# Coldwater Fisheries Research and Development in India

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# COLDWATER FISHERIES RESEARCH AND DEVELOPMENT IN INDIA

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## INTRODUCTION

The term 'coldwater' generally refers to the aquatic ecosystem, which maintains thermal and oxygen levels for well being of trouts, mahseers, snow trouts and other minor species. The temperature generally falls within the tolerance limits of trouts and salmons belonging to family salmonidae (<20°C). A number of physical, chemical, geochemical and biological parameters of different water bodies e.g. water temperature, dissolved oxygen, velocity, turbidity, substratum, trophic status, food availability etc. influence the distribution and abundance of various species of coldwater fisheries. In Indian subcontinent, coldwater fishes are generally the denizens of the Himalayan and sub-Himalayan zones in the north and watersheds draining the southern slope of Deccan plateau (Sunder *et al.*, 1999).

Coldwater fisheries occupy an important place in fisheries sector of India. The country is bestowed with vast and varied coldwater / hill fishery resources which are spread over the Himalayan and peninsular regions as upland rivers, streams, high and low altitude natural lakes and reservoirs. There are around 10,000 km long streams and rivers, 20,500 ha natural lakes, 50,000 ha of reservoirs, both natural and manmade, and 2500 ha brackish water lakes (Fig. 2) in the high altitude (Mahanta & Sarma, 2010).

The coldwater rivers and hill-streams are known for their high velocity, waterfalls, rapids, cascades, deep pools and substratum comprising with bedrock-boulder-sand. These water resources harbour 272 fish species belonging to 21 families and 76 genera in the country of which 203 are recorded from the Himalayas while, 91 from the Deccan Plateau (Sehgal, 1999). The North-Eastern states have also rich ichthyo-faunal diversity (Fig.1). Among these, some species are known for sports purpose, a few of them have potential ornamental value and majorities are recognized as food fishes. In the Indian Himalayas, the cultivation of fish contributes little to the overall freshwater fish production. Virtually, every facility created for fish cultivation in the Indian Himalaya produces fish for stocking into the streams and lakes primarily to meet the requirements of sport fishing. Commercial fishery is also dependent, to some extent, on the stocking of lakes and reservoirs with fry and fingerlings. While for a number of years fish hatcheries in the Himalayas have been raising eyed-eggs, fry and fingerlings of brown and rainbow trout, and fry and fingerlings of common carp for stocking, only recently have some hatcheries started producing seed for stocking the indigenous mahseers and schizothoracines. To meet the ever-increasing demands of angling, subsistence and commercial fisheries, there has been a need for modernization of some hatcheries, as past neglect has resulted in a decline in seed production (Sehgal, 1999; Sarma *et al.*, 2012).

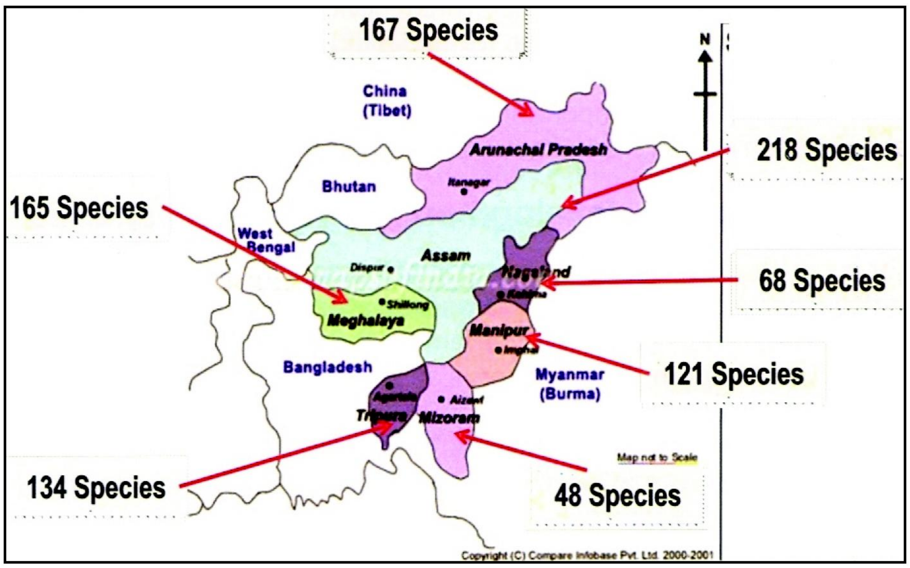



**Fig. 1. Species of North-East India (Source: Ali, 2010, Mahanta & Sarma, 2010)**

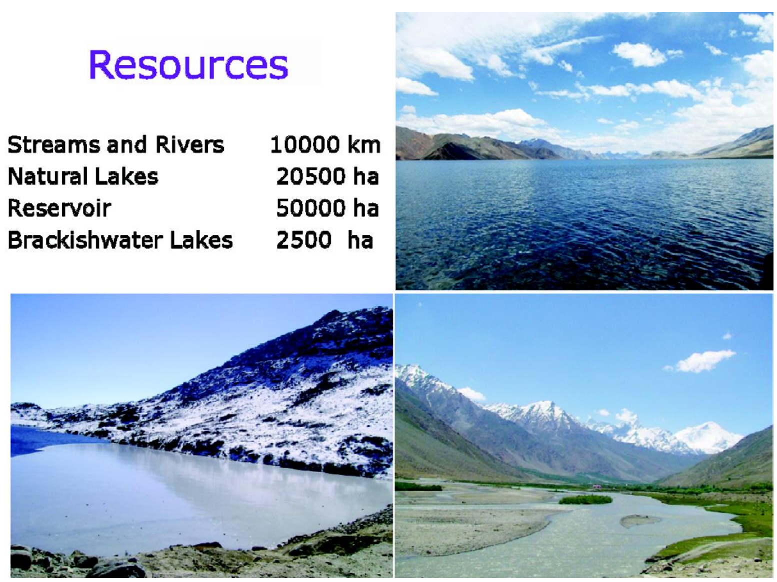



**Fig. 2. Coldwater fisheries resources of India** (See colour view on Plate-I, Fig. 1)

# COLDWATER ECOSYSTEMS

## The Coldwater Ecosystems (Gopal, 2012)

In order to understand the relationships among fish, hydel projects and climate change, let us first examine what are the "cold waters"? The words simply imply that the water temperature remains fairly low even during the summer season. From a North American perspective, Lyon *et al.* (2009) have distinguished cold waters from warm waters on the basins of mean summer temperature and the maximum mean daily temperature (Table 1). In cold waters, the maximum mean daily temperature remains lower than or nearly equals the mean summer temperature of warm waters. The atmospheric temperature declines with the elevation above the mean sea level as well as with the latitude. In India, the situation is a bit complex as the climate is greatly influenced by the monsoons and the Himalayan mountain ranges. Because almost the entire country lies within the tropical and subtropical zone (below 38° N latitude), and is well protected by the high Himalayan mountain ranges against the cold winds from the north, the mean daily temperature during the summer merely drops to 20 °C. Therefore, the altitude is the main determinant of the cold water conditions in the Himalayan belt. Generally, the aquatic systems lying above 2500 m above sea level are considered to constitute the coldwater habitats. It is noteworthy that the mean temperature of water in all Kumaon lakes during the summers remains above the 20 °C threshold, the maximum temperature rises well above 25 °C (Johri *et al.,* 1989). Thus, according to the criteria of Lyons *et al.* (2009), these lakes do not qualify to be coldwater lakes. However, Sehgal (1999a,b,c) and Raina and Petr (1999) included the aquatic habitats at elevations far lower than 1500 m also in their accounts of coldwater fish and fisheries. In general view, a distinction between cold- and warm waters must be based on the temperature thresholds of fish and other important aquatic biota in the Himalayan region. This is an important area for research in India (Gopal, 2012).

**Table 1: Thermal classification of streams in Wisconsin (Lyons *et al.,* 2009)**

| Class | MeanJuly-August | Mean July | Max. DailyMean |
|---|---|---|---|
| Coldwater | <17.0 | <17.5 | <20.7 |
| Cool water | 17.0-20.5 | 17.5-21.0 | 20.7-24.6 |
| Cool- Transition | 17.0-18.7 | 17.5-19.5 | 20.7-22.6 |
| Warm Transition | 18.7-20.5 | 19.5-21.0 | 22.6-24.6 |
| Warm water | >20.5 | >21.0 | >24.6 |

Besides the temperature regimes, which govern the vertical mixing patterns, and hence also the nutrient and oxygen circulation within the lakes, several other characteristics of the lakes and streams and their catchments affect their biotic composition and ecosystem functioning (Wang *et al.,* 2003, Brewer and Rabeni 2011). In the Himalayan region, the lakes and reservoirs differ greatly along the altitudinal gradient (Table 2) in their origin, mixing pattern, salinity, trophic status and total biodiversity including fish diversity. The catchment characteristics and the decreasing anthropogenic pressures at higher altitudes mean that the water bodies are poorer in nutrients with increasing altitude and the glacial lakes at a very high elevation are ultra-oligotrophic (Gopal, 2012).

