where quantitative data are scantily available and not available or both. Essentially this approach makes stakeholder involve in agreeing upon the main issues and importance of assessment of vulnerability to climate change (Malone and Engle, 2011), and stakeholders' expert opinion serves as alternative sources of information about climate change vulnerability. Community stakeholders of the region can very well contemplate and communicate what they are vulnerable to, who are vulnerable, how future vulnerability may be characterized, and what scale. According to Malone and Engle, 2011, several challenges may exists in the approach, including the need to (i) over perspective guidance against lack of direction (ii) to employ skilled felicitators (iii) to schedule sufficient time for gaining consensus, and (iv) to be aware of power relations among stakeholders. The main advantage of this approach is that user-decisions of the system yield useful insight into how stakeholders actually perceive vulnerability to climate change in specific context in which they work. Interested readers are directed to the literature by Malone and

Engle, 2011; Carter et al., 2010 for further details. Naskar et al. (2017) have successfully used this idea in the context of wetland fisheries of India.

Vulnerability assessment for inland open water fisheries

Though literature on vulnerability assessment to climate change for agriculture, health, poverty and other sectors are rich, but it is limited in the field of fisheries, especially inland fisheries. In the global level some studies on vulnerability assessment to climate change for fisheries sector have been carried out (Allison et al., 2005, 2009, McClanahan et al., 2008). But, the choice of adaptation strategies depends on national as well as state level. In case of inland fisheries, local coping strategies and traditional knowledge are used in synergy with government and local intervention for enhancing the livelihood fishermen. Obviously vulnerability assessment to climate change and subsequent formulation of adaptation strategies must account those components. Specifically, vulnerability assessment to climate change focusing particularly to inland fisheries in the tropical region is limited. In most of the cases fisheries component has been taken as a group of indicators for constructing overall composite vulnerability index. Moreover, Inland fisheries are very scattered and diverse over even very small spatial scale. It varies greatly not only over different country but also over regional scale like states. The quantitative assessment of vulnerability of small-scale fisheries sector and fishers to climate change is not available as such. Very recently Das et al. (2014) developeda quantitative framework of vulnerability assessment of inland fisheries to impacts of climate variability for India. The authors have emphasized on the quantitative vulnerability assessment even in the state level. The authors employed the method proposed by Iyenger and Sundarsan (1982) with indicators specifically relevant to inland fisheries. The framework is reproduced from Das et al (2014) as shown in

Figure 1 and interested readers are referred to consult Das et al (2014) for detailed analytical method.

Conclusions

The present article provides only a general overview of vulnerability assessment to climatic change. This can be modified to the vulnerability assessment to climatic variability, which will represent present vulnerability. Futuristic vulnerability based on climate change model (e.g. GCM) can be assessed by plugging the climate change parameters into the indicators for exposures. The main idea here is to supplement the understanding for vulnerability assessment with reference to inland fisheries so the readers can make use of it for future work. Inland open water fisheries, particularly in India, are mostly community driven. The framework provided by Das et al. (2014) can be extended further to well defined fishing communities. Naturally, further research may be focused on assessing vulnerability of fishing community to climate change, after defining fishing community for a region. In the socio-economic studies, one important area is to assess household (micro level) vulnerability to climate change. This idea can be implemented to assess fishermen household vulnerability. As inland fisheries are classified further as capture and culture, vulnerability assessment to climate change specific to culture and capture fisheries to climate change can be of substantive importance for future work. In the similar fashion, vulnerability assessment for culture based industry and capture based industry to climate change can be taken up for future research.

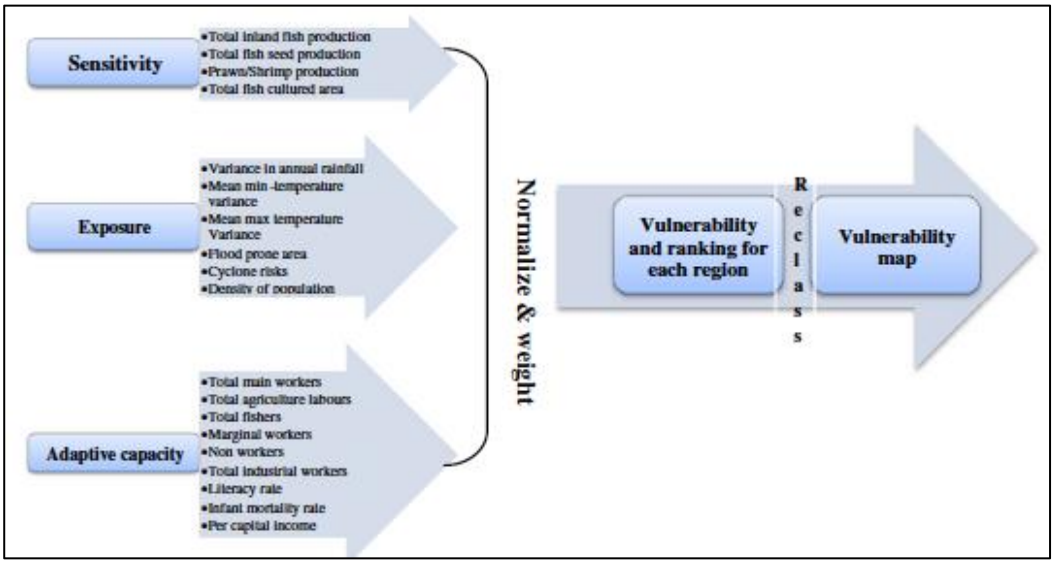

Fig.1. A framework for construction of Vulnerability index for inland Fisheries (Source: Das et al., 2014)

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Chapter 22

CARBON SEQUESTRATION POTENTIAL OF WETLANDS – AN OVERVIEW

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Introduction

Climate change is a global problem. The whole world is facing an increase in temperature of around 2°C over the 21st century. In India mean temperature has increased by more than 0.5°C (1901-2007). There are several consequences of global warming on the ecology and environment. For example, many fish species are highly vulnerable to climate change, particularly temperature. Global warming due to rise in earth's mean temperature is mainly caused due to emission of green house gases (GHG) like carbon-di-oxide (CO_2), methane (CH_4), nitrous oxide and few others. According to a report of Intergovernmental Panel on Climate Change (IPCC) global emissions of GHG have risen to unprecedented levels and in the decade 2000-2010 the rate was much faster than in each of the three previous decades. The average monthly concentration of CO_2 in earth's atmosphere has exceeded 410 ppm over the level of 270-280ppm in late 1700s. Scenarios show that to have a likely chance of limiting the increase in global mean temperature to 2°C, means lowering global greenhouse gas emissions by 40 to 70 percent compared with 2010 by mid-century, and to near-zero by the end of this century. According to IPCC Sixth Assessment Report limiting global warming to 1.5°C would require human caused emission of GHG to fall by 45% from 2010 levels by 2080 and near zero by 2050. Ambitious mitigation measures would be required for removing CO_2 from the atmosphere.

So considerable attention has been paid for stabilizing the abundance of CO_2 and other GHGs to mitigate the risks of global warming. One of the strategies for lowering the CO_2 emission to mitigate climate change is sequestering CO_2 from the atmosphere through natural or artificial techniques.

Wetlands as Carbon sink

Soils in general and that of wetlands in particular are rich reserve of C. In fact C stored in soils worldwide exceeds the amount of C stored in phytomass and the atmosphere. Table-1 depicts the distribution of terrestrial organic C among the IPCC climate regions. Excepting tropical moist and wet regions, in all other regions most of the OC is stored in soil than in above ground phytomass.

Table 1. Distribution of terrestrial organic C by IPCC climate region in soils and phytomass

IPCC Climate region	Soil (Pg C)	(%)	Phytomass (Pg C)	(%)	Terrestrial C pool (Pg C)
Tropical wet	128	(47.7)	140.2	(52.3)	268.2
Tropical moist	150.9	(49.9)	151.7	(50.1)	302.6
Tropical dry	136.2	(76.2)	42.5	(23.8)	178.7
Tropical montane	56.1	(58.1)	40.5	(41.9)	96.6
Warm temperate moist	63.0	(68.7)	28.7	(31.3)	91.7
Warm temperate dry	78.5	(76.4)	24.2	(23.6)	102.7
Cool temperate moist	210.3	(88.1)	28.5	(11.9)	238.8
Cool temperate dry	102.2	(91.8)	9.1	(8.2)	111.3
Boreal moist	356.7	(93.8)	23.5	(6.2)	380.2

Boreal dry	69.1	(93.1)	5.1	(6.9)	74.2
Polar moist	52.4	(96.0)	2.2	(4.0)	54.5
Polar dry	12.3	(96.2)	0.5	(3.8)	12.8
Total	1415.7	(74.0)	496.6	(26.0)	1912.2

Scharlemann et al., 2014

Wetlands are one of the largest biological carbon (C) pool among the soil ecosystems and important in global C-cycle (Chmura et al., 2003; Mitra et al., 2005). Out of a total of 1550 petagram (Pg) C stored in soils (Lal, 2007), 450 Pg (about one third) is stored in wetland (Roulet, 2000; Mitsch and Gosselink, 2007). According to Eswaran et al. (1993) the amount of carbon stored in wetland soils is ~ 498 Pg. Over a long period, wetlands are a C-sink, and play an important role in alleviating the global climate change regardless of the emission of GHGs particularly CH_4. However, there are considerable uncertainties about the amount of C stored and amount emitted from wetlands through emission of GHGs because of the site specific factors.

Globally wetlands cover about 4-6% of the land surface but contain 14% of the terrestrial biosphere carbon pool. The total extent of wetlands has been estimated to 700 - 1000 Km^2 globally (Mitsch et al., 1994). Carbon accumulates in wetland soils because of high rates of plant productivity and low rates of decomposition in these ecosystems. Excluding peat lands wetlands are among the most productive ecosystems in the world. The net primary productivity (NPP) of fresh water wetlands is very high (1180 g C m^{-2} yr^{-1}) compared to various ecosystems including tropical forest. Additionally wetlands are also anaerobic which gradually reduces the decomposition relative to aerobic system. Due to these facts production usually exceeds decomposition in wetlands and results in the net accumulation of organic matter and carbon. The organic matter accretion rates are in the order of mm to 1cm yr^{-1} for both constructed and natural wetlands.

Wetland soils play an unusual role in global carbon cycle. The amount of C stored in wetlands varies depending on the type of wetlands and other factors. The major factors affecting carbon cycling in wetlands are inputs, outputs, and storage capability. Inputs can occur as gas (photosynthesis, algae and macrophytes), solids (dust, water and soil erosion, and animal biomass), and dissolved substances (dissolved organic carbon, dissolved inorganic carbon). Outputs also occur in these three states: as gas through respiration (carbon dioxide, methane and nitrous oxide); as solids (e.g., harvesting of vegetation such as hay cropping); and as dissolved substances in water through surface and ground water flow (dissolved organic carbon and dissolved inorganic carbon).

Carbon fluxes in wetlands

Carbon inputs:

- Gas (Photosynthetic uptake by Phytoplankton, Macrophytes)
- Solid (dust, water & soil erosion, animal biomass)
- Liquid (Dissolved organic & inorganic carbon)

Carbon outputs:

- Gas (Respiration CO_2 & CH_4)
- Solid (Harvesting of vegetation)
- Liquid (Dissolved organic & inorganic carbon)

Storage (Input – Output): Peat/soils

Carbon is stored in wetland sediments over the long term. Short-term stores are in existing biomass (plants, animals, bacteria and fungi) and dissolved components in the surface and groundwater. Modifiers of carbon storage are numerous and include factors such as wetland class, vegetative zone, depth into sediment, north–south latitudinal gradient, salinity, climate cycles, temperature, hydrology and surrounding land use. Significant differences were found on carbon sequestration between wetland types in temperate and tropical regions, being consistently higher in the studied forested wetlands (260 ± 58 g C m^{-2} y^{-1}) than the riverine ones (113 ± 27 g C m^{-2} y^{-1}). The temperate wetlands were also consistently more efficient in sequestering carbon than similar tropical ones (230 ± 89 and 144 ± 57 g C m^{-2} y^{-1}, respectively). Wetland productivity and permanent anaerobic conditions are key in enhancing soil carbon sequestration. In the created wetlands carbon sequestration was strongly correlated with aboveground productivity. These temperate created wetlands sequestered 243 ± 24 g C m^{-2} y^{-1} after 15 years since creation, 26% more than the rate after 10 years (190 ± 7 g C m^{-2} y^{-1}) and 55% more than the similar natural wetland in the same region (140 ± 16 g C m^{-2} y^{-1}), implying that once created wetlands are fully functional and structured they can successfully sequester carbon, especially in their early years (http://senr.osu.edu/eventview.asp?eventid=5912).

