National Workshop on Impact of Climate Change on Coldwater Fisheries Resources:

Perspectives, Framework & Priorities

5th June, 2009

Souvenir

Directorate of Coldwater Fisheries Research
(Indian Council of Agricultural Research)
Bhimtal – 263136, Distt. Nainital, Uttarakhand

National Workshop
on
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National Workshop on
Impact of Climate Change on Coldwater Fisheries Resources: Perspectives, Framework & Priorities

DCFR, 2009

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डा. मंगला राय
सचिव एवं महानिदेशक
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Secretary & Director-General

भारत सरकार
कृषि अनुसंधान और शिक्षा विभाग एवं
भारतीय कृषि अनुसंधान परिषद्
कृषि मंत्रालय, कृषि भवन, नई दिल्ली 110 001

Government of India
Department of Agricultural Research & Education
And
Indian Council of Agricultural Research
Ministry of Agriculture, Krishi Bhawan,
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Message

It has been recognized that climate change will have drastic socio-economic and ecological consequences in the entire sphere. Fish being a coldwater creature is likely to be impacted by climate change, particularly by rising temperature, shrinking of glaciers and rising sea level. In general, the fishery resources of the country are still under constant pressure from various anthropogenic stresses and further considerable changes in climatic conditions would definitely aggravate the situation and would be detrimental for its rich fish germplasm resources.

I am glad to learn that Directorate of Coldwater Fisheries Research, Bhimtal, District Nainital, Uttarakhand is holding a National Workshop on "*Impact of Climate Change on Coldwater Fisheries Resources : Perspectives, Framework & Priorities*" on the 5th June, 2009. This workshop, being organized on the very special occasion of World Environment Day, would address the relevant issues of the sector and possible impacts of the much-talked climate change thereon.

I am sure the deliberations will address the pertinent issues on climate change and their impact on Indian fishery in general and coldwater sector in particular towards formulating possible measures to mitigate the impacts on our valuable species like golden mahseer, snowtrout, hill stream fishes and our culture systems.

I convey my best wishes for successful deliberations to the organizers and participants.

Dated the 4th May, 2009
New Delhi

(Mangala Rai)

डा. एस. अय्यप्पन
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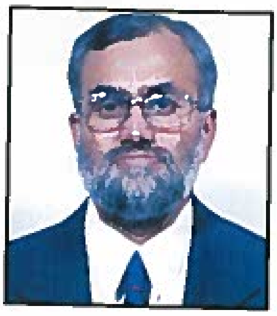

Message

The upland region of the country including Himalayas and peninsular Hill Ranges form an entirely different eco-geographical entity; hold diverse water resources and rich piscine diversity. In the mountainous region water temperature is found a major limiting factor in distribution of the upland fishes. The ambient water temperature determines many of the vital physiological activities of the fish like feeding intensity, growth, survival, maturity, spawning, and migration. Any drastic change in its thermal regime and other water quality parameters is detrimental to the fish life and force for migration or in extreme conditions leads to extermination of the species. Climate change is directly correlated with abrupt melting of glaciers, which leads to change in downstream river flow, velocity, temperature and water quality.

The National Workshop on "*Impact of Climate Change on Coldwater Fisheries Resources: Perspectives, Framework & Priorities*" being organized by Directorate of Coldwater Fisheries Research, Bhimtal, District Nainital, Uttarakhand on 5th June 2009 would address all the possible impacts of climate change on coldwater fisheries.

I am confident that the learned participants consisting senior fishery experts, University Professors, environmentalists, scientists and other experts in the field would discuss the different facets of the situation and suggest mitigation measures for development of coldwater fisheries sector.

I wish the workshop a grand success.

(S. Ayyappan)

Preface

The Himalayan region has the largest concentration of glaciers outside the polar caps. The Geological Survey of India has estimated occurrence of 5000-6000 glaciers in the Indian part of the Himalaya. These are repository of gigantic water in frozen form and source of water to the major river systems of the Northern India. A regulated melting and recharging process maintains a state of equilibrium in its process. Scientific studies have shown that most of the glaciers are retreating at a serious rate in the Himalayas, as a result of various cumulative factors in which climate change is the principal one. Melting of glaciers at a rapid rate might cause serious threat to the fisheries of the region and could lead to extermination of the valuable species. As the upland region of the country bestowed with vast and varied water resources and rich piscine diversity. The list of fishes comprises 258 species belonging to 21 families and 76 genera. Out of these a maximum of 255 species are recorded from North East Himalayas, 203 from the West and Central Himalayas and 91 from the Deccan plateau. These resources are still under constant pressure from various anthropogenic stresses and the further drastic changes in climatic conditions would definitely aggravate the situation and would be detrimental for its rich fish germplasm resources and valuable fishery.

The National Workshop on "Impact of Climate Change on Coldwater Fisheries Resources: Perspectives, Framework & Priorities" being organised on the occasion of World Environment Day (5th June) would provide a suitable platform to the experts dealing with the climate change issues, fishery experts, scientists, environmentalists, extension officials and planners to predict the consequences and suggest the befitting mitigation measures pertaining to the coldwater fishery sector.

I hope that the conclusion emerged out of this workshop will be formidable guidelines to tackle the consequences of climate change .

(P.C. Mahanta)
(Director)

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IMPACT OF CLIMATE CHANGE ON FISHERIES SECTOR: PERSPECTIVES AND PRIORITIES

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Introduction

Vast landmass with geographical and altitudinal variation, river valleys, mountains and level of vegetation cover has given rise to varying climates in different parts of our country. Such a diverse system holds immense water resources in the form of rivers, rivulets, streams, streamlets, lakes, swamps, backwaters, ponds, tanks, reservoirs, estuaries and seawater. All the aquatic resources are based on continuous water cycle largely driven by temperature, evaporation and precipitation. Based on round the year water availability, the river and river based aquatic bodies i.e. wetlands, swamps; reservoirs are categorized as perennial or seasonal. The most of the Himalayan rivers and associated water bodies are of perennial nature due to their glacial origin, while the rest of the inland water bodies are rain fed, hence seasonal. The present day natural aquatic biotic assemblages and fisheries are the result of the million years long evolutionary processes. Such a natural balance evolved and maintained through time series is now under severe stress from various anthropogenic factors, since a couple of decades. Climate change is the biggest global challenge before the human kind and fishery is one of the major sectors seems to be affected largely.

India is a major maritime country and is important as far as fish production and consumption is concern. Being home for more than 10% of the global piscine diversity, the country ranks third in the world in total fish production. The marine sector mainly contributes in capture fisheries while inland sector is emerging as a major aquaculture producer, with a share of 77%. India is producing annual fish production over 6.8 million tones and contributing over one percent of the total Gross Domestic Productivity and five percent of the agricultural productivity. Country earned a handsome amount of Rs.7, 555 crores accounting for about 14 % of the agricultural export.

It is estimated that about 5000-6000 glaciers are situated in the Indian part of the Himalayas. Which are retreating as a result of rise in atmospheric temperature. Some of these glaciers fed to our major northern rivers, therefore drastic changes in the glacial flow would change the biotic assemblage and fishery in the rivers. World Food Organisation conducted a symposium at Rome on impacts of climate changes on fisheries sector during 8-11 July 2008. The experts opined that the global fish production would decrease as a result of the consequences. Fish being a coldwater creature is likely to be impacted both positive and negatively by climate change. Fluctuations in ambient water temperature influence the basic metabolic rate (BMR), which regulate all the vital activities like feeding, digestion, growth rate, maturation, spawning and survival of the fish. In general, the fishery resources of the country are still under constant pressure from various anthropogenic stresses and the further drastic changes in climatic conditions would definitely aggravate the situation and would be detrimental for its rich fish germplasm resources and valuable fishery.

Possible impacts of climate changes

The increased emission of green house gases-carbon dioxide, methane, nitrous oxide and fluro-carbons warm the earth surface and results in shrinking of glaciers, influx of turbid water in the snow-fed rivers, excessive discharge of fresh water in the sea, rise in sea temperature and gradual rise in sea level. Information on the likely impacts of climate change on fisheries is very limited, but the situation seems very complex. Moreover, the inherent unpredictability of climate change and its mechanisms of possible impacts on fishery are very complex. To mitigate the possible consequences there is need to emphasize both the situation and its remedial measures.

In Himalayan region

The coldwater fish species have lower temperature tolerance, so temperature is a prime-limiting factor for these species. Though the native coldwater species like *Diptychus maculatus* and *Schizothorax richardsonii* can withstand freezing temperature but upper limit is very crucial for their growth and survival. In the principal coldwater fish species namely rainbow trout, brown trout, snow trout, mahseer etc. the optimum body activities (linked with basic metabolic rate, BMR) takes place when ambient water temperature ranges between 12-18 ^{0}C. But, the vital activities like maturity, spawning, hatching needs specific temperature for each species. Any deviation from the required temperature is highly detrimental for their survival. Climate change and resultant rise in atmospheric temperature would accelerate melting process of glaciers in the Himalayan region. The rapid melting process would cause increase in riverine flow and at the same time the water would engulf sizeable debris load; so result in considerable alterations in physico-chemical parameters of the river systems. The drastic changes in the ambient water might disturb the existing ecological balance among the different abiotic and biotic components. The changed eco-climatic conditions would further deteriorate the pristine feeding and breeding grounds of the native fish species, their population and composition structure, maturity condition, spawning and related vital life cycle phenomenon. Thus it would lead to migration or death of the stenothermal and ecologically sensitive fish species like mahseer, snow trout, barils and other hill stream fishes in the upland systems. In these circumstances, small sized weed fishes or alien species might occupy the new vacant habitats and niches.

Fresh waters in Northern plains

The possible impacts of climate change in the riverine systems and associated water bodies of the western, northern and north-eastern plains would be in the form of erratic river flow, increased silt load, higher water temperature. There would be a large-scale redistribution of the fish species in the aquatic systems. The changed aquatic habitats would pose great threat to the already shrinking native species-Indian major and minor carps, catfishes, murrels. The most of the river systems in the region are already facing serious threat from anthropogenic abuses like reduced flow, pollution, construction of dams and barrages across the rivers, aquatic pollution, boulders and sand mining from the river banks and wanton destruction of fishery resources. Further drastic alterations in water flow, increase in water temperature and alterations in quality by climate change would lead to complete extermination of existing fishery. The lethal effects of thermal extremes would result in mass mortalities of stenothermal species; diseases, infections and considerable mortality and migration in eurythermal species.

Estuarine and seawater

There are multi-pronged predictions on severe impacts of climate changes on estuarine and seawaters. This will inundate low-lying areas, swallow coastal marshes and wetlands, erode beaches, exacerbate flooding and increase the salinity of rivers, bays and aquifers. It has long been known that ocean conditions such as temperature, salinity profile and current patterns are changing due to climate change and these would directly affect the numbers and locations of different fish species. The projected influx of excessive fresh water from Himalayan rivers would significantly alter the salinity and other physico-chemical parameters of the estuarine and oceanic waters. This would lead to a massive redistribution of fish populations, migration local extermination in extreme conditions.

Efforts to safeguard fisheries

The likely impacts of climate change and resultant increase in temperature on riverine and associated water bodies, their physico-chemical profiles, biota and capture fisheries seems to be irreparable. The completely altered aquatic systems would not be congenial for survival, growth and propagation of highly sensitive species; as a result the valuable biota may vanish from these resources. Therefore, there is need to initiate all possible conservation efforts to protect valuable fish gene pool for posteriority. As the natural water bodies would be victim of the changes, therefore the *ex-situ* measures of conservation would only be effective instead of *in-situ* methods. There would be an alarming challenge to safeguard the diverse fish germplasm particularly the native Indian major carps, cat fishes, murrels, featherbacks, mahseers, snowtrouts, hill stream fishes, valuable estuarine and sea fishes, prawns, lobsters, mollusks etc. The drastic changes in natural aquatic systems would lead to extermination of ecologically sensitive native species and at the same time advent of hardy alien species like common carp in uplands and common carp, tilapia and magur in the fresh warm waters.

The climate change would also lead to drastic alterations in the morphological and physico-chemical characteristics of the varied culture systems. There would be need to develop feasible farming techniques in view of the changed thermal spectrum. The gradual climate changes have already started its appearance since a few decades. It is evident from the ongoing farming practices in the hills (1200-1600 msl) where Indian major carps, particularly *Labeo rohita* is thriving well in the pond conditions, while it could not survived in earlier trials made during past 8-10 years back, due to low temperature. This indicates that the increased water temperature might support culture of Indian major carps in the upland regions in coming years. But at the same time this would be an alarming signal for existence of valuable trout fishery. In these circumstances the snow line will rise to higher altitudes and accordingly the trout farming need be shifted to new locations. Similarly whole farming practices throughout the country or globe would need to be re-structured as per prevailing climatic conditions. The challenge is ahead, so we need to gear up with sound techniques for mitigation of the adversities, conserve the valuable germplasm and boost fishery production to fulfill the domestic and export demand.

IMPACT OF CLIMATE CHANGE ON ECOLOGICAL HEALTH ASPECTS NEEDS, NETWORKING OF RESOURCES INSTITUTES, PLANNING COMMISSION, STATE AND CENTRAL GOVERNMENTS

S.N. Dwivedi

President, ASET, Ex. Additional Secretary, DOD, GOI.

ABSTRACT

The basic object of this paper is to show global warming is already occurring. This has very serious impact on water availability and melting of glaciers in Himalayan regions. Worst scenario is Himalayan Glaciers may melt, rivers may dry up. Change is inevitable. Global warming is bringing changes from coastal areas to Himalayan regions. All these changes are interrelated. Himalayan region cannot be isolated. We must meet the challenges through better S&T approach. We can delay the process, can be check it? It is a national priority, we must do our best by collating information and plan interdisciplinary, interstate and national efforts based on scientific data and do the best we can. The Global Warming has attracted the attention of the various National and International Organizations across the glove. Major findings of some of the studies which have a direct impact on India are cited and discussed below:

CITATION 1: Global Warming can cause Ecological Disaster for India:

We keep reading about rising temperatures and sea-levels in other parts of the world like United States and the UK, but actually India is one of the most vulnerable countries when it comes to effects of global warming. India has a vast coastal line and the rising sea levels caused by global warming will cause an ecological disaster (United Nations Environment Programme study 1989).

"In India, the signs already back up forecasts that as the mercury rise the Indian subcontinent, home to one-sixth of humanity, will be one of the worst-affected regions."

A six-year study of the impact of future climate change on the world natural heritage site that India shares with Bangladesh, Sunderbans came up with alarming results.

Official records list 102 islands on the Indian side of the vast Sunderbans, where the Ganges and Brahmaputra empty into the Bay of Bengal.

But scientists have been able to map only 100 islands and found the other two have been swallowed up "Two islands, Suparibhanga and Lohacharra, which have gone under water, could not be sighted in satellite imagery. The disappearance of the two islands has rendered over 10,000 people homeless," (Sugata Hazra, director of Kolkata's School of Oceanography Studies, Jadavpur University).

CITATION 2: Loss of all Central and Eastern Himalayan Glaciers by 2035:

The Himalayan Region: The glaciers are retreating at average rate of 50 feet (15 m) per year. At this rate scientists predict the loss of all central and eastern Himalayan glaciers by 2035.

Since the mid-1970s the average air temperature measured at 49 places in northern India has risen by 1 degree centigrade, with hill stations showing the greatest warming. This is just the average and the situation is worse in some places. And this average is twice as fast as the average 0.6 degree centigrade average warming for the northern hemisphere, which shows that mountainous regions are more susceptible to climate change.

Ten years ago no one was quite sure as to why this was happening. There were theories and a lot of conjecture, but now there is nothing but certainty. (Citation)

CITATION 3: Rise in sea level along Indian Coast:

According to the National Institute of Oceanography, Goa, which monitors sea-level rises along the Indian coast, in a study of 24 stations during 1878-1994, the sea level computed for 11 stations out of the 24 showed rising sea levels at 5% level of significance. The only exceptions were two stations in Vizag and Chennai.

CITATION 4: Vulnerability of coast line – Loss of 5,764 Sq.Kms of land in Coastal areas and Displacement of 7 million people:

India is one of the 27 countries most vulnerable to rising sea levels, according to a 1989 United Nations Environment Programme assessment. There have been few studies that have explored the impact of rising sea levels on India. One of the first studies was carried out by the Jawaharlal Nehru University (1993), in which the consequences of a 1 meter rise in sea level were evaluated. The study concluded that, in the absence of protection, approximately 7 million people would be displaced and 5,764 sq km of land and 4,200 km of roads would be lost. A subsequent study by the Tata Energy Research Institute (1996) explored the relative vulnerability of various coastal regions including the Orissa coast, the effects of adaptive responses to the impact of rising sea levels, and the value of coastal protection for selected regions.

These studies clearly demonstrate that climatic changes have been occurring across the globe. Oceans cover 70 % surface of glove and 30% is covered by continents. Resent studies of United Nation have showed rise in temperature by 1^0C by the year 2050.

This will severely impact India starting from Islands and coastal regions to different states situated in Himalayan regions, starting from Jammu & Kashmir to Nagaland. 1^0 rises in temp will result in disappearance of few species of biota and impact the life cycle of some species which will result in increased primary productivity and faster growth of some fish species. A Study conducted by Dr. S. N. Dwivedi and others (UNESCO-IOC report/92) had indicated significant changes in the coastal regions and change in monsoon pattern in different areas of Himalayan regions and along Gujarat and Rajasthan. These projections been confirmed in last few years which resulted in floods in Rajasthan.

Due to global warming large quantity of warm sea water enters from Pacific Ocean into the Indian Ocean and pass around 10^0C South of Equator. These South equatorial currents strike the African Coast and due to the impact of temperature, winds and surface currents move towards Northern part of Arabian sea and then towards the Indian Coast along Gujarat. This has resulted unprecedented heavy rains in Gujarat and Rajasthan. A few decades ago monsoons used to start in Kerala and moved towards Karnataka, Goa and Maharashtra and towards various states situated in Himalayan region where heavy rains use to occur. Now, this has changed.

Similarly due to inflow of water from Pacific Ocean to Indian Ocean and rise in temperature above 26^0C, the cyclones have become more severe in Bay of Bengal. Jadhavpur University, Deptt. Of oceanography through the study of satellite had indicated the existence of hundred and two (102) Islands they could locate only hundred Islands other two Islands have been submerged. Other studies suggest, there has been loss of biodiversity in Sunderbans. Large scale cutting of mangrove forests appears to have the adverse impacts of cyclones .These factors have also resulted in decrease in rainfall in Himalayan States. These general trends indicate due to increase in temperature, melting of glaciers has been occurring .This results in increase inflow of cold water from Himalayan glaciers.

These changes are indicative of the fact that due to global warming some species may become endangered and a few may become extinct. This will lead to loss of biodiversity of flora and fauna. This will also lead to loss of some cold water fish species. Increase in temperature will increase productivity of plankton and related flora and fauna and faster growth of some species. Therefore, it is very urgent that a detailed study of fishes of the region should be conducted, to study biodiversity, life cycle and reproduction of likely endangered species.

I am glad to know that study on these lines have been started by Directorate of Coldwater Fisheries Research, Bhimtal and Dr. Lakra of NBFGR, Lucknow has also reported occurrence of 247 exotic species from India. Some of these species have come from colder regions of China e.g. Silver carp and Mud Carp and are reported to be well adapted to the colder regions of Himalayan states.

Initiatives taken by Directorate of Coldwater Fisheries Research, Bhimtal for aquaculture in hilly regions near rice fields for provision of animal food particularly for people residing in cold regions is very good and will result in increased production, ensures nutritional security and provides additional income to farmers and fishers. Water bodies interlinked with various streams in the region should be created. This will provide additional water area for cold water aquaculture and sport fisheries. Similar work has been successfully done near Hobart in Australia which apart from increasing area for fish culture has also resulted in creation of sport fishery, which has improved the tourism and enriched local economy. Therefore it will be very useful to create large and small impoundments. This suggestion will require detail panning and provision of adequate finances for the concerned Himalayan states through Planning Commission.

In order to create additional water area, they must use the NETWORKING APPROACH in which technology providers along with remote sensing and conducting satellite imagery DCFR, Bhimtal, NBFGR and State Governments must work together to create additional water areas to plan, implement aquaculture and sport fishery and to create KNOWLEDGE WORKERS, KNOWLEDGE SOCIETIES and KNOWLEDGE SYSTEMS should be created at village level. The formation of fish feed from local sources is also important Awareness programmes and vocational education at school level can also be very useful.

Conclusion

The paper briefly indicates that the impact of global warming is happening and will also affect the coastal areas and regions in Himalayan States. It can result in loss of biodiversity, impact life cycle of some fish species and a few can become threatened and others may disappear. The warmer temperature will enhance the growth of exotic fishes which come from colder regions.

The challenges of global warming can be partially met by training local farmers and fishermen. The threat has become a national priority of Himalayan region and can only be achieved by survey of water resources through Remote Sensing Aerial Photography and networking of institutes and knowledge providers, to bring a social change at village level by building, knowledge workers knowledge systems and Knowledge societies.

The global warming has started and it should be dealt as a National priority. ICAR Fishery Division and DCFR and NBFGR and Deptt. of Env. and Forest (remote sensing) Department of AH, Dairy and Fisheries and others may consider appointing an interdisciplinary committee to formulate plans to meet this crises.

STRATEGIES FOR MINIMIZING IMPACT OF CLIMATE CHANGE ON COLDWATER FISHERIES

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Global warming has significantly influenced physical and biological processes at global and regional scales. The observed and anticipated changes in global climate present significant opportunities and challenges for societies and economies. Climate change is a serious threat to development everywhere. The International Panel on Climate Change (IPCC) has unequivocally affirmed the warming of our climate system, and linked it directly to human activity. Slowing or even reversing the existing trends of global warming is the defining challenge of our ages.

Carbon dioxide (CO_2) is the main pollutant causing climate change. It rises through the atmosphere and captures heat, intensifying the effect of the greenhouse gases that keep the earth warm. This has dramatic consequences for the globe's climate system – more extreme and unpredictable weather conditions like droughts, floods, and storms more frequently, consequent raise in sea levels and changes of large ocean currents, and changes of regional weather systems during events like El Niño. Global warming has significantly influenced physical and biological processes at global and regional scales. These changes have thrown up many challenges for societies and economies.

Greenhouse gases released mainly by humans like burning coal, oil, and natural gas have led to a sharp rise in mean global temperatures over the last 50 years. Temperatures are expected to raise 1.4-5.8°C more by the end of the century. Fisheries resources are increasingly threatened by global warming. There have many instances where livelihood generating fisheries have suffered due to increased frequency and severity of cyclones, floods, coupled with intrusion of saline water into coastal areas due to thermal expansion of warming seas.

Possible impacts of climate change on fisheries

Primarily the impact of global warming and climate change will be felt by the water resources. The impact will be manifested into physical, biological and social changes. There may be changes in runoff and stream flow regimes at event, seasonal, and annual time scales, reductions in water quality associated with changes in runoff, increases in water temperatures. From the fisheries perspective the important changes other than temperature will be seen in melting of ice and glaciers which feed the rivers. Due to this and with changes in rainfall and evaporation, there will be alteration in lake levels and river flow, changes in ocean and wind currents, and increases in mean sea level. All these again will lead to ingression of salt water in low lying areas from the sea and there will be change in migration pattern, natural breeding and nursery grounds of many fishes. Because of the change in aquatic environment the aquatic biodiversity will be altered with more invasive species. There will be changes in timing of plankton blooms and composition resulting in potential mismatch between prey and predator. Higher water temperature will also bring changes in physiology and sex ratios of fish species. Altered timings of spawning, migrations will disrupt the recruitment and the problem of disease occurrences on epidemic scale are some of the consequences of global warming.

From the social point of view, changing levels of precipitation, unpredictable wet and dry seasons coupled with drought and floods will severely affect those people who depend on these resources for their livelihoods. Most of the countries that are most vulnerable to climate change impacts on their fisheries are the poorest and the poorest among these countries are likely to be affected mostly due to their minimal adaptive capacity. The people of these countries are also more dependent upon fish as source of protein.

Impact of climate change on coldwater fisheries

According to a new study by Natural Resources Defense Council (NRDC) and Defenders of Wildlife, 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. A 2°C raise in water may not have much impact on the warm water species but it will have lots of implications for the cold water species dwelling in the uplands. In many areas, the fish are already living at the upper end of their thermal range, meaning even modest warming could render streams uninhabitable. Regardless of location, the disappearance of cold-water fish will come at a significant cost to jobs, recreation and regional culture. These impacts will be felt more harshly by the poor and developing countries including India.

There are about ten upland states extending from Northwestern to northeastern Himalayas besides Western Ghats. Eventhough Cold water fisheries and aquaculture contributes only about 1.5% of the total inland fish production in the country, the coldwater fisheries resources have very rich and diverse gene pool many of them suitable for food, sports and ornamental value. About 258 fish species belonging to 21 families and 76 genera have been reported from Indian uplands as cold water fish species.

Water temperature is always an important limiting factor affecting geographical distribution and local occurrence of cold water species within the ecosystem. Fish being a poikilothermic animal, the impact of water temperature will affect their biological function. There is inverse relationship between water temperature and dissolved oxygen level which is critical for cold water fishes. Besides current velocity fluctuation in water, discharge, substratum, food availability are the factors which influence fish life in the upland areas. When exposed to warmer water, the fish were unable to get as much oxygen as they needed to cope with the increased temperature. Warmer temperatures mean also less oxygen dissolves into the sea's waters; not only are the fish able to get less oxygen out, but there is less oxygen available. This oxygen deprivation provides a mechanism for how climate change directly affects the ability of a species to thrive.

Responding to future challenges of climate change

Understanding, reducing and coping with climate change are the future challenges ahead of us. As the impacts of climate change and subsequent global warming will be felt by poor countries, its consequences will have more ramifications on its livelihood in particular and national economy in general. Mitigation measures need to be framed from biological, physical and social impacts which the climate change brings about.

At present climate change presents threats which are difficult to quantify in terms of changing temperature, weather, water quality and supply. The relevant research inputs are required to strengthen adaptive capacity and resilience of the fisheries sector. Assessment of overall range, combination, likelihood and potential impacts of climate related effects in cold water fisheries is urgently needed.