**Table 2: Differences in lake characteristics along altitudinal gradient in Himalayan region**

| **Altitude** | **1000m** | **3000m** | **>5000 m** |
|---|---|---|---|
| Lake types | Valley lakes | | Mountain lakes |
| Origin | Riverine | Tectonic blocked valley | Glacial |
| Mixing pattern | Polymictic | Dimictic Monomictic | Amictic |
| Species Richness | High | Moderate | Low |
| Salinity | Freshwater | Freshwater | Brackishwater |
| Trophic status | Eutrophic | Mesotrophic Oligotrophic | Ultra-oligotrophic |

Rivers and streams differ along their length - from their source to their confluence with another river or the sea. Flowing from a higher to lower elevation, they cross different climatic zones but the direction of their flow is important because the lower reaches may experience a colder climate than the upper reaches (e.g., northward flowing rivers) or there may be no change in the temperature regime (as in case of the east- or west-flowing streams). Though, in the rivers and streams, the water temperature of the deeper layer is lower than that of the surface water, there is no vertical mixing with the change in seasons. However, the most significant change in the river's water temperature occurs with the change in flow regime (both volume and velocity) and is influenced also by the nature of the substratum (rocky, sandy or silty), the nature of vegetation cover along the banks, and the turbidity caused by mineral and organic matter (Wang *et al.,* 2003, Chu *et al.,* 2008, Brewer and Rabeni 2011). The major divisions of the Himalayan river are placed in Table 3.

**Table 3: Major division of the Himalayan region (Sehgal, 1999)**

| | |
|---|---|
| The Greater Himalayas (Himadri) | Longest and continuous, mostly north part of Nepal and parts of Sikkim. Average altitude of about 6100 m (20,000 ft) asl. |
| Lesser Himalayas (Himanchal) | In the south and north of Siwalik. Average altitude ranging from 3700m (12,000) - 4500m (15,000 ft) asl. |
| Siwalik (Outer Himalaya) | Siwalik is the lowest and narrowest section of Himalaya. Average altitude about 900m (3000ft) to 1200m (4000 feet) asl. |
| Trans-Himalayas | Stretches across Himalaya from West to East for about 1,000 km. Average altitude varies from 4500 to 6600 m asl. |

## COLDWATER FISHERIES RESOURCES

In India the coldwater/hill fishery resources are spread from North-Western to North-Eastern Himalayan region and some parts of Western Ghats, encompassing about ten Himalayan states. The state wise water resources including rivers and canals and total replenishable ground water are given in Table 4.

**Table 4: State-wise water resources in the Himalayan region**

| State | Length of rivers/canals (thousand km) | Water bodies (lakh hectare) | Total replenishable ground water |
|---|---|---|---|
| Jammu & Kashmir | 27.78 | 0.30 | 4425.84 |
| Himachal Pradesh | 3.00 | 0.43 | 365.81 |
| Uttarakhand | 2.69 | 0.20 | – |
| Sikkim | 0.90 | 0.03 | – |
| Meghalaya | 5.60 | 0.10 | 539.66 |
| Tripura | 1.20 | 0.17 | 663.41 |
| Mizoram | 1.40 | 0.02 | – |
| Manipur | 3.36 | 0.46 | 3154.00 |
| Nagaland | 1.60 | 0.67 | 724.00 |
| Arunachal Pradesh | 2.00 | 0.04 | 1438.50 |

[Source: Hand book on Fisheries Statistics 1996, Department of Agriculture and Cooperation and Ground Water Statistics 1996, Central Ground Water Board] mcm: Million cubic Metres Water bodies include reservoirs, lakes, ponds, tanks, beels and oxbow, etc. Data for the hill districts of Assam and West Bengal are not available separately.

## FISHERIES OF HIMALAYAN WATERS

There are two basic types of fisheries in the Indian Himalayan waters: subsistence fishery and sport/recreational fishery. Fish production in mountain streams is low and therefore, any commercial fishery is on a very limited scale. The low biological productivity results in the prevalence of small-sized fish, except in pools where fish have some shelter and resting place. Water temperature is always an important limiting factor influencing geographical distribution and local occurrence within one water system. In India, the subsistence and commercial fisheries exploit carps (*Labeo* and *Tor* spp.), lesser barils (*Barilius* spp.), schizothoracines (*Schizothorax* and *Schizothoraichthys* spp.), garrids (*Garra* spp.) and sisorids (*Glyptothorax* and *Glyptosternum* spp.). The other genera are of small size and of low economic value. The exotic brown trout (*Salmo trutta*) has established itself in some areas of the Himalayas (Raina and Petr, 1999; Sehgal, 1999 a, b, c).

The sports or recreational fishery in Himalayan waters is mainly based on *Tor putitora*, called golden mahseer, other species of mahseers and trouts. Valuable mahseer, rare Indian and exotic trouts available in coldwater regions are highly demanded among the anglers. The Indian Himalayas are an abode for sport fishing. Anglers from all over the world flock to the Indian rivers to try and hook the mighty mahseer or trout. About 3,800 km lengths of river and stream stretches in the upland region of our country are holding sizeable mahseers and 714 km brown trout, for angling purpose (Raina and Petr, 1999). The revenues from fishing licenses support fish and wildlife management agencies and the expenditures of anglers from recreational fishing contribute to local and regional economies by providing opportunities for livelihoods for locales, especially in regions where fisheries have been preserved in pristine or near-pristine conditions. (Raina and Petr, 1999; Sehgal, 1999 a, b,c).

## HISTORY OF INTRODUCTION OF EXOTIC FISHES IN THE HIMALAYAN WATERS

### Trout

### North-Western Himalayas

### (a) Jammu and Kashmir

The first attempt to introduce the trout in the Himalayas dates back to 1899 when Mr. F. J. Mitchell sought to obtain a consignment of eyed-eggs of brown trout (*Salmo trutta fario*) from England. In this consignment, however, due to non-availability of a cool room in the ship, all the eggs perished on way to India. In 1900, another consignment of eyed-eggs of the same fish was procured from Jioweitonin in Scotland. In this attempt, Mitchell succeeded in bringing living eyed-eggs to India for the first time. The swim-up fry from these eggs were successfully reared up to adulthood and the first spawning or egg taking of the brown trout was done in December 1905 at Harwan near Srinagar (Kashmir). During the period 1902 and 1904, several consignments of eyed-eggs were inter-mittently transplanted to Harwan from England. All those batches of eggs hatched successfully. In the year 1905-1906, Mitchell succeeded in establishing a regular trout hatchery at Harwan having a capacity of producing and rearing 100,000 green eggs. Since then brown trout has established itself throughout Kashmir and parts of Jammu notably in Bhadarwah and Poonch providing fly and spoon fishing year after year to thousands of anglers visiting the state (Sehgal, 2012).

It was from Kashmir that brown trout was spread to other sections of the Himalayas. From the hatchery at Harwan, eyed-eggs of brown trout were transplanted to almost all suitable streams and lakes of Kashmir, Gilgit, Abbotabad, Chitral, Kangra, Kulu, Shimla, Nainital and Shillong. The batch of eyed-eggs of trout of 1904, that came from England also included a small number of eyed-eggs of rainbow trout (*Salmo gairdneri irideus*). The latter, however, did not hatch and the effort to introduce this species remained suspended till 1911. In 1912, Mitchell succeeded in hatching and rearing rainbow trout eggs from a consignment presented to him by the Bristol Water Works from their headworks at Blagdon, England. Simultaneously, efforts to transplant *Salmo hucho* into Kashmir were also made but at a later stage, it was discovered that the species was anadromous *Salmo salar,* which perished in the new environment (Sehgal, 2012).