As such, there is no clear understanding about the rate at which atmospheric C is sequestered tropical wetlands as compared to temperate and boreal wetlands. Though tropical wetlands are more productive but at the same time there would be more decomposition due to higher temperatures in the tropics. Overall C sequestration rate estimated from different boreal, temperate and tropical wetlands across the globe is depicted in Table.2. The rate varied from 8 to 480 g C $m^{-2}y^{-1}$.

Modifiers of carbon storage on wetlands

Carbon accumulation in wetlands is dependent on –

- Wetland type
- Topography & Landscape position of wetland
- Vegetative Zone
- Type of vegetation
- Depth into sediment
- North-South Latitudinal gradient
- Salinity
- Climate cycles
- Temperature
- Hydrology
- Surrounding Land Use
- Wetland Productivity
- Anaerobic condition of the wetland

Carbon budgeting in wetlands

- Water column primary productivity
- Macrophyte net above ground primary productivity
- Non-purgeable Organic Carbon (NPOC)
- Dissolved Inorganic Carbon (DIC)
- Fine Particulate Organic Carbon (FPOC)
- Coarse Particulate Organic Carbon (CPOC)
- Water column and soil respiration
- Methane emission

Table 2. Carbon sequestration in different types of wetlands

Wetland type	g C $m^{-2}y^{-1}$	Reference
General average for peatlands	12 - 25	Malmer (1975)
General range for wetlands	20 - 140	Mitra et al. (2005)
Peatlands (North America)	29	Gorham (1991)
Peatlands (Alaska and Canada)	8 - 61	Ovenden (1990)
Boreal peatlands	15 -26	Turunen et al. (2002)

Temperate Peatlands (North America)	10 - 46	- do-
Thoreau’s Bog, Massachusetts	90	Hemond (1980)
Thoreau’s papyrus wetland, Uganda	480	Saunders et al. (2007)
Created temperate marshes, Ohio	180 - 190	Anderson and Mitsch (2006)
Prairie pothole wetlands, North America Restored (semi-permanently flooded) Reference wetlands	 305 83	Euliss et al. (2006)
Tropical wetland, Indonesia	56 (24000 yr) 94 (last 500 yr)	Page et al. (2004)
Flow through freshwater wetlands Ohio (temperate) Costa Rica (humid tropical)	 124-160 250-260	Bernal and Mitsch (2008)

Carbon sequestration potential (CSP) of different lakes and swamps in China was investigated. Significant differences were observed among the CSP of different lakes determined by natural conditions and human disturbances. Swamps had much higher CSP than lakes and among the swamp types; mangrove had the highest C sequestration rate followed by coastal salt marsh (Table 3). Based on the plan of the Chinese government on wetland conservation and restoration, the CSP of conserved and restored wetland was huge (Table 4).

Table 3. C-sequestration potential in wetlands of China

Type	Area (km^2)	CSR (g-C $m^{-2}y^{-1}$)	CSP (Tg-C y^{-1})
Peatland	42349	24.8	1345.85
Freshwater marsh	24977	32.48	811.23
Inland salt marsh	22369	235.62	1501.18
Coastal salt marsh	1717	67.11	404.57
Mangrove Forest wetland	2561	444.27	1137.79

(Xiaonan et al., 2008)

Table 4. Carbon sequestration potential (CSP) of wetland restoration in China in 2006-2010

Type	Area potential (km^2 y^{-1})	CSP (Gg-C y^{-1})
Peatland	200	0.5
Coast marsh	100	1.18
Mangrove	37	1.65
Lake in eastern China	346	1.96
Lake in north western China	424	1.28

(Xiaonan et al., 2008)

Wetlands as emitter of GHG

Although wetlands can sequester carbon they can also act as source of GHGs. Wetlands can act as a source of CO_2 when decomposition of organic matter outpaces production. In addition, wetlands are sometimes drained for agricultural and other purposes in many parts of the world and as a result are becoming a significant source of atmospheric CO_2.

Wetlands are also a natural source of CH_4 which results from methanogenesis occurring in sediments. About 20-26% of the global CH_4 is emitted from wetlands (Mitsch and Gosselink, 2007). Once produced in the sediments CH_4 can be released as bubbles or diffused through the water column and then released to the atmosphere. It can also be released to the atmosphere directly from the sediments where it is produced by aquatic plants with hollow stems.

CH_4 is produced in wetlands when labile fraction of organic matter (OM) undergoes mineralization under anaerobic condition by microorganisms called Archaea. CH_4 producing bacteria or methanogens use low molecular weight compounds like acetate coming from anaerobic fermentation of OM and ferment them into CH_4 which is the end product of anaerobic decomposition of soil OM.

$$CH_3COOH + 4H_2 \longrightarrow 2\ CH_4 + 2H_2O$$

Alternatively CH_4 is produced from reduction of CO_2.

$$CO_2 + 4H_2 \longrightarrow CH_4 + 2H_2O$$

Methanogenesis requires strictly anaerobic and extremely reduced condition i.e. redox potential below -200 mV. Presence of other e- acceptors like NO^{3-}, Fe^{3+}, SO_4^{2-} can inhibit CH_4 production. Emission of CH_4 from wetlands to the atmosphere does not depend only on CH_4 production but also on its oxidation which takes place in the upper oxidized soil layer. During convective flow or diffusive transport of CH_4, produced in the lower anaerobic and highly reduced horizon, to the upper layer, the gas comes across with obligate aerobic methanotropic bacteria present in aerobic soil layer which use molecular oxygen to oxidize CH_4 to CO_2. Thus, emission of CH_4 to the atmosphere is limited. Methanotrophs are estimated to consume about 30 Tg CH_4 yr^{-1} an amount close to net annual increase in atmospheric CH_4.

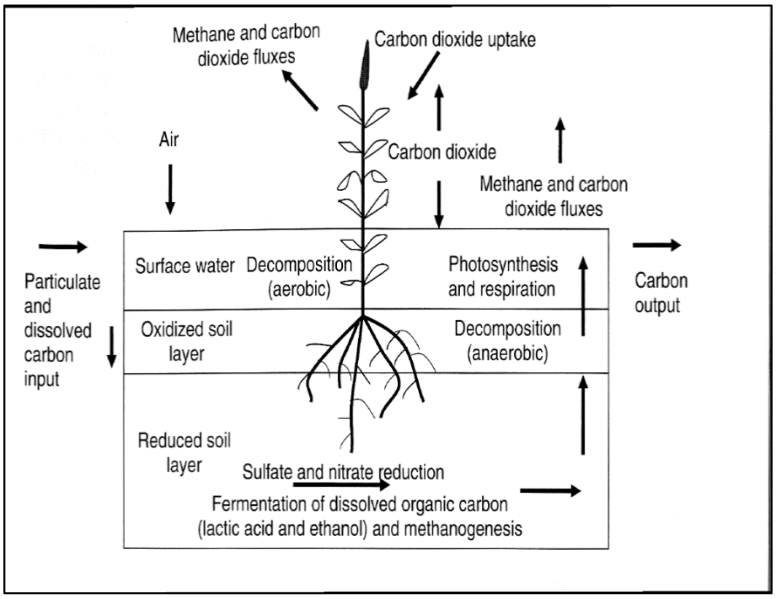

Fig.1. Schematic diagram of emission of CH_4 from wetlands

Table 5. Emission of CH_4 from different wetlands

Location	Biome	Wetland type	Methane ($g\ CH_4 m^{-2} y^{-1}$)	References
Vargem Grande, Amazon Basin	Tropical	Flooded forest Floating grass mat Open water lake Macrophyte mat	70 84 44 215	Devol et al. (1988)
Lago Calado, Amazon	Tropical	Oxbow open water	10	Barlett et al (1988)
SE Australia	Sub tropical	Oxbow	386	Boon & Mitchell (1995)
Varanasi, India	Sub tropical	Natural deepwater	155	Singh et al. (1999)
Lucknow, India	Sub tropical	Flooded forest Macrophyte mat	42 9	Singh et al. (2000)
Venezuela	Tropical	Floodplain open	9	Smith et al. (2000)
Louisiana, USA	Sub tropical	Bottomland Harwood Forest	249	Yu et al. (2008)
Earth, Costa Rica Le Selva, Costa Rica Palo Verde, Costa Rica	Tropical	Forested Marsh Rainforest Swamp Alluvial Marsh	44 293 350	Nahlik & Mitsch (2011)
Ohio, USA	Temperate	Riverine open	77	Nag et al. (2017)

Influence of riparian zones in C cycling in wetlands

Riparian zones are situated on the wetland fringe, where the vegetation is affected by the presence of the wetland. The cover type in riparian zones is varied. The impacts on carbon cycling of land management practices in riparian zones are unclear. While cultivation likely lessens carbon storage potential, the effects of grazing is open to question. Good grazing management should increase carbon-holding potential. The effects of burning are unknown. The condition of riparian zones may also influence the carbon cycling of adjacent wetlands, since riparian areas have various effects, such as protecting wetlands from chemical and nutrient inputs.

Wetland C dynamics

The importance of the wetland soil C in the global C budget has been recognized over the years. Because of a lack of fundamental knowledge of wetland soil C dynamics, the magnitude and timing of the response of this C reservoir to changes in climate and land use contribute to large uncertainties in global C cycle models. In order to understand the role of wetland soil C in the global C cycle and to predict future atmospheric CO_2 concentration it is crucial to understand the dynamics of C-cycling in wetland soils.

Techniques of measuring C flux and Stores

A variety of techniques are available to monitor and verify carbon fluxes and stores in wetlands. Determination of carbon inputs and outputs in association with water flows can be determined by volume determinations of the flows involved (surface and ground water, precipitation) and the concentration of carbon (dissolved and particulate, organic and inorganic) in those flows. Atmospheric uptake of carbon can be determined by biomass accumulation (above and below ground) of the primary producers in the system. Carbon inputs and outputs can be integrated by using stable isotopes to determine carbon pathways and allochthonous (exterior) versus autochthonous (within the wetland) carbon inputs. Decomposition studies can follow the movement of carbon from the death of plants and algae through to burial of material in the sediments. While requiring complicated techniques and analyses, gas-exchange studies can monitor gas losses (carbon dioxide, methane and nitrous oxide) from the system through respiration and decomposition processes. Sampling of the soil profile can provide information on carbon stored in wetland sediments.

Management practices to protect C-stores in wetland

- Conservation of wetlands and their sustainable use as natural habitats
- Restoration of degraded wetlands and creation of new wetlands
- Control drainage and other land and water management practices which lead to dewatering of wetlands and oxidation
- Control fires including deep burns
- Allow natural revegetation to occur
- Control peat harvesting and other removal of carbon from wetlands
- Public awareness and legal protection

Conclusion

From the above discussion it is quite evident that wetlands affect global C cycle in different ways but still, its role is poorly understood. The net C sequestering versus C release from wetland ecosystems are complex and also change over time. Much more information are required to be generated from different types of wetlands both as C sink and as C source so that a robust and effective model can be developed.

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Chapter 23

ADVANCES IN CLIMATO-ECOLOGICAL BASED MODELS FOR TROPICAL WETLAND MANAGEMENT: A REVIEW ON PLANKTON BASED APPROACH

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Introduction

Climate change scenarios predict additional stresses on wetlands, mainly because of changes in hydrology, temperature increases, and a rise in sea level. Wetland shelters a diverse spectrum of aquatic habitats, widely recognized as biodiversity hotspots and key components of global carbon budget. Wetlands are highly dependent on water levels, and so changes in climatic conditions (e.g. hydrological cycle) will highly influence its structure and functioning. Depending on the region, 30–90 % of the world's wetlands have already been destroyed or strongly modified in many countries with no sign of abatement. Wetlands cover approximately 6% of the Earth's land surface and contain a large portion of the world's biodiversity (Junk et al 2013, Meng et al., 2016). Tropical and subtropical wetlands contribute at least 50% of total wetland methane emissions, and over 80% of the natural sources, to the atmosphere partially due to large inundated areas and high temperatures (Riley et al 2011; Meng et al 2012, 2015).The ecosystem services and carbon storage of tropical wetlands are extremely vulnerable to the negative effects of climate change. Many impacts of climate change on marine ecosystems may be additive, synergistic or antagonistic, it is difficult to understand and predict responses at all spatial scales and levels of ecological complexity (Blanchard, 2012).