Detailed analyses of the vulnerability of cold water fisheries are required to have better indices of vulnerability, improve our predictive models and provide vulnerability maps and other analyses at scales useful to policy makers. The key is reducing vulnerability and increasing resilience of local stakeholders. Policies are to be framed by governing agencies by creating incentives for mitigation actions. Important strategies are to be directed towards the following:

1. Reduction of impact by reduced emission of green house gases

As the threat of climate change and global warming loom large on our head, it is time now to define ourselves what constitutes dangerous anthropogenic and prepare ourselves for a change in life styles, behaviour patterns and management practices that are needed. The intake and storage of the element carbon through Carbon sequestration may be one area to reduces emission of green house mainly CO_2. The most common example in nature is during the photosynthesis process of plants, which store carbon as they absorb carbon dioxide during growth. Because they soak up the carbon that would otherwise rise up and trap heat in the atmosphere, plants, trees and plants are important players in efforts to stave off global warming.

We need better understanding of our ecosystem dynamics and biogeochemical cycle such as carbon and nitrogen cycle. The mechanism of carbon sequestration by aquatic ecosystems should be studied to find innovative but safe ways to sequester carbon in aquatic ecosystems, and develop low-carbon aquaculture production systems. There is need to upgrade technologies with environmental issues as major component. The concept of carbon credit and an effective carbon-price signal could realize significant mitigation potential in all sectors

2. Adaptive capacity enhancement measures

While mitigation issues are valuable, the challenge of adaptation is both significant and potentially urgent. Adaptive capacity is dependent on such factors as wealth, technology, education, available information, skills, infrastructure, access to resources, and management capabilities. Levels of social capital, human capital and the appropriateness of governance structures are the elements of adaptive capacity. We have to build the capacity to adapt and respond accordingly. Policy support for adaptation involves supporting measures to reduce exposure of fishing people to climate-related risks, reducing dependence of peoples' livelihoods on climate-sensitive resources, and supporting people's capacity to anticipate and cope with climate-related changes.

Coldwater fisheries management should focus on conservation and improvement of the existing adaptability of fishers. Creating awareness of the impacts of climate change, promotion of environment friendly fishing methods and gears, restoring natural habitats and fishing grounds,

Conclusion

Implementing adaptation and mitigation pathways for communities dependent on fisheries, aquaculture and aquatic ecosystems will need increased attention from policy-makers and planners. Roles of NGOs and community-based organizations lie in identification of the current and future risks, potential impacts and resilience/recovery mechanisms within communities, and engage communities together with governmental and non-governmental agents in preparedness planning. They should create awareness about climate change among various stakeholders. They should communicate to policy-makers the importance of fisheries for poverty alleviation and the risks of climate change. They should build and support the resilience of coastal and other fisheries communities by supporting community-level institutional development and vulnerability reduction programmes. They can support risk reduction initiatives within fishing communities. On the positive note climate change may also increase the potential for coldwater fisheries and aquaculture in some regions and reduce it in others. We can try to exploit the potentials by new or adapted technologies in either case.

CLIMATE CHANGE, HIMALAYAN AQUATIC ECOSYSTEMS AND COLDWATER FISHERIES

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According to IPCC (2007), climate change refers to any change, in the mean and/or the variability of any climate parameter, that persists for decades or longer and occurs naturally or as a result of human activity. However, the United Nations Framework Convention on Climate Change (UNFCCC), considers only those changes which are in addition to the natural climate variability observed over comparable time periods and are attributed directly or indirectly to human activity that alters the composition of the global atmosphere. During the past two decades enormous amount of published literature has accumulated on a wide range of issues related to climate change. Irrespective of the discussion on the drivers of climate change, there is a general consensus about the current phase of accelerated rise in the Earth's surface temperature and increasing variability of precipitation and extreme events. Within the past 100 years, the global temperature has increased approximately 0.6 °C, and is projected to rise by 2 to 4 °C by the end of this century (IPCC 2007).

Climate Change and the Himalaya

The Himalyan mountain ranges rise sharply from 200-300 m to over 8800 m and include the world's highest mountain peaks. The region experiences a tropical to subtropical monsoonic climate at lower elevations which remain frost free throughout the year whereas with increasing elevation it changes to temperate and alpine climate. Peaks above 5000 m are generally covered with glaciers. The annual precipitation exceeds 5000 mm in the foothills in the east and decreases westwards and at higher altitudes to less than 500 mm. Most of the precipitation occurs during the southwest monsoon (June to September). The Tibetan Plateau is cold and arid.

Long-term data climate data are generally lacking for the Himalayan region. A recent study on the reconstruction of temperature changes based on tree ring analysis in northwest Himalaya shows annual to multiyear fluctuations punctuated with colder and warmer periods amongst which A.D. 1830-1852 and A.D. 1961-1972 were the coldest and warmest period respectively. (Shah et al. 2008). However, the IPCC assessment shows that the mean temperature is expected to increase by about 3.8°C at the end of 2100 whereas Agrawal et al. (2003) place the rise in temperature at 3.2 °C by 2100. The warming is expected to be greater at higher altitudes as accelerated melting of glaciers causes greater increase in temperature because of reduced albedo effect (see Meehl 1994). Also, the warming will be more during the summer months than in the winter months. The precipitation regimes are projected to change: the total precipitation and the total number of rainy days have declined in recent decades and are expected to decline further. The seasonal variability is projected to increase further with likely intensification of monsoon precipitation at lower elevations. It is projected that the northeast monsoon (winter rain) will bring more precipitation than the southwest monsoon (summer rain) and the intensity of extreme events is likely to increase. dry seasons become dryer and wet seasons wetter. Further, changes in the time of arrival and withdrawal of southwest monsoon are likely to occur (expected to arrive earlier), causing greater uncertainties and spatio-temporal variability.

Himalayan Aquatic Ecosystems

The Himalaya is the 'water tower' of Asia. Besides thousands of glaciers and permanent snow covered peaks, there are thousands of glacial lakes, and many large rivers and their hundreds of tributaries originate here. There are also a large number of natural lakes and wetlands scattered throughout the Himalaya at all elevations up to 6000 m. The tectonic forces together with the action of glaciers have created numerous shallow, though small lakes throughout the Himalaya. Many lakes are formed in valleys blocked by moraine or landslides. The rivers form narrow channels as they descend over steep slopes and pass through deep gorges. At lower elevations, passing through wide valleys, they meander and form vast floodplains and oxbow lakes.

Our understanding of these aquatic ecosystems is rather limited. Most of the studies have been made on the lakes and wetlands at lower elevations (below 2000 m) and a few on the rivers. Investigations at higher altitudes are very few. The aquatic biodiversity has not yet been properly inventorised.

Impacts of Climate Change

The impacts of climate change range from the direct effects of increasing CO_2 concentration and the consequent rise in temperature and to the indirect effects through alterations in the hydrology caused by the melting of glaciers and ice cover, and changes in the precipitation regimes (Fig. 1). The impacts will differ along the altitudinal gradient with cascading influence at successively lower elevations. However, there is very little known about the altitudinal differences in climate change. I have discussed earlier the impacts in some detail with reference to wetlands of the Eastern Himalayan region (Gopal 2008). Hence, only some aspects related to biodiversity and fisheries at high altitudes are highlighted here.

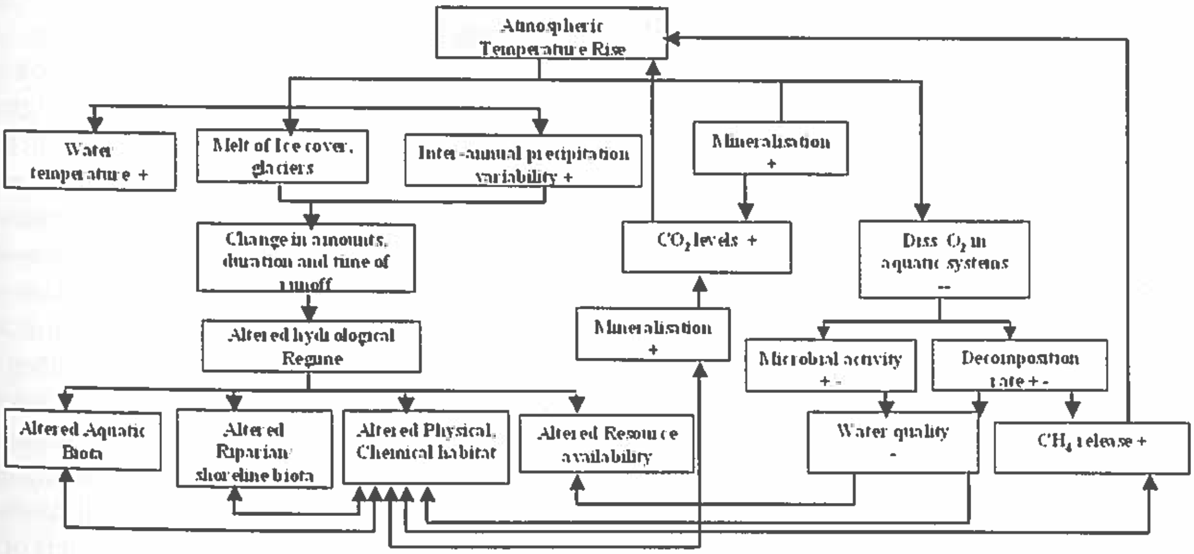

Figure 1. Possible impacts of climate change on aquatic ecosystems
(+ indicates an increase and – indicates a decrease)

An increase in CO_2 concentration has direct implication for the rate of photosynthesis to a certain level. In case of phytoplankton in rivers and lakes, increased CO_2 levels may enhance rates of photosynthesis at higher elevations but at lower elevations, its lower solubility at increased temperature is unlikely to affect the photosynthesis.

Of greater significance are the impacts of temperature rise. The melting of glaciers and their retreat which is occurring at an accelerated rate in recent decades, has received much attention (Yamada 1993, Kattelmann 2003, Agrawal et al. 2003). As a consequence, many glacial lakes have expanded and pose threat of an outburst flood, while others have disappeared.

The snow melt contributes relatively more to the total runoff in the Western Himalaya than in the East. Seasonal changes are expected in the timing and distribution of the surface runoff that is likely to increase during autumn and occur earlier and faster during the spring.

The temperature increase will affect practically all biological activity, though these affects have not been investigated in the region. Studies from northern latitudes of Europe and North America show that major changes may occur in the species composition, seasonality and production of planktonic communities, an increase in nuisance blue green algal blooms, and the food web interactions. Studies along an altitudinal gradient in Sweden show that the net production increases considerably with a rise in air temperature. These changes have a direct bearing on the water quality.

A rising snow line is expected to shift the species distribution to higher elevations. The atmospheric temperature generally drops by 1.5°C for every 300 m elevation, and therefore, with an average 1°C rise in temperature, most species are likely to extend their distribution upwards by 300 m. The exotic invasive species such as water hyacinth have already been extending their range into the hills and may spread further to higher elevations where they may also find refuge against lower winter temperature.

Another effect of rise in temperature will be through an increase in water temperature and consequently, lower availability of dissolved oxygen. This may affect a number of animals – both invertebrates and vertebrates. Many invertebrates and their larval stages have narrow temperature ranges for development and a rise by 1 °C may affect their life cycles. The rising temperatures will alter the ice-free period, longer growing season, changes in the patterns of thermal mixing in lakes, and greater incidence of anaerobic conditions for the benthic organisms including microbes. The consequences of these changes for food web interactions, community structure, nutrient dynamics and water quality are difficult to predict in the absence of any study in the region.

The composition of the aquatic plant, animal and microbial communities and practically all ecosystem processes are determined primarily and largely by the hydrological regimes. Even small changes in any one component of hydrology can affect one or more phases of the life cycle of aquatic organisms Therefore, aquatic ecosystems are highly vulnerable to hydrological changes – not only in quantity and quality but also the frequency, duration and timing of water availability. Water quality changes often act synergistically though the interactions are rather complex. The alterations in hydrological regimes caused by melting of glaciers and changes in precipitation regimes will have the most significant and pronounced impacts of the Himalayan aquatic ecosystems.

Of greater significance is the fact that climate change impacts will cascade down from higher elevations to lower elevations until the foothills, even if the real climate change is of different order of magnitude along the altitudinal gradient. This cascading effect will be caused by the hydrological connectivity between upstream (uphill) and downstream (downhill) systems. The aquatic ecosystems in the valleys and at lower elevations will bear the brunt of all changes taking place at higher elevations. However, with out current state of knowledge, it is difficult to predict the course and direction of change with change in climate.

Coldwater Fisheries

Much of our understanding of the climate change impacts on coldwater fisheries is based on the studies at high latitudes of Canada where great emphasis has been laid on the climate change impacts on both marine and freshwater fisheries.

The coldwater fisheries such as trouts are adapted to thresholds of lower temperature regimes. A rise in temperature by even 1 or 2 C is likely to affect their growth, physiology, reproduction and behaviour, and consequently the distribution pattern. The changes in hydrological regimes and timing of flow variations will alter the habitat characteristics and the available habitats. The changes in the species composition, distribution and productivity of foodweb components will also affect the fisheries. Further, migration corridors are likely to be affected resulting in a reduction or elimination of migration. Fisheries may also be influenced by climate change impacts on the introduction or altered distribution of exotic / invasive species, toxic algal blooms, parasite infestations and other disease organisms or their vectors.

Before voicing the need for greater research effort on climate change impacts and adaptation strategies, I would like to stress that it is often difficult to separate the impacts of climate change and other human activities. Humans alter the hydrological regimes in many ways and degrade water quality both directly and indirectly. These human interventions have already caused and are causing large-scale changes in aquatic systems similar to those anticipated due to climate change, even in the Himalayan region.

The changes that are expected to occur over a century under different scenarios of climate change have occurred or can occur within a span of few years due to anthropogenic pressures. Thus, the fate of aquatic ecosystems and their fishery resources will be governed and modified also by the level and kind of human interventions. The impacts of anthropogenic and climate change related processes will be synergistic, and climate change would only exacerbate the impacts of various human-induced stressors such as land-use and land cover changes.

Finally, it is stressed time and again that that the signs of global climate change were visible, but the in-depth knowledge and data from the Himalayan region was missing. "There is an urgent need to increase scientific understanding of the likely impacts and the approaches to their mitigation as well as for adaptation. There is an urgent need for policy relevant research on impacts and adaptation responses of fish, fisheries and aquatic resources to climate variation and its change.

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CHALLENGES IN UPLAND FISHERIES

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Introduction

One of the major challenges faced by Planners and Agricultural, Animal Husbandry and Fisheries Scientists in India is the production of adequate food for the exploding human population, the annual increase of which equals the total population of Australia and to simultaneously improve the quality of the diet of the people, with the generally increasing standard of life. This needs to be achieved in the context of the ever dwindling availability of land and other resources for food production, due to the conflicting onslaughts from key sectors such as housing, industries and infrastructure development and loss of precious arable land due to salination and desertification.

Only after the country gained independence, fisheries and aquaculture which had till then been largely neglected, have got their due recognition and fillip, registering rapid growth as a result of the R & D effort and investment put in, and have made significant contributions towards bridging the 'protein gap' in the food basket of the common man. However, fisheries, both marine and inland from the plains, have of late shown an alarming trend to level off, in the former case having more or less reached a plateau and with regard to the latter, declined, because of several constraints such as river training, indiscriminate reclamation of water bodies for agriculture and habitation, siltation due mainly to soil erosion in the upper reaches of rivers as a result of the anthropomorphic deforestation, etc. and the wanton discharge of untreated industrial effluents and municipal sewerage into the natural water bodies, causing severe pollution and consequent damage to open water fisheries.

Inland fisheries development in India till recently was mostly confined to the plains, with regard to both open water fisheries and aquaculture, where no doubt, major part of the resources and potential exist. Their warm-water conditions are conducive for rapid growth of fishes. But for some cursory efforts in rearing the coveted exotic trouts in some of hill stations like Udagamandalam, Munnar, Srinagar, etc. primarily for angling and sport fisheries, the available waters at higher altitudes were never seriously harnessed earlier.

Only during the past three decades or so the potential of the upland waters in increasing fish production in the country and improving the quality of life of the people of the hills and the need for developing and nurturing their fisheries have been recognized and R & D efforts are being stepped up. The pioneering and commendable work done by the erstwhile Coldwater Fisheries Research Unit of the Central Inland Fisheries Research Institute (CIFRI) in Srinagar (Jammu & Kashmir) and National Research Centre on Coldwater Fisheries (NRCCWF), Bhimthal, Uttarakhand, the predecessor of Directorate of Coldwater Fisheries Research (DCFR) merit special mention in this connection. However, a great deal still needs to be done in a very short timeline, to catch up with the level of R & D in the warm-water fisheries and aquaculture in the plains. In this backdrop, DCFR needs to be suitably equipped and research personnel strengthened, with adequate funding, to take up the challenges for bracing towards rapid development of this sector.

Upland (coldwater) fishery resources

Being a tropical country, in India the coldwater resources are mainly confined to the sub-Himalayan States of Jammu & Kashmir, Himachal Pradesh, Uttarakhand, Sikkim, Arunachal Pradesh, Meghalaya, the upland areas of Assam and the hill District of Darjeeling (West Bengal) and in the Peninsular region, the Districts of Udagamandalam (Tamil Nadu) and Munnar (Kerala). Inadequate connectivity and the difficult terrain impede easy access to many of these water bodies. The coldwater resources include a diverse spectrum of fast-flowing hill-streams and rivers, lakes, man-made reservoirs, tanks and ponds and shallow wetlands above 700 m asl, wherein the water temperature generally does not exceed 20ºC. The lakes, reservoirs and wetlands vary is size from a few ha to several sq. km and may hold fresh, brackish or saline water. They exhibit a great deal of diversity with regard to water quality, temperature regime, ecology, flora and fauna. Our upland water resources are vast, although much less in comparison to the warm-water fisheries resources in the plains, in terms of area.

About 260 species of fishes have been reported from the hills of our country. Among them the most common exotics are rainbow trout, brown trout and common carp. The important indigenous fishes include mahseers (*Tor putitora* and *Tor tor*) and schizothoracines, popularly called the snow trouts (*Schizothoraichthys esocinus, S. progastus, Schizothorax richardsonii, S. niger* and *S. curvifrons*). The major species of upland fishes in floodplain lakes of Kashmir Valley are *Schizothorax niger, S. micropogon, S. curvirostris, S. planifrons, Schizothoraichthys esocinus, Labeo dero, L. dyocheilus, Crossocheilus latius, Puntius conchonicus, Ġlyptothorax kashmiriensis* and *Gambusia affinis.*

Altogether 102 species of fishes have been listed from the waters of Western Ghats, situated between 750 and 2,000 m msl. Most of them are small in size and are exploited by subsistence fishers. Various species of cyprinids of the genera *Labeo, Cirrhinus, Puntius* and *Tor* contribute to commercial catches in the upland rivers and their principal tributaries, lakes and reservoirs. *Tor* spp. are important sport fishes, especially in the Cauvery. The exotic fishes in the Western Ghats are the common carp (*Cyprinus carpio*), the European carp (*Carassius carassius*), tench (*Tinca tinca*), tilapia (*Oreochromis mossambicus*) and the rainbow trout (*Oncorhynchus mykiss*; golden and ordinary strains). Subsistence fishermen capture medium-sized fishes such as *Barilius gatensis, Puntius carnaticus, P. sarana, Labeo* spp., *Cirrhinus fulungee, Crossocheilus latius, Garra* spp., *Mystus malabaricus, M. vittatus, Xenentodon cancila, Channa gachua* and *Mastacembelus armatus*. Commercial and sport fisheries target the highly valued endemic mahseers, *Tor khudree* and *T. mussulah*, the exotic rainbow trout and the ubiquitous common carp.

There are a number of lakes and reservoirs in the Western Ghats. Some of the small natural lakes, situated at altitudes ranging from 1,340 to 2,500 m msl, harbour rainbow trout and common carp, both introduced. The most important natural lakes of Peninsular India are located in Tamil Nadu. The littoral area of these lakes abound in fishes such as *Danio aequipinnatus, Rasbora daniconius* and *Gambusia affinis*. Reservoirs in the Nilgiris and High Ranges vary in size from 10 to 2,000 ha. Their fish catches constitute mainly of the rainbow trout and common carp. The true coldwater streams, however, lie in the upper reaches of the Cauvery and the Krishna.

Unfortunately, a detailed inventory of all the coldwater fisheries resources of our country is yet to be made. The limnological and fish faunistic diversity of only a very few of these waters have so far been documented. Exhaustive resource surveys of the upland waters need to be undertaken on a priority basis, being an essential prerequisite for planning and fostering their overall fisheries development.

Importance of coldwater fisheries

The upland areas are less populated compared to the plains, with the exception of the hill towns and their suburbs. In the absence of major industries and trades, the people of the uplands have to eke out their livelihood mainly by subsistence farming, depending on the unpredictable precipitation for irrigation of their crops. Most of the articles needed for their daily life have to be sourced from the plains which become costly, due to the high transportation costs and access constraints. On the other hand, their agricultural products which have to be marketed in the plains fetch a very low price at farm site, because of the hassles of transportation. Basic civic amenities such as piped water, roads, public transport, primary and secondary schools, hospitals, markets, etc. are generally wanting or inadequate in these areas. All these debilitating factors have individually and collectively contributed towards their general socio-economic backwardness. Hamstrung by very few employment opportunities, the majority of the people has extremely limited income and is forced to lead a subsistence life in the mountain areas of our country.

It is well known that the water bodies in our hill areas harbour a natural endemic fish fauna which are mostly slow growing, except probably the mahseers. Ranching of our upland rivers and lakes with appropriate species of game and other desirable species of fishes in a systematic way, after proper scientific investigations, only will augment their fish landings and open up new vistas for sport fisheries. This can trigger eco- tourism and related ancillary industries and trades and thereby usher in the economic development of the region and provide better employment prospects and thereby contribute towards the socio-economic upliftment of the generally marginalized resident rural population of the hilly areas.

By developing and demonstrating region based, viable technologies for cold-water aquaculture and with incentive subsidy from the Government in the form of funds towards the construction of ponds, seed and inputs and extension support, farmers could be motivated to construct ponds and impound water in suitable locations of their land holdings to undertake aquaculture, to produce protein rich and affordable fish for their own consumption and for the market. This will help to profitably recycle their agricultural, horticultural and kitchen wastes, employing green technologies, and improve the quality of their diet and diversify and increase the sources of income.

With the production from capture fisheries in the country, both marine and inland from the plains, having more or less reached the optimum sustainable levels, major increases in future will have to stem mainly from warm- and cold-water aquaculture and to some extent from the hitherto mostly under-harnessed upland open waters.

Desirable fish species for ranching and culture

The endemic species of fishes of our coldwaters mainly consist of several species of snow trouts (*Schizothorax* spp.), loaches (*Nemachielus* spp.), mahseers (*Tor putitora* sp., *Neolissocheilus hexagonolepis*, etc.), *Garra gotyla*, *Raiamas bola*, and minor carps such as *Osteobrama belangeri*, *Rasbora* spp., etc. Among them, except mahseers all the other species, being rather slow growing, are not very ideal sport fisheries and aquaculture candidates.

In the prevailing scenario of the paucity of suitable endemic candidates, keeping some of the typical cold-water bodies as 'reserves' for the specific purpose of conservation of the pristine water quality, endemic fauna and flora and their valuable germplasm, the other open water bodies and aquaculture ponds need to be stocked with choice, fast growing exotic species of fishes such as rainbow trout (*Oncorhynchus mykiss*) and brown trout (*Salmo trutta fario*), which are highly coveted and have great potential for sport fisheries, and common carp (*Cyprinus carpio* var. *communis*, *C. carpio* var. *specularis* and *Cyprinus carpio* var. *nudus*), in addition to the prized snow trouts (*Schizothorax richardsonii*, etc.) and mahseers, after proper, detailed investigations on their suitability for individual water bodies. Similarly, suitable fast growing exotic species such as common carp, Chinese silver carp (*Hypophthalmichthys molitrix*) and grass carp (*Ctenopharyngodon idellus*) and even some of the Indian major carps such as like rohu (*Labeo rohita*) also may have to be incorporated in the species matrix of cold-water aquaculture ponds in the mid-hill areas (700 to 1,500 m msl), depending on the ambient water temperature, for optimizing production and making the operation remunerative.

The currently available technologies permit the culture of a number of exotic and indigenous coldwater fishes of the Indian Himalayas. The most desirable exotic species are rainbow trout, brown trout and common carp and the exotics, mahseers (*Tor putitora* and *Tor tor*), and schizothoracines (*Schizothoraichthys esocinus*, *S. progastus*, *Schizothorax richardsonii*, *S. niger* and *S. curvifrons*). Among the endemics *Tor putitora*, *S. progastus* and *S. richardsonii* are ideal candidates due to their widespread distribution in the Himalayan States.

Success has been achieved in the captive breeding of the mahseers (*Tor putitora* and *Tor tor*) and schizothoracines (*Schizothorax richardsonii*, *S. niger*, *S. plagiostomus*, *S. planifrons*, *S. curvifrons*, *and Schizothoraichthys esocinus*). Fry and fingerlings of mahseers, produced in hatcheries, are already being stocked in some of the Himalayan rivers. However, further focused research work needs to be undertaken to evolve a viable technology for producing seed of snow trouts on a large, commercial scale.

A vibrant commercial fishery, in the absence of adequate natural recruitment, is dovetailed to ranching of the coldwater lakes and reservoirs with the seed of appropriate species of fishes. Although for a number of years fish hatcheries in the Himalayas have been raising eyed-eggs, fry and fingerlings of brown and rainbow trout and the seed of common carp for the purpose of stocking, only in the recent past that some of them have commenced producing the stocking material of the endemic mahseers and snow trouts for the purpose of stocking. To meet the ever-increasing demands of angling, subsistence and commercial fisheries, there is an urgent need for the scaling up the seed production capacity of at least some hatcheries by their upgradation.

Fish seed production for the ranching of the open waters and for undertaking aquaculture in the uplands will entail the setting up of Regional Hatchery Complexes and Fish Farms for brood-stock rearing and seed production. Unlike most of the warm-water fishes, the cold-water species take a longer time to attain maturity. Their fecundity is generally low. Hence their seed production calls for a much large number of brood-stock in comparison to Indian and Chinese major carps and common carp in the plains. The incubation of the embryos and larval and post-larval development of cold-water species such as the snow trouts, exotic trouts and golden mahseer and chocolate mahseer take much longer time. As a sequel, the cost of hatchery production of their seed works out to be much higher than those species of the plains.