During the past two decades, three other species of salmonids viz. the eastern brook trout (*Salvelinus fontinalis*), the splake trout (hybrid between the lake trout and the brook trout) both from Canada and the land-locked variety of Atlantic salmon (*Salmo salar* ) from North America have been transplanted into trout hatcheries of Kashmir. Of these introductions, only the splake trout did not establish. The above salmonids were received as gifts from the diplomatic missions of Canada and United States of America in India. It is thus seen that four species of salmonids were successfully introduced in Kashmir. These are the brown trout, the rainbow trout, the eastern brook trout and the land-locked strain of the Atlantic salmon. Relatively speaking, brown trout is established firmly in the streams of Kashmir; rainbow trout is available mainly in the hatcheries; the brook trout and the land-locked strain of Atlantic salmon do not do so well even in the hatcheries, their success of breeding and survival being of a lower order (Sehgal, 2012).

## (b) Himachal Pradesh

The eyed-eggs of brown trout were brought to Kangra and Kulu valleys of Himachal Pradesh from Kashmir in various years. The streams of Kangra valley that were stocked in 1911 were Baner, Awa and Binun (Binwa). All the eyed-eggs planted in the Binun were washed away by the heavy floods of that year. Yearlings of brown trout were seen in the Baner and the Awa streams during 1912 in appreciable numbers but, thereafter, none were encountered. From 1918 onwards, efforts to transplant eyed-eggs of brown trout into Baner and Awa streams were continued annually but with little success. As per the revenue records of the Kangra district of 1925, the eyed-eggs did hatch out but the progeny could not be kept track of. Occasionally one or two specimens of brown trout were caught in the two streams till 1947 when a devastating flood seems to have decimated the stock completely. On the whole, the results of transplantation in Kangra valley were not satisfactory. The failure was attributed to: (i) the limited stretches of the upper reaches of the streams suitable for trout did not have deep pools where fish could seek shelter during the monsoon floods when streams were raging torrents and (ii) in the lower reaches, the water was warmer and not suited to harbour brown trout. About 400 fingerlings of brown trout were transplanted in the year 1924 in a lake in Kangra valley called Kareri Dal located at an elevation of about 3,051 metres above msl. Attempts to transplant rainbow trout in the three above-stated streams were unsuccessful (Sehgal, 2012).

The introduction of brown trout into Kulu valley started with efforts of Howell, the then Warden of Fisheries, Punjab. Eyed-eggs of brown trout brought from Kashmir in 1909 hatched successfully at Mahili Hatchery, Katrain. 22,862 swim-up fry produced therefrom were released in the streams around Manali and Katrain. By 1912, egg-taking of brown trout commenced at Mahili hatchery. The transplanted fry started yielding fruit. Brown trout weighing about 1.5 kg were hooked near Katrain and as far downstream as at Mandi in 1911-1912. From Kulu, brown trout was taken to Barot in Uhl valley in 1916 and a full-fledged trout hatchery was established there. From Barot, trout further spread to Paber and Sangla valleys of Himachal Pradesh. Chirgaon hatchery in Pabar valley and Sangla hatchery in Baspa valley were subsequently set up.

A consignment of 5000 eyed-eggs of rainbow trout from Kashmir was introduced at Mahili hatchery in 1919. The progeny on attaining maturity were first spawned in 1922, which was repeated in subsequent years. Due to its greater susceptibility to infections and diseases, the introduced stock of rainbow, however, dwindled and the culture of the species was abandoned at Mahili. A batch of eyed-eggs of rainbow trout was also transplanted from Achabal, Kashmir to Barot hatchery in Uhl valley from where they were planted at Patlikuhal hatchery in Katrain and the Chirgaon hatchery. Brown trout culture also spread to the then princely State of Chamba in 1923 where they were first transplanted in a small hatchery at Srianghat, about 5.0 km from Chamba town. As per the revenue records of the former princely State (revealed to the junior author by Shri Madho Ram, the then Dewan of Chamba State) eyed-eggs and fry of brown trout were regularly stocked in the headwaters of the River Ravi and specimens weighing between 3.0 to 5.0 kg were repeatedly taken there till 1947. The devastating flood of 1947 adversely affected the stocked fish. Recently, the Himachal Pradesh Fisheries Department has revived their effort to establish trout culture in Chamba and restock the head-waters of the river Ravi (Sehgal, 2012).

## (c) Central Himalayas

Efforts to establish trout culture in Uttar Pradesh started with the transplantation of 10,000 eyed-eggs of brown trout from Kashmir to the Bhowali hatchery located about 12 km from Nainital. The reared fingerlings were planted in Nainital, Naukuchiatal, Sattal, Mewatal etc. However, trout culture did not prove a success in Kumaon hills probably due to comparatively high summer temperatures prevalent in the area. In Tehri region, trout culture commenced with the transplantation of eyed-eggs from Kashmir to Talwari and Kaldayani hatcheries. The two hatcheries were set up to provide stocking material for the Rivers Pinder, Birehi and Asiganga which were kept in reserve to provide angling pleasure to the guests of the then ruler. In 1951, the charge of the hatcheries was taken over by th~ Animal Husbandry Department of Uttar Pradesh. Due to lack of required technical knowhow the stocks of trout at Bhowali, Talwari and Kaldayani hatcheries started dwindling resulting in the closure of Bhowali and Talwari hatcheries. After the formation of a separate Department of Fisheries in Uttar Pradesh in 1966, efforts to revive trout culture have been made. A beginning in this direction was at Kaldayani hatchery where the few surviving remnants of brown trout stock are being propagated afresh.

### (d) Eastern Himalayas

Attempts at establishing trout in Eastern Himalayas have not been successful so far except probably in Arunachal Pradesh. Eyed-eggs of brown trout that were brought from Kashmir and planted directly in the streams of Darjeeling and Shillong areas apparently perished. The first attempt at transplanting eyed-eggs of brown trout in Arunachal Pradesh was also a failure. This is attributed to total freezing of the water in the supply channel to the hatchery at Sela which was especially built in 1967 to incubate the transplanted eyed-eggs. In subsequent attempts in the following year, yearlings were directly planted in certain streams where they were reported to have established themselves.

Two consignments of brown trout yearlings were airlifted from Srinagar to Nepal in the years 1970 and 1972. These are reported to be thriving in the streams of that country. It was reported the introduction of brown trout in the Ha valley in Bhutan situated at an altitude of 2,743 to 3,048 meters above msl. Availability of brown trout has also been reported in Sikkim (Sehgal, 2012).

## COLDWATER CAPTURE FISHERIES AND ECOLOGY

### Stream Ecology of North-West Himalayan Streams

### Kashmir streams

General creel census of important trout streams in Kashmir valley was undertaken to determine fishing pressure and productive potential. The study was to fix the bag limit for angling on a sustainable basis. This work assumes importance in view of promoting angling tourism of brown trout *Salmo trutta fario*. Similarly, in Jammu region, potential mahseer seed collection sites were identified and quantified in local streams of Jhajjarkotli, Anji, Beni, Duddar and Ujh. Based on various ecological parameters involving water quality and status of benthic population in different streams, a classification of streams was developed, which reflects the productive potential of each stream type. The results of this investigation were helpful in formulating any ecological action plan for stream management with focus on fisheries development and conservation (Sehgal, 2012).

### Ladakh streams

The investigations carried over on river Indus in Ladakh region of Jammu and Kashmir at above 3,000 msl by the DCFR in December 2007 revealed that Indus and its stream waters are alkaline having pH in the range of 8.1-8.8, temperature between -0.4 and 2.0°C, dissolved oxygen 9.2-12.0 ppm, alkalinity, 68-72 ppm, silicates, nil. The fish diversity within the system was found to be composed of 17 speceies, mainly comprising of snow trouts (5 spp.), loaches (9 spp.) and 3 exotic species (3). The snow trouts are represented by *Diptychus maculates, Schiopygopsis stolczkae, Schizothoraichthys labiatus, Schizothorax richardsonii, Ptychobarbus conirostris*. Amongst loaches, three belong to genus *Nemacheilus, N. araft, N. montanus, N. fascimaculatus*; six belong to genus *Triplophysa, T. choprai, T. gracilis, T. griffthi, T. ladacensis, T. microps and T. tenuicauda*. Exotics are represented by *Salmo gairdneri gardneri* and by *Cyprinus carpio communis* and *C.carpio specularis* (Sehgal, 2012).