Tropical wetland

The dominant wetland ecosystems in the tropics are forested peatlands, swamps, and floodplains (Aselmann and Crutzen, 1989). Page et al. (2011) estimated that there were 441,025 km^2 of tropical peat lands globally, distributed throughout 61 countries in Africa, Asia, Central America and the Caribbean, South America, Australia and the Pacific. The majority of tropical peat forests (about 56%) occur in Southeast Asia (Page et al. 2011). Tropical wetlands are not included in Earth system models, despite being an important source of methane (CH_4) and contributing a large fraction of carbon dioxide (CO_2) emissions from land use, land use change, and forestry in the tropics.

Table1. Description of Wetland Types

Wetland type	Description	Area(km^2)
Swamps	Forested freshwater wetlands on waterlogged or inundated soils where little or no peat accumulation takes place.	230,000
Peat lands	Peat producing wetlands in moist climates where organic materials have accumulated over long periods.	441,000
Floodplains	Periodically follower areas along rivers or lakes showing considerable variation in vegetation cover.	715,000

Status of wetland in Indian scenario

The distribution of wetlands in India is wide ranging from the cold areas of Ladakh to highly wet Manipur, the warm desert of Rajasthan and Gujarat to the monsoon drained Central India and humid zones of South India. Literally, the wetlands include a wide variety of dynamic ecosystems from perennial rivers, streams, estuaries including mangrove swamps, natural depressions & marshes (locally known as beels, chaurs, dhars, pats, etc.), ox-bow lakes, ponds and tanks and seasonally inundated floodplains. In India floodplain wetlands are spread across 5.54 lakh ha area (Sugunan et al., 2000, Pathak et al., 2014, Sarkar et al., 2016). The high productivity within floodplains supports various ecosystem services such as flood regulation, water depuration, and provision of habitat for many commercially important species in table 2 (Costanza et al. 1997, Adame et al., 2017). It is expected that India will lose about 84% of coastal wetlands and 13% of saline wetlands with climate change induced sea water rise of 1 m (Sarkar et al., 2016).

Table 2. Ecosystem functions, goods and services that can be quantified for tropical wetland

Function	Goods and services	Units
Water regulation	Water supply to local communities	Water yield: m^3 freshwater/household/year; seasonal discharge/base flow (m3/s)
Climate regulation	Atmospheric CO_2 sequestration	Mg carbon captured/ha/year
Breeding/nursing habitat for reef and off shore fish	Fishery production / protein source	Annual catch(mg/year)
Wave energy attenuation, substrate stabilisation	Coastal defence/protection of settlements and infrastructure	Numbers of households protected, dyke maintenance costs avoided, etc.
Biodiversity conservation	Habitat for endangered, threatened or vulnerable species	Number of species protected
Timber production	High value timber	m^3 timber/ha/year

Non-timber forest products	Fish, crabs, medicinal plants, seeds, ferns etc.	Economic value: monetary unit/year; kg product consumed/year
Cultural/heritage	Use of traditional religious sites	Frequency and number of people using site
Ecotourism	Boat rides, wildlife viewing, camping etc.	Number of tourist/year; income generated from tourism

Role of primary producer

Tropical wetlands are among the most productive ecosystems on Earth, containing unique aquatic and terrestrial communities high in biodiversity (Posa et al. 2011). The productivity of floodplains has long been associated with trees and fast-growing aquatic macrophytes, which by far have the highest biomass contribution of all primary producers (Finlayson et al. 1993, Junk & Piedade 1997, Silva et al. 2009, Adame et al., 2017). Qualitative and quantitative changes at the base of aquatic food webs may subsequently alter the trophic energy transfer conveyed to consumers (Behrenfeld, 2014) and thus potentially affect the entire food chain.

Influence of climatic variability on lower aquatic organism

Climatic factors in combination with anthropogenic activities act upon biotic communities in wetland ecosystems. Global climate change scenarios predict lake water temperatures to increase up to 4°C and extreme weather events, including heat waves and large temperature fluctuations which may result in a reorganization of the plankton community structure, causing shifts in diversity and structure toward a community dominated by fewer species that are more adapted to endure warmer and irregular temperature conditions (Rasconi et al., 2017). Temperature and food are considered to be two of the most important factors controlling the abundance of freshwater zooplankton (George, 1991). Temperature generally controls growth and hatching rates of zooplankton, whereas the availability of food affects the fertility of females and the survival of their offspring (George et al. 1990). Decreasing plankton diversity is one of the most evident effects of global warming (Thomas et al., 2012). Among all climatic parameters temperature fluctuation and environmental instability are expected to cause changes in phytoplankton diversity and community structure (table 3) which plays basic role in ecosystem functioning and trophic transfer. It is also evident that temperature affects Cnidarian community composition, abundance and spatial distribution patterns (Guerrero et al. 2018). With reference to the current climate change scenario, warm-water species abundances will be positively favoured, and the community will experience changes in their latitudinal distribution patterns. Spatial distributions of planktonic community especially gelatinous zooplankton study are much more important since spatial changes are sensitive indicators of climate change (Guerrero et al. 2018). Freshwater plankton experienced an advance in phenology in response to climate change (Vadadi et al., 2014). Plankton phenology can be a useful indicator of climate change as it is no exception to the rule (Hays et al., 2005; Richardson, 2008). Rasconi et al. (2015) suggested that warming by 3°C in aquatic ecosystems of low trophic state may cause planktonic food web functioning to become more dominated by fast growing, r-trait species. Further the multivariate autoregressive analyses of community time-series also proved that water temperature was the dominant driver of change in the zooplankton community in Alaskan Lake (Carter et al., 2017).

Implications of climatic variability such as thermal regime and precipitation pattern are the foremost regulating factors which manifested into altered phytoplankton biomass or primary productivity in aquatic ecosystems (Schabhuttl et al. 2013). Consequences of climate change reflected into warming of surface waters during heat waves that not only create thermal stratification of lotic systems but also activate excessive blooms of phytoplankton (Cloern et al. 2014). In addition to anthropogenic agricultural activities, climate change is also seen as a factor that can accelerate the cynobacterial blooms events in freshwater open water system particularly in warmer months (Paerl and Huisman, 2008). The cynobacterial blooms are hazardous as the toxins (neuro and hepato toxins) produced by them often causes serious health implication through biomagnifications. Hence it's imperative to predict future bloom events with reliable models. Higher evaporation in summer often results into increased phytoplankton biomass in aquatic ecosystems (Jeong et al. 2001).

Model based studies in plankton research

The plankton serve as a key organism responsible for recycling of nutrients and essential elements in aquatic world. They also play a pivotal role as a primary producer in an aquatic food web. Since their abundance and biomass are dependent on the prevailing temperature and available nutrients they are considered as an indicator to ecosystem change and hence understanding their biological dynamics offers great avenues in studying impact of climate change on aquatic ecosystems across the world.

Models evaluate the health of wetland ecosystems through responses of habitats (peat lands and mangroves) to climate variability and change. They estimate reference levels and in the framework of climate change mitigation and also developed to support the decision making process by providing policy relevant information on the consequences and trade-offs of adopting different management module to mitigate climate abnormalities. Some of the modelling approaches that influence our understanding on the function of these systems have been separately discussed under below mentioned points:

a) Responses of aquatic communities to altered temperature scenarios based upon long-term and multi-seasonal studies: An amplified temperature and rapid changing weather events affect phytoplankton diversity and community structure. Study suggested increasing prevalence of cladocerans against calanoid copepods in Alaskan lakes. The study also indicated negative impact on calanoid copepod by continued global climate warming scenario (Carter et al., 2017).

b) Danubian Phytoplankton Growth Model (DPGM): It is performed using the Solver optimizer program of MS Excel. It is used to describe the seasonal dynamics of phytoplankton biomass based on daily temperature, but also considers availability of light as well (Sipkay et a., 2012).

c) Nutrient Phytoplankton Zooplankton Detritus (NPZD) modeling: It is one of the early models to use role of nutrient, phytoplankton, zooplankton and detritus in assessment of interaction and dynamics of aquatic systems with biotic compartments. Later on NPZD-type models have laid foundation for many more 3D general circulation model (GCM) for biogeochemical modeling studies (Anderson, 2005).

Aquatic ecological modeling and its present status

The history of aquatic modeling approach has revealed the characteristic simple mathematical description of key factors and interplay between these factors viz. nutrients, organic matter and plankton as a variable biotic component (Anderson, 2005). The use of plankton proprieties in the aquatic systems was popular when assessed at higher aggregation levels giving fairly reliable insight in to complex natural systems (Scheffer et al., 2003) but the lower sensitivity to sudden external events such as meteorological events, higher eutrophication rates may impact the reliability as indicator of shift in ecosystem structure (Schindler, 1990; Frost et al., 1995). Owing to this fact the simpler models are not perceived as reliable indicators of the changing environments and many times considered as obsolete management tools (Flynn, 2005, 2006; Le Quere, 2006). The modellers are now giving more focused approach to develop newer models which comprise the functional diversity variables to depict the complex interaction between plankton community and immediate environment (Van Nes and Scheffer, 2005). This kind of functional grouping offers varying patterns of adaptive strategies by plankton groups while simultaneously containing effects by external and internal factors on the community dynamics (Reynolds et al. 2002). The limitation in the field of modeling based on plankton is that still the ecology of these microorganisms remains poorly understood and this causes the modellers to conceive the functional groupings based on insufficient knowledge available to do so sometimes derived during model fitting exercise to gathered data (Thingstad et al., 2010).

Therefore, recognizing the functional group modeling need not necessarily improve the model predictability and it is advised that the gradual incorporation of complexity in the model parameterization coupled with rigorous assessment can be done to mitigate this shortcoming (Arhonditsis, 2010). The above issue has been discussed in detail using more than hundred biogeochemical models in one of the first attempts in scientific literature dealing with the plankton functional group modeling. Generally, cynobacteria and diatoms remains as the most frequently modeled plankton groups depicting significantly different growth rates relative to trophic status of the water bodies considered for the modeling. Though, cynobacteria and diatom based model development has been attempted by various researchers mostly working at higher latitude regions, still the model performance for the mentioned plankton functional groups (PFGs) has been found to be of relatively lesser than models based on chlorophytes and dinoflagellates (Shimoda and Arhonditsis, 2016). At higher latitudes the maximum growth rates for diatoms and other algal groups is mainly regulated by ambient water temperature regardless of the trophic status of water bodies. The growth rate is negatively correlated with the increasing latitude viz. slower growth rate at higher latitude and vice versa.

Finally it is observed that the single species eco-physiological data is not that merely increases the performance of the model tested instead we need more and more data on the community dynamics and interaction between various plankton groups together with better understanding on the dynamic influence on individual groups and as a whole on the complete plankton groups. The lack of data constraints on the PFGs characterization is a bigger problem now a day and must be adequately addressed to improve the model predictability in real environment scenario. One way to address this is via better synchronization between modelers and the mathematician group working on these aspects. The integration of process based plankton models with empirical approach could be a better solution to arrive at better models in the era of climate change. At the same time more emphasis is to be given to establishment of a standardized protocol to be adopted as methodology dealing with PFG models along with better performance criteria by the modeling community.

DNA based technologies and its implication in plankton research

The ecological status of a natural water body is of utmost important in the era of climate change due to increasing level of pollution, habitat disintegration owing to rapid surge in anthropogenic disturbances. In order to address its impact on natural flora and fauna inhabiting within these natural systems various biological attributes viz. plankton, benthic flora and fauna and fishes can be studied for revealing the present diversity by means of morphological identification within the set of sub samples derived over a time period. However, the process itself is cumbersome, expensive and time consuming and many times are limited by the level of expertise of the person carrying on the assessment. The above mentioned shortcomings may be solved by either replacing or complementing with advanced procedures based on DNA contained within the environmental samples and metabarcoding approach. The DNA based methods can be based on a wide range of modern techniques where the DNA can be either collected directly from the organisms or via extracting it from environment i.e. water. Despite this the quantity of DNA extracted may be at very low concentration and could be heterogeneous in distribution which has a large bearing on the species identification.

The DNA barcoding is one of the method by which individual specimens collected could be assigned to its taxonomic position which enables its popular use in conservation biology, environmental management, invasive species dynamics, trophic interaction and food safety (Cristescu, 2014). Instead of all these use it is still considered relatively costly as it not able to simultaneously determine taxonomic position for bulk samples containing DNA from many different species groups.