Brown trout was introduced in some rivers and streams of the southern slopes of the mountain arc of the Western Ghats for catering to recreational fishery and has succeeded in establishing self-regenerating populations in some of them. Schizothoracinae is the predominant group of indigenous fishes captured from streams and rivers, and mahseer (*Tor* spp.) and *Neolissocheilus hexagonolepis* are the favourites of anglers. Indian trout (*Raiamas bola*) is another potential candidate species for stocking upland waters of the Ghats. This fish could be ideal for sport and recreational fishery and can be easily propagated on the lines adopted for mahseer.

Presently aquaculture in the uplands of the Western Ghats is confined primarily to the fish farms owned by the States concerned. Their main objective, however, is the production of the seed of rainbow trout and common carp for ranching open waters and for aquaculture.

Overfishing has become a menace in many cold water streams and rivers, as well as in some lakes in India. Deterioration of catchment soils due to inappropriate agricultural practices and indiscriminate deforestation and pollution are already showing ominous signs of adversely affecting the water quality, harming the cold-water fish stocks in some rivers, streams and shallow lakes, calling for immediate remedial action.

The way forward

In the context of enhancing the productivity of wholesome animal protein food in the country to meet the ever increasing demand as well as improving and diversifying the income and the quality of diet of the people in the uplands and to stimulate the overall economic development of these regions, coldwater fisheries and aquaculture can make significant contributions. As already mentioned, hill fisheries had been neglected and has got the deserving importance only in recent years, unlike that of the plains. Consequently, the R & D effort in this field also has not been much and a great deal of effort is needed to leapfrog and catch up. To generate the required basic data within a short timeline, a focused, Mission/ Coordinated Project/ Consortium mode of approach involving DCFR and all the Universities and other Research Institutions and interested NGOs and other stake holders in the hill areas, with adequate funds, and the former as the coordinating agency will be desirable, in a fast track mode, with the following clear-cut objectives:

- A detailed survey of all the diverse upland water bodies, such as rivers, streams, lakes, tanks, ponds and wetlands should be undertaken, making use of modern tools such as remote sensing satellite images (through different seasons), Global Positioning System (GPS), Geographical Information Systems (GIS), digital imaging and modeling, further verified, geo-rectified and digitized with the help of Survey of India toposheets, to ensure the ground reality. This will, within a relatively short timeframe, give a broad data base regarding the extent of water resources and other facilities available and help in formulating strategies for their integrated, holistic and eco-friendly management and conservation.

- Studies on the temperature regime, limnology, primary productivity and fish fauna and their abundance in representative water bodies need to be undertaken to determine their productivity profile and amenability for the development of fisheries/ aquaculture.
- After a detailed field survey, an atlas/ inventory of all the species of fishes, both endemic and exotic, should be made. The abundance, food and feeding habits, age and growth, maturity and breeding, maximum size attained of the important species should to be investigated. The studies will facilitate choosing the most suitable species of fishes for propagation and culture and provide a clue as to whether some of the species are endangered and need immediate attention for conservation.
- Technology packages need to be developed for rearing brooders and spawning and seed rearing of desirable species of fishes for both ranching and culture.
- Dietary requirements of cultivable species of fishes through different stages of life should be determined. This will help in formulating their cost-effective, supplemental feeds with good conversion ratio.
- Packages of practices for aquaculture for different altitudes (under different ambient temperature regimes, water quality, etc. in midlevel, upland areas, etc.) will have to be evolved, with region-specific fish species combinations.
- Cost-effective, efficient supplemental feeds should be developed for seed and table-fish rearing of cultivated fishes, as far as possible utilizing locally available ingredients and agricultural and animal husbandry wastes.
- Viable cage culture technology packages of desirable species of fishes will have to be evolved, including their supplemental feeding, for undertaking captive fish culture in large water bodies and optimizing production therefrom. The number of such cages installed should be regulated to avoid deterioration of water quality in such water bodies due to over-crowding.
- The common fish diseases in the upland open waters and aquaculture ponds and their causative factors should be studied and prophylactic and therapeutic measures developed.
- Global warming is expected to seriously affect the hill fisheries and suitable measures need to be envisaged to tackle the likely emerging situations.
- Eco-friendly technologies need to be developed for fisheries conservation and sustained exploitation of upland open aqua-systems, ensuring that their water quality parameters and the ecosystem health are robustly maintained. Such a value system will necessarily stimulate fisheries and arrest, both in the near term and long term, the downturn in fish productivity from open waters.
- Upland lakes already holding self-sustaining stocks of brown and rainbow trout and snow trouts need to be carefully managed to avoid overfishing. Some of these water bodies may have to be conserved as fish sanctuaries.
- The ecosystem attributes and resilience of upland aquatic ecosystems needs to be studied employing appropriate ecosystem modeling tools for formulating and implementing effective management measures.

Our coldwater resources and their biological diversity are nature's gift and the country's national wealth and the conservation of the precious aquatic bounty of germplasm with vision and prescience is our bounden duty to posterity. It should be our earnest endeavour to maintain the water quality parameters and health of these diverse habitats and ensure their sustainable development. In the backdrop of the burgeoning population pressure and declining availability of land for agriculture and animal husbandry practices due to the ever growing demand from other priority sectors and to upgrade the wholesome animal protein content in the diet of the common people, the sustainable, eco-friendly exploitation of our upland water resources for production of fish should get both national focus and priority. Development of upland open water bodies will steer eco-tourism and water sports and will invariably have a positive cascading effect on the overall development of the hill areas concerned. It also needs to be emphasized that expansion of coldwater fisheries and aquaculture will, in addition to improving the food security of the rural people in general, generate additional income to the fishers and marginal farmers and will help mitigate their economic backwardness. The spin off from all these transformations will propel the poverty amelioration, socio-economic development and inclusive growth of the people of the hills. DCFR has to play a leading, proactive and crucial role in this national endeavour.

THE INITIAL IMPACT OF CLIMATE CHANGE OVER SCHIRMACHER OASIS IN ANTARCTICA

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The planet Earth is facing the one of the greatest environmental, social and economic threats due to climate change. The warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global mean sea level. The Earth's average surface temperature has risen by 0.76° C since 1850. Most of the warming that has occurred over the last 50 years is very likely to have been caused by human activities. In its Fourth Assessment Report published on 2 February 2007, the Intergovernmental Panel on Climate Change (IPCC, Intergovernmental Panel on Climate Change (IPCC, http://www.ipcc.ch) projects that, without further action to reduce greenhouse gas emissions, the global average surface temperature is likely to rise by a further 1.8-4.0°C this century. Even the lower end of this range would take the temperature increase since pre-industrial times above 2°C, the threshold beyond which irreversible and possibly catastrophic changes become far more likely.

Projected global warming this century is likely to trigger serious consequences for humanity and other life forms, including a rise in sea levels of between 18 and 59 cm which will endanger coastal areas and small islands, and a greater frequency and severity of extreme weather events. Human activities that contribute to climate change include in particular the burning of fossil fuels, agriculture and land-use changes like deforestation. These cause emissions of carbon dioxide (CO_2), the main gas responsible for climate change, as well as of other 'greenhouse' gases. To bring climate change to a halt, global greenhouse gas emissions must be reduced significantly (IPCC, 2007).

The European Union is at the forefront of international efforts to combat climate change and has played a key role in the development of the two major treaties addressing the issue, the 1992 United Nations Framework Convention on Climate Change(http://unfccc.int/2860.php) and its Kyoto Protocol, agreed in 1997(http://unfccc.int/kyoto_protocol/items/2830.php).

Among these is the pioneering EU Emissions Trading Scheme, launched on 1 January 2005, which has become the cornerstone of EU efforts to reduce emissions cost-effectively. As part of this emission trading/carbon trading, many scientific, social and commercial activities have been launched all over the world (http://en.wikipedia.org/wiki/ Emissions trading) and there is an International Emission Trading Association (IETA), which is taking steps to commercialize and steps to curtain emissions of various green house gases (http://www.ieta.org/ieta/www/pages/index.php) and in India too, many initiatives are being taken.

1. Heat-trapping-gas emissions

Human activities produce emissions of several gases that scientists believe will

Table 1. Direct global warming potential of various green house gases wrt CO2

Constituent	Anthropogenic sources	Total global emissions in metric tons	Direct Global Warming Potential over 100 years
CO_2	Burning of fossil fuels, cement manufacture, deforestation and other land-use changes	26,073,000,000	1
Methane	Livestock, wet rice agriculture, solid waste, coal mining, oil and gas production	250,000	11
Nitrous oxide	Nylon production, nitric acid production, biomass burning, cultivated soils, automobiles with three-way catalysts	Accurate data not available	270
Chlorofluorocarbons (CFCs)	Chemical products and processes, including refrigeration, industrial solvents, blown-foam insulation	400	3400 - 7100

Sources: J.T. Houghton et al., *Climate Change 1992: The Supplementary Report to the IPCC Scientific Assessment* (New York: Cambridge University Press, 1992), 14-15; World Resources Institute, *World Resources 1994-95* (New York: Oxford

contribute to global warming. The chart below lists emissions levels for these gases, along with the human-caused emission sources. The last column of the chart lists the "direct global warming potential" of each gas — a measure the Intergovernmental Panel has devised to show "the possible warming effect on the surface-troposphere system arising from the emission of each gas relative to carbon dioxide"(Table 1.). The Table shows, for example, that the Panel concludes that each ton of methane will have 11 times the global warming impact over a hundred-year period as a ton of carbon dioxide. Even though total emissions of chlorofluorocarbons are quite small compared with emissions of carbon dioxide, their impact is significant since their global warming potential is so large. Nevertheless, carbon dioxide emissions still account for about half the total global warming potential of emissions from human sources.

2. Human activities increasing green house gases concentrations?

It is clear from all the observations and theoretical considerations that concentrations of atmospheric greenhouse gases and their radiative forcing have continued to increase as a result of human activities The atmospheric concentration of carbon dioxide (CO_2) has increased by 31% since 1750 (Fig.1.). That CO_2 is increasing is beyond doubt, and the steady increase is unquestionably due to human activity: the burning of fossil fuels. Knorr et al. estimated global CO_2 concentration by averaging the measurements made at Mauna Loa in Hawaii and those from the south pole (atmospheric concentration is expressed as "ppmv," or "parts per million by volume"):

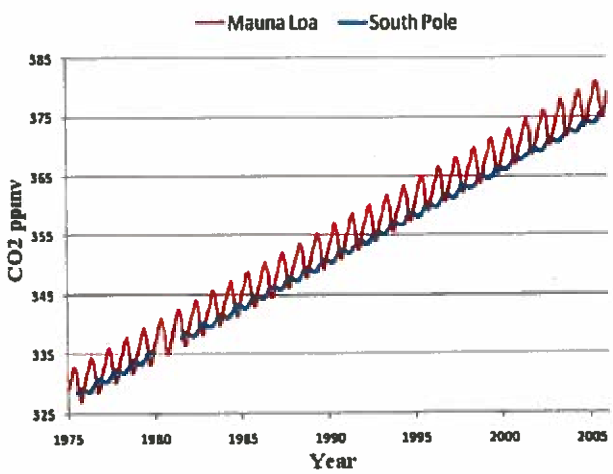

Fig. 1 For both the Mauna Loa and south pole data.

From the ice core data obtained from Antarctica, it has been found that the present CO_2 concentration has not been exceeded during the past 420,000 years and likely not during the past 20 million years (Jouzel, et al., 1996; Petit et al, 1999). The current rate of increase is unprecedented during at least the past 20,000 years (Fig. 1). About three-quarters of the anthropogenic emissions of CO_2 to the atmosphere during the past 20 years is due to fossil fuel burning.

3. Regional impacts of climate change

Complex physically-based climate models are required to provide detailed estimates of feedbacks and of regional features (Andreae et al., 2005). Such models cannot yet simulate all aspects of climate (e.g., they still cannot account fully for the observed trend in the surface-troposphere temperature difference since 1979) and there are particular uncertainties associated with clouds and their interaction with radiation and aerosols. The world's climate is not similar everywhere, therefore, the impact of climate change shall be different at different locations (Shepherd et al., 2004; Emanuel, 2005). Also, initially regions like Antarctica were thought to be isolated and perhaps stable to climate change, but strangely, the systematic increase of CO_2 at South Pole has shown that the polar regions do respond to global climatic changes and are the best places in the world to detect 'climate change'. Therefore, efforts have been made both in the Arctic and Antarctic to look for climate change signatures (Jones et al., 2001; Doran et al., 2002; Ikeda et al., 2009).

At the beginning of the expeditions and looking at the mammoth size of the continent, nobody could even imagine that this continent will show any sign of change. But, on the basis of measurements it has been found that Carbon Dioxide is increasing (Fig. 1) and is a signal of worry to the entire world community. Many explained the reasons for this CO_2 enhancement (Dieter et al., 2006) and many are advocating manmade emissions to be frozen at certain levels (Ahn and Brook, 2007).

It is believed that Antarctic ice sheet is controlling global temperature and this may have strength to counter the global change (website http://www.worldviewofglobalwarming.org/). Since CO_2 is a green house gas, mankind is worried about the global warming and to confirm some of these findings and its possible impact on various systems, many investigators all over the world are pouring their results and thoughts.

4. Ice-air-ocean interactive system of antarctica

Antarctica presents the most efficiently coupled ice-air-ocean system in the world (Naithani, 1995; Gajananda, 2002), in which the katabatic winds flowing outward of the dome shaped continent form severe cyclones over the oceans around Antarctica. These cyclones, in-turn replenish the loss of cold and charge the interior of the continent with fresh snowfall. Over the ocean, cyclones churn the ocean to mix the oxygen in the oceanic waters, promoting an extremely high rate of biological production all around Antarctica. This coupled system is also responsible for creating extremely harsh weather conditions for the support of any life forms over the continent. However, only micro flora and fauna have been able to evolve with time and survive in the extreme weather conditions, forming one of the most important subjects in Antarctica for human understanding (Gajananda, 2002, 2007). Fig. 2 shows this interactive scheme.

It is important to note that as far Antarctica is concerned, its dome shape development over the past millions of years has resulted in a unique pattern of surface air temperature. It's temperature is around 0 °C at the periphery in the local summer season and around -30 °C during local winter season. Moreover, due to absolute transparency of the atmosphere, surface based inversions are always present over the icy surfaces, leading to extreme cooling and maintenance of the icy surfaces.

Therefore, due to global warming, no noticeable impact will be noticed in the interior of the continent and it is only the periphery, where physical, chemical, biological, geological changes will be promptly noticed.

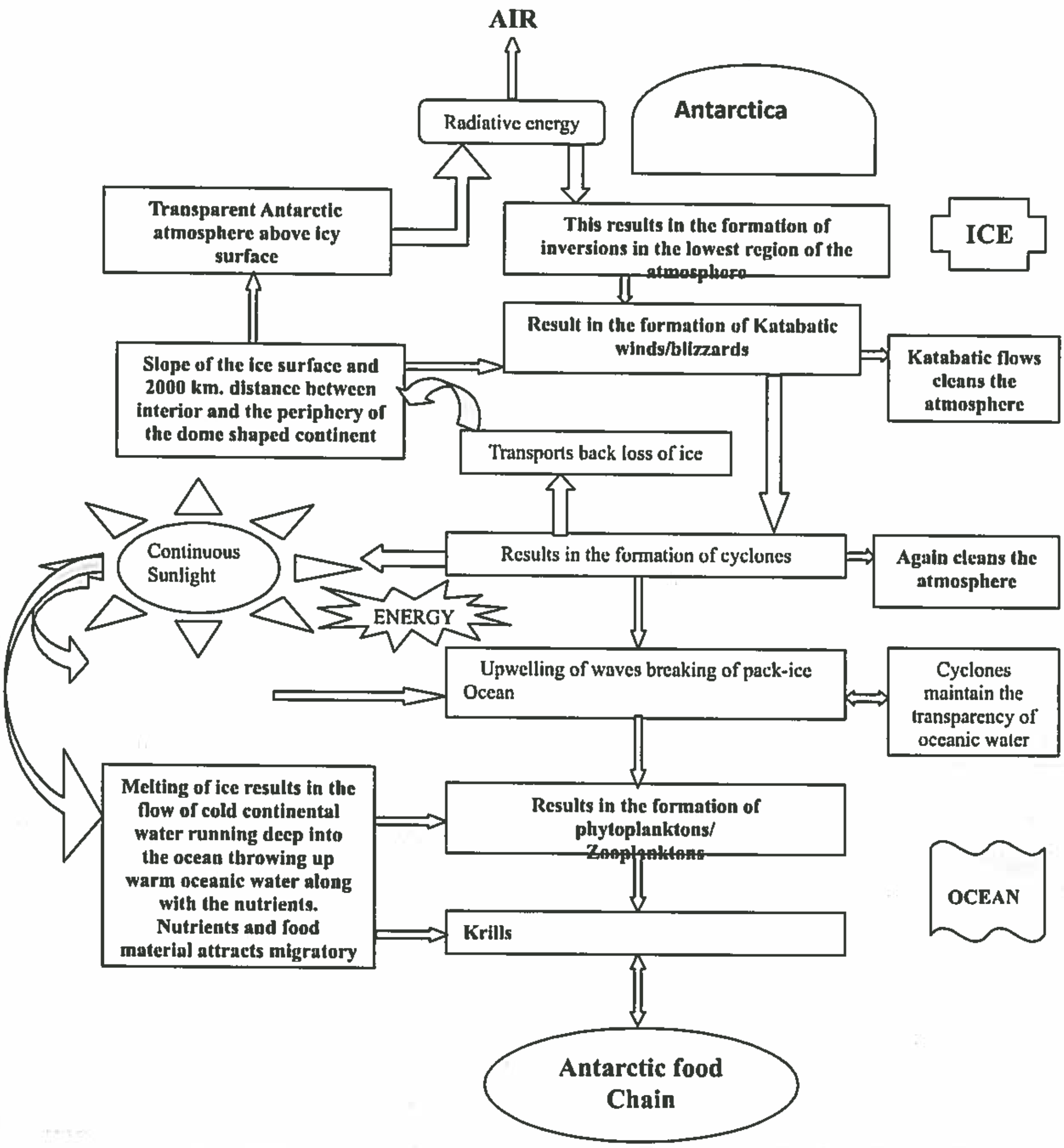

Fig. 2 Most efficiently coupled Ice-Air-Ocean Interaction System in the World. It maintains itself strongly but gets influenced by the global changes

Fortunately, the Indian Antarctic station, Maitri is situated at the periphery of the continent and it offers the best site in Antarctica to study climate change

5. The Indian Antarctic Station

The Indian Antarctic station Maitri (70.75°S; 11.73°E) and the Russian Antarctic station, Novolazarevskaya(70.81°S; 11.82°E) are situated at the periphery of the continent in a small hilly oasis known as Schirmacher oasis. Due to proximity, these two stations offer a complementary data for studying many Antarctic problems in collaborations with each other (Gajananda et al., 2007). However, it may be pointed out the Novolazarevskaya started in the year 1961, while Maitri started in 187-88.

Fig.3 shows part of the east Antarctic periphery, where the Maitri and Novolarevskaya stations have been built over the Schirmacher oasis. The Antarctic polar ice dominates the weather but in the oasis regions, local heating may add to thermal convection in local summer due to intense heating of the dry rocky surfaces (Gajananada et al., 2004) and it may also help in the development of many biological species(Gajananda, 2002; Gajananda and Dutta, 2005).

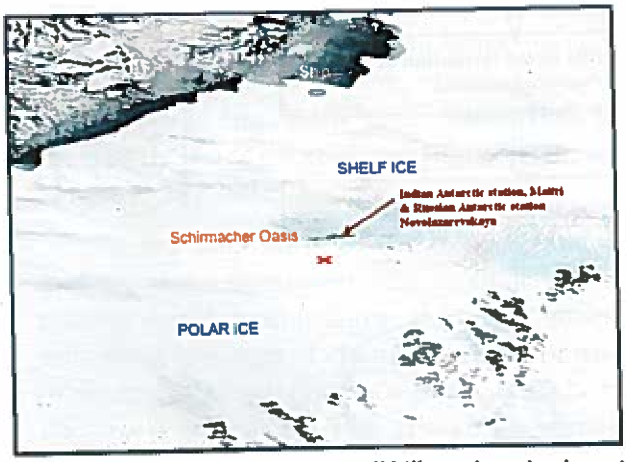

Fig. 3 The Schirmacher oasis is a small hilly oasis region in east Antarctica. Its area is only 35 sq km and is aligned in the EW direction.

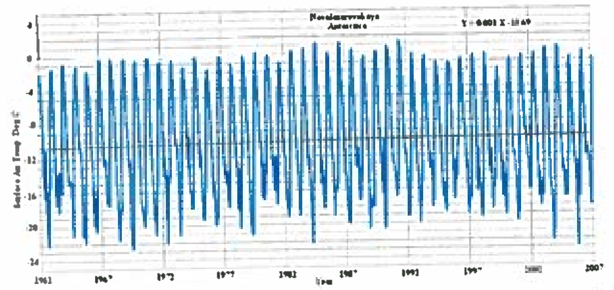

Fig. 4 Variation of surface air temperature during 1962-2007 indicating an enhancement of ~0.5°C

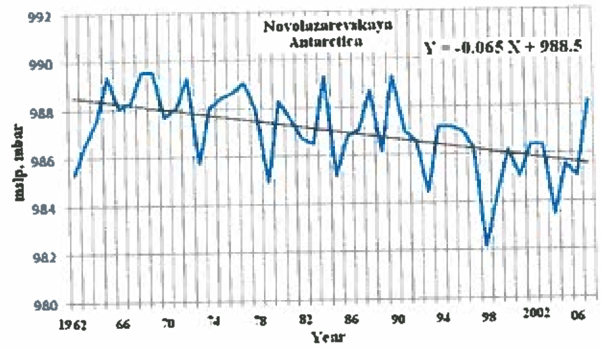

Fig. 5 Variation of mslp in the past 45 years shows that there is certainly a decrease in mslp

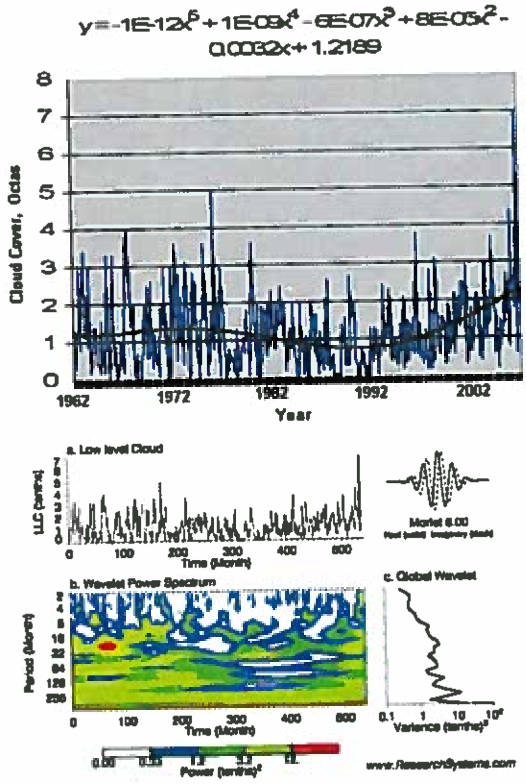

Fig. 6 The low level cloud cover is increasing and this would mean more trapping of radiated energy from the surface of Eart

6. Signatures of climate change

It is important to note that for seeking signatures of climate / global change, a long series of systematic data is a pre-requisite and therefore, Novolazarevskaya data has been utilized to understand the various impacts. Fig. 4 shows that the surface air temperature has rises in the past 45 years by about 0.5°C. But, if we look at the mslp (Fig. 5), it has certainly lowered by 3 mbars. A decrease of 3 mbars would mean enhancement of clouds (Fig. 6), which is evident. These figures indicate that the periphery of Antarctica is certainly under the influence of climate change.

7. Biological precursor: A new finding

In Antarctica, only oases regions situated at the periphery of the continent, get deglaciated during local summer and therefore present the most favorable conditions for the survival, growth and function of the micro flora and fauna in the otherwise harsh climatic conditions. Virtually no higher plant life form exists on the Antarctic continent. However, minute organisms survive in small pockets of ice-free areas (Hopkins et al., 2008; Gajananda et al., 2004; Gajananda and Dutta, 2005). Algae, lichens and mosses are the only poikilohydric microbiotic crusts inhabiting the continent (Gajananda, 2007). In the driest and coldest habitats, especially where fog and dew are the major water sources, desiccation-tolerant algae or cyanobacteria, bryophytes and lichens may form the only vegetation (Alpert 2005). The Schirmacher oasis is covered by snow/ ice during the winter (June–August) and spring (September–November) seasons. In summer (November–February) season, the region becomes deglaciated, thereby exposing the rocky moraine surrounded by the polar ice cap and ice shelf (Gajananda et al., 2004). It has a range of virtually barren and rocky low-lying hills, which provide a habitat only for the cold-hardy microbiota (algae, lichens, mosses, midges, mites and tardigrades) that thrive in harsh cold desert, dry permafrost polar region, generally known as 'oasis'.

About 30 freshwater lakes (large, small, shallow lakes) and many thaw streams exist during local summer season in the oasis. Most of these lake banks are covered with thick, dark moss carpets. Lichens are observed mostly on the rocky surface, away from the lakes. The soils of this region have significant organic carbon, low humus content and low microbial activity, which is common in Antarctica (Gajananda, 2007). Also, during local summer, the availability of 24-hour sunlight and the melted water from the local snowfall offer favorable conditions for the growth of such micro flora and fauna (Gajananada, 2002, 2004; 2007).

It may be pertinent to note that the deglaciation of the east Antarctic oasis might have started very rapidly close to the Pleistocene/Holocene boundary, probably favored by both a marine transgression, sea level falls and climatic warming (Bernd and Bernd, 2006). Antarctic continental soils are arid and saline (Gajananda, 2007; Phoebe and Wilfried, 2008), whereas maritime soils, in wetter environment, range from structure-less lithosols to frozen peat (Lewis Smith, 1994,). Two important factors in the development and diversity of terrestrial communities are water availability and the period of exposure since deglaciation. Moreover, the cyclones from the periphery carry almost all the micro materials and deposit them over the continent along with the snowfall (Lambert et al., 2008).