## Himachal streams

The investigations carried over on the hill streams of four basins (Satluj, Beas, Yamuna and Ghaggar) by many investigators showed that these streams can be classified in four types depending on altitude and bed type. Streams (Faujal, Sarvari, Parvati, Sainj, Tirthanand, Jeuni) which are in the altitude range of 850-1,440 ill and above having temperature range of 10- 16°C, pH range of 7.0-9.4 and total alkalinity range of 38-90/mg have only 1-2 species, trout and *S. richardsonii,* latter being the dominant. Streams in the altitude range of 700 m to 1,100 m with temperature range of 18-20°C, total hardness range of 46-139/ mg and alkalinity range of 112-210/ mg commonly present in valleys (Ashni, Giri, Jeuni, and Jarol) support a variety of 5-8 fish speceies with mahseer being the dominant. Streams (Ali, Baner, Gaj, Suketi and Dabar) in the altitude range of 400-700 masl having temperature range of 20-22°C, total hardness range of 71-162 mg/litre, have 4-15 fish species with no group being dominant. *T. putitora* and *S. richardsonii* are important fish species from commercial point of view. *Barilius bendelisis* is present in almost all streams of lower and middle reaches of Himachal Pradesh. Fishes like *Channa spp, Xenentodon sp., Sperata sp.,* and *Heteropneutes sp., Mastacembelus sp*., have started colonizing the streams but do not form an important fishery. Presence of exotic fish, *Cyprinus carpio* in nursery streams is a worrying factor (Mahanta *et al.*, 2011).

## North-East Himalyan streams:

The streams within north-eastern Himalaya above 1,000 masl have usual coldwater characteristics but in regions like Meghalaya and other parts where coal mining is going on, these do not show typical coldwater characteristics because of the impact of acid mine drainage (AMD, i.e removal of vegetation and soil to gain access to metal or coal deposits). The dissolved oxygen content range from 5.7-11.6 mg/L, have presence of free carbon dioxide, 5-9 mg/litre and certain stretches are acidic. Coldwater fish germplasm within these streams is represented mainly by snow trouts (*S. richardsonii, S. esocinus, Schizopygae progastus*) mahseers (*T tor, T. putitora, N. hexagonolepis*) and carps (*L. dero, L. pangusia, S. semiplotus*) (Mahanta & Sarma, 2010).

## Central Himalayan streams

### *Kumaon Himalayan streams*

The investigations were carried out in Gaula, Gandaki, Ladhiya and some other lotic systems in the region. These streams have pH in the range of 7.3-8.2, temperature range of 13.2-22.3 mg/litre, dissolved oxygen range 8.8-11mg/litre and total alkalinity range of 54.0-120 mg/litre. The productive potential of the systems was evaluated in terms of biodiversity. The fish biodiversity of Gaula stream was represented mainly by indigenous mahseer (*Tor putitora*) and snow-trout (*Schizothorax richardsonii*) along with other species, viz. *Garra gotyla, Barilius bendelisis, Nemacheilus sp*. and *Botia birdi*. The snow-trouts of 160-250 g in weight and 150-260 mm in length were frequently encountered. The sex ratio of *T putitora* was recorded at 1: 1.6 (175-255 mm in length). On the other hand the sex ratio of male to female of *S. richardsonii* in the stream was 0.5: 1. The males were in oozing stage in June while gravid females were encountered between July and August. The experimental fishing revealed the CPUE value to range between 107 and 500 g/man/hr. The contribution of *S. richardsonii* to total catches was nil-67.3% and that of *T putitora* between nil and 59%. Other species also contributed significantly to total catches at specific stretches.

The rivulet Ladhiya flowing through the Middle and Lesser Himalayan belts of the Central Himalayas, in district Champawat (Uttarakhand) is a tributary of the river Kali. A total of 10 fish species have been observed from the system, in which all 10 were recorded from the lower stretch, 5 from upper and 10 from its major tributary - Kwerala.

The fishery in the rivulet is predominated by *S. richardsonii* (36.07 %), followed by *T putitora* (34.25 %), *G gotyla* (7.46 %), and *B. bendelisis* (6.85). The experimental fish catch per unit effort (CPUE) from the rivulet varied from 0.0 g to 42.2 g

Fishes once abundant in Kumaon Rivers and streams have now become rare. One of the principal reasons for decline in fish fauna is their mass killing by poisoning, dynamiting and using small-sized mesh nets or catching. The rapid deforestation along the catchment of the streams and rivers facilitates soil erosion, which ultimately deteriorates natural feeding and breeding grounds of fish. Apart from these activities, the habitat loss due to water abstraction for agriculture, domestic and other uses leads to an appreciable reduction in minimum water volume required for fish growth. These physical and chemical modifications of the river result in an ecological imbalance for fish communities, which cause loss in their diversity.

## COLDWATER FISHERY RESOURCE ASSESSMENT

Resource assessment in the hilly regions is a herculean task due to its unique topographical features and inaccessibility. However, the mapping of coldwater fishery resources and a well designed information system such as geographical information system (GIS) and remote sensing may play an important role in sustainable development and management of coldwater fisheries. Information available so far on coldwater resources of India is obsolete. The development of an information system will immensely help the coldwater fisheries sector for comprehensive planning on regional basis.

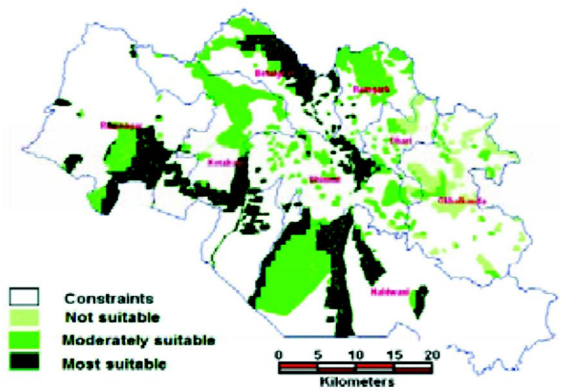



**Fig. 3. Site suitability map for aquaculture in Nainital *District***

The resource availability status in an area with information on culture potentiality will definitely provide a basis for development and scientific management planning for the coldwater fisheries sector. In this context, DCFR, Bhimtal has consistently been working for the development of GIS based decision support system based on the spatial database on physico-chemical parameters of soil, water and infrastructure facilities for aquaculture in the hill states. Initially on a pilot scale, district Nainital of Uttarakhand has been selected for the study (Fig. 3). Spatial and non spatial databases have been arrived at and an attempt has been made to develop a Decision Support System for retrieving intelligent inference much to the utility of the planners and people at large. The suitability map was created based on GIS which would be made available for common man use. This Decision Support System will enhance the possibility of developing aquaculture in hills (Kumar *et al.*, 2012).

## COLDWATER FISH PRODUCTION

The present exploitation of fishery resources in upland Himalayan regions comes mainly from capture fisheries, though fish production through culture practices is gaining momentum. At present the total fish production from upland areas forms about 2 % of total inland fish production of India, which forms a very small contribution to the total fish production. The aquaculture production potential of the coldwater sector has not been exploited to its fullest extent. As far as coldwater fisheries development is concerned, except a few hill states like Kashmir valley and Himachal Pradesh other mountain regions of India are still poorly developed or underexploited.

To enhance the fish production, these hill states endowed with natural lakes and reservoirs could be better utilized under culture based capture fisheries programme. Initiatives for open water cage culture in Himalayan lakes have also been taken up by DCFR for the stock enhancement as well.

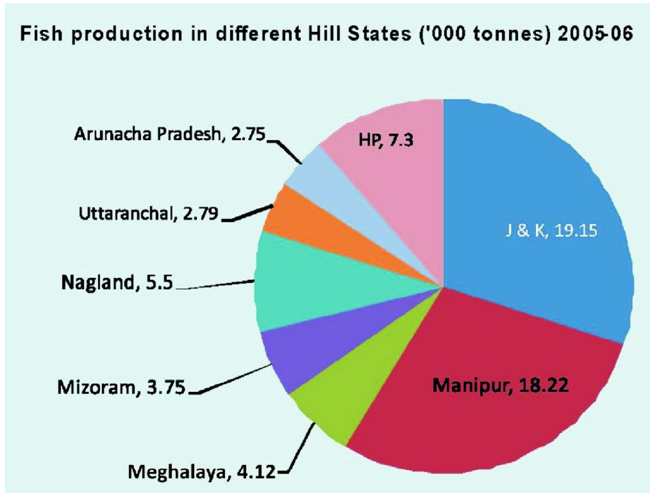



**Fig. 4. Total fish production in different hill states (Mahanta & Sarma, 2010)**

**Fig. 5. Floating cages installed at Bhimtal Lake by DCFR for *in situ* seed rearing**
(See colour view on Plate-II, Fig. 2)

## AQUACULTURE

### Culture of Indigenous and Exotic Coldwater Fishes

Today, the available technologies allow the culture of a number of exotic and indigenous coldwater fish species in the Indian Himalayas. The most common exotic species are rainbow trout, brown trout, common carp, while the indigenous fish are: mahseers (*Tor putitora* and *Tor tor*), and schizothoracines (*Schizothoraichthys esocinus, S. progastus, Schizothorax richardsonii, S. niger and S. curvifrons*). Among these *Tor putitora*, *S. progastus* and *S. richardsonii* are preferred because of their wide range of distribution in the Himalayas.