The scientific development of recent times has mitigated this limitation poised by DNA barcoding by high throughput sequencing techniques (HTS). This method can simultaneously achieve the barcodes from many different organisms from a single reaction enabling identification via DNA metabarcoding. The characteristic advantage possessed by DNA metabarcoding over the single specimen DNA barcoding approach allows timely assessment of whole community including rare species which can be difficult to sample thus saving time and money. Despite the advancement in this field of science its applicability in the tropical wetlands still needs more attention as the possibility of degradation of DNA is higher here owing to higher mean average water temperature as well as persistent higher enzymatic activity in the sediments. The use of environmental DNA (eDNA) in ascertaining the presence of micro algae occurring in the aquatic environments has already been demonstrated recently (Kelly et al., 2017). The historical developments in eDNA studies finds its root in paper published explaining an extraction protocol for eDNA from sediments (Ogram et al. 1987). In a first DNA metabarcoding study the bacterioplankton diversity of Sargasso Sea was analysed (Giovannoni et al. 1990). In eDNA assessment protocol, the microalgae identification is carried based on entire unprocessed samples before using DNA metabarcoding approach (Elbrechtet al., 2017). One key factor that must be considered prior to DNA extraction from environmental sample is the choice of primer. A smaller primer is to be preferred for achieving more taxonomic resolution (Taberlet et al., 2018). Also smaller primers have better probability of achieving success even in case of degraded eDNA samples. It is advisable to carryout morphological identification along with eDNA assessment in case of phytoplankton as the availability of species specific DNA barcodes in libraries is far from being sufficient and needs much more effort in this aspect.

Conclusion

The plankton as a biotic component has been studies continuously by many authors in the past. The morphotaxonomy based documentation being the most abundant among available literature. Beside this its biological attributes like abundance and biomass has been a popular means of studying the change in ecological functioning in response to external stimuli. Still the knowledge relating to its ecophysiology is rather poorly available. Only a few plankton functional groups has received much needed attention it deserved and a large number of groups have been omitted from in depth assessment by scientists. Climatic variabilities have altered the quantum of plankton communities which implicated their growth rate, biomass and diversity in aquatic water bodies. Proliferation of heat waves during extreme summer triggers the cyanobacterial bloom which produces toxins causing human health implications. Thus, assessment of toxin producing algae in various environment have become need of the hour. The more advanced methods utilising the next generation sequencing methods in metabarcoding to ascertain the diversity from environmental samples has shown a lot of potential as advanced tool to assess the functioning of ecosystem in relation to climate change but still suffers from the inadequacy in reference barcode availability in DNA libraries. This may however improve with time when more and more species specific barcodes become available. Till then it is advisable to use this approach in combination with the traditional morpho-taxonomic approach. Most of the models based on plankton require a through effort in order to increase their performance in predicting bloom events which are extremely important in relation to human health. The increasing level of complexity in the model is a way forward which could be achieved with close integration between modellers and the mathematicians.

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Chapter 24

THERMAL ADAPTATION AND MITIGATION OF AQUATIC ANIMAL THROUGH DIFFERENT APPROACHES

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Introduction

The fifth report of the IPCC revealed that, extinction of large number of organism in fresh and marine water species is mediated mainly due to climate change, as it interacts with other stressors such as inorganic and organic contamination (IPCC, 2014). Extinctions of species will be driven by several climate-associated drivers such as warming, variations in precipitation, reduced river flows, ocean acidification and lowered ocean oxygen levels and the interactions among these drivers and their interaction with simultaneous habitat modification, over-exploitation of stocks, water pollution, eutrophication and invasive species (IPCC, 2014). Morover, rising temperature has ability to make contamination more vulnerable in the aquatic water bodies (Kumar et al. 2014; 2016; Patra et al 2007) and leads to reduction in the thermal tolerance of the aquatic organism especially fish. Temperature is the key factor that can bring drastic physiological effects on living systems and may directly influence the thermal limits of the toxic substances in the aquatic biota (Olsvik et al. 2016). Therefore, it is absolutely imperative to conduct intensive research on this aspects, so that, solution would be ready for implementation at a certain time period. Fishes are poikilothermic animals hence alterations in the water temperature would have a marked serious impact on many of the key physiological processes and behavioural activities (Jonassen et al., 1999). To comprehend the possible effect of thermal stress on aquatic organisms, especially fishes, imperative efforts have been made to define their thermal tolerance, the effect of thermal consequences on fish health and their adaptive strategies towards the changing thermal environment. Increase in water temperature is a major concern for temperate climate fishes and vast literature documents the efforts that have been made to understand its consequence in these regions. However, little is known about the effect of thermal stress and adaptive strategy of fishes inhabiting the tropical region, like India.

Thermal tolerance in aquatic animal

Although fishes are known to inhabit varied thermal habitats, from –2.5 °C to 44°C, no species can survive to the full range of these temperatures. Each fish or fish species will have its own specific range of temperature that it can tolerate (Elliott, 1981). At one extreme are the polar species that live under the ice and in ice tunnels, and have a narrow thermal range with limits of –2.5°C and 6°C (Elliott, 1981). At the other extreme are the pupfishes, living in the North American desert, are the most Eurythermal of fishes with limits of about 2 and 44°C (Brown and Feldmuth, 1971; Elliott, 1981). The range of body temperature within which an ectothermic organism can live is often called its "tolerance zone". Pre-exposure of animals to near-lethal temperature induces a transient increase in the heat tolerance this is termed as, 'heat hardening' (Huey and Bennett, 1990). Temperature tolerance will thus depend upon the thermal history of the fish, i.e. the temperature that was experienced by the animal prior to exposure. Temperature tolerance of fishes is usually measured in the laboratory by two methods; the static method or Incipient Lethal Temperature (ILT) and dynamic temperature or Critical Thermal Methodology (CTM) (Beitinger et. al., 2000). In the first method, groups of fish acclimated to a different temperatures are plunged in to a series of constant test temperatures near the estimated lower and upper temperature limits of the species. In this case the lethal effect of temperature will be treated by time mortality. This method provides information on the overall temperature tolerance and resistance, but has an added disadvantage that the final stress response may not be due to thermal stress but also due to handling stress when the fishes are transferred from the acclimation temperature to the new temperature (Elliott, 1981). The critical thermal methodology (CTM) is the second laboratory approach to characterize temperature tolerance in fishes. In this technique, random samples of fishes acclimated to specific temperatures, subjected to linear increase or decrease in temperature until a predefined sublethal but near lethal, endpoint is reached (Beitinger, et. al., 2000). The CTM is known as parameter as well as methodology, where the critical thermal maxima (CTMax) and critical thermal minima (CTMin) are the measured end points. CTMax and CTMin respectively defined as pre-death thermal point, at which locomotory movement will be disorganized. As a result, loss of equilibrium (LOE) is reached when they are unable to maintain dorso-ventral orientation and onset of muscular spasm is reached. Subsequently, fishes loss their ability to escape from the situation which may lead to its death. The CT Maximum (CTMax) and CT Minimum (CTMin) are calculated as the arithmetic mean of the collective thermal points at which the endpoints was reached by individuals of a random sample of fish (Lowe and Vance, 1955). Incapacity is often taken as the equivalent of death for two reasons; first, the indicator must provide an unambiguous point under such rapidly changing conditions; second, it is assumed that if the animal becomes incapable it will not be able to escape from stress conditions and will be trapped in a lethal conditions (Fry, 1971). This method is fast, requires few fishes and does not confuse handling stress. The method does not consider death as the end point and the fishes can be recovered on transferring to the pre-trial acclimation temperatures (Beitinger et al. 2000). From the ecological point of view the CTM is useful and is above all extremely economical of material (Cocking, A. W., 1959), requires few fishes and more closely approximates natural conditions.

Stress during thermal Stress

The concept of biological stress has stimulated numerous, formal definitions in the scientific literature, the variety of which bearing testimony to the difficulty of establishing a single, comprehensive definition. Seley (1950) defined stress as, "The sum of all physiological responses by which an animal tries to maintain or re-establish a normal metabolism in the face of a physical or chemical force". Brett (1958), defined stress as " A state produced by any environmental factor which extends the normal adaptative responses of an animal, or which disturbs the normal functioning to such an extent that the chances of survival are significantly reduced". Chrousos and Gold, 1992 defined stress as, "A condition in which the dynamic equilibrium of organisms called homeostasis is threatened or disturbed as a result of the actions of intrinsic or extrinsic stimuli". However stress is better defined as, "The effect of any environmental alteration or force that extends homeostatic or stabilizing processes beyond their normal limits, at any level of biological organisation" (Esch and Hazen, 1978). Unfortunately, the term stress is used inconsistently. It is sometimes taken to mean the environmental alteration (stressor) itself and sometimes the response of the fish, population or ecosystem.

Stress responses in fish

The physiological systems of fish can be challenged or stressed, by a wide array of biological, chemical or physical factors. Stress produces effects that threaten or disturb the homeostatic equilibrium and elicit a coordinated set of behavioral and physiological responses thought to be compensatory and or adaptive, enabling the animal to overcome the threats. However, during chronic stress, the stress response may lose its adaptative value and become dysfunctional, which may result in inhibition of growth, reproductive failure and reduced resistance to pathogens. Similarly, thermal stress can adversely affect fish health by increasing metabolic rate and subsequent oxygen demand, invasiveness and virulence of bacteria and other pathogens that cause a variety of pathophysiological disturbances (Wedemeyer et al., 1999). Changes in the environmental conditions have multifaceted effects on fishes, which can be grouped in to five factors (Fry, 1971).

Lethal factor:

An environmental characteristic, that acts as a lethal factor when its effect is to destroy the integrity of the organism.

Controlling factor:

They govern the metabolic rate by their influence on the state of molecular activation of the components of the metabolic chain, of which temperature is the most outstanding of the controlling factor. They permit a certain maximum level in the absence of a limiting factor through their influence on the rate of chemical reactions.

Liming factor:

They operate by restricting the supply or removal of the materials in the metabolic chain. For example the reduction in the supply of oxygen below certain level can reduce the metabolic rate, and below this level it can be said that the oxygen supply is limiting. The effect of a limiting factor is to throttle the maximum metabolic rate permitted by the existing level of the controlling factors.

Masking factor:

A masking factor is an identity, which modifies the operation of a second identity on the organism. The organism achieves all its physiological regulation by exploitation of the masking factors through the channeling of the energy by some anatomical device, for example, the mechanism of thermoregulation in tunas and sailfishes.

Directive factor:

A directive factor is an environmental identity, which exerts its effect on the organism by stimulating some transcend response. It operates by the impingement of energy on some appropriate target. The energy absorbed initiates a signal, which appropriately channels metabolism into the appropriate response.

Exposure of fish to environmental stressors induces a characteristic series of endocrine, and other responses that are termed as primary, secondary and tertiary stress responses depending upon the level of biological organisation monitored. These stress responses are as follows,

A) *Primary stress responses*
   i. Release of adrenocorticotropic hormones (ACTH) from the adenohypophysis.
   ii. Release of "stress hormones" (Catecholemines and Corticosteroids) from the interrenal.

B) *Secondary stress responses*
   i. Blood Chemistry and hematological changes, such as hyperglycemia, hyperlacticemia, hypochloremia, leucopenia, and reduced blood clotting time.
   ii. Tissue changes, such as depletion of liver glycogen and interrenal Vitamin C.
   iii. Metabolic Changes, such as negative nitrogen balance and Oxygen debt.
   iv. Diuresis, with resultant blood electrolyte loss.

C) *Tertiary stress responses*
   i. Whole animal:
      a. Impaired growth, Parr-smolt transformation, Spawning success, and migration behaviour.
      b. Increased disease incidence (infectious and noninfectious)
   ii. Population parameters:
      a. Reduced intrinsic growth rate, recruitment, compensatory reserve.
      b. Altered species abundance and diversity.

Adaptive option for changes in thermal environment

Though the body temperature of many poikilotherms is similar to their ambient environmental temperature, they are able to survive and function at widely different habitat temperatures. This apparently relates to the alterations in their biochemistry and physiology, which compensates for the changes in their thermal environment. Biochemical mechanisms underlying such temperature compensations are discussed by, Hochachka and Somero, 1971 and Hazel and Prosser, 1974. Compensation to change in the environmental temperature may occur at three distinct time-course periods *viz*., instantaneous compensation, after a period of acclimation or over evolutionary time spans (Hochachka and Somero, 1971; Hazel and Prosser, 1974).