On the other hand, the micro-climate over the oasis regions is changing fast and is evident from the fact that the area of the deglaciated region is increasing and if by chance, some seed falls from the entire material that is carried to Antarctica, the soil has become so conducive that it supports the germination. This situated has been witnessed over the Schirmacher oasis

Fig. 7: The first plant ever seen growing naturally over the rocky soil of the Schirmacher oasis. It indicates favorable conditions developing for the growth of higher-level plants over the Schirmacher oasis. It is the first direct sign of global warming over the east Antarctic region.

during 2007, when a plant was sighted over the oasis (Fig. 7).

These results show that there is an impact of climate change at the periphery of Antarctica and the solution to mitigate these impacts still lies in the hands of mankind. We have to be united at the world level to curb certain emissions to save the most precious gift of nature-the mother Earth and its climate for our own survival.

Acknowledgement

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GLOBAL WARMING AND COLDWATER FISHERIES

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Global warming is the increase in the average temperature of the earths near surface air, inland waters and ocean in recent decades and its projected continuation. The average air temperature near the earth surface has increased by 0.74 ±0.18°C during the past century. The atmosphere around the earth is made up of Nitrogen (78%), Oxygen (21%), Carbon dioxide (0.037%), Water vapour, Methane, Nitrous Oxide, Ozone, Fluorinated gases (Sulpher Hexa fluoride), Chloro Fluro Carbon (CFC), Hydro Fluro Carbon (HFC), Per-Fluro-Carbon (PFC), also known as the Green House Gases (GHG's).

The climate & its changes

The Director general, ICAR, Dr. Mangala Rai (2007) explained the climate of a place usually includes the rainfall, sunshine, wind, humidity and temperature, which is dynamic and keeps changing but the changes take long time to get noticed. However, the rapid pace at which the climate changes in the recent years have occurred, it is definitely a matter of great concern. Global atmospheric concentrations of the green house gases have increased markedly with the industrial resolution. The global increase in carbon dioxide concentration, which is responsible for global warming, is primarily due to fossil fuel use and land use change, while increase in methane and nitrous oxide is due to agriculture. Other reason of warming being solar variation, volcanic eruptions, forest fire, urbanization, excessive air conditioning, damage to ozone larger, injudicious use of power and electricity, indiscriminate use of green house gases and deforestation etc. As a result we have been experiencing global warming.

The climate models suggested by the intergovernmental panel on climate change (IPCC) projected that global surface temperature are likely to increase by 1.1 to 6.4°C between 1990 and 2100. Data shows that eleven of the last twelve years rank among the 11 warmest years since 1850. The mean earth temperature has changed by 0.74°C between 1906 and 2005. The projected temperature increase by the end of the century is likely to be in the range of 2.0 to 4.5°C with the best estimate of about 3.0°C and is very unlikely to be less than 1.5°C. Increase in atmospheric temperature affects global hydrological cycle. As a result, it is likely that there would be change in rainfall, evaporation and run off affecting life and life forms, as explained by Dr Dilip Kumar in a lecture in 2008.

While the pre-industrial value of carbon dioxide was about 280 ppm, it has been recorded as 379 ppm in 2005. The increase in GHG's was 70% between 1970 and 2004. While the deleterious affects of Global Warming is many fold, it can be summarized below:

Affects on natural environment

It would cause ice shelf disruption, level of sea would rise endangering even countries, change rainfall pattern as seen in 2007 over the southern states and Maharashtra killing over

200 human lives in India. Increased intensity & frequency of extreme weather events may even change the mountain peaks.

Affects on human life

The calamity would involve increased susceptibility to diseases, probable spread of diseases, habitat destruction due to floods and natural calamities etc.

Economic Losses

An estimate indicate that extreme weather might reduce global domestic product by 1% and in worst case scenario the global per capital consumption may even fall up to 20% or so.

Mitigation Strategies

The mitigation strategies at International level may involve appropriate policy making, implementation of policies, keeping watch on standards including periodic reviews. The strategies may involve reduction of energy use per person, shifting from carbon-based fossil fuel to alternative energy sources, carbon capture and storage, geo-engineering planning and building design etc.

National Level

The mitigation at national level may include policymaking, setting up of regulatory body and ensuring implementation.

Regional and Local level

Regional and local level demands implementation of national policy and initiation of public awareness programmes. Individual level needs domestic management primarily. The strategies in these regards may include adoption of electrical & hybrid automobiles, alternative energy sources, carbon capture & storage, screening but sunlight, population control, and nano-technology etc.

Manipulation of GHG's through carbon registration, reduction of methane etc, is worth attempting.

Impact on Agriculture

The agriculture sector (Ministry of Environment & Forest, 1994) contributes 28% of the total GHG emission from India. A globally warm environment would lead to increased emissions of nitrous oxide and other GHG's. Increased temperature would lead to higher emissions even at the current level of fertilizer consumption, the report observed.

The climate changes could considerably affect, as per Dr. Mangala Rai, DG, ICAR (2007) the food supply and access through their direct and indirect effects on crops, soil, livestock, fisheries and pests. In general, increase in temperature can reduce crop rotation, increase crop respiration rates, effect the equilibrium between crops and pests hasten nutrient mineralization in soil, decrease fertilizer use efficiency, increase evaporation, affect fisheries directly and indirectly. Increase in temperature leads to higher distress in animal & also reduces feed and fodder availability uncertainty in precipitation would cause droughts and floods causing famines rural poverty and migration.

There may be impact on agricultural land use indirectly due to snow melt, availability of water for irrigation, frequency and intensity of inter and intra seasonal droughts and floods, soil organic matter transformations, soil erosion, soil biota decline in arable areas due to likely submergence of coastal lands and availability of energy.

Increasing glacier melt in Himalayas will adversely affect availability of irrigation especially in the Indo-Genetic plains, which in turn will have serious consequences on our food production, Dr. Rai further commented.

Probable affects on Fish Fisheries and Aquaculture

Fishes, being poikilothermic aquatic animal, are sensitive to temperature fluctuations and habitat alterations. The increase in temperature would hasten nutrient mineralisation, decrease fertilizer use efficiency. Probable increased evaporation would decrease water depth making fish life uncomfortable or even fatal in extreme cases. Higher temperature may hamper natural fish food production and their feeding rates, affect adversely, the breeding environment leading to breeding failures in extreme cases.

Warming of water temperature at the upland areas may make the coldwater fishes uncomfortable including feeding and reproductive failures and compel them to adapt to the changing environment or get extinct. The warm waters getting uncomfortably warmer may compel the fishes to migrate upstream, adapt for life processes to continue or else to get perished.

Floods would adversely affect the fish habitats and similarly the droughts may even perish the fishes of all ecosystems. Global warming would definitely cause behavioral change in fishes and in many cases altering the normal distribution.

Pathogens are strongly dependent upon temperature and humidity and so increase in these parameters will change their population dynamics with possible impact on the host-pathogen-pest relationship causing disease vulnerability.

Temperature influencing fish reproduction

Temperature has been reported as one of the dominant factors influencing the reproductive cycle of fishes. While rapid and high fluctuations will definitely be detrimental to fish reproduction, but temperature increase to the comfortable limits may be useful as well. Maturation process of gonad of carps commences during February-March when the temperature gradually increases and completes prior to onset of monsoon in May-June. The environmental factors stimulate the endocrine gland, which helps in the maturation of gonads of carps (Bhowmick, 2002). The grass carp matures in 2 years in India but it takes more than 6 years to mature in cold temperatures of Russia. Another example is Gold Fish, which could be spawned at least 3 month before the normal spawning season by manipulation of water temperature.

Water temperature rise to a reasonable limit during winter months at the cold places like northern part of India would enhance fish growth including gonadal maturation. In Sri Lanka, temperatures are steady throughout the year in absence of winter, ranging from 24 to 32^{0}C. With 2 monsoons like our southern India, the reproductive physiology of Indian major carps got changed accordingly and they attain gonadal maturity, throughout the year and could be regularly induced to breed during 2 monsoons covering almost 12 months (Bhowmick, 2002)

Rainfall affecting fisheries

The global warming may cause change in rainfall pattern to the detriment of fishes and fisheries by altering the habitats as mentioned earlier. But little higher rainfall may be advantageous to fish breeding as observed in Bundh type of Tanks of W. Bengal, A. P. and M.P. The heavy rainfall brings chemical changes in the natural habitats, rivers in respect of temperature, oxygen, pH and other essential parameters turning the habitat in to a conducive one for successful fish breeding. The northern part of India also would derive benefits in fish spawning with higher rainfall but up to optimum limit.

Threat to Genetic of the Fish

The extreme and prolonged natural threats of the Global Warming, coupled with anthropogenic, stresses, would affect ultimately the genetic thresholds of the fish to the detriment of fish germplasm, devastating fisheries and aquaculture.

Need for Conservation

However, the apprehended high increasing sea and inland water temperatures is likely to affect fish feeding, breeding, migration and consequently, the harvest. Coral reefs in the Indian seas are predicted to decline from 2040.

The global warming, complete with the on going anthropogenic stresses on the fish habitats and the fish genetic resources, are likely to hasten species extinction unless appropriate conservation efforts are taken on time.

Research needs for perpetuating fish and fisheries

The possible affects and mitigation of Global Warming on Fish and Fisheries are anticipatory as yet. Though some research has been initiated at the fishery sector of ICAR, it is high time to intensify and strengthen the research in this direction in general and regarding mitigation strategies in particular. Besides mitigation strategies, more efforts would be required in adaptation research. The fish will have to be genetically architectured to adapt to changing climatic conditions and survive in this wonderful world of ours.

Coldwater Fish Genetic Resources: Issues of Habitat Degradation, Climate Change and Biodiversity

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Introduction

India has very rich aquatic biodiversity spread across different ecosystems. The upland Himalayan ecosystem is a kaleidoscope of diverse topography, climate, resources, traditional knowledge and ecology. The coldwater aquatic habitat is characterized by high gradient, high altitude, high transparency, high level of dissolved oxygen, low temperature, rocky substrate and low organic content. In the upland ecosystem coldwater fish genetic resources play an important role in the food and nutritional security of the people dwelling in the mountainous zones of the country and also in the upliftment of the socioeconomic life. In upland streams and rivers, the main factors which exert influence on the occurrence and distribution of fish are; temperature, substrate, water flow, gradient and type of microhabitat (pool, riffle, run, rapid etc). However, these habitats are threatened by many threats and as a result, the fish diversity is declining sharply in coldwater ecosystems. According to UNESCO (2003), freshwater biodiversity has declined faster than either terrestrial or marine biodiversity over the past 30 years. Therefore, conservation of freshwater fish germplasm resources should be given priority taking into consideration the distinct, diverse and fragile nature of aquatic habitat types. Many problems related to freshwater fish biodiversity and conservation has been reported by several authors (Lakra et al 2007, Sarkar et al 2008). The fisheries of the entire Himalayan region, in contrast to warm water fishes are considered to be poorly developed primarily due to difficult terrain and its inaccessibility. The present paper synthesizes various issues, knowledge gaps, strategies and implications with reference to climatic changes on coldwater fisheries and the role of scientific interventions for conservation and management.

Coldwater Resource Potential of India

The water resources located above 914 m asl are generally known as coldwaters. The temperature limits of the water vary from 9 – 25^0 C .The estimated approximate area holding cold water fisheries includes 10000 Km streams/rivers, 20000 ha natural lakes, 50000 ha reservoirs and 2500 ha brackish water lakes and impoundments (Sunder and Joshi, 2002). The Greater, lesser Himalayas and Siwalik mountains in the north are traversed by the Indus, Ganga, Brahmaputra and their numerous tributaries Nineteen major rivers drain the Himalayas of which the Indus and Brahmaputra are the largest each having a mountain catchments of about 160000 km^2. Among the rest of seventeen five rivers belong to the Indus system (Jhelum, Beas, Sutlej, Chinab and Ravi) of which Beas and Sutlej have a total catchment area of about 80000 km, nine (Gana, Yamuna, Ramganga, Sarda, Karnali, Kosi, Rapti, Gandak and Bagmati) belong to the Ganga system draining nearly 150000 km^2 and three (Tista, Raidak and Manas) belong to

Brahamaputra system draining another 110000 km^2 (Sehgal, 1999).

The Sahyadri, Nilgri, Annamalai, and Cardmom hills in the Western Ghats also harbour many tributaries of the Krishna and Couvery rivers. Important upland lakes are Wular and Dal in Kashmir; Nanital, Sattal, Bhimtal, Naukuchiatal in Uttarakhand; Ooty and Kodai lakes in Western Ghats. Amongst the fully formed reservoirs in Himalayas, the Gobindsagar and Pong are important. Apart from these a number of dams and barrages are under construction in Jammu and Kashmir, Himachal Pradesh, Uttarakhand and North Eastern States. Such diverse aquatic resources harbour numerous fish species.

Genetic Resources

The upland waters of the country are famous for its most prized game fishes like mahseers, snow trout and Indian trout. The major coldwater fishes are belongs to six different family including Cyprinidae, Cobitiidae, Salmonidae, Sisoridae, Psilorhynchidae and Homalopteridae (Kumar, 1996). Sehgal (1999) had listed 241 species from different coldwaters of this country while Sunder et al.(1999) has reported 258 fish species belonging to 21 families and 76 genera of which 203 are from Himalaya and 91 from the Decan plateau. NBFGR, Lucknow has validated 157 species as coldwater fish (Ayyappan et al 2007). Some of the important coldwater species having food, ornamental and conservation value are ; *Tor tor, Tor putitora, T. mosal, T. progeneius, T. khudree, T. mussullah, T. chillinoides, Neiolissochielus hexagonolepis, Schizothoraichthys progastus, S. esocinus, S. longipinnis, Schizothorax richardsonii, S. kumaonensis, Barilius bendelisis, B. vagra, B. shacra, B. (Raiamas) bola, Bangana dero, L. dyocheilus, Crossocheilus diplochilus, Garra gotyla gotyla, Glyptosternum pectinopterus* and *G. stoliczkae.*

Conservation Status

Distinctly threatened species are characteristically those fish belong to very defined taxonomic units of restricted geographic range, and appears to be particularly sensitive to one or more human threats and those populations or range which have undergone a significant decline and seems likely to continue. While no coldwater fish species have so far been listed as threatened except *Schistura sijunensis*(endemic to Garo hills, Meghalaya) by the World Conservation Union Red Data Book, the following species have been listed as endangered (EN) by NBFGR due to their reduced abundance. These are *Tor putitora, T. tor, T. mosal, Schizothoraichthys labiatus, Semiplotus modestus, Glyptothorax kashmirensis, Glyptothorax garhwali, Aborichthys elongates, A garoensis, Barilius dogarsinghi, Botia almorhae etc.* One species *Gymnocypris biswasi,* has not been reported after its original discovery and has been enlisted as Extinct (EX).

Threats to Coldwater Aquatic Biodiversity

Throughout the world, all aquatic environments are experiencing serious threats to both biodiversity and ecosystem stability and many strategies and priorities have been proposed to solve this crisis (Suski 2006, Sarkar et al 2008). Any loss of genetic variation results in erosion of evolutionary flexibility in the adaptation to changing environment and risk of extinction. The environmental threats could be man made and natural or in combination with cascading and interlinked impacts. Such threats are wide ranging including overexploitation of resource, habitat alterations, reduction of natural habitat area, construction of dams, diversion or reclamation of river beds for urbanization, that reduce water discharge in rivers, unsustainable fishing, introduction of non native species and global climatic variations etc. Kottelat and Whitten (1996) considered the biological change that environmental degradation brings about, and enumerated pollution, increased sedimentation, flow alteration and water diversion, and introduced species as the main causes for decreased ichthyofaunal diversity in Asian countries. In hillstreams, the present trend of decline of fish is primarily due to interference of several factors.

Ecological Stresses

Habitat destruction and alterations in ecological conditions of aquatic resources cause decline in fish germplasm resources. Deforestation and over-grazing activities along sloppy catchments erode soil structure and cause decline in fish germplasm resources. Siltation from catchment areas of major upland rivers has destructed breeding and feeding grounds of many fishes. Construction of dams and barrages hampers spawning migration of mahseers. As a result of the increasing demand of water for irrigation, drinking and industrial purposes, excessive withdrawal from the river courses leaving inadequate water for comfortable fish life is another problem. Pesticide washing from agricultural fields have also been creating detrimental environment for fish life in many water bodies. The existing hydroelectric projects have also adversely the abundance and distribution of coldwater fishes. The activities pertaining to the projects under construction are responsible for increase in the silt load and destruction of fish food organisms due to loss of ecological integrity.

Exotic Species

Uncontrolled introduction of exotic fishes also exterminated the indigenous fishes in some ecosystems. Common carp introduced into Kashmir valley has almost exterminated the native Schizothoracine fishes in the Kashmir valley. In the Gobindsagar reservoir Indian major carps, especially catla, has already been replaced by the exotic silver carp. The introduction of trouts in almost a virgin niche at high altitude coldwater streams has, however, remained encouraging.

Over-exploitation

Over-exploitation of fishery due to high prices of fish has drastically declined some prized fishes in different ecosystems. Wanton killing by the use of dynamiting and poisoning has affected a number of upland fishes. Victim species of such destructive devices are *Tor putitora, T. tor, Schizothorax* spp., *Labeo dero, L. dyocheilus* and *Barilius bola*. The use of bleaching powder and even fish toxicants eradicates all the biotic components of the effected waters.

Climate Change

Climate change that is linked to a build up of greenhouse gases and aerosols in the atmosphere is now a widely accepted phenomenon, with the International Panel on Climate Change stating with very high confidence(90%) that the net effect of human activities since 1750, has been one of warming (Alley et al 2007). There is still much debate, however, about the extent of climatic change and its effects on fish and aquatic ecosystem (Kennedy 1990). Ecosystems are dynamic and undergo change as a function of time to response to a variety of stressors, including climate. Global climate change is likely to result in severe droughts and floods with major impact on human health and food supplies, according to the India's report to the United Nations Framework Convention on Climatic Change. The impact of climate change on fish population will result from both biological and abiotic change, as well as shifts in the man-made environment. For coldwater fisheries, changes in water temperature, species distribution and habitat quality are the main direct impacts expected to result from climate change. Changes to water temperature, water levels, extreme events, and climate driven shifts in predator and prey abundances will all impact fish community. However, the limited understanding of the mechanisms controlling the behavioural response of fish to climate, limitations in data to account for the delayed impacts of environmental variability reduce the ability to project net impacts at the moment. The impact of these stresses lead to decline in effective population sizes over a period of time, depending upon original population size and magnitude of the threat. Therefore, research is being perused globally to develop systematic conservation planning to protect aquatic biodiversity (Saunders et al., 2002, Nel et al., 2008; Moilanen et al., 2008).

Climatic factors, such as air and water temperature, and precipitation and wind patterns, strongly influence aquatic genetic resources. Changes such as those associated with a 1.4–5.8°C increase in global temperature, as have been projected by the Intergovernmental Panel on Climate Change (IPCC) for the current century could have significant impacts on fish populations (Albritton and Filho, 2001). This is because most fish species have a distinct set of environmental conditions under which they experience optimal growth, reproduction and survival. If these conditions change in response to a changing climate, fish could be impacted both directly and indirectly. Some potential impacts include shifts in species distributions, reduced or enhanced growth, increased competition from exotic species, greater susceptibility to disease and/or parasites, and altered ecosystem function. These changes could eliminate species from all or part of their present ranges and would affect sustainable harvests of fish.

Potential Impact of Climate Change

There is ample evidence that recent climate changes have affected a broad range of organisms with diverse geographical distributions. Temperature plays a significant role in influencing biogeographic distributions and will affect cold tolerant species move from equator ward edge of their ranges may retreat towards the pole. Increasing water temperature have been associated with increased biological demand and decreased dissolved oxygen, without changes in flow. It is presumed that changing climate in Indian rivers will have implications for sustainable harvests, fishing practices and subsistence fisheries. In rivers and streams water flow can influence water chemistry, habitat, population dynamics and water temperature. It is reported that higher temperature will affect different fish species in different ways. The magnitude of potential temperature changes in freshwater sites significantly greater than that of marine environments. Fishes are commonly divided in to three guilds (cold, cool and warm water), based on the optimal thermal habitats around which their thermal niche is centered. Rising in temperature in rivers, lakes and oceans means less food and less oxygen for fish populations.

Climate change is likely to produce profound modifications to the structure and functioning of the aquatic ecosystem and has the potential to affect freshwater ecosystem use by fishes through habitat alteration and will result changes in the distribution and abundance of species (James et al. 2008).Water quality changes will have impact on fishes in terms of change in concentration of ions, dissolved gases and organic materials. Changes in monsoon rains due to climate change, affects reproduction and recruitment of fish species and their fisheries might be put at risk by precipitation modifications. Changes in food availability, species specific differences in thermal tolerance and disease susceptibility and shifts in the competitive advantage of species will alter species assemblages, distribution and migration. As per recent report, reduction in river discharge due to combined effect of climate change and water withdrawal will make the up to 75% global freshwater fish biodiversity to become extinct by 2070 (Marguerite et al., 2005). It is expected that poorer countries will have more impact than rich countries, as people mainly rely on indigenous fish for food. Recent studies of NBFGR, Lucknow (unpublished data) indicated biogeographical shifting of some warm water fish species (*Cirrhinus reba, Macrognathus aral*) in the upper Ganga river stretch upto Haridwar which might be caused due to effect of climatic and other environmental factors. High altitude or cold tolerant species may be intolerant of increased temperature, so the equatorward edge of their ranges may retreat towards the poles. Many studies of species abundance and distribution corroborate predicted systematic shifts related to changes in climatic regimes, often via species specific physiological thresholds of temperature and precipitation tolerance.Therefore, research is required to link available biological and ecological information on the impacts of climate change to water resource and the immediate priority should be to conduct studies of closely linked species, ecosystems and fisheries that have data and information rich Climate Variation and Changes (CVS) response in cold water ecosystem.

International Status

A substantial number of observational and experimental studies have generated evidences that the 0.6°C warming in average global temperature during the 20th century has already affected physical and biological process (Fraser 2004). While it is broadly acknowledged that changes in the climate have the potential to impact fish population, relatively few studies have addressed this issue in the developing countries. It is well documented that global warming is causing the world's waters to heat up while rainfall patterns and sea levels are changing (WWF 2007) and therefore fishes are increasingly threatened by climatic change (Walther et al. 2002). It has been reported that warm water fish sturgeon and bass, generally benefit from increased water temperature, whereas cold-water fish like trout and salmon tend to suffer. Even a 2°C increase in water temperature reduced the growth rate (Ojanguren et al. 2001), (King 1999), survival (Reid et al. 1997) and reproductive success (Vanwinkle et al. 1997) of rainbow trout. Temperature extremes, high winds, extreme precipitation and storm events have all been shown to impact the growth, reproduction and metabolism of fish species. Increase in the intensity or frequency of such events as a result of climate change could substantially increase fish mortality in some lakes. Climate change would also result in shifts in the distribution of fish species. It has been recorded that the warming associated with a doubling of atmospheric CO_2 could cause the zoogeographical boundary for freshwater fish species to move northward by 500 to 600 kilometers, assuming that fish are able to adopt successfully. Such changes in species distribution would affect the sustainable harvests of fish in rivers and lakes. It is also expected that warmwater fish will migrate to regions currently occupied by cool and coldwater fish.

Studies indicate that climate change will alter annual and seasonal precipitation patterns, which is expected to affect lake water levels and stream flow. Climate change also effects on water levels. Lower water levels in the Great lakes, resulting from increased evaporation and shifts in surface-water and groundwater flow patterns, would threaten shoreline wetlands that provide vital fish habitat and fish nursery grounds. The lower water levels would expose new substrate, may facilitate the invasion of exotic and/or aggressive aquatic plant species. Global warming has also significantly reduced overall phytoplankton numbers as reported by Charlson (1987) and Kennedy (1990). A relationship between temperature and adaptation at the population genetic level has been reported by Mathews and Zimmerman (1990). Mitton and Lewis (1989) reported a relationship between less stable environments and genetic variation.

The climate change is expected to alter the regions of suitable habitat for coldwater fish, both within drainage basins and in the lakes. This could changes thermal stratification and these, in turn, alter the dominant species and potentially cause the extirpation of certain fish species. A large number of studies show that climatic factors, including temperature and drought, are important controls on water acidity and a wide range of biological and geochemical processes. Higher water temperature has been shown to increase microbiological activity, which enhances the release of metals from the substrate to the water. As fish tend to be well adapted to a certain range of environmental conditions, shifts in any of these factors could cause stress and higher mortality rates in certain fish species.

Management Issues

1. Identification of major drainages using maps/data
2. Preparation of base maps with the help of these data to locate water bodies. Documentation of different types of land uses and types of human interference can be carried out using this data.
3. Effect of changing climate on fish species of fishery, recreational and biodiversity can be studied by recording of annual and seasonal thermal regimes (both ambient and aquatic) and major habitat parameters. multitemporal data can be used to detect seasonal changes in water spread area, which may alter the habitat characteristics in different seasons.
4. Assessment of the fish species with restricted distribution in the designated areas.
5. Estimation of Critical Thermal Maximum (CTM) to understand the ability of fish species to survive environmental extremes.
6. Studies on the adaptability, changes in growth and reproductive traits of selected fish species under *in-situ* and *ex-situ* condition.
7. Development of heat tolerant genotypes using biotechnological tools.
8. Intensify research efforts search for genes for stress tolerance across plant and animal kingdom.
9. Develop new coldwater aquaculture for climate change scenarios

Interventions

Uncertainties concerning the impacts of climatic change on Indian fisheries and potential adaptation options are many. Cold water ecosystem are extremely diverse and complex and future research is needed to improve understanding of both the underline process affecting fish biodersity, distribution and abundance and their response to climate change. Some of the important interventions include the following;

- Improved monitoring and prediction of the impacts of climate change on species and freshwater ecosystems
- Investigations in to the best methods to increase the resilience of hillstream fishery systems and improve their ability to respond the change

- Research targeted to assist the development of policies and programs that will help hill communities deal with potential fish expansions and contractions
- Studies that address the socio economic consequences of climate change and fisheries

Conclusion

Cold water fish and other aquatic species are sensitive to environmental conditions and respond to changes in air and water temperature, precipitation, water circulation, and other climatically controlled factors. We can expect to see many changes in species distribution, fish growth, reproductive traits, the susceptibility of fish to diseases and competitive interactions between species. As a result sustainable harvest of fish will be impact. However, isolating the impact of climate changes from other stresses affecting coldwater and hillstream fisheries is difficult. Given present uncertainties about the nature of future climate changes, emphasis should be placed on management and conservation activities that promote resources sustainability and habitat preservation, and help to ensure a range of healthy sub-populations of fish species over wide areas. Improving the accessibility and availability of information through increased research and communication, and enhancing the flexibility and resilience of the sector are also important components of addressing climate changes.