The distribution of rainbow trout worldwide attests to its ability to adapt itself to a variety of aquatic environments under aquaculture conditions. Rainbow trout can be propagated artificially, which is important for its production as food fish. The fish can be fed artificial feed and withstand temperatures of up to 26.6°C for short periods. It also tolerates low dissolved oxygen content of water, resistant to some fish diseases and grows fast. In open waters, water temperature and precipitation are the primary factors affecting the survival and production of naturalized populations. The optimum thermal regime for the species lies in the range of 12-20°C and the annual precipitation and freshets are important.

The snow trout or mountain barbel (*Schizothorax richardsonii*) is widely distributed in the Indian Himalayas, from Ladakh in the North-West to Sadiya in the East. The species is an inhabitant of snow-melt and glacier-fed streams in the Greater and Lesser Himalayas. They undertake migration during winter months when the temperature in the Greater Himalayan waters reaches the near-freezing point. This induces them to migrate downstream and frequent the warmer spring-fed streams in search of suitable spawning grounds. The optimum temperature for spawning is 18-21.5$^{0}$C. The fish is a typical benthic feeder with a mouth well suited for rasping the microbiota growing over the bottom rocks, boulders, stones, etc. The early fry and fingerlings (15-65 mm in total length) consume mainly the larvae of Diptera, Nymphs of Mayflies and larvae of Caddis flies (66.4%, 23.2% and 9.5% respectively). Fish of 85 to 105 mm total length consume primarily Diatoms (66.6%), Blue-Green algae (11.9%), Insect larvae (6.7%) and Detritus (11.8%). Fish of 133 to 300 mm subsist mainly on Diatoms (60%), Blue-Green algae (9.6%), Green algae (8%), Insect larvae (10.2%) and Detritus (8.7%). Presence of gravel and sand in the gut is due to rasping the algal encrustations from stones and rocks (Sehgal, 1988, 1999; Vass & Raina, 2002).

**Fig. 6. Carp culture in poly tank in Uttarakhand Integrated fish farming in Arunachal Pradesh**
(See colour view on Plate-I, Fig. 3)

Traditional fish farming is not in regular practice in most of the hill states. Therefore, there is immense scope for the development of the farming to provide a source of employment to the hill people. Many suitable sites are available in different parts of the hill states, which could be utilized for fish production through aquaculture. The suitable sites are lying along the banks of the rivers, rivulets, streams and streamlets. Depending upon the micro-climatic conditions of the region, such suitable patches of water bodies should be identified throughout the region and brought under any one of the three-pronged fish farming practices.

The aquaculture of coldwater fish in the Himalayas is limited, considering the total area of this region and the vast resources of water. At the end of the 1980s only 63 ha were under aquaculture in an area of 594,000 km$^2$. The present status of aquaculture of trout, common carp, mahseers and schizothoracines is described as follows (Sehgal, 1999).

## Trout Cultue

Trout farming has immense scope in the Himalayan and some peninsular regions where sufficient quantity of quality water is available (Singh *et al.,* 2017). Trout need highly oxygenated (above 6 mg l$^{-1}$) cool water (5-20$^0$C) and high investment in the form of pond construction, procurement of seed, feed and maintenance of fish health. So, its expansion has limitations due to these barriers coupled with limited. At the beginning of the 1990s farming of trout was being carried out on several fish farms in Kashmir (4), Himachal Pradesh (3), Uttaranchal (2), Arunachal Pradesh (1) and Sikkim (1). The siting of these aquaculture facilities was based on the availability of water in required quantity and quality, i.e. from rheocrene springs and snow-melt/glacier-fed streams. Most farms receive water supply from snow-melt/glacier-fed streams. The old facilities at Laribal, Harwan

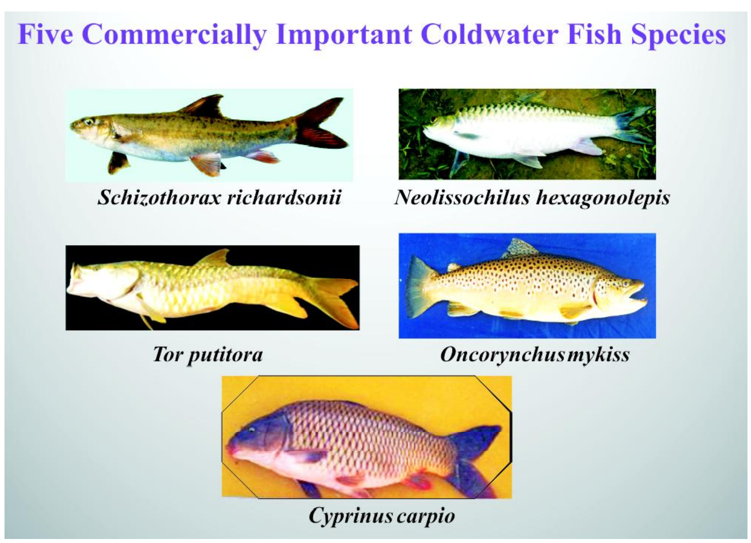



**Fig. 7. Commercially important major coldwater fish species** (See colour view on Plate-I, Fig. 4)

and Achabal (the last receiving seepage water of the Bringhi stream and hence not a true spring-fed facility) in Kashmir, Katrain in Himachal Pradesh, and Kaldhayani in Uttarakhand might have been established when the stream water did not have the present level of silt load. At present a heavy load of silt reaches these farms from February to September. This is the result of soil erosion in their largely deforested catchments. Only from October to January is the silt load low. This has adversely affected the performance of these farms.

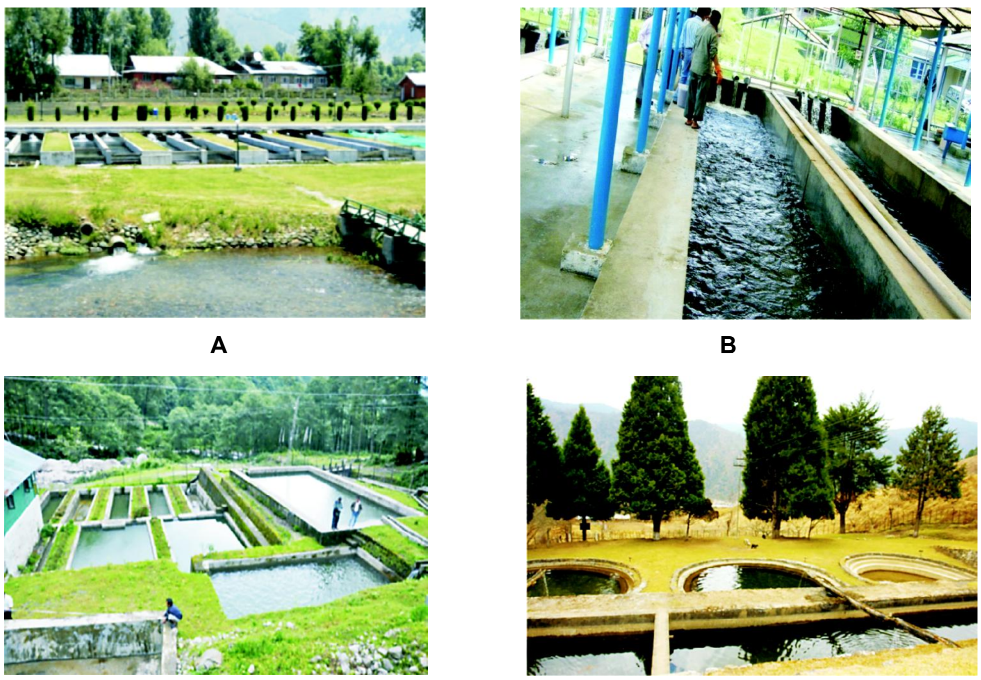
**Table 5: Trout farms located in different states (Joshi, 2010)**

| S. No. | States | Numbers |
|---|---|---|
| 1. | Jammu and Kashmir | 7 |
| 2. | Himachal Pradesh | 5 |
| 3. | Uttarakhand | 4 |
| 4. | Sikkim | 3 |
| 5. | Arunachal Pradesh | 2 |
| 6. | Manipur | 1 |
| 7. | Tamilnadu | 1 |
| 8. | Kerala | 2 |
| | Total | 25 |