Thermal adaptation and oxygen consumption rates

The sum of the chemical reactions in an organism, which yield energy to be utilized by an organism, is termed as Metabolism. Whole animal metabolic rates are generally measured by determining oxygen consumption rate. Measurement of oxygen consumption has been employed more than any other parameter to monitor the change in metabolism associated with thermal stress (Fry, 1971). Metabolic responses that are quantified in terms of oxygen consumption show a linear correlation to temperature due its direct effect on the kinetics of the reactions involved. The rate of oxygen consumption often increases in a regular manner with the increasing temperature, within the temperature tolerance rage of that animal. In general, with a rise of 10°C in temperature the rate of oxygen consumption may be twofold or threefold. The increase in oxygen consumption rates caused by 10°C increase in temperature is expressed as Q_{10} value and is represented by the following equation.

$$Q_{10} = (R_2/R_1)^{(10/T_2-T_1)}$$

Where, R_1 and R_2 are the rates at temperature T_1 and T_2

The rate doubles if the Q_{10} value is 2 or triples if the Q_{10} value is 3. However, it is not necessary to determine two rates exactly 10°C apart in order to calculate the Q_{10}. Any temperatures can be used, provided that they are sufficiently far apart to give reliable information about temperature effect.

Mechanism of low temperature tolerance in fish

Fish belong to ectothermic (heterothermic) animals, in which temperature of the environment is a major factor controlling phenomena such as growth and breeding because their body temperature is affected by ambient water temperature (Brett 1971; 1979; Kuamr et al. 2014; 2016; 201a, b). Generally, the aquatic animal (fish) move for search of a suitable water temperature (Schurmann and Christiansen 1994; Claireaux et al. 1995) to adopt their self for growth and breeding. Recently, it has been reported that several fishes control their body temperature using a heat generation system, in addition to moving to areas with appropriate water temperature. This group of endothermic fishes includes the bigeye tuna *Thunnus obesus* and the opah *Lampris guttatus* (Holland et al. 1992; Wegner et al. 2015). However, the temperature that they can retain is not high compared with that of homeothermic animals. Furthermore, they lack a heat-radiating mechanism for keeping the body temperature constant, which homeothermic animals possess. The several questions arise in our mind that "How do fish respond to ambient temperature change? One way is behavioral thermoregulation, in which fish move to an area with suitable water temperature to maintain homeostasis for continuing physiological functions. As the optimum temperature differs for various physiological phases, such as growth and maturation, fish must migrate according to their temperature requirement for each phase in the life cycle. Migratory fish are able to travel through a wide area, but fishes that have poor swimming ability and inhabit a specific environment are forced to adapt to the ambient temperature, even if the temperature fluctuation is large. These species respond to adverse conditions (i.e., when the water temperature deviates from the appropriate range) by reducing their physiological activity as much as possible. Especially in areas with cold water, fish generally cease physiological activity during the winter season, a condition that is extremely close to the state of hibernation. Meanwhile, fishes living in environments where the water temperature is low throughout the year, such as the polar zone, have physiological mechanisms for adapting to low water temperatures. Some of these adaptations include the synthesis of an antifreeze protein (AFP) and antifreeze glycoprotein (AFGP) (Harding et al. 2003; DeVries and Cheng 2005), formation of tubulin that can be synthesized at low temperature (Guderley 2004), and lack of haemoglobin (Hemmingsen 1991).

Use of antifreeze protein during low temperature environment

In the colder regions such as Arctic and Antarctic, the water temperature can drop below zero due to supercooling. Fishes in these regions use antifreeze mechanisms to adapt to the extreme temperatures. The plasma freezing point of the bald notothen *Trematomus borchgrevinki* inhabiting the Antarctic Ocean is -2.75 °C, whereas in the black perch *Embiotoca jacksoni*, which is distributed in the temperate zone, it is -0.7 °C. Therefore, body fluid in some fishes does not freeze even if the water temperature drops below zero (DeVries 1982). The mechanism for this phenomenon is antifreeze protein. Glycoproteins that enable a lower plasma freezing point have been isolated from the plasma of fish belonging to the Notothenioidei suborder inhabiting the Antarctic Ocean, and several proteins that can reduce the plasma freezing point are found in other species of fish (Harding et al. 2003). These proteins, called antifreeze glycoproteins (AFGPs) and antifreeze proteins (AFPs), inhibit the growth of ice crystals in plasma by covering the water-accessible surface of ice, resulting in a lower freezing point for plasma and enabling polar fish to survive in seawater below the freezing point.

Thermal adaptation and metabolic pathways

The biochemical processes of animals are catalyzed by array of enzymes that are specific for their reaction. The reaction velocity of any chemical reaction is governed by temperature such that as the temperature increases the chemical reaction becomes accelerated. As the temperature rises or falls their physiology can be modified in a variety of ways that may be adaptative, extending the thermal range tolerated by individuals of the species. The primary stress response of release of stress hormones provides an important mechanism for modulating the enzyme activity over a time scale of few seconds or to several hours. There are four types of mechanisms that could be instituted during such changes (Willmer et al., 2000),

1. The enzymes effective concentration or activity could be altered.
2. The concentration of the relevant substrate could be altered.
3. The energy supply of the reaction being catalyzes increased or decreased.
4. The interacellular environment could be altered to modify the enzyme effects.

Role of HSP70 and molecular chaperon in thermal adaptation

Heat-shock proteins (HSPs) were first thought to be merely as products of gene whose expression is induced by heat stress. It is now known that HSPs are induced by a variety of biotic and abiotic factors and are commonly referred to as 'stress proteins'. However, research is now focused towards understanding the roles of HSPs as molecular chaperones. This has revealed to us their close relatives, their molecular partners, and many new proteins that are now known to play diverse roles, even in unstressed cells. These are known to facilitate in successful folding, assembly, intracellular localization, secretion, regulation, and degradation of other proteins. HSPs function as molecular chaperones; i.e. they interact with other proteins and, in so doing, minimize the probability that these other proteins will interact inappropriately with one another. HSPs recognize and bind to other proteins when these proteins are in non-native conformations, whether due to protein-denaturing stress or because the peptides they comprise have not yet been fully synthesized, folded, assembled, or localized to an appropriate cellular compartment (Feder and Hofmann, 1999). HSPs are induced due to various environmental, pathological and physiological stimuli and can act as biomarker for monitoring stress in fish (Pal and Mukherjee, 2004). Extensive studies have revealed diverse forms of heat shock protein which are classified into different families based on their molecular weights *viz.,* HSP90, HSP70, HSP60 and ubiquitin (low molecular weight HSPs) (Kopecek et al., 2001). HSP60 allows multivalent protein binding. Ubiquitin group have low molecular weight varying from 15 to 30 kDa, which tags proteins to be degraded by the proteosome. Low molecular weight HSPs have diverse functions that are species specific and not like other HSPs. The HSP70 family is very large, with most organisms having multiple members; most eukaryotes have at least a dozen or more different HSP70, found in a variety of cellular compartments and are involved in protein folding and several other cellular functions (Fink, 1999). Some of the better known mammalian members are HSC70 (or HSP73), the constitutive cytosolic member; HSP70 (or HSP72), the stress-induced cytosolic form; BiP (or Grp78), the ER form; and mHSP70 (or mito-HSP70, or Grp75), the mitochondrial form (Fink, 1999). HSP70 is highly conserved protein and shows 50% similarity at amino acid level between E. coli and human (Gupta and Golding, 1993). The 70 kDa heat shock protein is known to exist in two forms, the constitutive form also known as the "Heat shock cognate protein 70" (HSC70) and the inducible form (HSP70) (Ali et al., 1996). The HSP70 chaperones help in protein folding and unfolding, provides thermotolerance to cell on exposure to heat stress.

Oxidative stress and thermal efficiency

The oxidative stress in the form of catalase, SOD, GST and GPx during lethal thermal minima (LTMin) and lethal thermal maxima (LTMax) has tremendously affected by thermal stress. These specific enzymes have been elevated during thermal stress because resulting in generation of reactive oxygen species (ROS). It was originally expected that the reduction in oxygen availability would result in a concomitant decrease in ROS production because oxygen is required for the generation of ROS (Welker et al. 2013). Meanwhile, several studies have shown, however, that reduced oxygen availability (hypoxia) may also cause oxidative stress (Welker et al. 2013). While the connection between hyperoxia and the generation of ROS has been unequivocal, the relation between hypoxic conditions and the formation of ROS has been debated intensively. The high temperature plays major role in the over production of reactive oxygen species (ROS), which creates oxidative stress (Kumar et al., 2014, 2016). Further, membrane fluidity and phospholipid bilayer dynamics are affected, leading to improper folding and the production of free radicals. The animal/fish is aerobic organisms and need to deal with reactive oxygen species (ROS). ROS are chemically reactive molecules containing oxygen. They form as a natural by-product of the normal metabolism of oxygen and have important roles in cell signalling and homeostasis (Cadenas, 1989). However, during times of environmental stress (e.g. ultra-violet radiation or heat exposure); ROS levels can increase dramatically (Gerschman et al., 1954; Cadenas, 1989). When the production and accumulation of ROS is beyond the organism's capacity to deal with these reactive species there is oxidative stress. This can damage lipids, proteins and deoxyribonucleic acid (DNA). Some ROS can initiate lipid peroxidation, a self-propagating process in which a peroxyl radical is formed when a ROS has sufficient reactivity to abstract a hydrogen atom from an intact lipid (Halliwell and Gutteridge, 1999). The reaction of ROS with lipids is considered one of the most prevalent mechanisms of cell damage (Halliwell and Gutteridge, 1999). Under most physiological states, ROS production is closely matched by antioxidant response. Enzymatic antioxidants, such as superoxide dismutases, catalase and peroxidases, form an important part ofthe antioxidant response (Lesser, 2006).

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Chapter 26

ASSESSMENT OF GREEN HOUSE GAS (GHG) EMISSION FROM AQUATIC SYSTEMS

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Introduction

Greenhouse gases can be released to the atmosphere in two ways: diffusive emission (emanation) and emission as bubbles. In diffusive emission, gases dissolved in water molecularly diffuse from water to the air. Bubbles form naturally in the bottom and go up periodically. In anaerobic conditions, the gas forms methane, whereas in oxygenated bottoms, carbon dioxide dominates. As methane is not consumed by aquatic organisms, it dissipates in the water column. Gas flow between water and the atmosphere changes by the time of day and can be quite variable. To quantify emission rates, a diffusion chamber can be used. Gas concentrations inside the bubbles formed in pond bottoms can be obtained by capturing bubbles in a flask filled with water on the top of a submerged canvas funnel placed inside water for 24 hours. The samples should be analyzed through specific gas-chromatographic analysis. Results represent the sum of diffusive and bubbles emissions, expressed in terms of kg/ha/day. The sum of all gases is presented in an equivalent value for carbon dioxide. The methodology is complex and unfamiliar to most aquaculture researchers. In addition, the analysis is also expensive. Indirectly the emission of gases can be predicted through carbon footprint analysis of any culture system or life cycle analysis (LCA) of a crop production system. For carbon footprint analysis, all the inputs added to an aquaculture system are converted into carbon equivalence (CE). As an example, the inputs of carp practices are shown in the tables 1, 2 and 3.

Table1. Inputs for carp culture practices

Culture systems	Pond area (ha)	Stocking density (10^3/ha)	Final body weight (g)	Final biomass (kg/ha)	Cow dung (kg/ha)	Synthetic fertilizers (kg/ha)	Amount of lime (kg/ha)	Total feed (kg/ha)
Indian Major Carps	0.5	5-8	600-800	4000-5000	1000	Urea:200 SSP:300	300	3000

Table 2. Pond inputs and their respective CE emission (Adhikari et al. 2013)

Pond inputs	CE emission/kg
Cow dung[a]	25-30 % C (on dry weight basis)
Nitrogen	1.35/kg fertilizer nutrient (Lal,2004)
Phosphorus (P_2O_5)	0.20/kg fertilizer nutrient (Lal,2004)
Pelleted Feed[a]	35-40 % C (on dry weight basis)
Lime	0.16/kg (Lal,2004)
Amortization for pond construction[b]	0.00896-0.01118 kg CE/kg fish

[a] The C content of feed, and cow dung has been considered directly as CE emission

[b] Pond construction for carp culture = 760-950 L diesel fuel/ha. Ponds are 15 years old. Amortized fuel use = 50.66-63.33 L/ha/yr. Average carp production in these ponds= 4130 kg/ha. Fuel use = 63.33 L/ha/yr. 4130 kg/ha/yr =0.01533 kg fuel/kg fish. Energy use = 0.01533 fuel/kg fish. 1 L diesel = 38.80 MJ energy = 2.68 kg CO_2 emissions = 0.7309 kg CE. CO_2 emissions = 0.01533 kg fuel/kg/fish, so 2.68 kg CO_2/L fuel = 0.041 kg CO_2/kg fish= 0.01118 kg CE/kg fish.