The significant impacts of climate change on freshwater ecosystem indicate that future climatic variation will impact Indian fisheries. Therefore, baseline information needs to be generated on the anticipated effects of changing climate on coldwater fish species, fragile hilly aquatic habitats, the shifting pattern of species and distribution from warm water zones to coldwater habitat. The impact on critical life history stages of coldwater fishes should be ascertained from the multilocation data as well as experimental observation. Based on the current information on major aquatic habitat variables like concentration of ions, dissolved gases of the selected rivers/ streams/ lakes predictive models may be developed. This will certainly help in decision-making process for the biodiversity managers for conservation strategies of the fish species, which may require immediate and enhanced protection. Effective adaptive measures to be taken up for species at risk for sustainable utilization of native cold water fish genetic resources.

ICAR has already established a network project with the involvement of 15 institutions and SAU's for critical research on crops, livestocks and fisheries. NAIP (National Agricultural Innovative Project) has also identified climate change as a thrust area. A multidisciplinary expert group should be constituted for increased capacity and expanding initiatives for undertaking research in coldwater ecosystem. There is also need to intensify efforts for increasing climate literacy among all stakeholders as well as farmers.

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INTEGRATED WATER RESOURCES MANAGEMENT IN RIVERS IN THE CONTEXT OF FISHERIES

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Rivers in India

Harmony between man and nature is the essence of India's religio-cultural ethos and thus, the rivers in the country have been venerated and worshiped since Vedic times. Among them, Ganga, the presiding river, is not only the lifeline of the country's economy, but it is also considered as the cultural mainstream, epitomizing a supreme symbol of purity. But ironically, the very same Ganga and many other rivers in India are subjected to desecration of the worst order, causing concern among all the right thinking people across the country. Apart from receiving untreated sewage and a variety of industrial and agricultural wastes, the riverine environment is subjected to a number of man-made changes in the hydrodynamics and the physiography, that have far-reaching ecological implications. Environmental degradation in the riverine ecosystem is a universal phenomenon, which, if left uncontrolled, can upset the natural balance and threaten the very survival of human race on this planet.

A large number of rivers, small and big, with their ramifying tributaries cascade down the various hill ranges of India. The river systems of the country comprise 14 major rivers, each draining a catchment of 20,000 km^2 or more, 44 medium rivers having an average catchment between 2,000 and 20,000 km^2 and innumerable small rivers and desert streams that have an average drainage of less than 2,000 km^2. The combined linear length of all the rivers in the country along with their tributaries and distributaries is estimated at 45,000 km, which carry 6% of the total drainage of the surface of the globe.

Biological impact of environmental perturbations in the riverine ecosystem

Basin modifications due to anthropogenic reasons and their ill effects on the riverine environment are well chronicled, especially from public health, aesthetic and economic angles. But the studies conducted so far invariably lack a fisheries perspective. The man-induced environmental stresses in the riverine ecosystem, having a direct bearing on the biological production functions, can be broadly grouped into five major categories *viz.*, water abstraction, sedimentation, river training, dams, and effluxion.

Water abstraction

Large-scale diversion of water for off-stream purposes and the resultant diminutive flow in the main channel pose serious threat to the stability of local communities in many river basins of the world. Environmental changes associated with water abstraction manifest themselves through velocity, depth, width of the channel and the solid transport, each of them having its own impact on the riverine biotic communities. The most important among the abiotic factors influenced by the flow regime is the velocity. The fluviatile biocoenos are highly oriented to currents of water. A fall in velocity may physiologically upset the communities specially adapted for the rapids, which may give way to populations adapted for lesser velocities (like the ones living in the marginal pools).

Discharge rate plays a vital role in the dilution of contaminants thereby ameliorating the hazards of pollution as a reduced flow can aggravate the situation in the affected stretches. In many advanced countries, flow augmentation has been used as a tool to mitigate problems related to water pollution.

One of the direct impacts on fish populations stems from the fact that lotic environment is a specialized habitat, the inhabitants of which are geared to centuries of evolutionary adjustments to the seasonal variations of their flowing water environment. Many riverine fishes have a preference for particular velocities and any man-made changes in the stream flow regime can upset the physiological rhythm of fishes. Many fish populations are dependent upon annual flooding for food and spawning. Stream-flow rate has a direct impact on the migratory habits of fishes. Discharge can cause migration to commence, create barriers at high or low flows, cause delays, disrupt normal routing and change the speed of travel. In many cases, it is the nuances in discharge rates that trigger the migratory instincts.

Sedimentation

The catchment of Indian rivers is characterized by a prolonged dry season followed by a turbulent monsoon and flood discharge, causing high rate of natural sedimentation. This sedimentation rate is further accelerated by the removal of vegetative cover of the catchment area and the subsequent erosion of topsoil in almost all the rivers and their tributaries. Erosion of topsoil in the catchment area is the main man-made factor that leads to increased sediment load in rivers. Vegetative cover on the slopes acts as an adherent of topsoil during the surface runoff. Removal of forest cover in the slopes for logging, cattle grazing, road making or for human settlements makes the soil susceptible to erosion, leading to increased sediment load in the river. Rivers in the world are known to carry as much as 3 billion t of material in solution and 10 billion t of sediment every year. Sediment load of different rives are shown in Table 2.

River training

The main purpose of river training is to allow the movement of bed and suspended load without damaging the banks. Protection of banks becomes necessary to control floods, to safeguard towns, roads, railways, *etc.*, and to facilitate navigation. The most common river training devices are the guide banks, spurs (groynes) and river revetments. The spurs are essentially the devices to nudge the stream flow to a desired channel, whereas the river revetments smoothen the banks by masonry or other structures to prevent the river from excoriating its banks. Almost all forms of river training have been practiced in India for various purposes. Guide banks are generally constructed upstream of barrage and canal head works. A typical bank protection work through stone spurs in the Ganga can be seen at Mansi. A more extensively used flood control measure in the Ganga is bank revetting or channelization as has been done in Varanasi and Patna.

River training, in various forms, upsets the energy expenditure balance in rivers. The embankments decrease the roughness or friction along the riverbanks, but this leads to increased velocity and accelerated transport of bed material through the protected stretch. Such disequilibria created due to bank embankments tend to readjust at points where stream channelization ends and destruction of bank and bed resumes with added vigor.

One of the direct impacts of river embankment is the increase in velocity, which upset the life habits of organisms. River training may also lead to deepening of channels and they often severe the natural links with oxbow lakes and deep pools upsetting the biological cycle of many organisms. It destroys the benthic and littoral habitats, the two key links in the trophic events leading to fish productivity. Increased velocity, deepening of beds and the attendant turbulence can adversely affect the migratory behavior of fishes.

Hydraulic structures

Effects of dams, barrages, weirs and other hydraulic structures on riverine ecosystems are manifested in three ways *viz.*

i) reduced discharge,

ii) habitat destruction due to impoundment, and

iii) obstruction of migratory pathways of fishes.

One of the direct effects of dams on fishes is obstruction in migratory pathways. Hilsa is a classical example of anadromous fishes getting affected due to obstruction in their upriver migratory path.

Effluxion

Rivers, in the past, were considered to be the ideal places for waste disposal (effluxion), perhaps prompted by the irrational belief and misplaced sense of safety that the running water carries the dirt away. Thus, the rivers were increasingly subjected to the onslaught of industrial, municipal and agricultural wastes, commensurate with the rapid pace of industrialization and urbanization since the days of industrial revolution, about 75 years ago. As the human activities in the river basins escalated, it became apparent that the running waters of the river did not solve the problems of pollution, but only shifted them to other areas. In more recent years, on account of the reduced discharge rates and balkanization of rivers, offending wastes even stopped moving downstream, but staying in the vicinity to punish the offenders.

The industrial effluents include a wide variety of chemical toxicants and heavy metals apart from contributing substantially to the BOD load. Such effluents also include large quantities of pesticides, which are used in processing the raw materials in many industries. In addition to the sub-lethal chronic effects on the environment, certain direct impacts are also discernible.

The major adverse effects of sewage pollution are deoxygenation, high BOD load, rapid eutrophication and accumulation of heavy metals in the environment. Sharp fall in dissolved oxygen of water puts the biotic communities under severe stress. While some species can tolerate a wide range of dissolved oxygen, many communities are highly sensitive to this parameter. Chronic effects of elimination of some component populations from the riverine community due to oxygen depletion may cause far-reaching changes in the trophic cycle. The agricultural runoff affects riverine environment mainly through increase in salt and alkali levels in water, increase in nutrient load and accumulation of pesticides in the environment.

Problems of riverine fisheries

Riverine fisheries is riddled with many problems mainly:

- Seasonality of riverine fishing
- Unstable catch composition
- Diffuse nature of landing and marketing centres
- Absence of national marketing strategy, infrastructure and distribution system

- Conflicting multiple use of watersheds
- Cultural stresses leading to nutrient loading and pollution
- Lack of understanding of the fluvial ecosystem and infirm database
- Fragmentary and outmoded conservation measures lacking adequate enforcement machinery
- Inadequate infrastructure and supporting systems
- Socio-economic and socio-cultural determinants, and
- Environmental constraints.

Need for integrated river basin management

What is a river?

The layman's perception of river is a large body of water constrained in a channel (Rao, 1979) although it needs to be viewed in terms of the entire watersheds rather than just in terms of actual body of water flowing in channels. For centuries, geo-morphologists and geo-chemists have been viewing rivers in their right perspective, but the common and more importantly the policy makers who make decisions on rivers seldom had this broad vision. The result is improper utilization of river and river water for many centuries. It is Leopold and Maddock, who argued in 1953 that both rivers and the landscapes upon which they flow have been considered as systems in several senses of the word. This is mainly due to the dynamic interrelationship of factors affecting stream flow, sediment transport, stream channels, and the enclosing canyons. The hydraulic functions of a river are closely linked with the catchment and the channel, which together constitute its hydraulic geometry. It has been empirically shown that water depth, width, and velocity are functions of the load transported by the river and that one could thus predict, for example, the effects of changes in load supplied by side streams upon the entire geometry of the system. This clearly shows that any river stretch cannot be considered in isolation while trying to understand its hydraulic geòmetry. The same is true with the physico-chemical characteristics of water, soil and the suspended particles in a river. Thus, the environment in which the riverine communities live is influenced by a number of natural and man-made variables all along the course of a river, its catchment and tributaries.

For centuries, man has been using rivers for multiple water use and there is bound to be conflict in its use among individuals, groups of individuals, states of a country and between countries. There are also inter-sectoral conflicts in water allocation for irrigation, power generation, navigation, fisheries, recreation and so on. Accommodating the opposing interests in the river use and working out trade-offs are very difficult tasks often involving compromise on social, political and environmental issues. This underscores the need for an integrated approach in riverine resources development, which links the management of environment, industries, agriculture, power generation, forestry and fisheries. In the process, many vital problems related to forest protection; soil conservation; disposal of industrial, agricultural and urban wastes; and conservation of biodiversity will have to be addressed. The need for such an approach is suggested in this paper.

Integrated water resource management (IWRM) is essentially arriving at a tradeoffs between genuine developmental needs and sustainability concerns. The right approach to any rational water management envisages interdependence of water, land and the people. Conditions on land are directly dependent on the behaviour of stream flow and the accumulation of groundwater. Thus, integrand water management needs to be done on a basin scale, often referred to as Integrated river basin management. River basins are large and complex watersheds and the basin projects may involve watershed protection, their impoundment and management. This necessitates a basin-wise approach in planning storage reservoirs, industries, crops, and programmes in health and education.

Multiple agencies

In India, diverse agencies are working at various riverine resources often at cross-purposes. Many a times, action taken by one development agency is at conflict with that of other. The problems are further compounded by the diverse and conflicting perceptions and policies of different State Governments through the territory of which the river flows. Therefore, an integrated approach in development and conservation at national level is essential to ensure sustainable development of all sectors connected with riverine resources. Management policies should involve planning of land use within the river basin as a whole. Such a system will link management of fisheries, forestry and agriculture to agro-industrial and hydroelectric units. This will facilitate recycling of nutrients, optimization of river basin production and minimization of pollution eutrophication and toxic contamination that arise consequent to the changes in hydrological and socio-cultural regime.

There is an urgent need to adopt an IWRM approach in river management in order to ensure that the biological wealth from the rivers can be conserved for the present and posterity. Environmental stress inflicted upon any component populations affects the community metabolism and succession and will be reflected in the entire community and ultimately impairs the production at fish level. Therefore, the habitat constraints, which have no direct bearing on fish, can also affect the fish productivity indirectly. Conservation of the whole community, rather than the specific economic species, is therefore imperative in preserving the biological wealth from the rivers. Similarly, the on-stream benefits and use such as fisheries and aquatic biodiversity should not be compromised while focusing attention on off-stream water used such as irrigation, power generation, industrial/urban water needs. It needs to be ensured that adequate water flows down the river to sustain the ecosystem processes. Estimation of environmental flow requirements and its implementation is a major challenge for the river basin managers.

Conclusions

Integrated water resources management or integrated river basin management is, by no means, an easy task as it calls for radical changes in the planning and developmental processes at social and political level. The following are the essential components of integrated riverine resources management.

1. Basin-wise approach in development, taking into account the multiple use of river water and impact of developmental activities on the biotic wealth.
2. A comprehensive computer model for environmental impact assessment and resource management.
3. A judicious water allocation policy for various sectors taking into consideration the biological threshold levels.
4. Keeping fisheries at par with other developmental and conservation activities in the river basins.
5. Developing and standardizing methodologies for collection, presentation and evaluation of data on multiple river uses,
6. Developing policies which recognize that ecosystems are dynamic resources, and
7. Improving communication among various sections of the society such as fishery scientists, economists, new media, regulating/enforcement agencies and the average citizen.

[IM]PACT OF CLIMATE CHANGE ON COLDWATER FISH AND FISHERIES

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Coldwater fish vaguely refers to fish species belonging to family Salmonidae, viz., brown trout (*Salmo trutta*), rainbow trout (*Salmo gairdneri*) and eastern brook trout (*Salvelinus fontinalis*) which are much sought after fish by anglers all over the world. In India fishes inhabiting streams, lakes and reservoirs receiving snow melt water directly from their watershed are also included. These fishes tolerate temperature at lower levels of thermal scale. This thermal range affects composition of biotal community in upland waters and also limits existence of fish and aquatic life. The fishes tolerate near freezing temperature and the upper level determined survival and distribution of species.

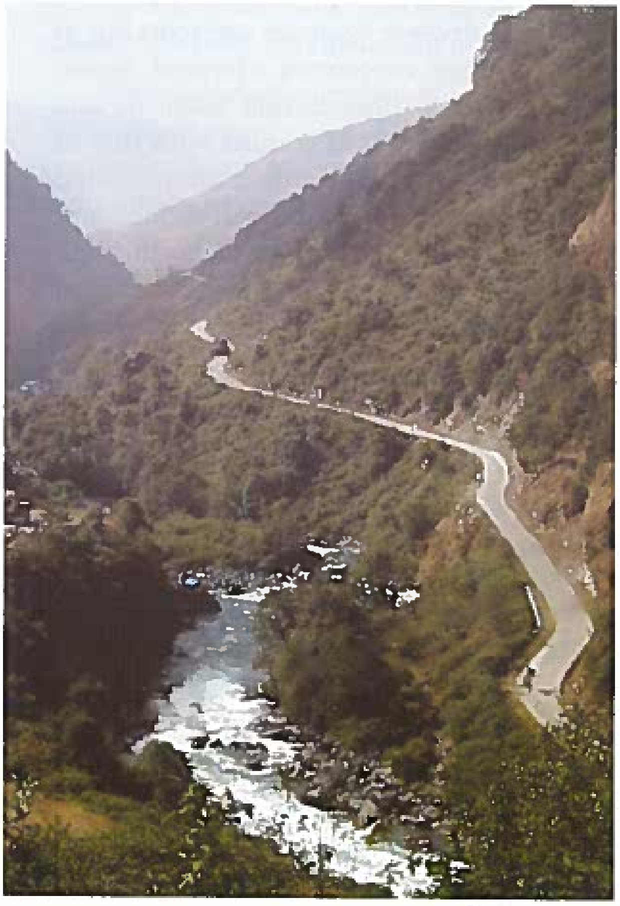
While stenothermal species tolerate a narrow range from freezing temperature to about 10°C, eurythermal species tolerate wider range of temperature, i.e., upto about 20 °C. Trouts belong to the first category while snow trouts (*Schizothorax*), common carp (*Cyprinus carpio*) and barils (*Barilius*) belong to the later.

Coldwater Resources of India.

Cold waters of India may be grouped into three.

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.

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



Tawang River, Arunachal Pradesh

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

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.


Snow fed coldwater lake in Tawang, Arunachal Pradesh

Rangit stream, Sikkim
Rain-fed Mat River, Mizoram

Coldwater Fishes of India

Trouts of the family Salmonidae, viz., *Salmo trutta fario*, *Onchorhynchus mykiss* etc. are introduced in many parts of the Himalayan region for coldwater fisheries. ***Lesser barils***, belonging to subfamily Rasborinae (Family Cyprinidae) constitute major coldwater fishery in coldwater streams. The species are: *Barilius barila*, *B. bendelisis*, *B. vagra*, *B. dogarsinghi* etc.


Rangit stream, Sikkim


Rain-fed Mat River, Mizoram

The ***Indian trout*** include *Raiamas bola*, *R. guttatus*, which grow to comparatively larger than lesser barils. ***Carp minnows*** having both food and ornamental values are the zebra fishes: *Danio* and *Devario* species. ***Mahseers*** constitute major food fisheries. The species are: *Neolissochilus hexagonolepis* in Ganga-Brahmaputra basin and *N. stracheyi* in Chindwin basin. *Tor tor*, *T. putitora*. *T. mosal* are the delicacies of upland waters. ***Snow trouts*** of the family Schizothoracinae are restricted to coldwater torrents and greatly constitute to coldwater fisheries in the Himalayan subregions.

Other carps of value are *Bangana dero*, *Semiplotus* species, *Crossocheilus*, *Garra*, *Nemacheilines*, *Balitora* etc.

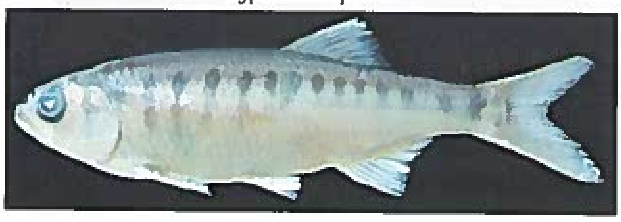
The term 'climate change' commonly refers to influences on climate resulting from anthropogenic activities. Increases in the concentration of so-called greenhouse gases in the atmosphere resulting largely from burning of fossil fuels and deforestation, have led to an observed and projected warming of the earth, known as the 'enhanced greenhouse effect'.

The gases that contribute directly to the enhanced greenhouse effect are carbon dioxide, methane and nitrous oxide emitted from combustion of fossil fuels, deforestation and agriculture, and sulphur hexafluoride,


Snow trout and Mahseers on sale in Sikkim

Cyprinus carpio

Barilius barila



Barilius dogarsinghi

Raiamas bola

Devario aequipinnatus

Schistura kangjupkhulensis

Schizothorax richardsonii

Tor putitora

perfluorocarbons and hydrofluorocarbons arising from industrial processes. It is these six gases that are controlled under the UN Framework Convention on Climate Change. Some other gases, including carbon monoxide, nitrogen oxides and volatile organic compounds, contribute indirectly to global warming through chemical reactions in the atmosphere. Other emissions, such as sulfate aerosols have a cooling or dimming effect on the climate as they reflect some of the short-wave radiation before it reaches the earth's surface.

The concentration of carbon dioxide in the atmosphere in 2005 was 379 ppm, and is rising at 1.9 ppm per year (1995-2005 average). The increase in concentration of greenhouse gases in the atmosphere has altered the earth's radiative balance, resulting in more of the sun's heat being absorbed and trapped inside the earth's atmosphere, producing global warming. Unless mitigation measures are taken up, the concentration of carbon dioxide in the atmosphere is predicted to rise to at least 650-1200 ppm by 2100. As the concentration of CO_2 in the atmosphere is directly relatd to its temperature, it is expected that average global temperature may rise upto 6°C by the end of the century. To avert catastrophic impact it is desirable to restrict the atmospheric CO_2 concentration to 550 ppm, which may limit the temperature increase to 2°C.

The IPCC's (Intergovernmental Panel on Climate Change) 2007 report incorporating input from more than 450 lead authors, 800 contributing authors and 2500 scientific expert reviewers emphatically states dire picture of wildlife if steps are nor taken to protect species from global warming. Increasing temperature and associated climate change directly affect wildlife habitat.

Impact on aquatic system

The impacts affecting aquatic systems and fisheries, especially in estuarine and marine areas, are rising sea level, increasing acidity of marine waters, 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.

Impact on coldwater fisheries

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.

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.

In freshwater systems water temperature stress will be most marked 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

Temperature and Water Quantity

The body temperature of a fish is essentially equal to the temperature of the water where it lives. Each species exhibits a characteristic preferred temperature. As the temperature rises to the preferred temperature from below, rates of food consumption, metabolism, and growth rise slowly. But the activities drop after it is exceeded until reaching zero at the lethal temperature.

The fishes respond strongly to natural variations in climate that involve changes in water volume, water flow, and water temperatures. Responses to such environmental changes fall into two broad categories: 1. changes in fish distributions, including shifts in the large-scale centers and boundaries of individual species and species groups, and shifts in the distributions of individual population members at local scales, and 2. changes in the overall production of the entire fish community in a particular region and changes in the relative productivity of individual populations within a community.

Individual fish actively select and rapidly change living areas based on suitable temperatures, oxygen concentrations, and food availability. Cold-water fish will actively avoid temperatures that exceed their preferred temperature by 2 to 5°C. They try to find refuge areas of cooler water such as groundwater or seepage areas and headwater streams. Boundaries of the zoogeographic range of species are determined in part by the interaction of thermal tolerance and behaviour of the fish with local climate. The potential effects of climate warming on such boundaries include expansion, contraction, or shift of species ranges. For freshwater fish, physical constraints such as drainage patterns, waterfalls, and land-locked areas play a large role in determining the location of zoogeographic boundaries, and in the rate at which a species may respond to the release of a climate-determined boundary.

Warming will have greater effects on streams and small inland lakes than on large, stratified lakes, because the large lakes usually have refuges of deep, cold, oxygenated waters below the surface layer for cold-water fishes. Upland streams, currently permanent ponds, and lakes are more likely to become wetlands, dry lands, or intermittent waters than lower main-stem rivers and drainage lakes. Lakes with associated wetlands will likely have a decrease in dissolved organic carbon inputs while those without such wetlands will see little change. In addition to the rural and urban development patterns, the glacial history of an area will also mediate hydrologic responses to changing climatic conditions, where groundwater-dominated areas will respond more slowly than those areas fed solely by surface waters.

In America, climate change will disturb distribution of freshwater species, It is likely to shift northward, with some extinctions of local species likely throughout the southern ranges of these species and expansion in their northern ranges. Warmer freshwater temperatures and changes in the pattern of flows in spawning rivers could reduce the abundance of species like salmon, trout, and bass. An 8°F increase in mean annual air temperature would eliminate more than 50 percent of the habitat of brook trout in the southern Appalachian Mountains. In addition, projected changes in water temperatures, salinity, and currents could affect the growth, survival, reproduction, and distribution of marine fish species and their competitors and predators.

The loss of fishing opportunities due to climate induced changes in fisheries could be severe in some parts of the country, especially at the southern boundaries of the habitat ranges of cool- and cold-water species. Cold water fish habitats could be lost entirely in such states as Maine, Massachusetts, Connecticut, Ohio, and Nebraska. Presently, more than 750,000 people fish for trout in those states each year. This loss would make those people engaged in fishing jobless and have to switch to other profession.

Situation in India will be worse. Habitat already in danger due to various anthropogenic activities: human inhabitation, abstraction of water for human use and agriculture and construction of dams for irrigation and power generation would face more severe problems.

How to save Coldwater Fish ?

The only way is to help reduce greenhouse gas. Cut emission of carbon dioxide and other heat trapping gases. Use fuel efficient (or non-motorized) mode of transportation and use energy efficient devised appliances.

Secondly, we have to protect fish habitat. Reduce threat – dams, deforestation, urban sprawl, pollution, chemical pesticides, fertilizers (which ultimately flows into streams & lakes). Volunteer clean local waterways, observe fishing regulations and protect wild stock.

IMPACT AND ADAPTATION OPTIONS FOR INDIAN MARINE FISHERIES TO CLIMATE CHANGE

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Introduction

Marine capture fisheries have very important roles for food supply, food security and income generation in India. About one million people work directly in this sector, producing 3 million tonnes annually. The value of fish catch at production level is about US $ 2.8 billion (CMFRI, 2007) and India earns US $ 1.6 billion by exporting fish and fishery products. The country has a fishing fleet consisting of 58,911 mechanized craft, 75,591 motorized craft and 104,270 non-motorized craft (CMFRI, 2006). Due to overfishing, unregulated fishing, habitat destruction and pollution, production from marine fisheries is stagnant in the last ten years. Being open access to a large extent, there is intense competition among the stakeholders with varied interests to share the limited resources in the coastal waters. Fishing remains coastal, restricted mostly to waters within 100 m depth, and deep sea and oceanic fishing is not progressing as expected. It was realized about ten years ago that the scope for increasing fish catch from the coastal waters is limited (Devaraj and Vivekanandan, 1999). Climate change is projected to exacerbate this situation and act as a depensatory factor on fish populations. Warming of water has potential impact on fish diversity, distribution, abundance and phenology, which will have, in turn, effects on the ecosystem structure and function. Global warming and the consequent changes in climatic patterns will have strong impact on fisheries with far-reaching consequences for food and livelihood security of a sizeable section of the population. Acidification of water will have effects on calciferous animals. Increased incidence of extreme events such as storms, floods and drought will affect the safety and efficiency of fishing operations, flow of rivers, area covered by wetlands and water availability and will have severe impacts on fisheries. Sea level rise will have effects on the coastal profile and livelihoods of communities. The potential outcome for fisheries may be decrease in production and value of fisheries, and decline in the economic returns from fishing operations.