Trout hatcheries in the Himalayan region are of moderate size, having the capacity to incubate 64,000-480,000 green eggs. After the swim-up fry emerge they are fed initially on emulsified yolk of hen's egg followed by a mixture of yolk of hen's egg and bovine liver emulsion in 1:1 ratio. After having learnt the acceptance of initial artificial feeds, the fry are transferred to outdoor nurseries. In the northwest Himalayan farms the emergence of fry of brown and rainbow trout coincides with spring rains and hailstorms. The hailstorms may chill the already cold water to a low temperature, which may lead to high mortality of the young fry. In March-April the snow /glacier-melt fed water containing fine silt is also detrimental to the survival of trout fry in trout farms. During the first three months the survival of fry fed on a diet of bovine liver and dry powdered silk-worm pupae, varies between 10.8-15.8%. Thus the principal factors responsible for fry losses are silt load, hailstorm-cooled water, diseases such as myxosporidiasis, octomiasis, ichthyophthiriasis, and nutritional deficiencies. Better quality feeds result in a survival from 50 to 61%, with maximum feed efficiency of 79.9% at 35% crude protein level. Yearlings and 1+ age group are raised in growing ponds and raceways. Trout is fed there on a conventional diet consisting of local raw fish, mutton, slaughter house waste, dry silk-worm pupae, etc. The most serious loss of growing trout is due to nutritional imbalance and non-observance of prophylactic measures (Sehgal, 1999).

**Table 6: Annual trout production in India and the world (Mahanta & Sarma, 2010)**

| World production | 500,000 t |
|---|---|
| Indian production | 500 t |
| Jammu & Kashmir | 150 t |
| Himachal Pradesh | 250 t |
| Other states | 100 t |



A B

C D

**Fig. 8. Trout farm of Kashmir (A), Himachal Pradesh (B), Sikkim (C) & Arunachal Pradesh (D)**
(See colour view on Plate-II, Fig. 1)

## Culture of Schizothoracines

The culture of schizothoracines is still in its experimental stage. Like the mahseers this group of cyprinids has shown a sharp decline in catches all along the Himalayas due to indiscriminate fishing and environmental degradation. It is believed that the introduction of exotic common carp has adversely affected the schizothoracine fishery in the lacustrine environment of the Kashmir valley lakes. While in the Jhelum River the presence of the common carp has had no impact on schizothoracines as reported by the some work. Sehgal (1974) started experiments with collection and artificial fertilization of eggs from *Schizothorax planifrons, S. curvifrons and S. plagiostomus*. These fish make spawning runs from Lake Wular into two inflowing streams. Subsequently, egg taking of *S. plagiostomus* and raising of post-larvae and fry was successfully carried out using mature specimens caught from several streams of Himachal Pradesh. Eggs of *S. niger* from Lake Dal were artificially fertilized and achieved a hatching rate of 10-40%. The result of induced breeding and artificial fertilization and incubation of *Schizothoraichthys esocinus* in a running water system gave cumulative hatching of 30-55%. Further rearing of *S. esocinus* up to fry and fingerling on artificial feeds met with some success. There is still work to be done on schizothoracine seed production to achieve a fully viable fingerling stage ready for release into rivers and lakes (Sehgal, 1999).

**Fig. 9. *Schizothorax richardsonii* collected from the stream of Arunachal Pradesh**
(See colour view on Plate-II, Fig. 2)

## Culture of Common Carp

In the Himalayan region two German phenotypes of common carp (mirror carp and scale carp) are commonly produced in aquaculture. These species are cultivated primarily to produce seed for extensive pond culture and for stocking of lakes and reservoirs. Common carp is produced in fish farms of the State Fisheries Departments of Himachal Pradesh, Uttaranchal, North Bengal, Arunachal Pradesh, Meghalaya, Manipur and Nagaland. The majority of the farms are located in the Lower Himalayas and the Himalayan foothills (Siwaliks). In the Indian Himalayas the common carp is successfully bred in cement tanks, in rectangular cloth containers fixed in ponds (hapas), and in earthen ponds. Since common carp eggs are adhesive and need a spawning bed, aquatic plants such as Hydrilla and Najas, palm leaves, dried pine and cedar needles and banana leaves are used as a substrate in different parts of the Himalayas.

As the slow growth rate and unwanted reproduction have been identified as the potential constraints on yield of common carp in hill aquaculture, DCFR, Bhimtal has imported two improved Hungarian strains of common carp (Ropsha scaly & Felsosomogy mirror carp) at its field centre, Champawat, Uttarakhand to ascertain and evaluate the traits. The growth performance of these Hungarian strains and existing local strain of scale carp (Bangkok strain) has been evaluated. Highest growth was recorded in Hungarian mirror carp under polyculture system followed by Hungarian scale carp (Mahanta *et al.*, 2010).


**Fig. 10a. Hungarian scale carp** (See colour view on Plate-II, Fig. 3a)


**Fig. 10b. Hungarian mirror carp** (See colour view on Plate-II, Fig. 3b)

The breeding of these two improved strains has been done successfully at Champawat centre and the seeds of F1 generation (named as Champa-1 and Champa-2 respectively) have been transported to other hill states to assess its culture and growth potential on experimental field trial basis. We hope these improved strains will help in improving hill aquaculture production in near future (Srivastava *et al.*, 2012).

## USE OF POLYHOUSE IN FISH FARMING

Low water temperature during winters is the main limiting factor in hill aquaculture, particularly in high altitudinal regions. Hence, raising the water temperature by use of polyhouse is of paramount significance. Therefore, experiments were conducted at DCFR's Champawat farm during winters (November to February) to ascertain the impacts of greenhouse effects on ambient water quality, temperature and manifestation of the raised temperature on the growth and survival of common and grass carp fry in the agro-climatic conditions of Lesser Himalayas. The ponds covered with polyhouse revealed drastic increase in temperature in the covered area. The air temperature in the polyhouse was

6.05°C higher than the control at morning (minimum range), while it was 9.24°C higher in the afternoon (maximum). Likewise, the water temperature in the pond raises 7.06°C in the morning and 10.96°C at the afternoon, than the control ponds. As a result, growth rate attained by common carp fry in the experimental ponds was 39.07 % higher than that of the control ponds. The grass carp fry also registered marginally higher (3.41 %) growth rate over the control ponds (Mahanta *et al.*, 2011).

## ARTIFICIAL BREEDING OF SNOW TROUTS

Different species of snow-trouts are indigenous to Kashmir inhabiting both lacustrine and riverine systems. Most of the species are endemic in the valley and through the years of anthropogenic and environmental stresses, their fishery is on the decline. To restore this fishery, the first initiative for artificial propagation was attempted in Kashmir and success was achieved in obtaining pure and healthy seed of different species such as *Schizothoraichthys niger,* S. *esocinus,* S. *curvifrons,* S. *micropogon* and *Schizothorax. richardsonii* through artificial fecundation. The fecundity per kg body weight of fish was reported to range between 17,000 and 35,000 ova in different species. The size of eggs ranged between 3.0 and 4.5 mm and the rate of fertilization ranged between 70 and 90%. The fertilized eggs of *Schizothorax niger* could be incubated both under still and flowing water conditions, while in other species the larval hatching was successful only under flowing water. The reported cumulative survival from egg to swim-up fry was 80% in *Schizothorax niger* and 60% in *Schizothorax micropogon* in a specially designed incubator with flowing water facility. However, the percentage survival in *Schizothorax esocinus,* S. *curvifrons and S. richardsonii* ranged between 35 and 55, 25 and 30, and 30 and 35 (Sehgal, 1999). Joshi (2001) did some commendable work on brood stock rearing of threatened *Schizothorax richardsonii* in aquaculture.