Table 3. CE of inputs and outputs in the carp culture practices

Different inputs	Total N (kg/ha/yr)	Equivalent C (CE/kg)	Total P (kg/ha/yr)	Equivalent C (CE/kg)	Total carbon (C) (kg/ha/yr)	Total equivalent carbon(kg CE/ha)	Total CE of all inputs (kg CE/ha)	Fish live weight (kg/ha/yr)
Cow dung					250			
Feed					1050			
Urea	92	124						
SSP			48	10				
Lime						48		
Amortization						44		
Total CE							1526	4000

Now, total inputs into the pond = 1526 kg CE/ha

Total output in terms of production = 4000 kg/ha/yr.

Carbon sequestration in these ponds = 0.74 Mg C/ha at 1.0 cm depth = 740 kg C/ha (Adhikari et al. 2012).

The carbon converted into the fish flesh = 4000*13% C kg/ha = 520 kg C/ha.

The chance of C emission = Total input – Carbon sequestration-Carbon removal through produce =1526-740-520 = 266 kg CE/ha/yr.

Considering 80-90% of the carbon converted into CO_2 as the dissolved oxygen concentration in the pond environment is 5.0 mg/l (aerobic condition). The 10-20% chance of the carbon to be converted into CH_4 as an emission (under anaerobic condition).

Now, 239 kg CE/ha/yr will be emitted as CO_2 and 27 kg CE/ha/yr will be emitted as CH_4

Accordingly, 239*3.66=875 kg CO_2- e/ha/yr will be emitted and 27*1.33 = 36 kg CH_4-e/ha/yr will be emitted in a year for the production of 4000 kg fish.

Now, 875 kg CO_2-e/ha/yr = 2.40 kg CO_2-e/ha/d and 36 kg CH_4-e/ha/yr = 0.098 kg CH_4-e/ha/d will be emitted.

Also, 0.21 kg CO_2-e/kg fish and 0.009 kg CH_4-e/kg fish will be emitted.

Preto et al. (2015) reported that approximately 1,683 kg carbon dioxide/ha were released during the whole river prawn grow out cycle which was corresponded to 459.58 kg of carbon equivalent. They also reported that total carbon di-oxide emission was 5.04 to 11.04 kg/ha/day while total methane emission was 0.21 to 0.50 kg/ha/day during grow out cycle of river prawn. They measured these emissions using diffusion chamber and canvas funnel with a submerged flask and measure the gases using specific gas-chromatic analysis.

Conclusion

It has been reported (FAO 2017) from a life cycle model that Indian major carps in India, Nile tilapia in Bangladesh and stripped catfish in Viet Nam had the average emissions intensities (EI) from cradle to farm-gate, including emissions from land use change (LUC) of 2.12, 1.81, and 1.61 kg CO_2-e/kg live weight fish, respectively. It is very complex to determine the emission of different green houses gases from the aquaculture systems. The assessment of gas emissions, particularly, the emission of carbon-di-oxide from the fish ponds can be done from the carbon footprint and carbon sequestration analysis.

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Chapter 26

GIS TOOLS IN CLIMATE CHANGE RESEARCH AND INLAND FISHERIES

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Introduction

The most abundant natural resource on our planet that sustains and supports life is water. It moves through the hydrological cycle in different forms and supports numerous ecosystems, maintaining bio-diversity, nutrient cycling and primary productivity. There has been a rise in pressure on water resources that will continue to increase in the coming years. According to United Nations' World Water Development Report's (WWDR4) latest edition, climate change is likely to bring about a decrease in the availability of fresh water in many regions due to an increase in demand for water. The report allots four main sources of demand for water to agriculture, production of energy, industrial uses and human consumption.

For many years nature conservancy efforts has been supported by leading organizations providing environmental expertise with GIS and Remote Sensing as these technologies have been used to better understand a complex situation. They are a means to assess, plan and implement sustainable programs that are effective long into the future.

The atmosphere, continents and oceans generate a huge amount of information which is retrieved by Remote Sensing (Sabins, 2000). Unmanned satellites were launched for the first time, by United States in 1960 to monitor the environmental and meteorological conditions. One of the greatest global concern about the environment is the depletion of Ozone that causes ultra violet radiation from the sun to reach Earth surface threatening all life forms. A polar-orbiting Nimbus-7 satellite was launched in 1978 to make global measurements of ozone by *total ozone mapping spectrometer* (TOMS).

Clouds are fore-bearers of weather conditions, their patterns indicate advent of precipitation. They are a link to both the water and energy cycles, which can be altered by natural causes over a long time. Thus observing clouds to study climate change assists in understanding adversities in atmospheric constituents resulting from anthropogenic activities. In April 1960, TIROS 1 initiated satellite remote sensing of clouds.

Precipitation is a universal source of water affected by global changes and it affects the atmospheric circulation of the Earth. For meteorologists, measurement of precipitation is the most challenging task, which has been simplified with the intervention of remote sensing. The remote sensing instruments used to measure rainfall, was initiated by ground based radar system followed by earliest satellite images which presently determine rainfall from visible range, reflected IR and passive microwave ranges. The Geostationary Operational Environmental Satellite (GOES) data are used to estimate precipitation from convective storm systems.

Wind, is another environmental factor that bring about changes in weather conditions as they drive ocean currents. They are responsible in bringing about fluxes of heat, moisture and momentum across the air – sea boundary resulting in formation, movement and modification of water masses. Intensification of storms near the coast as well as over open ocean are a result of their interaction. An example may be set of warm and saline Atlantic water flowing into cold waters of Barents sea, south of Arctic Sea, significantly influencing its biomass production and fish distribution (Sando *et al*.

2010). Effect of temperature as observed in estuarine waters brings forth health indication of its aquatic system. With increase in water temperature, there is a decrease in its capacity of holding dissolved oxygen and therefore there is a increase in fish mortality (Floyd R. F. 2011).

Remote Sensing is used to generate timely wind pattern maps, which are developed by measuring velocity and direction of surface winds. Roughness of the sea is recorded by Radar Scatterometers to estimate surface wind vectors with a little compromise on direction. Mid- and high-level winds are manually processed from cloud-motion wind vectors which are automatically computed for low level winds.

Geostationary Operational Environmental Satellite (GOES) data are applied to estimate freeze warnings, for snow-cover analysis, hurricane classification and forming animated cloud images.

1. Application of GIS and Remote Sensing in different aspects of climate change research and inland fisheries.

GIS and Remote Sensing has been applied to study the different aspects of climate change on varied phenomenon of the Earth like agriculture (Adiningsih E. S., 2010, Pandey A. *et al.*, 2006), Natural Resources (Forest and Water) (Tian H., *et al.*, 2017) Temperature, Rainfall and Floods Soil Land degradation Land Use Land Cover (Khanday, M. Y. 2008, Mercy M. W., 2017) Stream Flow and Water Bodies.

Several factors affect climate change and GIS aids the study of these factors in a more detailed manner. Average atmospheric condition of a particular place that changes every 30 to 35 years and defines the climatic change of that place. Factors that affect climate of a place can broadly be divided into natural and human factors.

Factors affecting climate of a place

Natural

- Latitudes are imaginary lines on Earth's surface and play an important role in defining climatic character of a place. Equator being the longest latitude (all others are shorter in comparison to it), defines the equatorial climate. As one moves higher up towards either poles the latitudinal values increase however, the temperature decreases bringing in cooler climatic zones away from the equatorial belt (geographic belt located through 5°-8° N lats and 4°-11° S lats). The vertical sunrays at the equator causes hotter climatic conditions and the slating sunrays at the higher latitudes causes colder climatic conditions.
- Increasing Altitude causes decline in temperature with a 1° C drop with every ascent of 165 meters. Thinning air at higher altitudes causes cooler climates from lower absorption of heat.
- Distance from the sea greatly influences climatic condition of a place as it's moderating influence is brought about by the land and sea breezes.
- Ocean Currents influence coastal regions only with warm currents creating warmer climates and vice-versa
- Direction of prevailing winds influences the climate of a place with winds from easterly direction causing dryness and those from the west result in moist conditions. A simple explanation can be sought from the heavy summer monsoon rain from moist monsoon wind and light rainfall from dry winter monsoon winds.
- Relief or topography referring to uplands hills or mountains is responsible for orographic rainfall a phenomenon that happens on the windward side making it wet. The slope on the leeward side is cold and dry.

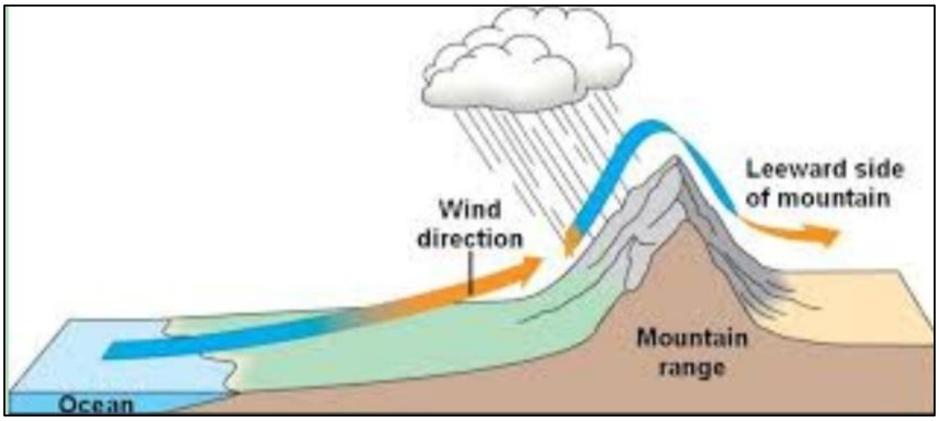

Fig. 1. Orographic Rainfall

- The *El Nino* phenomenon happens specifically over the Pacific Ocean and causes uncertain weather conditions throughout the South Asia and South America. This causes droughts and floods respectively. It increases temperatures globally causing huge climatic as well as socio-economic changes.
- Soil quality affects climatic feature of a place. Sandy soil reflecting solar radiation makes surrounding climate warm. Alluvial soil with it’s organic matter has a cooling effect on the climate of places surrounding it by storing solar radiation.
- Increase in greenhouse gas emissions are a major cause of bringing about climate change. It is considered to be a critical global challenge as recent events have reflected the world’s growing vulnerability to climate change. Industrial activities and motor transportation have resulted in emissions of greenhouse gases due to burning of fossil fuels. Loss of forests, which act as “carbon sinks”, has further increased building up of carbon dioxide along with other gases in the atmosphere enhancing the “Greenhouse Effect”. This effect causes the atmosphere to retain heat that has increased mean

global surface temperature by 0.2 to 0.3 degrees over the last 40 years. (UN, 2007)

- Diurnal changes in the sun's energy affect the amount of energy reaching Earth's surface. Increase or decrease in solar output can affect our climate directly or indirectly. Direct effect will be expressed through change in solar heating of the Earth and it's atmosphere and indirect effect will be reflected in changing cloud forming processes.

Human

- Population growth There is a significant impact of population expansion and socio-economic development on wetland ecosystems and agriculture already influenced by pressure of climate change. It also influences pressure on water resources and their sustainability (Ahmad M. T., 2018) reducing mean annual runoff by 2-12% as found in a case study on water resources in Korea. Managing water resources is the need of the hour in developing countries and space technology plays a fundamental role in evolving a comprehensive management plan in data scarce regions (Sundaram K. S., 2014).
- Industry is one of the key sectors where any action can make a big difference on climate (UN, 2018). Climate change implication on extractive and primary industries was assessed and reported by Intergovernmental Panel on Climate Change . The report highlighted that reduction in availability of renewable natural resources including water and damage to infrastructure and industrial capital assets will be initiated by climate change. Between 1970 and 2010, greenhouse gas (GHG) emissions from industries has almost doubled. By 2050 increase in demand for industrial

goods will create pressure thus increasing industrial emissions. Mitigations strategies should be followed to reduce these emissions.