Impact of climate change on climatic and oceanographic parameters

There is now a widely-held consensus among scientists and policy-makers that human activities are increasing the levels of carbon dioxide and other 'greenhouse' gases in the atmosphere, leading to a rise in temperature. This links in turn to changes in seawater temperature, varying with latitude and topography, and to thermal expansion and melting of ice caps and sea level rise. The world's oceans are affected by changes in precipitation, wind and currents, themselves the result of geographical differences in temperature and humidity of the atmosphere. Thus, important oceanic weather systems such as the El Niño Southern Oscillation (ENSO) and the Indian Ocean monsoon will be affected by global warming.

There is now ample evidence of the impacts of global climate change on marine environments. Organisms, however, do not respond to approximated global averages.

Regional changes are more relevant in the context of ecological response to climate change. Hence, global-scale climate models may be unable to simulate observed changes in temperature and rainfall or the intensification of coastal upwelling in many areas, but regional-scale models may be able to do this (Clark, 2006).

Analyzing the data set on sea surface temperature (SST) obtained from International Comprehensive Ocean – Atmosphere Data Set (ICOADS) (ESRL PSD www.cdc.noaa.gov) and 9-km resolution monthly SST obtained from AVHRR satellite data (provided by the NOAA/ NASA at http://podaac.jpl.nasa.gov/), Vivekanandan et al (2009a) showed warming of sea surface along the entire Indian coast. They found that the SST increased by 0.2°C along the northwest (NW), southwest (SW) and northeast (NE) coasts, and by 0.3°C along the southeast (SE) coast during the 45 year period from 1961 to 2005. For instance, the annual average SST, which ranged between 27.7° C and 28.0° C during 1961-1976 increased to 28.7° C-29.0° C during 1997-2005 between 9°N, 76°E and 11°N, 77°E (southwest coast). The warmer surface waters (29.0° C-29.2° C) expanded to a very large coastal area (between 8°N, 72°E and 14°N, 75.5°E) in the 45 year period. The cooler waters (25.2° C-25.5° C) in 23°N, 68°E (off Saurashtra in the northwest coast) during 1961-1976 disappeared completely in the later years. Similar pattern of warming was evident in the Bay of Bengal too. Based on the trajectory suggested by HadCM3 for SRES A2 scenario, Vivekanandan et al (2009b) predicted that the annual average sea surface temperature in the Indian seas would increase by 2.0°C to 3.5°C by 2099.

To understand the temporal changes in the climatic and oceanographic variables off Kerala (southwest coast of India), Vivekanandan et al (2009c) gathered monthly average data on sea surface temperature (SST), relative humidity (RH), total cloudiness (TC), zonal wind (U), meridional wind (V), scalar wind (W), Multivariate El-Nino Southern Oscillation Index (MEI), Southern Oscillation Index (SOI), Coastal Upwelling Index (CUI) and chlorophyll concentration (chl *a*). They found that the SST showed peaks at an interval of about ten years (1969-70, 1980, 1987-88, 1997-98, 2007) during 1961-2007, and the decadal number of SST anomalous (+ 1 or – 1 deviation from the 47-year mean) months increased. For example, only 16% of the months were SST anomalous during 1961-1970, but 44% during 2001-2007. The meridional wind speed (V) increased in the last ten years. They further made the following conclusions on the climatic and oceanographic parameters off Kerala: (i) For some parameters, the anomalies of some of the variables are increasing, and for others, the annual trend is changing. (ii) The annual CUI and chl *a* concentration increased during 1999-2008. (iii) If the changing annual trend and anomalies affect the well-defined seasonal oceanographic settings, it is possible that the biological processes may be affected in the future.

Response of the ocean to human-induced changes is different between ocean basins. Prasanna Kumar et al (2009) showed that the impact of global warming on the Arabian Sea is the disruption of the natural decadal cycle in the SST after 1995, followed by a secular increase in temperature. This increase in temperature is associated with a 5-fold increase in the development of most intense cyclones (> 100 kmph) in the Arabian Sea (May-June) after 1995 (1995-2007), compared to the previous 25 years (1970-1994). Concurrent with these events, there are progressively warmer winters, decreased monsoon rainfall, both occurring over India and an increase in the phytoplankton biomass in the Arabian Sea during fall and winter, all of which are linked. They further showed that the warmer winters cause a reduction in the annual wheat yield while decreased rainfall results in the decline of vegetation, increase in aridity and increased occurrence of heat spells over India. They attributed the synchronous increase in the phytoplankton biomass to iron-fertilization during fall and winter by enhanced dust-delivery from the surrounding landmass under increased aridity. Further, the increased phytoplankton biomass is tightly coupled to the higher fish (oil sardine) catch in the eastern and western Arabian Sea after 1995.

Sea level rise in the Indian seas

Inter-governmental Panel on Climate Change has projected that the global annual seawater temperature and sea level would rise by 0.8 to 2.5°C and 8 to 25 cm, respectively by 2050 (IPCC, 2007). The historic sea level rise for Cochin (southwest coast) is estimated to have been 2 cm in the last one century (Emery and Aubrey, 1989; Das and Radhakrishna, 1993). However, the rate of increase is accelerating, and it is projected that it may rise at the rate of 5 mm per year in the coming decades. Considering this, it is possible that the sea level may rise by 25 to 30 cm in 50 years (Dinesh Kumar, 2000). An increase in mean sea level will affect waves, currents and bottom pressure in the near shore region. In general, an increase in mean water depth will be accompanied by an increase in mean wave height, resulting in a more severe wave attack on the coast and a greater wave induced littoral drift. The erosion due to sea level rise for the region is estimated to be 7125 m^3 per year, implying an erosion rate of 0.3×10^6 m^3 per year, which could be attributed to the effects of wave attack. Using the extreme conditions of wave height and sea level rise, future erosion potential is expected to increase by 15.3% by the year 2100 (Dinesh Kumar, 2000). Besides destruction through increased rates of erosion, the sea level rise situations also increase the risk of flooding (Nicholls et al., 1999).

Impact on marine fish

Marine ecosystems are not in a steady state, but are affected by the environment, which varies on many spatial and temporal scales. Fish populations respond to the variation in different ways. As examples, during short term weather changes such as storms, fish may take refuge from rough conditions through minor changes in distribution. Interannual or El Niño scale changes in the ocean environment may result in changes in the distribution patterns of migratory fishes and can affect reproduction and recruitment in other species. Decadal and longer scale variations may have other impacts, potentially including cyclic changes in the production level of marine ecosystems in ways that may favor one species or group over another.

Temperature is one way we measure ocean variability, but temperature is also an indicator of more complex ocean processes. Changes in temperature are related to alterations in oceanic circulation patterns that are affected by changes in the direction and speed of the winds that drive ocean currents and mix surface waters with deeper nutrient rich waters. These processes in turn affect the abundance and variety of plankton which are food for small fish. The biological responses to those ocean processes are complex and not well understood.

Many tropical fish stocks, for instance, are already exposed to high extremes of temperature tolerance, and hence, some may face regional extinction, and some others may move towards higher latitudes. Coastal habitats and resources are likely to be impacted through sea level rise, warming sea temperatures, extremes of nutrient enrichment (eutrophication) and invasive species. Most fish species have a narrow range of optimum temperatures related to their basic metabolism and availability of food organisms. Being poikilotherms, even a difference of 1°C in seawater may affect their distribution and life processes. At shorter time scales of a few years, increasing temperature may have negative impacts on the physiology of fish because oxygen transport to tissues will be limited at higher temperatures. This constraint in physiology will result in changes in distributions, recruitment and abundance. Changes in timing of life history events (phenological changes) are expected with climate change. Species with short-life span and rapid turnover of generations such as plankton and small pelagic fishes are most likely to experience such changes. At intermediate time scales of a few years to a decade, the changes in distributions, recruitment and abundance of many species will be acute at the extremes of species' ranges. Changes in abundance will alter the species composition and result in changes in the structure and functions of the ecosystems. At long time scales of multi-decades, changes in the net primary production and its transfer to higher trophic levels are possible. Most models show decreasing primary production with changes of phytoplankton composition to smaller forms, although with high regional variability.

The tropical fisheries are characterized by several fast growing (von Bertalanffy's annual growth coefficient: 0.5 to 1.0) and multiple spawning species. Low levels of spawning take place throughout the year for most of the species, however, there are one or two distinct spawning peaks in a year. The eggs of most of the species are pelagic, directly exposed to the higher temperature and currents. As temperatures increase, the development duration of eggs decrease, but the size of emerging larvae decreases (Vidal et al., 2002). In the warmer years, the adults may grow faster, but there will be a point where growth rates would start to decrease as metabolic costs continue to increase. In the case of the squid *Loliolus noctiluca* (Jackson and Moltschaniwskyj, 2001), it has been found that the average life-span will decrease as a function of increased growth rate, and the individuals will mature younger at a smaller size. This will in turn reduce the absolute fecundity, as smaller individuals produce lesser number of eggs. The scale of these organism-level changes on the recruitment, biomass and fishery may depend on the environmental variables and food availability in different regions.

Long-term records of the abundance for most species are limited to historical commercial landings. These records are often influenced by economic factors such as the relative price paid for different types of fish, and changes in fishing methods or fishing effort. These non-climatic factors often obscure climate related trends in fish abundance. Most studies of variations in ocean climate and their relationships with fish abundance have been on inter-year time scales, such as El Niño and La Niña cycles and the North Pacific Decadal Oscillation and Indian Ocean Dipole. We can only speculate at what prolonged warming over the next century could bring, and our best guesses would be based on the types of variability in fish observed in the inter-year and decadal scales.

Generally, the more mobile species should be able to adjust their ranges over time, but less mobile and sedentary species may not. Depending on the species, the area it occupies may expand, shrink or be relocated. This will induce increases, decreases and shifts in the distribution of marine fish, with some areas benefiting while others lose. From the recent investigations carried out by Indian Council of Agricultural Research, the following responses to climate change by different marine species are discernible in the Indian seas: (i) Changes in species composition of phytoplankton at higher temperature; (ii) Extension of distributional boundary of small pelagics; (iii) extension of depth of occurrence; and (iv) phenological changes.

These changes may have impact on nature and value of fisheries (Perry et al., 2005). If small-sized, low value fish species with rapid turnover of generations are able to cope up with changing climate, they may replace large-sized high value species, which are already showing declining trend due to fishing and other non-climatic factors (Vivekanandan et al., 2005). Such distributional changes would lead to novel mixes of organisms in a region, leaving species to adjust to new prey, predators, parasites, diseases and competitors (Kennedy et al., 2002), and result in considerable changes in ecosystem structure and function.

Currently, it is difficult to find out how much of catch fluctuation is due to changes in fish distribution and phenology. A time series analysis on stock biomass of different species along the Indian coasts does not exist. Long-term records of the abundance for most species are limited to historical commercial landings. Moreover, availability of time series data on climatic and oceanographic parameters and fish catches in India may be too short to detect displacements of stocks or changes in productivity. Moreover, these records are often influenced by economic factors such as the relative price paid for different types of fish, and changes in fishing methods or fishing effort. For instance, introduction of mechanized craft in the 1960s, motorized craft, high opening trawlnet, minitrawl and ringseine in the 1980s, and large trawlers for multiday fishing in the 1990s substantially increased the fish catch along the Indian coast. These non-climatic factors often obscure climate related trends in fish abundance. Perhaps a de-trending analysis for removing the impact of non-climatic factors may help arrive at conclusions on the impact of climate change on marine fisheries.

The effects of changed fish migrations and distribution caused by climate variability and climate change are likely to be most difficult to deal with for highly migratory species, such as tuna. Climate plays a large role in determining short-term, seasonal and multi-year patterns of variability in the location and productivity of these optimal tuna habitat zones. It is not clear whether the spurt in yellowfin tuna fishery in the Bay of Bengal and eastern Arabian Sea in the last five years is due to climate driven changes in the migration route of the fish. We have to find answers to several questions. What will be the influence of rising seawater temperature on the bombay duck, whose northern boundary is landlocked? The sex of sea turtles is critically determined by the soil temperature at which the embryo develops. Temperature above 28° C produces only females. How the turtles would adopt to this crisis? Will there be species succession of phytoplankton with the domination of temperature tolerant species? Is the massive intrusion of pufferfish and medusae into the Indian coastal waters in recent years a fall out of climate change?

Vulnerability of corals in the Indian seas

Coral reefs are the most diverse marine habitat, which support an estimated one million species globally. They are highly sensitive to climatic influences and are among the most sensitive of all ecosystems to temperature changes, exhibiting the phenomenon known as coral bleaching when stressed by higher than normal sea temperatures. Reef-building corals are highly dependent on a symbiotic relationship with microscopic algae (type of dinoflagellate known as zooxanthellae), which live within the coral tissues. The corals are dependent on the algae for nutrition and colouration. Bleaching results from the ejection of zooxanthellae by the coral polyps and/or by the loss of chlorophyll by the zooxanthellae themselves. Corals usually recover from bleaching, but die in extreme cases.

In the Indian seas, coral reefs are found in the Gulf of Mannar, Gulf of Kachchh, Palk Bay, Andaman Sea and Lakshadweep Sea. Indian coral reefs have experienced 29 widespread bleaching events since 1989 and intense bleaching occurred in 1998 and 2002 when the SST was higher than the usual summer maxima. By using the relationship between past temperatures and bleaching events, and the predicted SST for another 100 years, Vivekanandan et al (2009b) projected the vulnerability of corals in the Indian Seas. The outcome of this analysis suggests that if the projected increase in seawater temperature follows the trajectory suggested by the HadCM3 for an SRES A2 scenario, reefs should soon start to decline in terms of coral cover and appearance. The number of decadal low bleaching events will remain between 0 and 3 during 2000-2089, but the number of decadal catastrophic events will increase from 0 during 2000-2009 to 8 during 2080-2089.

Given the implication that reefs will not be able to sustain catastrophic events more than three times a decade, reef building corals are likely to disappear as dominant organisms on coral reefs between 2020 and 2040 and the reefs are likely to become remnant between 2030 and 2040 in the Lakshadweep sea and between 2050 and 2060 in other regions in the Indian seas. These projections on coral reef vulnerability have taken into consideration only the warming of seawater. Other factors such as increasing acidity of seawater would affect formation of exoskeleton of the reefs, and scientists are of the opinion that if the acidification continues as it is now, all the coral reefs would be dead within 50 years. Given their central importance in the marine ecosystem, the loss of coral reefs is likely to have several ramifications.

Options for fisheries sector for adaptation

Options for adaptation are limited, but they do exist. The impact of climate change depends on the magnitude of change, and on the sensitivity of particular species or ecosystems (Brander 2008).

Develop knowledge base for climate change and marine fisheries

As the ability to sustain fisheries will rest on a mechanistic understanding of the interactions between global change events and localized disturbances, it is important to recognize the regional responses to climate change. Hence, considerable effort should be made for gathering historical climatic and oceanographic data in addition to monitoring these key parameters to suit climate change research. It is also important to recognize the importance of the changes in these parameters as drivers of change in marine communities including fish. Initiating a commitment on long-term environmental and ecological monitoring programmes is important as such data cannot be collected retrospectively. In India, spatial marine fish catch and effort data are available for the last four decades. However, a synergy between the climatic and oceanographic data and fisheries data does exist. Projections on climate change impact on fish populations have not been performed so far. Such projections need to be developed as the first step for future analytical and empirical models, and for planning better management adaptations.

Adopt Code of Conduct for Responsible Fisheries

Fish populations are facing the familiar problems of overfishing, pollution and habitat degradation. In India, fisheries still remain, to a large extent, an open access. Seasonal closure of mechanized fishing for 45 to 60 days is perhaps the only regulatory measure that is being followed at present. Though the fish catch has not reduced conspicuously, it is stagnant for the last one decade and there are indications of decline of several fish stocks. Fishing and climate change are strongly interrelated pressures on fish production and must be addressed jointly. Reducing fishing mortality in the majority of fisheries, which are currently fully exploited or overexploited, is the principal means of reducing the impacts of climate change (Brander, 2007). Reduction of fishing effort (i) maximizes sustainable yields, (ii) helps adaptation of fish stocks and marine ecosystems to climate impacts, and (iii) reduces greenhouse gas emission by fishing boats (Brander, 2008). About 1.2% of global oil consumption is used in fisheries, and it is found that fish catching is the main contributor to global warming in the fish production chain (Thrane 2006). Hence, some of the most effective actions which we can take to tackle climate impacts are to deal with the old familiar problems such as overfishing (Brander 2008), and adapt Code of Conduct for Responsible Fisheries and Integrated Ecosystem-based Fisheries Management (FAO, 2007). In countries like India, the primary mechanisms for managing large-scale commercial fisheries such as total allowable catch (TAC) or total allowable effort (TAE), which are applied through a proportional allocation system, do not exist. Hence, it is relatively difficult for managers to accommodate for changes in stock abundance and it is a challenge to fully comply with the CCRF. The challenge becomes severe considering the high level of poverty prevalent in the coastal communities involved in traditional fishing methods, and the lack of suitable alternate income generating options for them. These factors make these communities highly vulnerable to future changes, as their capacity to accommodate change is very limited. Effort to reduce dependence on fishing by these vulnerable communities is essential.

Increase awareness on the impacts of climate change

Being a signatory to the United Nations Framework Convention on Climate Change (UNFCCC), India has submitted the first National Communication to the UNFCCC in 2004. The second National Communication is under preparation for submission in 2011. National climate change response strategies are under preparation on a sectoral basis. Specific policy document with reference to the implications of climate change for fisheries needs to be developed for India. This document should take into account all relevant social, economic and environmental policies and actions including education, training and public awareness related to climate change. Effort is also required in respect of raising awareness of the impact, vulnerability, adaptation and mitigation related to climate change among the decision makers, managers, fishermen and other stakeholders in the fishing sector.

Strategies for evolving adaptive mechanisms

In the context of climate change, the primary challenge to the fisheries and aquaculture sector will be to ensure food supply, enhance nutritional security, improve livelihood and economic output, and ensure ecosystem safety. These objectives call for identifying and addressing the concerns arising out of climate change; evolve adaptive mechanisms and implement action across all stakeholders at national, regional and international levels (Allision et al., 2004; Handisyde et al., 2005; WorldFish Center, 2007; FAO, 2008). In response to shifting fish population and species, the industry may have to respond with the right types of craft and gear combinations, on-board processing equipments etc. Governments should consider establishing

Weather Watch Groups and decision support systems on a regional basis. Allocating research funds to analyze the impacts and establishing institutional mechanisms to enable the sector are also important. The relevance of active regional and international participation and collaboration to exchange information and ideas is being felt now as never before. For this, action plans at regional level need to be taken by (a) strengthening regional organizations and place climate change agenda as a priority; (b) addressing transboundary resource use; and (c) evolving common platforms and sharing the best practices. Action plan at international level also need to be taken by (a) linking with mitigation activities; (b) enhancing co-operation and partnerships; and (c) applying international fishery agreements.

For the fisheries and aquaculture sector, climate change notwithstanding, there are several issues to be addressed. Strategies to promote sustainability and improve the supplies should be in place before the threat of climate change assumes greater proportion. While the fisheries sector may strive to mitigate climate change by reducing CO_2 emission especially by fishing boats, it could contribute to reduce the impact by following effective adaptation measures by providing fiscal incentives for reducing the sector's carbon footprint, and for following other mitigation and adaptation options.

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IMPACT OF CLIMATE CHANGE ON COLDWATER FISHERIES OF HILLS

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Introduction

The climate change is a world wide phenomenon. It refers to any significant change in climate through temperature and rainfall patterns etc. for an extended period of decades or longer, as a result of natural processes like sun's intensity and ocean circulation, and human activities causing serious changes in lower atmosphere through fossil fuel burning and deforestation etc. The term climate change is often used interchangeably with the term global warming. In common usage, global warming often refers to earth's warming that can occur as a result of increased emissions of greenhouse gases from human activities, e.g. carbon dioxide, methane, and fluorinated gases, which act like a green house around the earth, trapping the heat from the sun into the earth's atmosphere and increasing its temperature.

It is now considered by the overwhelming majority of scientists that the global warming is the most important threat to the biodiversity of ecosystems. The climate change is one of the most critical global challenges in the present times. Recent events like floods, hurricanes, torandoes, and forest fires have quite emphatically demonstrated our growing vulnerability to climate change. Climate change impacts encompass several sectors like agriculture and fisheries, further endangering our food security, sea level rise and the accelerated erosion of the coastal zones increasing intensity of natural hazards, species extinction and the spread of vector-borne diseases.

The impact of climate change on the aquatic ecosystem is an inter-linked event between the melting of polar ice or glaciers feeding the rivers and the alteration in salinity in the riverine and estuarine waters of the tropics, temperate and sub-temperate zones. Thus climate change is not one story but many parallel stories of several ecosystems, only sporadically connected so far without very concrete data base. However, some of the studies on climate change are made in respect of glaciers, forests, and some aquatic water bodies including the Indian Sunderbans (Mitra *et al.*, 2009).

Indicators of climate change

There are several indicators of climate change, some of which are not easy to determine. The Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2001) stated that, "there is new and stronger evidence that most of the warming observed over the last fifty years is attributable to human activities". The IPCC has predicted an average global rise in temperature of 1.4 to 5.8 ^{0}C between 1990 and 2100. Current estimates indicate that even if successfully and completely implemented the Kyoto Protocol will reduce that increase by somewhere

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between 0.02 to 0.28 °C by the year 2050. Detecting climate change is difficult because any climate change "signal" is superimposed on the background "noise" of natural climate variability. Nevertheless, there is now good evidence that climate is changing. The global average land and sea surface temperature increased by 0.6± 0.2 °C over the 20th century . Nearly all of this increase occurred in two phases: 1910-1945 and more specifically since 1976. Historical data shows an increase in temperature by 0.3-0.6 °C between 1890 to 1990 and projections by the end of the century show a range of 2 to 4.5 °C increase (IPCC, 2007).

As global warming continues to increase the atmospheric temperature, it will lead to a continuous shift of zero temperature line (snow line) towards higher altitudes. Das (2007) reported that increased temperature was one of the reasons of advanced breeding by 1-2 months of Indian major carps in West Bengal during last many years. At the regional scale warming has been observed in all continents, with the greatest temperature changes occurring at middle and high latitudes in the northern hemisphere.

Impact of climate change on coldwater fisheries

Impact of climate change on coldwater fisheries in hills may be discussed under the following heads:

1. **Changes in flow regimes of streams:** Since the climate change is affecting the melting of glaciers feeding our rivers, it is likely that variability in environmental flows would be automatically affected. The pictorial plot based on historical evidences and recent data on Gangotri glacier retreat in researches by Jeff Kargal (2002), a geologist of U.S.G.S. also supports the increased rate of retreat of the Gangotri glacier in Garhwal Himalayas. Altered environmental flows affect the riverine fisheries by causing changes in the depth of riffles and pools, water velocity, and wet and dry areas of the substratum.

2. **Changes in aquatic temperature of water bodies:** Changes in aquatic temperature could have implications for all types of biotic communities and uses of water. For example, higher temperatures could affect recreational use of streams, their productivity and fishery potential of the area. Changes in water temperature also affect other parameters especially the DO and growth and metabolism of fisheries. In a rhithron section of a river the DO ranges from 8-14 ppm and in the potamon it may be lower than that and could be anything between 6-9 or so, depending on the temperature, turbulence, velocity, weather and other climatic factors.

3. **Changes in food chains, planktonic species and productivity:** Fish food organisms including plankton of a water body play an important role in productivity and finally decide the distribution and abundance of fisheries. Climate change is likely to affect all types of food chains through changes in flow and temperature regime, transparency, and other hydrological parameters.

4. **Changes in microhabitats:** The microhabitats of a stream or any lotic water body play an important role as spatial and trophic niches for various types of food organisms of fishes and their eggs and juveniles, etc. Therefore, any change in flow patterns and meandering of a river will naturally affect its microhabitats which in turn affect the fisheries.

5. **Risk of extinction of species from climate change:** The IPCC reviewed relevant

published studies of biological systems and concluded that 20-30% species may be at risk of extinction from climate change if global mean temperatures exceed 2-3 ^{0}C related to pre-industrial levels. The climate change also affects the local migrations and movements of fishes. In some cases fishes have changed their distributional ranges.

6. **Other effects:** Other indirect effects associated with climate change may be reflected through changes in water chemistry, geochemistry, rate of evapo-transpiration and siltation etc. in the catchments of rivers. These changes may also serve as indicators of climate change.

The coldwater fisheries of our streams and rivers-trouts, snow-trouts, mahseers, and other species are likely to suffer from climate change through changes in environmental flows, temperature regimes related changes, food chain erosion, and fragmentation of habitats leading to alterations of macro and micro habitats. As a result of climate change some of our precious coldwater fish may disappear completely or may change their geographical distribution range through eco-physiological adaptations. Therefore, it is suggested that the effects of climate change on coldwater fisheries should be studied thoroughly as a pilot project and it should be given top priority for the gene pool of our endemic fauna is very precious and unique to us.

Summary

The climate change is affecting all types of ecosystems and their biotic communities. It refers to any significant change in climate through temperature and precipitation etc. for an extended period as a result of natural processes and anthropogenic activities causing changes in atmosphere's composition through burning of fossil fuels and deforestation etc. Many factors are promoting climate change, some of which are global warming, GH gases and pollution. Climate change is affecting coldwater streams and rivers and their fisheries resources through its impact on flow regimes, temperature, food-chains, and overall productivity, flow of energy, and growth and metabolism of coldwater species. It is suggested that the effect of climate change should be studied as a pilot project to determine its adverse effects on the regional biodiversity in general and on coldwater fisheries in particular.