## MAHSEER BREEDING AND CONSERVATION

In order to save mahseer from extinction, it is necessary to culture them and propagate their seed on a large scale and transport them to streams, lakes and reservoirs for ranching. Earlier, seed of mahseer was collected from natural sources but recently seed has been produced through artificial propagation. With the approach of spawning season, the brood fish leave their safe haunts in deep pools of rivers, lakes and reservoirs and ascend shallow areas for breeding. The brood stock is obtained from natural grounds in rivers, lakes and reservoirs. Where ripe fish congregate at the breeding grounds in the streams and at the outfall of the streams in the lakes/reservoirs are carefully collected either by cast net or gill net. The selected ones are stripped of their eggs and milt by exerting pressure on the caudal portion of the fish in a particular manner. The stripped eggs are collected in the plastic trays and the milt is spread over the eggs. The eggs and milt are thoroughly mixed with the help of a bird's quill and allowed to stand for 5 minutes.

After that, the eggs are washed thoroughly with clean oxygenated water 3-4 times to remove the excess milt. Then the trays containing eggs are filled with fresh water and allowed to stand for 15-20 minutes in shade to allow the eggs to swell and harden before releasing them in hatching trays. The fertilized eggs are demersal, lemon yellow or brownish golden in colour. The percentage of fertilization is about 90-100%. Hatching period of *Tor putitora* is 80-96 hours in water temperature 22-24.0 °C. Once the yolk-sac is completely absorbed and swim- up fry start moving freely, the stock is shifted to nursery tanks and stocked @ 8,000 - 10,000/tank with water flow of 2-3 litres per minute. The young ones are fed with artificial feed. With a view to develop table size fish or brood stock, the natural seed or hatchery reared seed can be stocked in the earthen ponds, cement ponds, running water ponds or cages (Mahanta and Sarma, 2010; Sarma *et al.*, 2012).

Recently, DCFR has made tremendous success in brood stock management of golden and chocolate mahseer in pond environment and seed has been produced from the pond-raised brooders. To facilitate the distribution of Mahseer seed to distant places, Mahseer eggs are being transported in moist cotton by air. Fertilized eggs after water hardening process were placed between the layers of moist cotton in 2-3 layers and then kept in plastic boxes. As the minimum hatching period is 70 hours, sufficient time is available to transport the eggs to long distances (Sarma *et al.*, 2009)

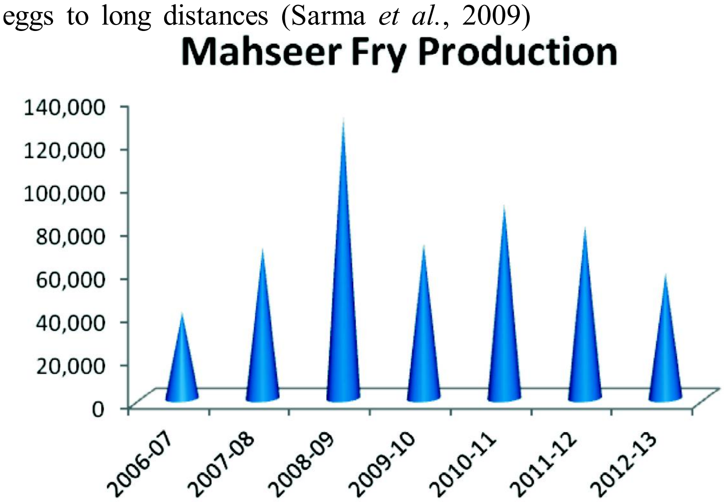



**Fig. 11. Seed production of golden mahseer fingerling at ICAR-DCFR**

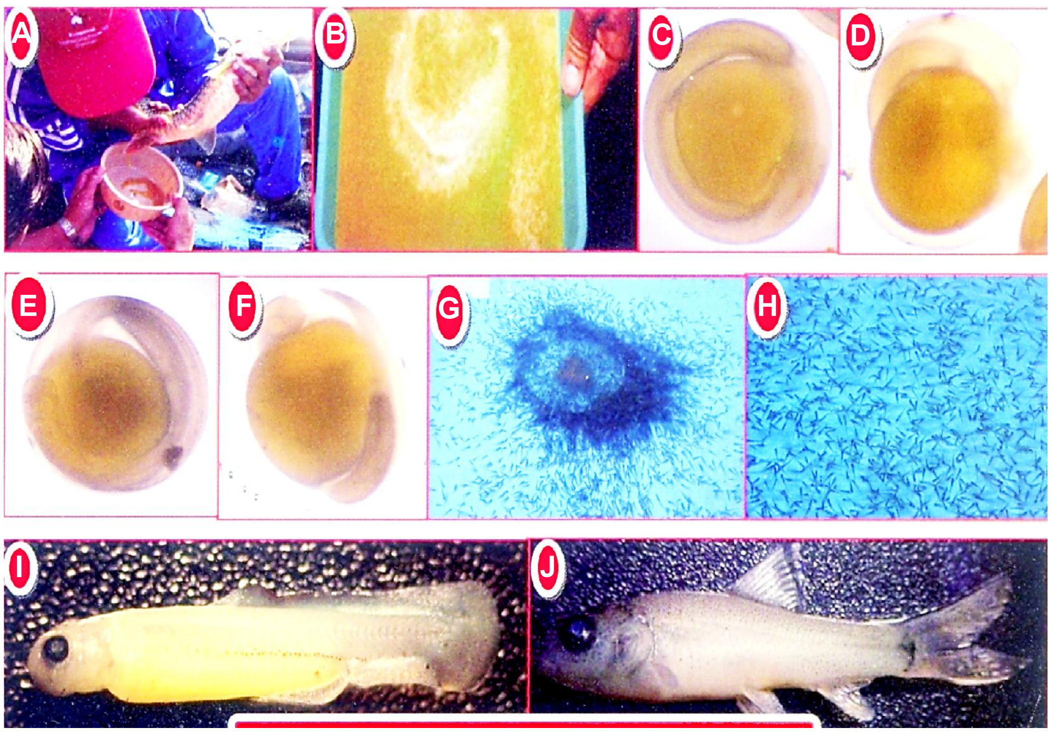
The lack of a well established hatchery technology for Mahseer and for rearing of its seed was one of the major obstacles in introducing the Mahseer ranching. The Directorate of Coldwater Fisheries Research, ICAR, India has taken a very bold step for seed production of Golden Mahseer and Chocolate mahseer in the Hatchery Complex of the Directorate and releasing the seed in the different streams/rivers/lakes in all over India as well as abroad to increase the population of this fish in the natural habitat and also to conserve the germplasm from extinction. The hatchery produced seed has been transported to Department of Fisheries, West Bengal, Department of Fisheries, Sikkim as well as other Institutions. The seed has also been transported to Papua New Guinea to stock in the Ramu River. Directorate of Coldwater Fisheries Research has also stocked golden mahseer in Shyamlatal Lake in Kumaon, India in 2001 wherein it has survived very well, grown to mature sizes and now turning out to be an attraction for tourists. It can be expected that stock so introduced may continue for generations and may serve as natural sanctuaries. These kinds of efforts can be suggested in all the regions wherever mahseer exists (Sarma *et al.*, 2012; Akhtar *et al.,* 2013).

**Fig. 12. Ranching of golden mahseer in Kosi River & Naukuchiatal Lake by DCFR**
(See colour view on Plate-III, Fig. 1)

It was observed that environmental degradation and human greed are the main factors responsible for sharp decline in mahseer fisheries. Since conservation and rehabilitation of endangered mahseers are of national importance, the production of stocking material through artificial propagation is important to stock those water bodies, which are having facility of natural breeding and nursery grounds (Mahanta *et al.*, 1994). Some of the research and management suggestions are listed below for their conservation and propagation in the country (Sarma *et al.*, 2010)

- Illegal killing, netting and destructive fishing methods must be strictly prohibited.
- Suitable devices for facilitating the crossing of the barriers during migration.
- Detailed survey and mapping for the available resources of the juveniles and adults.
- Strict enforcement of closed season for commercial fishing of mahseer is needed.
- Proper sanctuaries of mahseer must be identified and developed.
- Creel census of the natural water bodies must be taken up.
- Modern hatcheries in the vicinity of water bodies inhabited by mahseer must be developed.
- The techniques of induced breeding of mahseer must be standardized.
- Intensive stocking practice technology must be developed for stagnant and running water systems involving monoculture or polyculture along with indigenous and exotic fishes.

- Nutritive artificial feeds for different stages of mahseer must be developed.
- Selective breeding must be adopted for developing healthy and fast growing mahseer.
- Pen and cage culture must be taken up near the breeding / chasing areas of brooders in the reservoirs during natural breeding migration.
- Removal of sand, pebbles and stones in the mahseer breeding grounds must be banned.