- Exploitation of fossil fuels for their consumption results in the release of huge amounts of CO_2, a greenhouse gas, into the atmosphere, which is a direct cause of global warming. Such temperature increase causes changes in global weather patterns and in the long term causes climate change.
- Deforestation produces 24% of global greenhouse gas emission making it the second leading cause of global warming (Earth Day Network, 2019). GIS and Remote Sensing technologies have been applied to observe and monitor carbon content and for forest carbon mapping. GIS mapping and analysis is useful for change identification, planning and implementing action plans. Predicting future changes in climate, modelling to predict impact on locations an displaying maps, graphs and charts for viewing and analysis purpose is also possible through GIS (Pore M., 2013).
- Plastics being made from fossil fuels can have a drastic effect on the environment and augment climate change. A team of researchers has revealed that methane and ethylene are released from plastic when it is exposed to the natural elements. To control the greenhouse effect effort has to be made to fight plastic pollution.
- Methane is a very strong greenhouse gas emitted naturally from wetlands and freshwater systems (rivers and lakes). It also emitted in large quantities from agriculture and fossil fuel industry.

Thus factors that affect climate change of a place are air pollution, excessive use of water, deforestation, sewage, un-degradable substances polythene and the like. All these in turn, affect fisheries environment and amount of fish produced.

Climate Change as a continuous process is affecting the Earth at micro, meso and macro scales. Visible, non-visible, direct, in-direct, effects of climate change, like spatial changes, occurring in the anthropological space are observed by change detection studies. GIS and Remote Sensing technologies aid such studies on the effects of climate change at these different scales. They can also assist in controlling further damage. These studies can judge the feasibility to actually contain the damage in their *in situ* condition. They can also assess whether the damage has reached an irrecoverable stage.

The impacts of climate change range from affecting agriculture to further endangering food security, to rising sea-levels and the accelerated erosion of coastal zones, increasing intensity of natural disasters, species extinction and the spread of vector-borne diseases.

- GIS assists the study of climatic factors that affect fishery resources (as discussed above)

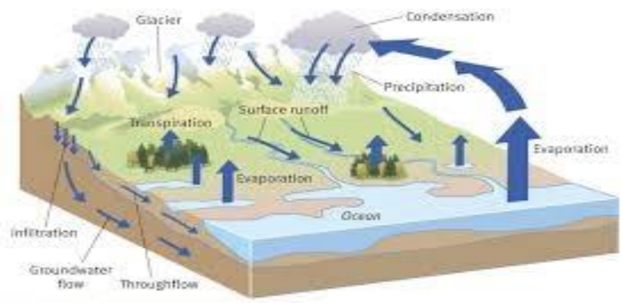

Fig. 2. Hydrological cycle

- GIS as well as Remote Sensing aids in the study of climate as well as fishery resources.

2. Application of GIS Tools/ Instruments/ Wizards for processing climatological data

Our climate system consists of five major components: the atmosphere, the hydrosphere, the cryosphere, the land surface and the biosphere. External forces, either having natural origins (e.g., solar variability) or resulting from human activities (e.g., emissions of chlorofluorocarbons), exhibit themselves on all these factors at decade to century time scales. The primary type of radiative forcing that exhibit decade to century variability are greenhouse gases, stratospheric ozone, aerosols and solar radiation. Understanding mechanisms (greenhouse gases and carbon cycle, stratospheric ozone and aerosols) and forces (external and internal to climatic system) that bring about climatic variation enhances abilities to predict it.

Climate research and climate change

The aim of climate research is to improve scientific understanding a) of past climate history and its impact on humanity, b) The course and causes of climate change and c) prospects for the future. The strongest impact of climate change is evident in rising temperature that inevitably influences spatial distribution of fishing and aquaculture activities also their productivity and yields. Wetlands are an important constituent of climate research as they are a major component of global carbon cycle and play an important role in terrestrial ecosystem and atmosphere interactions. New research confirms that coastal wetlands are the best marine ecosystems to fight climate change.

Scope of using GIS and RS as Mapping Tools exist under the following headings

- Prior conditions: Natural and socio – economic conditions existing in a region before the occurrence of any kind of phenomenon that bring about climatic change can be detected from remote sensing observations. They become the initial time point from where further analysis can be done.
- Affected areas – Spatial characteristics over the physical spread of an area affected by any phenomenon can be efficiently detected by remote sensing studies.
- Area – the very dynamic nature of the geo-spatial soft-wares allow the prompt calculation of an area which may be under any natural or manmade effects.
- Water quality – Coming together of geo-spatial soft-wares and the marvels of mathematics can create magical tools that are able to quantify and visualize water quality.
- Production – Attribute table creation with any data and their attachments with map objects can represent themes, which are otherwise mechanical, in a bright and appealing manner
- Disease – Ailments, so common in the polluted world, can be mapped, not only independently but also together with their causative factors. They can be represented either in their epidemic or endemic formats in any suitable scale depending on the type of analysis.
- Habitat Change – A basic and common application of remote sensing lies in its ability to study change over space be it for natural characteristics or man – made ones. Thus habitat change brought about by climatic alterations can be studied with great efficiency using the techniques of GIS and Remote Sensing.

3.1 ESRI powered version of Climate Wizard – it was launched in 2009 by The Nature Conservancy. They are able to create efficient maps that allow anyone to click a map location and get up-to-date data of climate change trends. Along with this a user can also choose between different climate change models to predict climatic impacts with respect to fisheries on that location. They can see the range of future climate projections in graphical and tabular format. They can also view and analyze dynamic data using GIS functionality to see highly specific details relevant to their unique projects.

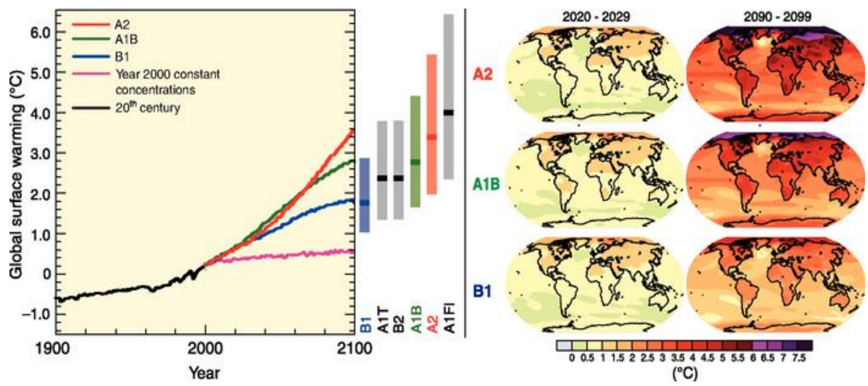

Fig. 3. Use of Climate Wizard by IPCC to analyze climate trends globally and locally

3.2 The dewnet network JESAT a toolset for environment system assessment, analysis and management. The dewnet initiative is funded by the Federal Ministry of Education and Research (BMBF) of Germany and strives to generate synergy from combining international professional research expertise from Europe and Australia in the field of landscape assessment, analysis and modelling for management and decision support in IWRM and irrigation management. (PDF) The dewnet network: JESAT a toolset for.

3.3 Generating an Integrated Landscape Management System (ILMS) for Water Management, Local and Regional Planning

Sources of GIS and RS Mapping Tools

- Paid or Commercial Tools
- – ERDAS – Imagine
- – TNT-MIPS
- – ARC-Info
- Unpaid or Open Source Tools
- – Q-GIS

3. GIS and RS as Resource Mapping Tools in inland fishery resources

- Water area variation mapping – Reservoirs

  Satellite data from remotely sensed images and GIS together bring about accurate and efficient extraction of water area. The technology of capturing earth surface information by observing reflected electromagnetic radiation helps in computing surface water existence at their *in situ* location and their areal spread.

- Water Quality Mapping-Rivers, Surface Water Oceans

  Mapping of water quality has been done through GIS using it's inbuilt tool "Geostatistical Wizard"

- Habitat Change

  Habitat change detection has been made easy with the help of GIS and remote sensing. This makes monitoring very easy, time saving and accurate and repetition of procedures does not bring about any complications

- Landuse/Landcover is a basic area where remote sensing plays a very important role. Together with GIS it brings about a clear visualization of changes occurring over

- Sea Level Rise for coastal areas
- Flood Prone, Cyclone affected Sea Water Ingress Mapping

4. **GIS Tools** can be divided into a) Desktop Tools, b) Internet Tools and c) Mobile Tools

   1) Desktop tools

   Commonly used on desktop GIS platform

   - Overlay and proximity

   One of the most widely used GIS platforms have broadly classified geo-processing tools based on two most basic questions in geography-*What's on top of what?-and-What's near what?*- leading to "*Overlay analysis*" and "*Proximity analysis*".

   Overlay Analysis is done with the help of two approaches

   a) Overlay methods and b) Overlay tools.

   i) Overlay methods

   Overlay analysis is broadly performed by two methods

   i. feature overlay and
   ii. raster overlay

Overlay tools

- ❖ Vector overlay tools
  - Identity
  - Intersect
  - Symmetrical difference
  - Union
  - Update

- Raster Overlay Tools
  - Zonal Statistics
  - Combine
  - Weighted Overlay
  - Weighted Sum
  - Surfaces

Geographic phenomenon are not discrete and have a continuous variability over the Earth's surface. Such continuous data leads to the formation of surface that can be modelled with rasters.

- Spatial and non-spatial statistics
- Table management
- Selection and extraction

Other Essential Geo-processing Tools

- The Buffer Tool
- The Clip Tool

2) Internet tools

When a tool uses internet as a primary means of providing access to distributed data and other information, disseminating spatial information, and conducting GIS analysis, it is considered a network-centric GIS tool forming the basis of internet GIS.

These tools allow the user to participate in the community planning and decision making procedure anytime anywhere.

Overcoming obstacles like dominant views of vocal participants and inflexibility of meeting times of a traditional town-hall meeting, internet GIS allows all participants to 'speak up'. It offers citizens instant access to data and data-processing tools anytime anywhere. In the early stages of internet GIS development, the internet was used as a means to disseminate spatial data. In the later developments, existing GIS programs was linked with the web servers to provide users some limited GIS functionality on the web. This approach takes advantage of the existing GIS programs and their functions and delivers them to users through web browsers. Recent advances adopts the client server model and explores the three-tier architecture to distribute data and GIS processing components from server to the web client more efficiently. A schematic representation of three-tier architecture for Internet GIS-based public participation is given below;

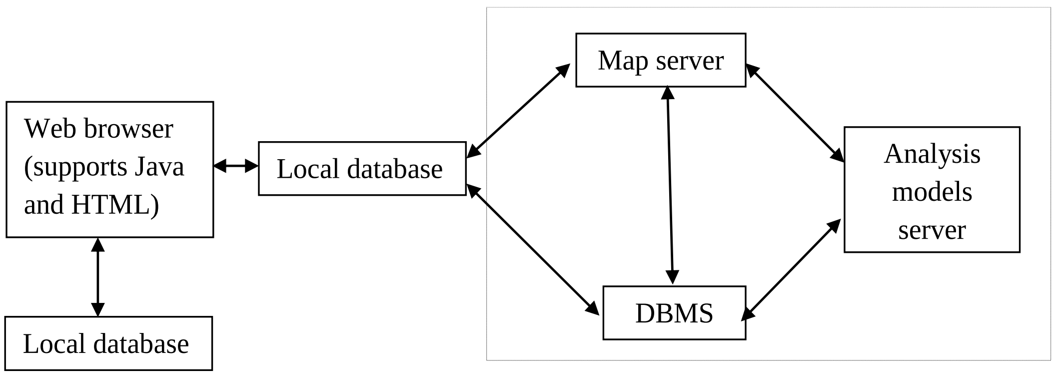

Fig. 4. A three-tier architecture for Internet GIS-based public participation.

3) *Mobile tools*

Expansion of GIS technology from office to the field has introduced the concept of mobile GIS. It integrates one or more of the following technologies:

- Mobile devices
- Global positioning system (GPS)
- Wireless communications for Internet GIS access

Technological advancements have enabled GIS to be taken to the field as digital maps on compact, mobile computers, providing field access to enterprise geographic information. This allows real time information to be added to their database and applications, hence speeding up analysis, display, and decision making by using up-to-date, more accurate spatial data.