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CLIMATE CHANGE: ISSUES OF COLDWATER FISHERIES RESOURCES IN THE UPPER GANGA

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The global mean temperature in 2005 was 14.5°C. This was the second warmest year in the last 125 years. During the last decade, 9 out of the 10 years were the warmest during the past 125 years. Hence the impact of global warming may become the most important environmental issue in the 21st century. India is a large developing country with nearly 700 million rural population directly depending on climate-sensitive sectors (agriculture, forests and fisheries) and natural resources (such as water, biodiversity, mangroves, coastal zones, grasslands) for their subsistence and livelihoods. Further, the adaptive capacity of dry land farmers, forest dwellers, fisher folk, and nomadic shepherds is very low. Climate change is likely to impact all the natural ecosystems as well as socio-economic systems as shown by the National Communications Report of India to the UNFCCC. Thus, India has a significant stake in scientific advancement as well as an international understanding to promote mitigation and adaptation. This requires improved scientific understanding, capacity building, networking and broad consultation processes. The latest high resolution climate change scenarios and projections for India, based on Regional Climate Modelling (RCM) system, known as PRECIS developed by Hadley Center and applied for India using IPCC scenarios A2 and B2 shows the following:

1. An annual mean surface temperature rise by the end of century, ranging from 3 to 5°C under A2 scenario and 2.5 to 4°C under B2 scenario, with warming more pronounced in the northern parts of India.
2. A 20% rise in all India summer monsoon rainfall and further rise in rainfall is projected over all states except Punjab, Rajasthan and Tamil Nadu, which show a slight decrease.
3. Extremes in maximum and minimum temperatures are also expected to increase and similarly extreme precipitation also shows substantial increases, particularly over the west coast of India and west central India.

Current and future climate patterns: The mean annual precipitation over India as computed from the CRU data was seen to be about 1094 mm and the mean annual temperature was about 22.7°C. The projected climate (average for 2071–2100) for the more moderate B2 scenario is both wetter (an average increase of about 220 mm) and warmer (an average increase of about 2.9°C) compared to the HadRM3 baseline. The corresponding values of increase for the more extreme A2 scenario are about 300 mm and 4.2°C respectively. The mean annual precipitation for the projected values for B2 scenario turns out to be 1314 mm and the projected mean temperature is about 25.6°C. There is considerable geographical variation in the magnitude of changes for both temperature as well as rainfall.

Even though the ability to project regional differences in impact is still emerging, the consequences of climate change are projected to be more drastic in the tropical regions. This is true for all sectors that are likely to bear the brunt of climate change - sea level, water resources, ecosystems, crop production, fisheries, and human health. The populations of the developing world are more vulnerable as their infrastructure is not strong and extensive enough to withstand a deleterious impact. With respect to water resources in India it is predicted that the hydrological cycle is likely to be altered and the severity of droughts and intensity of floods in various parts of India is likely to increase. Further, a general reduction in the quantity of available run-off is predicted. The widespread retreat of glaciers and icecaps in the 21st century will also lead to higher surface temperatures on land and increasing water stress.

Most models project **enhanced precipitation during the monsoon season, particularly over the northwestern parts of India.** However, the magnitudes of projected change differ considerably from one model to the other. There is very little or no change noted in the monsoon rainfall over a major part of peninsular India. Other opinion is that the Northwestern India is likely to become drier, while northeastern India is likely to become much wetter.

As far as the temperature trends into the future are concerned, all the models show positive trends indicating widespread warming into the future. Examination of the spatial patterns of annual temperature changes in the two future time slices for different models indicates that **the warming is more pronounced over the northern parts of India.** Also, the warming is more pronounced during winter and post-monsoon months compared to the rest of the year. Interestingly, this is a conspicuous feature of the observed temperature trends from the instrumental data analyses over India. One projection is that the temperature increase in northwestern India is also much more than that in the northeast. Southern and southeastern parts of India are likely to experience only a moderate increase in temperature.

The projected scenarios suggest that rainfall will not correlate to increase in surface runoff and vis-à-vis. A close examination also reveals that the increase in rainfall is not resulting always in an increase in the surface runoff as may be general perception. For example, in the case of Cauvery River basin an increase of 2.7% of rainfall has been observed but the runoff has in fact reduced by about 2% and the actual evapo-transpiration has increased by about 7.5%. On the contrary, a reduction in rainfall in Narmada has resulted in increase in the runoff, which is again contrary to the usual expectation. Similarly, the Krishna and Mahanadi, one with predicted severe drought conditions and the other with pronounced flood conditions, respectively, show the kind of variations that are possible due to synergistic effect of precipitation and evapo-transpiration. A close examination of the results for the Krishna river basin reveals that this river basin is expected to receive reduced level of precipitation in future. Reduction has also been predicted in evapo-transpiration and water yield of the basin.

The Ganga basin is a part of the composite Ganga-Brahmaputra-Meghna basin, which drains an area of 1,086,000 square kilometres. The basin lies in China, Nepal, India and Bangladesh. It is bounded on the north by the Himalayas, on the west by the Aravalli as well as the ridge separating it from Indus basin, on the south by the Vindhyas and Chotanagpur Plateau and on the east by the Brahmaputra ridge. The Ganges originates in the Himalaya after the confluence of six rivers: the Alaknanda meets the Dhauliganga at Vishnuprayag, the Mandakini at Nandprayag, the Pindar at Karnaprayag, the Mandakini at Rudraprayag and finally the Bhagirathi at Devaprayag (after which point the river is known as the Ganges) in the Indian state of Uttarakhand (Fig. 1). The Bhagirathi is considered the source stream; it originates at the Gangotri Glacier, at an elevation of 7,756 m (25,446 ft). The streams are fed by melting snow and ice from glaciers including glaciers from peaks such as Nanda Devi and Kamet. The length of the Alaknanda from the Badrinath shrine (near its origin) to the point of its confluence with the Bhagirathi), is around 179 km and that of the Bhagirathi from Gaumukh to is 196.1 km. From source to the foothills the river forms the uppermost (Himalayan) zone of the Ganga in India, the Alaknanda®Ganga amounting to 266.7 km. These two river systems form the core of essentially coldwater fisheries in the State of Uttarakhand, comprising the Upper Ganga.

Upper Ganga: Climate, vegetation and landuse

From the snow bound mountains (alpine zone) to the foothills (subtropical zone) the length of dry and wet period varies in the Himalayan cross section. These zones experience snowfall, 100-250 cm of annual rainfall, the number of rainy days being 100-150. The atmospheric temperature varies from <10-20°C. Thus, in the upper catchment (alpine, > 4000 m; high montane, 3000-4000 m; montane 2000-3000 m; submontane zone), the dry period range from 3-4 months in alpine/highest montane zone and 2-3 months in montane and sub montane zone. Forest is the major landuse next only to subsistence agriculture[1] (Fig. 2). The crops depend on rain in the terraced fields along the high mountain slopes and on irrigation in the valleys. There are pockets of apple, apricot, citrus, peach and walnut orchards. The region lacks major industries. A 23 yr old dam exists at Maneri on the Bhagirathi while two more are coming up and downstream of Harsil, famous for apple orchards. A dam has recently (yr 2007) come up on the Alaknanda at Vishnuprayag.

Physiography

In the upper section it flows through narrow channel and rocky gorges, though not as a rule. Close to the origin wide valleys are rare for instance the Bhagirathi near Harsil. The Alaknanda channel is not wide along its course, but does flow through the wide valley of Badrinath, quite close to its origin. The particle size of the substrate gradually decreases from predominantly boulders (>250 mm) to predominantly boulders and cobbles. The slope was high in the upper section; Bhagirathi 22.1 m km^{-1} from Gangotri to Gangnani, 15.4 m km^{-1} to Uttarkashi, Alaknanda 41.5 m km^{-1} from Badrinath to Bhimtala.

Issues related to climate change

Fish Diversity

The Gangetic drainage in the Himalaya is primarily restricted to the State of Uttarakhand in India and Nepal. Estimates vary for the Nepal Himalaya:182 fish species from 92 genera under 31 families and 11 orders; 156 species; 41 species in Bhutan. Recently 134 species have been enumerated from the entire state of Uttarakhand. The fish fauna comprised primarily cyprinids, cobitids, sisorids and others. Forty two spp. are known from the Alaknanda, 39 from the Bhagirathi and 56 spp from the Ganga.

Fish Community

The fish community in the upper and middle section comprised *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 included *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.

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 Hardwar 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.

In the foothill stretch the total fish catch per month, day and hour ranged from the 600-2460, 20-82 and 2.2-9.1 Kg, respectively. The highest catch was recorded during the month of April while lowest catch in July. As far as mahseer fishery was concerned the catch ranged from 1.5 - 22 Kg day^{-1} and 0.16 – 2.4 Kg hour^{-1}. The maximum mahseer catch was recorded during October while minimum in August. The catch per unit effort (CPUE) for total fishery was found to range from 2.0 - 8.2 kg. The most harvested size class of mahseer was found to be 28–31 cm (11.6%) followed by 37 - 40 cm. (8%). The decadal trends (1980-81 to 1994-95) show increase in total mortality, exploitation rate (0.23 to 0.37) and ratio (0.76 to 0.85) and decline in the asymptotic length (L8 = 272 to 216 cm, K = 0.056 to 0.055 year-1). Mortality was largely caused by fishing, natural mortality being very low. Broad based pyramid owing to predominance of 0 to 2+ age groups indicated a recovering population and thus poor ecological health attributed to inherent (late maturity, low fecundity, slow annual growth rate) and created constraints (lack of close season; barrages; overexploitation).

Differential Distribution and Migration of Himalayan Mahseer

The Himalayan mahseer is differentially distributed in the Ganga R. and its mountain tributaries. Adolescents and adults reside in the foothill section of the Ganga between Rishikesh - Hardwar and further downstream. The spawn and larvae occur primarily in the Nayar, where the brooders ascend for spawning. The larvae grow to become juvenile (<19 cm) within a year. It exhibits tri-phased migration. The 1st & 2nd phase are ascending migrations, while 3rd phase is descending migration. The purpose of migration between the 2nd and 3rd phase was breeding. This is achieved by undertaking an elaborate migration (duration 6 months late February to September). The migratory habits of *T. putitora* stock seem to serve as a means of dispersing the stock to utilise the depleting food resource in the Ganga in addition to its annual cycle of laying spawn in suitable environment. Migration is thus crucial for its survival. In addition to water temperature the depleting food resources in the Ganga seem to trigger the ascending migration.

Problems of the Himalayan Mahseer

Role of natural (life-history traits especially reproductive biology) and created (human activities) constraints in decline (Nautiyal 1989)

- Slow growth rate (Avg. increase is 10 cm year^{-1}), hence delay in attainment of sexual maturity attained (after 47-60 cm size in riverine mahseer)
- Low fecundity and poor breeder (6000 eggs Kg^{-1}. body weight, *T. putitora* compared with 2.6 lakh Kg^{-1} body weight in *Catla*)
- Demersal eggs, hence need bed of sand and gravel
- The long hatching period of 60-80 hrs at 24-28 C compared with 18 hrs for *Catla* and a 6-day semi-quiescent stage renders them vulnerable and is crucial for their survival in the natural waters. In Nepal hatching period of 48-72 hrs was reported.
- Exploitation pattern [pre 1990]
  - 16-40 cm [immature, mature] account for > 40% in Alaknanda
  - <20 cm [immature] most exploited in the Nayar
- Low fecundity of surviving adults leads to low recruitment rate as <20 cm [immature] most exploited. Hence, mortality exceeds recruitment.
- Habitat destruction: Construction of dams and barrages by blocking migratory passage. Impact of barrages.
- The delayed attainment of sexual maturity gets coupled with the exploitation pattern. The exploitation pattern: the greatest concern as it interferes with the biological processes and accelerates depletion of stocks.

Perceived impacts

In the Upper Ganga, if the predicted change of slight warming and decline in rainfall comes true, the important issues will be taxonomic richness, communities, fisheries and threats to Himalayan mahseer and other rare fish species. However, the situation will be complicated by the series of run-off-the-river hydroelectric projects (HEP), as the continuum will cease to exist. The impact of these projects will trigger changes much before the dawn of climate changes.

Fish Diversity: The richness and diversity will be impacted, however, the magnitude will vary. An increase in the diversity and richness would be natural from the viewpoint of warming, but this will not be true for the upper Ganga and its parent tributaries, the Alaknanda and the Bhagirathi, as low rainfall would mean shrinkage of the available habitat.

Fish communities: The sub-himalayan communities may extend their range to the foothills, wile those in the foothills may extend their range to middle sections. The fish communities in the upper and middle sections may extend their range closer to the headwaters, which are at present devoid of fish communities or contain the exotic brown trout, the habitat of which will shrink. Besides, a general change in the communities may also occur due to variation in their abundance.

Moreover, the change cannot be linear because of the proposed HEP and hence predictions cannot be made because exotic fish species may be introduced into the reservoirs. As disturbed ecosystems spawn invasive species, the fish communities may be altogether different. The structure of the food web can change and shifts in species competition is also possible.

Fisheries: Riverine fisheries may possibly get enhanced as the species not possible to culture in the mountains earlier may establish in the reservoirs. However, the components will change in the middle stretch and foothills, likely to be dominated by exotics. The snow trout[2] will be restricted to the stretch close to headwaters if it does not face competition from brown trout.

Himalayan mahseer: The upcoming run-of-the-river hydroelectric schemes in the lower section (Devprayag to Rishikesh) of the Ganga will extirpate the mahseer from the mountain reach of the Ganga, as its migration and hence breeding will be arrested by these projects. The sibling species *Tor tor* which is highly abundant in Central India could have possibly populated the Upper Ganga in the absence of impoundments, but does not appear likely. In recent (last two years) times I have seen few peacock in the lower hills upstream of Rishikesh and even in the middle hills between Srinagar and Tehri, where they are not known to occur and have never been seen by anybody. Thus, the life forms which can move at their will can extend or change their range. Warming, in general in conjunction with low rainfall leading to habitat shrinkage will be detrimental to recruitment process in all fish species.

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UTTARAKHAND FISHERIES: PRESENT STATUS AND POSSIBLE IMPACTS OF CLIMATE CHANGES

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The state of Uttarakhand is spread over a geographical area of 53,204 km.^{2} in the altitudinal range between 198 to 7,816 msl in Central Himalaya, in which 88.9 % area is mountainous. The altitudinal and geographical variation, mountain slopes, expansion of river valleys and vegetation cover has given rise to varying climates in different parts of the state. The state is blessed with plenty of aquatic resources and valuable fish diversity. The aquatic resources and fishery of the state are under severe stress from various anthropogenic factors. Impacts of gradual climate change on precipitation, frost covering, thermal regime etc. is already being observed in the state since 4-5 decades. The long-term implications on native valuable species seem to be highly detrimental and would also change the farming scenario as well.

Water resources

The region receives water from snowfall in higher peaks and rainfall in the lower altitudes. A number of glaciers are present in the state lying above 3,600 msl. The major glaciers are Gangotri, Yamunotri, Pindari, Kafini, Sunderdhunga, Nakuri, Milam, Baldhunga, Poling, Balati etc. The major river systems of the state namely Ganga, Yamuna, Bagirati, Alaknanda and Kali are of glacial origin hence are perennial, where as a number of tributaries receives water from discharges of springs and seepage through faults, fractures, joints and permeable layers. Numerous rain-fed seasonal streams are also debauching into these river systems. The total length of the major river systems in the state is estimated about 2,686 km.

A number of natural lakes also constitute valuable water reserve. The total water area under lacustrine systems is about 300 ha. The principal lakes in Uttarakhand are- Nainital, Bhimtal, Sattal, Naukuchiyatal, Khurpatal, Shyamlatal, Taragtal, Deoriatal. A number of lakes situated in the Greater Himalayan region like- Hemkund, Roopkund, Kagbhusandital, Kedartal, Sahastratal, Arwatal freezes during at least a part of the year.

Some reservoirs have been constucted in the state under multipurpose river-valley projects for irrigation and hydroelectric purposes. The total area under reservoirs is 20,075 ha. The most of the reservoirs are located in Lesser Himalayan region. The main reservoirs are- Nanaksagar, Tumaria, Baigul, Kalagarh. Still some big reservoirs like Tehri, Dhauliganga, Maneri are under construction and some others- Pancheswar, Thuligad etc. are proposed for future construction.

Fish diversity

The vast and varied water resources in the state harbours rich piscine diversity. The list of fishes distributed in the upland waters of Uttarakhand comprises 83 species classified under 39 genera, 12 families and 3 orders. As far as commercial importance is concern, 5 species are known for sports, 40 as food fishes and 8 for their potential ornamental value The principal species are - *Tor putitora, Tor tor, Tor chelynoides, Labeo dero, Labeo dyocheilus,* *Schizothorax richardsonii* among native species; *Labeo rohita, Catla catla, Cirrhinus mrigala* are the transplanted and *Ctenopharyngodon idella, Hypophthalmichthys molitrix, Cyprinus carpio, Oncorhynchus mykiss* are the exotics.

As far as the cultured and cultivable species in the state are concern, the species could be classified as:

The species being used for culture: *Ctenopharyngodon idellus, Hypophthalmichthys molitrix, Cyprinus carpio, Labeo rohita, Catla catla, Cirrhinus mrigala* and *Oncorhynchus mykiss.*

The cultivable species: *Tor putitora, Tor tor, Tor chelynoides, Labeo dero, Labeo dyocheilus* and *Schizothorax richardsonii.* Due to slow growth rate these species are not used for culture in the region at present.

Status of fishery

Due to prevailing low water temperature, scarce aquatic flora and least organic constituents, the fish production in upland waters is registered very low. Beside this, the inaccessible river stretches, difficult ravines prevents fishing activity.

The most of the lotic systems in the state are under severe deterioration from incoming silt load, decreasing flow rate, and large-scale abstractions. The excessive rate of soil erosion from the catchments has destructed the natural deep pools within the stream and rivers, therefore the healthy ratio of 1:1 between pools and riffles has adversely affected the fishery resources. The sudden influx of the massive silt load in the stream or river waters after heavy rains, sometimes cause choking of the gill rackers, eye and head injury and mass mortality in the fishes. The heavy silt load coming from adjoining mountain peaks around Nainital lake have deposited a layer of about 6 m. on lake bottom in the last 5 decades. The residue of the forest fire that is a common phenomenon during summer months further aggravates the problem. The resultant ashes of the forest fires have also caused fish mortality due to sudden drastic changes in physico-chemical characteristics of the natural waters.

While the most of the high altitude lakes in the state are still in pristine condition, but contrary to that the lakes situated in middle Himalayas are under pollution load of varying magnitudes and are over exploited too. The world famous mahseer (*Tor putitora* and *Tor tor*) has almost been exterminated in eutrophic Nainital lake. Where as in other oligotrophic lakes such as Bhimtal, Naukuchiatal, Sattal and Khurpatal mahseer percentage is declining in total annual catches

The rich fishery resources in the varied water systems of the state in general and sport, food, typical hill stream fishes in particular are under severe stress from habitat degradation, over exploitation and wanton destruction. The valuable sport fishes (especially the golden mahseer), available in the water bodies are highly demanded among anglers throughout the world. Owing to the effect of multifarious stresses, there is sharp depletion in mahseer population. The fish fauna, particularly in the water bodies traversing near townships, villages and roadside are under massive threat from wanton killing with the help of illegal destructive devices. Hence these resources are under threat of "Malthusian Overfishing", where adults or brooder fishes are being virtually eliminated by destructive fishing.

Climate change and hill fisheries

Clear indications of gradual climate change are discernible in the hill region. It is evidenced that the major glaciers located in the Uttarakhand Himalayas are retreating at a rapid rate due to increase in the atmospheric temperature. Further, the snowline is also retreating to the higher altitudes year by year.

Many of the mountainous areas located at about1500 msl were known for conspicuous snowfall during winters (December to March) in many spells, are rarely receiving snowfall nowadays. Many of the hill stations like Mussoorie, Nainital, Mukteswar situated in the state were reportedly received copious snow fall (1-3 m) for longer period during past decades are getting just a thin layer for lesser days. Owing to the effect of gradual climate changes, farming calendar need to be is shifted. The renowned apple orchards located at Ramgarh, Munsyari and other similar altitudes of the state are deteriorating due to insufficient chilling period required for the crop.

As far as fishery of the state is concern, presently it is facing other anthropogenic stresses. The aquatic resources are under influence of habitat destruction, lesser flow in the rivers, increasing silt load and the fishery is facing the menace of wanton destruction. The coldwater fishery is known for its sensitivity and is best indicator of the aquatic habitats. Most of the species are stenothermal so have narrow thermal tolerance. Thorough natural adaptation process has evolved a peculiar class of hill stream fishes which are able to tolerate a particular range of ambient water temperature, dissolved oxygen, substratum etc. Further, a few species undertake the process of migration to escape the harsh temperatures. As water temperatures decreases in autumn, the metabolism of fish's decrease, feeding, digestion and growth rates are drastically reduced. In these circumstances, the fish react towards their changing environment in characteristic way, by being able to adjust physiologically within their genetic limits or move to congenial habitats. Such adjustments with their environmental cycles are adaptive and imperative for their survival.

The principal coldwater fishes- *Tor putitora* and *Schizothorax richardsonii* are migratory in nature. *Tor putitora* start downward migration for over wintering from upstream river stretches as ambient water temperature drop below 16.0^{0}C and *Schizothorax richardsonii* below 13.0^{0}C, during September-October. The migrated stock of both the species congregates at the foothill zone up to March-April, where they feed, grow and attain sexual maturity. The stock starts upward movement during March-April as the water temperature in the midstream of the Kali gradually rises above 13.0-16.0 ^{0}C. Both the species breed in the upstream waters. Another feature of coldwater fishes is their breeding season related with the ambient water temperature, diurnal cycle, river flow conditions. Besides native species the valuable exotic rainbow trout breeds during severe winter conditions. Therefore temperature is a principal limiting factor in growth, survival and propagation of the coldwater fishes. The major deviations expected from climate change in their habitats, biotic assemblages, feeding and breeding grounds etc would be highly detrimental and lead to extermination of the native species and emergence of the hardy eurythermal species like common carp. In these circumstances there would be need to incorporate warm water fishes like *Labeo rohita, Cirrhinus mrigala, Catla catla* and Chinese carps in the upland farming system instead of valuable trout and other indigenous species.

IMPACT OF CLIMATE CHANGE IN FISHERIES OF ASSAM

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Global climate change and related issues have gained attention among to scientists and policy makers in recent times. It has possessed a major challenge to researcher, academia, social scientist and environmentalist to conserve the rich biodiversity from the threat of anthropogenic stress. North Eastern Region in India is endowed with plenty of water resources including 56 major rivers/ tributaries several small rivulets and streams. The region has two major river systems *viz.* Brahmaputra and Barak River. North Eastern State is slated to be India's future powerhouse with 168 large hydro power projects generating 63,000 MW planned in the region and Brahmaputra and Barak basins together constitute 50% total hydel power potential of the country. Assam is the second largest state in the North Eastern Region of India covering about 30% geographical area of the region. The State is known for its rich and variety of floristic and faunistic diversity and is surrounded by sub Himalayan mountain ranges of Bhutan, Arunachal Pradesh, hills of Nagaland, Meghalaya and Mizoram on three sides. The combined length of the river in the State is 5050 Km. The river Brahmaputra alone has 27 tributaries on Northern bank while 15 on the Southern bank. Concentration of Nitrogen and phosphorus in these tributaries increases sharply as watersheds increasingly domesticated that is as the percentage of watershed area in agricultural and urban use increases. Assam is endowed with 3.83 Lakh ha of water resources that include individual ponds and community tanks, beel and oxbow lakes, derelict water bodies and river fisheries.

Physiographic Feature

The physiographic feature influences the occurrence and distribution of water resources within the region, particularly the orography plays an important role in influencing the rainfall and other climatic factors such as temperature, humidity and wind. However, with given geographical locality and physiographic framework, it is primarily rainfall and the climatic factors which effect evapo-transpiration that determines the totality of the water resource in the region. The annual average rainfall in Assam during the year 2006 was 1741.00mm. The rainfall in the State is associated with tropical depression originating in the Bay of Bengal. The climate of Assam is sub tropical monsoon type and is highly humid during rainy season of South West Monsoon which starts from June till August. The maximum during this period is recorded 40 ^{0}C temperature. Winter season starts from the end of the October and last till February and the minimum temperature during the period varies between 6 and 8 ^{0}C.

Stream Ecology

According to CIFRI, Barrackpore; following rivers *viz.* Jia Bharali, Manas, Beki, Kapili, Lohit, Kulsi, Borgung have been identified as important coldwater rivers of the States which have sandy (87.5-98.5%) texture, acidic to alkaline pH (6.5-7.5), low organic carbon content (0.12-0.46%) characterized by cool water temperature (11.5 – 22.7^{0}C), medium to high total alkalinity (34.3- 207.7mgl^{-1}) with low phytoplankton population (49-177ul^{-1}) and low net phytoplankton primary production (Bhattacharjya,2005). The severity of flood in these rivers are related to intensity of precipitation and watershed characteristics where runoff is more rapid and infiltration is less flood are more sever. Channelisation and increase in impermeable surface associated with urbanization may cause increased flooding.

Fish & Fisheries

These rives harbor 38 fish species belonging to 27 genera under 9 families and 4 orders consisting of *Tor tor, T putitora, Neolissochilus hexagonolepis, N. hexastchus, Labeo dyocheilus, Raimus bola, Rasbora rasbora, Gara nastuta, Gara kempi, G gotyla gotyla, G lamta, Cyprinion semiplotus A. kempi, Hara hara, Badis badis, Labeo devdevi, Labeo dero, Barlius barlius, Canta canta, P sophore, etc.* Besides many ornamental fish like *A mola, A jaya, S bacaila, E danricus, R. daniconius, Badis badis, Conta conta , B barna , P. chola , Hara hara, G. cavia, B. vagra, C. nama, S. gongta, C. ranga, A. coila, A. morar* also found in these rivers. The upper stretch of the River Jia bhoreli of Sonitpur has become an excellent sport fishing ground and several important species like *Tor putitora, Tor tor, Schizothorax richardsoni, Schizothorax progastus, Neolissochilus hexagonolepis* have been caught. Fishing season in all the rivers starts from October and last till March. Some of these fishes have become endangered due to over exploitation, habitat fragmentation, and anthropogenic stress. In view of this, study River Manas formed by the three confluences of three streams *viz.* Dumukhi, Pangmang and Xangchu in eastern Bhutan is habitat of coldwater sport fish and could be further developed.