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Dr. B. K. Das is a leading fish pathologist and currently working as Director, ICAR-Central Inland Fisheries Research Institute, Barrackpore. He has professional experience of more than 22 years in Fisheries. He has one patent, over 100 research papers with more than 3200 citations. He is a post-doctoral fellow of FRS Marine Lab, University of Aberdeen, Scotland. He has travelled widely to Europe, South-East Asian Countries and other countries of Indian sub-continents as Fisheries expert and contributed immensely to the development of international linkages and programmes in the areas of fish immunology and inland open water fisheries. He is the recipient of more than 10 awards/honours such as Dr. M.S. Swaminathan Award for Best Indian Fisheries Scientist, Krushakbandhu and Krushaka-Ratna by KrushakaSamaj, Fellow of International Society Environmental Protection (ISEP), Fellow of National Academy of Agricultural Sciences, DBT Overseas Associateship Lal Bahadur Shastri Young Scientist Award (ICAR), Dr. Hiralal Chaudhuri Annual Awards, etc.

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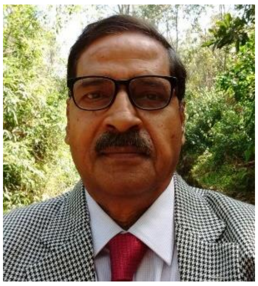

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Dr. M. K. Das had a career of retired head, Fishery Resource & Environment Management Division, ICAR-Central Inland Fisheries Research Institute, Barrackpore and his major research contribution has been in the field of taxonomy and epidemiology of fish pathogens; developing the clinical blood and cellular profiles of healthy and stressed fish; riverine ecosystem health assessment; and assessing the impact, vulnerability and adaptation of inland fisheries to climate change. He has 144 national and international publications consisting of scientific research papers, books, book chapters, policy papers etc. Awarded Bioved Fellowship Award (2012), Dr. B. S. Chauhan Gold Medal (2010) by the Zoological Society of India (ZSI); Fellow of Inland Fisheries Society of India (FIFS) and Zoological Society of India (ZSI). Served as Expert representative of NACA in NACA/FAO on fish health and quarantine, 1995.

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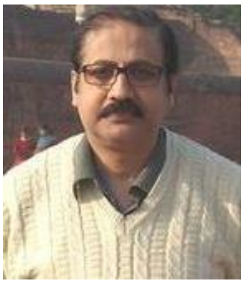

Dr. Abhijit Mitra, Associate Professor and former Head, Dept. of Marine Science, University of Calcutta (INDIA) has been active in the sphere of Oceanography since 1985. Presently, he is serving Techno India University, West Bengal as the Director of Research. He has 498 scientific publications in various National and International journals, and 36 books. Dr. Mitra is presently the member of several committees like PACON International, IUCN, SIOS, etc. and has successfully completed about 19 projects on biodiversity loss in fishery sector, coastal pollution, alternative livelihood, climate change and carbon sequestration. Dr. Mitra also visited as faculty member and invited speakers in several foreign Universities of Singapore, Kenya, Oman and USA. In 2008, Dr. Mitra was invited as visiting fellow at University of Massachusetts at Dartmouth, USA to deliver a series of lecture on Climate Change. Dr. Mitra also successfully guided 36 PhD students.

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Prof. S. K. Das, Ph. D. has been in research work on aquaculture and fisheries since 1987 and currently serving the Faculty of Fishery Sciences, West Bengal University of Animal and Fishery Sciences, Kolkata, West Bengal, India as Professor, Department of Aquaculture. Prof. Das has been awarded Visiting Fellowship from the Science and Engineering Research Council (SERC), Department of Science and Technology, Govt. of India and Research Associateship from the Council of Scientific and Industrial Research (CSIR), Govt. of India to carry out post-doctoral research. Prof. Das has been associated with several major Research Projects as Principal Investigator/Co-Principal Investigator funded by the Indian Council of Agricultural Research, Govt. of India and Department of Science and Technology, Govt. of West Bengal etc. He has published more than fifty research papers in National and International Journals of repute from the esteemed publishing house.

Dr. Bibha Chetia Borah, Fisheries Research Center, Assam Agricultural University, Jorhat

Dr Bibha Chetia Borah presenly working as Principal Scientist and Officer in Charge of the Fisheries Research Center, Assam Agricultural University, Jorhat, Assam, has 31years of experience in research, extension and teaching in the field of Fisheries and aquaculture.She has 35 nos of research papers, 6 nos of books, 5 booklets send 37 book chapters published so far, besides contributing to formulation of package of practices for Aquaculture in Assam. She is the Life Member of 14 Professional Societies and member of editorial board of 10 nos of reputed journals. She has been conferred upon the Best Researcher Award, 2017 of Assam Agricultural University and Prof. B.C Pandey Madal award by the Zoological Society of India in 2019 for her outstanding research and academic contribution in the field of Fisheries and aquaculture. She is the honorary Fellow of the Zoological Society (Calcutta) and the Society of Life Sciences.

Dr. S. Adhikari, ICAR-CIFA, Rahara Research Station, Kolkata

Dr. Adhikari is serving as Principal Scientist and Scientist-in-Charge (SIC) at Regional Research Centre (RRC) of ICAR-CIFA, Rahara, Kolkata. His research areas include soil and water chemistry, fish pond environment, water and nutrient budgeting, contaminants in fish pond, climate change and aquaculture. He is the recipient of the XII International Congress Commemoration Awardof the Indian Society of Soil Science; Dr. B.C. Deb Memorial Awardfor Soil/Physical Chemistryof Indian Science Congress Association; ICAR awardfor outstanding team research as team member; and Best Young Scientist Award of ICAR-CIFA, Bhubaneswar. Dr. Adhikari is the Fellow of International Society for Environmental Protection (ISEP), Gorakhpur. He has published more than 100 research papers and 01 book with h-index of 19, i10-index of 28 with more than 1160 citations in international literature.

Dr. F. H. Rahman, ICAR-Agricultural Technology Application Research Institute, Kolkata

Dr. F. H. Rahman is currently serving as Principal Scientist in the discipline of Agriculture Chemistry & Soil Science and Nodal Officer of NICRA project of ICAR-Agricultural Technology Application Research Institute, Kolkata. His area of research is Soil Chemistry-Fertility-Microbiology and his research is documented in the form of research publications: 45 research papers, 54 No. of Book/Book Chapter/Manuals. He had presented more than 65 papers in various seminars/symposia, etc. He was awarded Fellow of Indian Society of Extension Education; Young Scientist Award 2014 by SEEA; and Best KVK Professional Award by SEEA.

Dr. Archana Sinha, ICAR-Central Inland Fisheries Research Institute, Kolkata

DR. Archana Sinha is working as Principal Scientist in ICAR-Central Inland Fisheries Research Institute, Barrackpore; involved in research, teaching & extension activities for last 28 years. She had taught fisheries and aquaculture, expertise in the field of ornamental fish culture, fish nutrition and feed. Her area of interest is working with fishers for their livelihood security. She has published more than 80 research publications in the form of research papers, articles, technical report, bulletins, training manuals, extension materials for the society, etc.

Dr. Malay Naskar, ICAR-Central Inland Fisheries Research Institute, Kolkata

Dr. M. Naskar is working as principal scientist in the discipline of statistics at ICAR- CIFRI, Barrackpore. His work experience is in Statistical Computing, including MCMC techniques, Survival Analysis, Generalized Linear Models, Longitudinal Data Analysis, Non parametric Bayesian Analysis and application of Dirichlet Process. Application of statistical methodologies for inland fisheries data analysis such as species richness modeling; fish family-mesohabitat modeling; Hydrology and migratory fish catch modeling; pre-spawning fitness modeling; stakeholder-driven approach proposed to assess impact of climate change in inland fisheries. He has published 30 Research article. He was honoured with Jawaharlal Nehru Award for Post-Graduate Agricultural Research for the year 2007 of ICAR.

Dr. Subir Kumar Nag, ICAR-Central Inland Fisheries Research Institute, Kolkata

Dr. Subir Kumar Nag, Principal Scientist (Agricultural Chemistry) at ICAR-CIFRI is engaged in research on various aspects of environmental pollution. He has about 65 publications including research paper, book chapters, popular articles, manuals etc. in his credit. He is recipient of ICAR Lal Bahadur Shastri Young Scientist Award, Endeavour Research Fellowship of Govt. Australia and Fellow of Range Management Society of India. Dr. Nag has experience of working at Carbon Management & Sequestration Centre, Ohio State University, USA in the field of carbon sequestration and greenhouse gas emission potential of wetlands.

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Dr. Md. Aftabuddinis working as Principal Scientist in the Division of Reservoir and Wetland Fisheries, ICAR-Central Inland Fisheries Research Institute, Barrackpore. He had his Doctorate from Indian Veterinary Research Institute in Animal Biochemistry. He has research experience of 21 years in wetland and reservoir ecology and fisheries especially in the area of biochemical indicator of wetland health, fish nutrient profiles, thermal stress tolerance mechanism, immunity of catfishes, feed development for carps in cages and wetland microbial diversity and has about 25 research papers, 10 book chapters, 2 bulletins and 4 training manuals in his credit.

Dr. Arun Pandit, ICAR-Central Inland Fisheries Research Institute, Kolkata

Dr. Arun Pandit is a principal scientist and currently serving as In-charge of Agricultural Economics Section of ICAR-CIFRI, Barrackpore. His area of expertise is animal science, agricultural economics and marketing, ecosystem services valuation and livelihood and contingent valuation method. He has published more than 70 research publications in the form of research papers, articles, technical report, bulletins, training manuals, etc.

Dr. Preetha Panikkar, ICAR-Central Inland Fisheries Research Institute, Kokata

Dr. Preetha Panikkar is a principal scientist and currently serving as In-charge of Bangalore Regional Centre of ICAR-CIFRI. She has experience in the area of aquatic ecosystem modeling (ECOPATH, ECOSIM & ECOSPACE), culture based fisheries in reservoirs, etc. in inland open water bodies. She has published more than 30 research publications in the form of research papers, articles, technical report, bulletins, training manuals, extension materials for the society, etc.

Shri S. K. Sahu, ICAR-Central Inland Fisheries Research Institute, Kolkata

Shri S. K. Sahu is a Scientist specialized in Electronics and Instrumentation and has been associated with fisheries and fishery management research through the application of these technologies since the last eighteen years. He has contributed his experience towards successful completion of major projects which were focused upon fish and fisheries, aquaculture, wetlands, riverine studies and the effect of climate change on them.

Dr. D. Debnath, Guwahati Regional Centre, ICAR-Central Inland Fisheries Research Institute

Dr. D. Debnath is presently serving as Scientist and involved in research in ecology and fisheries of reservoirs and wetlands as well as climate impact on inland fisheries since last 10 years. He was awarded DBT (India) Overseas Associateship, Ghent University, Belgium in the year 2013-14; Young Scientist Award of AFSIB (2008); Sir Dorabji Tata Trust Scholarship (2005); and Dr. N.R. Menon Best postgraduate Thesis Award (2005). He has published more than 70 research publications in the form of research papers, articles, technical report, bulletins, training manuals, etc.

Dr. A. K. Sahoo, ICAR-Central Inland Fisheries Research Institute, Kolkata

Dr. A. K. Sahoo is working as scientist in the division of Riverine Ecology and Fisheries, ICAR-Central Inland Fisheries Research Institute, Barrackpore. He has research experience of 10 years in ICAR in the field of riverine ecology, environmental flow, fish immunology, fish pass, etc. He has documented his work in more than 50 numbers of publication comprising research papers, articles, policy papers, book chapters, technical reports, etc.

Dr. Soma Das Sarkar, ICAR-Central Inland Fisheries Research Institute, Kolkata

Dr. Soma Das Sarkar is serving as scientist in the discipline of fishery resource management since past 8 years at ICAR- CIFRI, Barrackpore. Her area of research is aquatic ecology, taxonomy of plankton, impact of pollution studies on plankton, etc.Dr. Das has documented her research work in more than 24 research publications comprised of research papers, articles, technical report, bulletins, training manuals, extension materials for the society, etc. She has been awarded best Young Scientist Award in the 29th All India Congress of Zoology.

Dr. Neeraj Kumar, ICAR-National Institute of Aboitic stress Management, Baramati, Pune

Dr. Neeraj Kumar is a Scientist of ICAR-National Institute of Aboitic stress Management (NIASM), Baramati, Pune since 2014 and worked in the field of stress management and fish nutrition and climate change. He has documented his research work in more than 30 research papers in peer reviewed international and national journals and has more than 500 citations.

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Ms. Gunjan Karnatak is working as a scientist in the discipline of Aquaculture in Reservoir and Wetland Fisheries Division, ICAR-Central Inland Fisheries Research Institute, Barrackpore. Her research focus include culture based fisheries and enclosure culture in reservoirs and wetlands, climate change impact on fish biology. She has 32 research publications in the forms of papers, articles, technical report, bulletins, training manual, etc