Climate Change

Over the years in general, the climate of the earth has been warming approximately by 0.6^{0}C over the past 100 years with two main periods of warming, between 1910 and 1945 and from 1976 onwards (Walther et al., 2002). The rate of warming during the latter period has been approximately double that of the first and thus greater than at any other time during last 1000 years (IPCC, 2001). The increase in the proportion of greenhouse gases in the Earth's atmosphere is likely to cause an average global warming of 1-3.5^{0}C over the next century. This warming will vary spatially and is predicted to be most intense in the winter at high northern latitudes (Houghton, 1996). An increase of a few degrees of temperature will not only raise the temperature of the ocean but also cause a major change in hydrologic affecting physical and chemical properties of water. Fishes have evolved physiographically to live within a specific range of environmental variation, and the existence outside the range can be harmful Recruitment of fish population also is strongly influenced by climate variability. Organisms, populations, and various ecological communities at different trophic level do not respond to approximated global averages. Thus, United Nations Framework on Climate Change (UNFCC) in its Article 1 defines Climate Change "as a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods". Of late, Assam has also experienced a situation of rainless winter and pre monsoon periods a question was raised over the issue of global warming and viewed as a fact that winter rainfall over the region is the product of western disturbances originating in Mediterranean sea, even as the pre monsoon rainfall activities here are mainly governed by the located thunderstorm activities. However, the monsoon rainfall over the region is basically the product of a well defined monsoon trough and monsoon low pressure system associated with cyclonic circulation or trough in the low lower atmospheric layer. Assemblages of species in ecological communities reflect interactions among organisms as well as between organisms and the abiotic environment (Walther et al., 2002). Extreme environmental factors such as dissolved oxygen, pH, and salinity can have deleterious affect foraging, growth and fecundity, alter metamorphosis and affect endocrine homeostasis and migratory behavior of fish. Many auto ecological effects of temperature on fish are known and this knowledge has been incorporated into population level relations that have been used to assess the possible effects climate change on fish as well as their habitat. However, there is a problem of extrapolation of to multi species fisheries given the complexity of community level phnomena. Climate change affects two key aspects at population level:

1. Changing climate shall change the distribution of habitat suitable for establishment, growth and reproduction so that an area protected as suitable for species may become unsuitable in future.
2. With changing climate difference, suitable areas shall be needed for species at different times.

During 2009, Assam is experiencing a heat wave condition with temperature steadily soaring due to scanty rainfall. The highest temperature was recorded was at 37.6 °C during April which is very high when the other part of the country usually experiences heavy to moderate rainfall during this month. Cumulative rainfall for Aril is only 68 mm which is much lower than 153.6 mm rainfall that took place during the last year.

Emerging threats

1. Increase in air temperature is threatened to dissolve Himalayan Glaciers and modify hydraulic flow regime of the river and associated biotic communities in the floodplains
2. Modification of suspended load and bed load along the bottom of the river,
3. Delinking between head water streams fed by infiltration of the soil and subsurface sediment for maintaining the flow of the cold water streams.
4. Modification of availability of water in the basin can facilitate establishment alien plant and animal species;

Remedial Measures

1. Promotion of concept of reduction of green house gases in consultation with State Union Territories, NGOs and related scientific institutions.
2. Long term and short term strategies to be evolved as it involves several local departments.
3. To support discussion, campaign, program, mass action, preparation of audiovisual, visual and printed IEC materials.
4. Foster global, intergovernmental and regional level cooperation to avert risk of global climate change.

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CLIMATE CHANGE AND ITS IMPACT ON COLD WATER FISH AND FISHERIES OF MANAS RIVER, ASSAM (INDIA)

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Introduction

Currently, the magnitude of global climate change is such that most of its effects on freshwater fisheries could be easily masked by or attributed to other anthropogenic influences, such as deforestation, over-exploitation and land use change (McDowall 1992; Genta *et al.* 1998; Nobre *et al.* 2002). Global climate change appears to represent an additional stressor to the suite that includes pollution, over-fishing, water diversion, and introduction of exotic fishes.

Global climate change will affect freshwater systems support artisanal, sport and commercial fisheries, global climate change will impact those fisheries, changes in fishery productivity will in turn affect the human populations and economics that are reliant on those resources.

Large-scale human activities like water diversion, land-use changes, and deforestation often have dramatic and rapid impacts on fish populations, while the effects presently attributable to climate change exist in the background and may go unnoticed. However, even though the effects of climate change have not yet manifested themselves through large and widespread fish kills.

To provide effective support for management, river fisheries ecologists must analyse and predict processes and impacts at the level of species, assemblages and ecosystem processes. It is not only sufficient to observe, identify and classify fishes present in rivers and other freshwater environment but also it is essential to record their physical and chemical properties in order to help define ecosystem that leads to a sustainable fishery.

Assam, the second largest province of N.E. India is a global hotspot for fish faunal diversity not only for plain water fisheries but also for cold water fisheries. The Manas River system is one of the important cold water fisheries resources of Assam.

About Manas River

The River Manas, drains about 18,300 km^2 in eastern Bhutan, rising beyond the Great Himalayan rânge. It enters Bhutan from the Kameng frontier district of India and runs southwest again it enters India via Manas National Park. Prior to the entry of Manas National Park, the River divided at Mothonguri to form another River Beki. In Assam, the River

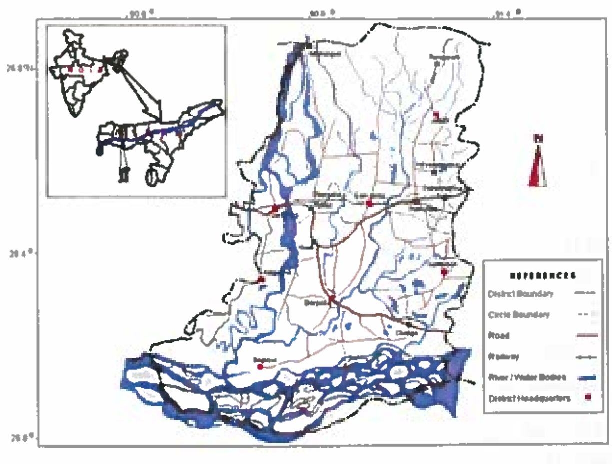

Fig: Map of Manas River System

flows through a region having altitude in between 650 m and 215 m before joining to mighty River Brahmaputra. The Manas River and its tributaries are known to have predominantly cold water fish.

Species like *Schizothorax progastus, Schizothorax molesworthii, Schizothorax richardsonii, Neolissocheilus hexagonolepis, Crossocheilus latius, Tor putitora, Tor tor, Barilius barna, B. bendelisis, Garra garra, Garra annandalei, Garra gotyla,Garra kempi, Hara hara, Labeo pangusia, Neolissocheilus hexagonolepis, Botia derio, N. botia, Conta conta, Barilus vagra, Gagata gagata, Gagata cenia, Barailius bendelesis, Sisor rabdophorus, C chagunio etc.* were reported from the area.

Impact of Climate Change

In recent years, the physico-chemical parameters of the River system have reported rapid changes especially in water temperature and DO_2 level. As a result of which fishery resources of the River system reduced drastically. The mean annual water temperature of the river system were recorded between 15 ^{0}C and17 ^{0}C in 1995 in certain pre selected site near the Manas National Park (Sen, 1995) and DO_2 level reported in that site were in between 9.0mg/l and 10.0 mg/l.

A preliminary survey was conducted in 2007 to throw some light on the present status fish and fishery of the River system along with certain physico-chemical parameters. It has been found that in comparison to earlier report, the level of water temperature found in increasing trend in between 2^0 and 3^0 C along with decreasing trend in the level of DO_2 in between 6.5 mg/l and 7.5 mg/l. estimated at the site of Manas National Park. This might have another factor for declining trend of fish diversity of the River system

Fishes are cold blooded animal therefore fluctuation in water temperature must have derelict effect in the life history and physiology of the fishes. As water temperature is one of the master variables in freshwater system because of its widespread effect on the life history, physiology and behaviour of most fresh water organisms, including fishes. Water temperature can also alter the physical habitat available to a species, primarily through thermal stratification and heterogeneity within a system. Freshwater fishes are all poikilothermic and rely on behavioural thermoregulation (Nevermann and Wartsbaugh, 1994).

Oxygen solubility in water has an inverse relationship with water temperature. The aerobic metabolic rates of most cold-blooded aquatic organisms increase with temperature. Environmental DO_2 levels must be high enough to support aerobic metabolism in fishes (Moyle and Cech, 2004). Increased water temperatures result in an increased frequency or duration of hypoxic episodes, it is likely that fish that persist will experience reduced growth rates and reduced reproductive output.

Changes in global temperature will affect fish communities and the fisheries dependent on those communities through direct effects on fish physiology and indirectly through effects on water quality, water chemistry, and hydrographs. Even when the increase in temperature is not sufficient to prove acutely or even chronically lethal, the sub-lethal impacts on fish physiology, particularly on growth and reproduction, may be sufficient to cause significant changes in the structure and composition of fish faunas especially in cold water fish. The impacts of global climate change on the critical physical and chemical characteristics will likely prove to be the driving factors in determining the well-being and composition offish communities and thus cannot be discounted in discussions concerning global climate change.

Therefore, it is very much essential to keep a strong monitoring on the changing environment of the Manas River System of Assam to stop further erosion of cold water fishery resources. Sustainable fishery is not about fishing for economic purposes only it has also a great concern to save the fish habitat or aquatic environment. It is not only necessary to save freshwater resources but save the whole aquatic environment including fishes and other aquatic organisms to keep the ecosystem undisturbed as far as possible. The best chance being resolved with minimal environmental damage when management is coordinated at an appropriate ecological scale. A collective effort to determine the priorities and to concentrate the available resources on these is surely an essential precondition for a better tomorrow.

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CLIMATE CHANGE AND ITS EFFECTS ON COLDWATER FISHERIES

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The contribution from fisheries to a nation like India is enormous in terms of providing nutritious food supply in this health conscious era, generating employment for millions. In addition to this, it adds to export earnings as well as enhances national income. Worldwide, fish provide over 2.6 billion people with more than 20% of their animal protein, and are even more critical regionally. The world's fisheries generate over US$130 billion annually, and contribute significantly to the economies of many countries. Worldwide, over 38 million people earn an income by fishing or raising fish, and if activities associated with fisheries production are included, it supports over 200 million people.

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, leads 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.

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.

Global warming is expected to result in considerable changes in freshwater fish populations, fisheries and aquaculture. Effects of global warming on the environment include glaciers, ecosystems, ocean currents, and rising sea levels. The most popular effect of global warming is its' impact on glaciers. The biggest concern would be the failure of the glaciers in Hindu Kush and the Himalayas. These glaciers are the main water supply for China, India, and most of Asia. The complete melting of these glaciers would result in a major flow for several decades, however after that the most populated areas in the world could potentially run out of water. Changes in mean rainfall and temperate as well as the increase in extreme events will affect agriculture, livestock, forestry as well as fisheries. Many impacts, such as increased land degradation and soil erosion, changes in water availability, biodiversity loss, more frequent and more intense pest and disease outbreaks as well as disasters need to be addressed across sectors.

Fish may not have enough oxygen to breathe, as the water grows warmer. Fish filter oxygen from the water they are swimming in, but the amount of oxygen dissolved in water decreases as temperatures rise. So many fish will experience an "oxygen squeeze" as the climate warms – they will need more oxygen to support their elevated metabolisms, but may not be able to get it from the warmer, oxygen-poor water around them. Fish physiology is inextricably linked to temperature, and fish have evolved to cope with specific hydrologic regimes and habitat niches. Their physiology and life histories will be affected by alterations induced by climate change. Genetic change is also possible and is the only biological option for fish that are unable to migrate or acclimate. These impacts on fisheries may make it difficult for developing countries to meet their food demand, and developed countries may experience economic losses. As it strengthens over time, global climate change will become a more powerful stressor for fish living in natural or artificial systems. Furthermore, human response to climate change will exacerbate its already-detrimental effects. The distribution of freshwater species is likely to shift northward, with some extinction of local species likely throughout the southern ranges of these species and expansion in their northern ranges. Warmer freshwater temperatures and changes in the pattern of flows in spawning rivers could reduce the abundance of species like salmon, trout, and bass.

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^{0}F during the last century, and scientists project that temperatures will increase anywhere from 2 to 10 ^{0}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^{0}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.

Water may all look the same to us, but for fish, the world is made up of very distinct layers – each with its own temperature and supply of food and oxygen. Surface temperatures have risen and more freshwater is flowing into the sea from melting glaciers and increased precipitation. This lighter layer of warm, fresh water has reduced vertical mixing in the Gulf, and there are now fewer nutrients to feed the small organisms that fish depend upon.

As water warms up, many parasites and microbes that cause fish diseases grow faster and become more virulent. And as harmful microbes and parasites become stronger and more numerous, fish whose immune systems are already stressed by warm water, low oxygen, and crowding, become even more susceptible to diseases and parasites. Warmer fish tend to mature more quickly, but the cost of this speedy lifestyle is often a smaller body size. Many fish will also have less offspring as temperature rise, and some may not be able to reproduce at all. Increased warming could lead to the extinction of up to 20 species that are found nowhere else in the world.

Massive fish die-offs due to toxic algae and the risk of human illness from eating poisoned fish will also increase as temperatures climb. Lakes that remain stratified longer tend to have more blue-green algae, which produce toxins harmful to fish, their prey, and humans who consume the fish. Fish die-offs and human illness can also be caused by ciguatera fish poisoning, in which fish are poisoned by tiny organisms called dinoflagellates.

It is very important that we know the causes of global warming in order to stop global warming; however knowing the causes of global warming without applying solutions for global warming prevention is fruitless. Greenhouse gases make up only a tiny fraction of the atmosphere, but they can have a big impact, and their proportion is rising rapidly as economic development speeds up around the world. Since the beginning of the Industrial Revolution in middle of the 18th century, levels of carbon dioxide have jumped 30 percent, nitrous oxide 15 percent, and methane 100 percent.

Global warming needs to be fought on three different levels:

a) The government must make it easier for companies and individuals to use alternative energy sources and less pollution causing and toxic energy sources like oil and dirty coal.

b) Businesses need to step up and do the right thing as far as preventing global warming and promoting a healthy environment.

c) Finally we as individuals must play a huge part in using alternative energy sources, recycling and cutting down on waste.

The collapse of a large portion of the Antarctic ice sheet would shift the Earth's axis. One of the most startling predictions is that the sea change could shift the Earth's rotation. The ice sheet is especially vulnerable to global warming and may be prone to collapse, which could trigger a rise in sea levels. The melting of the ice sheet would change the balance of the globe much the same as tsunamis that move massive amounts of water from one area to another. That the sea level in the area of the shelf actually drops, while other areas see dramatic increases. A massive depression in the bedrock that is currently underneath the ice shelf, will fill with water if the sheet collapses. But as the sheet melts and its weight disperses, the depression will rebound, thereby pushing water into other areas.

Conclusion

The longer we wait and ignore global warming and its effects, the harder it will be to reverse the consequences of global warming. Our concern should be to reduce destructive effects of global warming and to utilize the resources in a sustainable manner. In this context it is worth to quote and make a slogan: **"An ounce of prevention is worth a pound of cure".**

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A GIS-BASED FRAMEWORK FOR CLIMATE CHANGE STUDIES IN COLDWATER REGION

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A GIS-based approach to climate change studies provides a framework for understanding and addressing the entire breadth of climate change science issues in a holistic manner. Researchers have long classified various phenomena into logical groupings. The classifications have helped greatly to advance the understanding of component physical, biological and social systems, yet often create artificial boundaries between disciplines that can be detrimental to the understanding of larger issues. While advancing the understanding of each of these individual systems is very important, ultimately we need to bring all of these systems together to understand how they are interrelated and dependent upon one other.

Such a framework provides a base enablement system for global data management, visualization, analysis, modeling and ultimately design. In order to move climate change studies from a massive collection of unrelated or loosely linked endeavors towards an open, integrated framework, there are four areas we need to change: data, model, organization and mindset. Various frameworks and programs already address a number of the issues and challenges in establishing such a framework. These programs will help us to identify concepts and components that can be leveraged as well as gaps that can be filled by a GIS-based framework for climate change studies.

The review below presents some representative examples, and is not meant to present a comprehensive inventory of such frameworks and programs.

GIS has proven to be an important and reliable tool for management of spatial information at all geographic levels, from local to global. Over the past 15 years, a number of national, regional and international organizations have moved towards a vision of building a Global Spatial Data Infrastructure (GSDI) for the sharing of spatial data. The GSDI is promoting this framework, with a goal of mapping the globe at a resolution of 1 km or better and including information on a wide variety of geographic features.

Geomorphological Changes in Major Kumaon lakes

In the study, changes in the physical parameters of Kumaon lakes are depicted with the help of GIS and remote sensing technique. Satellite data of IRS-1 C LISS III of the Kumaon region was collected from National Remote Sensing Agency, Hyderabad for the year 1997 and 2004. Analysis and interpretation of Satellite data has been done by digital image processing. Different physical parameters of various Kumaon lakes are obtained for the year 1997 and 2004. It is observed that the maximum length, width and area of Bhimtal Lake are 1670 m, 468 m and 44 ha respectively in the year 2004. But a decreasing trend of the parameters is seen from the year 1997 to 2004. Similar trend is observed in case of Nainital Lake. In contrast to above, Naukuchiyatal Lake is found almost in constant phenomena regarding the above parameters during the last decade. However, drastic changes are probably happened in the last century. There is a decreasing trend in area of the remaining lakes - Garudtal, Khurpatal, Sattal and Shyamlatal except Hanumantal Lake from the year 1997 to 2004.

Besides climate changes, there are innumerable causative factors responsible for destruction of the aquatic habitats. Some of these are massive deforestation activities along the fragile mountains during the past to fulfill multifarious demand of the people, construction activities, grazing and browsing by domestic cattle herds, faulty farming practices and forest fire. The resultant silt, cobbles and boulders from the mountain slopes find way to the lakes through adjoining streams and causes shrinking of the systems. The heavy silt load coming from adjoining mountain peaks around Nainital lake have deposited a layer of about 6 m on lake bottom in the last 5 decades. The residue of the forest fire that is a common phenomenon during summer months further aggravates the problem. The fire burns the varied forest litter, destroys the topsoil layer and accelerates the process of erosion. The first heavy shower wash away the inorganic matter along with the ash, eroded silt and debris into the nearby streams that ultimately reaches lake and alters the physico-chemical characteristics of the natural waters and causes fish mortality. It is estimated that the construction of 1 km road in Himalayan region results in erosion of 40-80 thousands m^3 of hills and the regional rate of soil erosion from Kumaon region has been estimated as 1 mm/year.

In order to draw long term policy for developing the aquaculture and sport fishery in these lakes depends on the accuracy of the available data regarding the type of the resource, way of change in the resources against time. It was concluded that the sizes of the various Kumaon lakes are decreasing in the last few decades even though a significant change is not occurred during the last century except for Naukuchiyatal.

Standalone and GIS-based models

An ever-growing number of models currently exist for abstracting, simulating and understanding complex details of physical, biological and social systems and subsystems. The domain of the individual modeling packages vary widely, from soils to hydrology, from socioeconomics to land-use transportation. While much progress has been made in recent years to develop models to help us to better understand our world, there is still much more to be done, especially in the area of integration. As we gain more detailed understanding of different granular systems and their components, the challenge in addressing complex issues such as global climate change is coupling these models together to gain a more complete picture. The combination of powerful hardware, sophisticated software, and increased human knowledge have all contributed to better models and more accurate simulations but a GIS-based framework for integrating these disparate representations of past, present and future states is key to understanding the whole earth.

Organizations

Climate Collaboratorium: The Climate Collaboratorium is a project of the Massachusetts Institute of Technology (MIT) Center for Collective Intelligence in the Sloan School of Management (http://cci.mit.edu/research/climate.html). The Climate Collaboratorium project aims to leverage new information technology and social media to bring together large numbers of like-minded yet geographically and socially dispersed individuals to collaborate on issues surrounding the global climate change debate. The Climate

Collaboratorium project hopes to show that adopting a framework that is decentralized yet carefully managed can be an effective method to approach large, resource-intensive problems such as global climate change.

Planet Action: Planet Action is a non profit collaborative initiative launched in June 2007 by Spot Image. Its purpose is to encourage the earth observation industry and professional GIS communities to address climate change by supporting projects that investigate and assess climate change environmental impacts in five areas of focus: human dimensions and habitation, drought and water resources, vegetation and ecosystems, oceans and ice and snow cover. By assisting in and funding projects that will support understanding and action on environmental impacts, the Planet Action initiative hopes to strengthen international cooperation and response to climate change problems.

Conclusion

With the relatively recent arrival of powerful geospatial visualization tools such as Google Earth, ArcGIS Explorer and NASA World Wind, it is now easier than ever for the citizen researcher to have some fun with maps while making a potentially important scientific contribution. First we need to create an environment that successfully brings together a plethora of data sources and modeling systems. Once the data and technology is in place and a clear framework is established, then comes the opportunity to organize a large group of volunteers who would do the 'grunt work' of tackling one of the biggest challenges facing us.

The Kumaun hills and the lakes are known for their unparallel beauty and attraction for millions of the tourists across the country. Besides tourists attraction the lakes, streams and rivers are lifeline to the people of the region. A GIS-Based framework for climate change studies in the coldwarer region in general and Kumaun in particular would help in assessment and prediction of the possible impacts of the changes on all the natural resources including aquatic systems, fishery and related socio-ecnomic issues.

DEVELOPMENT OF ADAPTATION MANAGEMENT STRATEGIES IN RESPONSE TO CLIMATE CHANGE IMPACTS ON COLDWATER FISHERIES AND AQUACULTURE

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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. Fish 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 cold water. This is especially important in freshwater river systems where temperature stress is likely to be more variable than in coastal systems.

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 brown trout fingerlings, farming technologies for brown trout and common carp in Kashmir and for rainbow trout, and for poly-culture of common carp, silver carp and grass carp, in Kumaon Himalayas where the water temperature ranged from 5-26 ^{0}C. Coldwater fish are important ecological indicators for climate change as they are very sensitive to changes in water temperature and other environmental conditions. Cold-water 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 cold-water fish habitat. It is essential 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.

Climate change projections in Himalayas

The Himalayas have the largest concentration of glaciers outside the polar caps. With glacier coverage of 33,000 km^2 it provides around 8.6 X 10^6 m^3 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 Himalaya s 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.

Potential risks and impacts

In general, the primary risks concern to cold water fisheries are changes in water temperature and stream flow that may be attributable to changes in air temperature and precipitation. Potential impacts of climate change on coldwater fish will be mediated

Table 1. Impact of climate change on coldwater fisheries

Drivers	Risk	Biophysical effect and implications for coldwater fisheries
Water temperature	Increase in water temperature	Critical to reproduction even though some adult fish may tolerate higher stream temperatures, microbial diseases, survival of fish
	Increase of average temp by 3°C	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	High rate causes fluctuations in stream flow	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	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 levels and reduced stream flows	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.
	Declining water levels and ice cover	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	Reduce the amount of cold water entering the water table.	Implications for hatchery – Decreased amount of water available for hatchery use, reduce production or increase cost due to use of expensive mechanical water chilling devices to produce high quality juveniles.

through changes in thermal habitat and stream base flow, as well as changes in stream geomorphology, groundwater recharge and input, water quality and other habitat variables. The potential impacts of coldwater fish to climate change is given in Table 1. However there is limited understanding on the severity of these impacts due to limited studies. These limitations in data, and the inability of models to account for the delayed impacts of environmental variability, reduces our understanding to the net impacts.

Vulnerabilities

Streams that will be especially vulnerable to climate change impacts will vary geographically and within regions depending on the condition of individual streams. Streams in undisturbed watersheds with sufficient groundwater input may be well buffered to climate change impacts and those in urbanized watersheds or flowing through agricultural areas exhibiting severe erosion may be more vulnerable to climate change impacts.

Researchers developed an Index of Sustainable Coldwater Streams (ISCS) to quantify fish community changes affected by water temperature and physical habitat quality for small streams in the River Philip Watershed, Nova Scotia, Canada. The ISCS was modified from an Index of Biotic Integrity (IBI) and intended for assessing the quality of streams as coldwater habitats. This tool is useful to identify fish species vulnerable to two major aquatic threats viz., global warming and habitat degradation that could significantly reduce the amount of undisturbed coldwater streams and to monitor fish community changes in relation to water temperature and physical habitat quality. It is a promising index to identify priority conservation areas and to monitor changes in aquatic environments. However more investigations are required to identify the vulnerabilities of stream fish populations to climate change impacts.

Mitigation

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 optimise the quality and extent of cold-water fisheries habitat. Fisheries related organisations 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 prioritise restoration and protection efforts to secure the best habitat in 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.

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 in 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:

- Data needs are required to address the identification of risks, vulnerabilities, and adaptation strategies are many and varied:
  - Climate change predictions for air temperature and precipitation
  - Hydrologic models linking changes in air temperature and precipitation to changes in water temperature and groundwater input to streams
  - Watershed-scale and reach-scale habitat data in response to climate change and influence on streams and fishes
  - 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.

Conclusion

Climate change is real, however careful planning supported by research prioritization will help us to address the impacts. With the continued rising of global temperatures that are expected during this century the hazards for those living in mountainous regions are set to become very severe. The focus should be on immediate actions for adaptation rather than making future projections. Responses to global climate change cannot be limited to mitigation efforts alone, but also demands adaptive measures such as implementation of ecosystem approach at all scales, and comprehensive risk assessments of sites, development of new technologies, new strains and species for diversification and planning for uncertainty to take care of extreme weather events. The researchers and all stakeholders must step up the efforts to fill the critical knowledge gaps on climate change impacts, assessment of related vulnerability, development of prediction models for different scenarios, assessment of carbon emissions, refining and development of adaptive tools to make cold water fisheries sustainable and productive in the face of climate change.

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