**A– Stripping, B– Fertilization, C– Blastopore, D– Three quarter of the egg surface covered, E–Appearance of eve, F– Appearance of pectoral fin, G– Feeding, H– Haul of Fry, I– Hatchling, J– Fry**

**Fig. 13. Breeding and development of golden mahseer (Sarma *et al.,* 2010)**
(See colour view on Plate-III, Fig. 2)

***Mahseer conservation initiative in Kumaun-A success story:*** A natural lake Shyamlatal in Kumaun region was developed as a conservation site for the threatened mahseer species *Tor putitora*. Mahseer fingerlings stocked for first time have established themselves well in the lake with 98% return in experimental netting. The maximum size of mahseer caught during the trials in gill net operations was 700 g in weight and 260 mm in length. With the establishment of mahseer stocks in the lake, the availability of mature spawners for artificial propagation will be ensured, opening an additional resource for conservation and revival of endangered mahseer in Kumaun region. This will also promote angling tourism in Shyamlatal lake area.

## SPECIES DIVERSIFICATION

Carps are the main stay of aquaculture in India. But being low valued fish in the domestic and international market, carp farming yields low benefit cost ratio compared to the culture of other species elsewhere in the globe and therefore, attracts poor entrepreneurial acceptability. Further, the consumers today with their increased purchasing power looking forward for wide spectrum of fish protein. In this context, diversification of the system and species spectrum forms one of the important strategies for aquaculture development in the coming years. There is a need to bring more and more high valued fish species either under monoculture or polyculture with carps to make aquaculture more remunerative to encourage the entrepreneur investment. However, bringing any new species into the main stream aquaculture practice would require standardization of their breeding, seed production, seed rearing and grow-out technology along with the study on their nutrition, physiology and health management. As the premier research institute of the country, DCFR has the Herculean task to shoulder the responsibility of diversification in the coldwater fisheries sector (Sarma *et al.*, 2012).

The upland region of the country including Himalayas and peninsular hill ranges form an entirely different eco-geographical entity. The mountainous region bestowed with vast and varied water resources in the form of rivers, rivulets, streams, streamlets, lakes, ponds, tanks and reservoirs. The diverse aquatic habitats of the hills region harbour rich piscine diversity. Owing to complex microclimatic conditions coupled with thermal variables, the production from upland region is still at very low pace. Though, attempts for fish culture in the upland states of the country have been initiated since 1863, but the culture fishery remained in infant stage, till recently. Now, the scenario has changed and several progressive farmers have started mono and composite fish culture in small ponds and a few of them have achieved considerably good production. In the upland waters the Indian major carps do not grow well, due to the low thermal regime. Chinese carps are found suitable for the Mid-Himalayan region as the candidate species for polyculture. The Directorate of Coldwater Fisheries Research (erstwhile NRCCWF), Bhimtal, Uttarakhand has played pivotal role in development of location specific feasible and viable fish farming techniques, breeding protocols, feed and standardized husbandry practices and has introduced the polyculture of three exotic carps for the mid hill region. Presently, the high priced low volume coldwater fish species, rainbow trout is in the culture practice in higher altitudinal area and polyculture of exotic carp is popular in mid altitudinal area. For the further development of aquaculture in hills, diversification of existing practice is needed with more potent candidate indigenous species (Sarma *et al.*, 2012).

A number of fish species are also found distributed in the different reaches of the river having high consumer preference as well as good market value. These indigenous species would be a candidate species for aquaculture after the development of their breeding, feeding and culture protocol. In this context based on the previous studies carried out by the earlier workers from different agro climatic conditions five species were selected as new candidate species for hill aquaculture by DCFR. They are Chocolate mahseer (*Neolissocheilus hexagonolepis), Labeo dero, Labeo dyocheilus, O. belangari and Semiplotus semiplotus*.


**Fig. 14. New candidate species of hill aquaculture** (See colour view on Plate-IV, Fig. 1)

*Labeo dero, L. dyocheilus* are mid distance cold water migrant fish. These species perform upstream migration in stream during May to June when water temperature rises in the stream. After rainy season in Aug-Sep, spent fish start downward migration. No distinct spawning ground was identified for the natural breeding of this species. The body of these species is ordinarily white and more linear. It has relatively small head. Generally these species are herbivorous in nature consisting 80% algae and debris in the gut content. Identification of sex is only possible during spawning season. Individual gross weight of the fish in natural condition is 91-153 g in one year. *Labeo dyocheilus* can breed in natural environment by induced breeding using Ovaprim. The female with a soft, distended abdomen showing unripe light gray eggs near genital aperture may be selected for hormone treatment. The males show milt oozing with gentle pressure near the genital pore. At onset of ovulation the males chase the female fish. The eggs are released in the tank by self-spawning method and fertilized eggs are incubated in the same tank. Another method of egg collection is stripping of eggs and milt from the brooders and fertilized the eggs by artificial dry methods. Standardization of breeding protocol in coldwater climate and evaluation of growth of these species in captive condition is required for mono and polyculture with carps either in pond or in floating cages in mid hills. DCFR has made tremendous progress for its culture and breeding in recent times especially in mid Himalayan region (Sarma *et al.*, 2012).

Chocolate mahseer (*Neolissochelus hexagonolepis*) is a coldwater fish species belonging to the family Cyprinidae and is one of the member of the pride indigenous mahseer group. In India it is present in the hill stream water bodies of Northeastern states. *Neolissochelus hexagonolepis*, the snub nosed chocolate mahseer is an economically important game as well as food fish. Distinguishing character-back olive green, silvery white on the belly, scales above the lateral line coppery colored, fins dark gray paling towards the margins. It is recognized as a cultural icon in the water bodies of high lands of Eastern Himalayan region. Chocolate mahseer is easily adaptable in comparison to other mahseer species. It thrives well in captive environment and can be grown well with other Indian major carps and Chinese carps in pond culture. The species have the potential to become a candidate species in the hill aquaculture systems in the Kumaun Himalayan regions of India considering the similarities of climatic conditions and as well is its adoption in captive rearing. The distribution of chocolate mahseer is available upto a gradient of 1500 msl in coldwater N-E states. It prefers an optimum temperature in the range of 19-23 degree centigrade for desirable growth. (Sarma *et al.*, 2012)

The study at DCFR, Bhimtal revealed that chocolate mahseer under temperature 19 – 23 °C (March) gained high body weight as compared to the other months in both the culture systems. Chocolate mahseer doesn't show any competition while culturing with golden mahseer. Their growth performance results also indicate that both the species under culture were highly correlated with each other. The fecundity of chocolate mahseer is 6000-8000 eggs/kg body weight, breeding period August-September, Fertilization- 95%, hatching- 80%, Incubation period 38-40 hrs., egg colour light yellow- lemmon yellow. It is a coldwater rheophilic fish. Column to bottom dweller and occasionally rise to the surface for nibbling the flowing food item. It is carni-omnivore in fry and fingerling stage & herbi-omnivore in juvenile stage. RGL values increased with the increase in length of the fish. RGL value is lowest in fry stage and intermediate in juvenile stage. Presence of sand and mud in the gut shows that fish is column to bottom dweller (Sarma *et al.*, 2012).

## FISH BASED ECO-TOURISM

### Eco-tourism

Eco tourism is a sustainable form of resource use, which contributes to environmental conservation, while providing accrued socio economic benefits to the people through the

**Angling**

**Fig. 15. Angling & Rafting** (See colour view on Plate-IV, Fig. 2)

non-consumptive uses and indirect values of the natural biological resources. Considering the vulnerable nature of our environment eco tourism based on optimum multiple uses of the resources on sustainable basis must be encouraged. Fishery based eco tourism is emerging potential area for employment generation.

## Eco-tourism as Livelihood

Valuable mahseer, rare Indian and exotic trout fishes available in coldwater regions are highly demanded among the anglers. Angling and recreational fishing is one of the most popular outdoor activities throughout the world. In the United States, over 34 million people participated in recreational angling in 2001 and 29.4 million recreational fishing licenses were issued. The revenues from fishing licenses support fish and wildlife management agencies at all levels of government and the expenditures from recreational fishing contribute to local and regional economies, especially in regions where fisheries have been preserved pristine or near- pristine conditions (Sarma *et al.*, 2012).

## Types of Eco-tourism

1. **Sport fishing/angling:** Angling or sport fishing is classified under eco-tourism as it has minimum adverse impact on the environment and also helps in retaining the beautiful natural environment, help to preserve and protect the river system and its surroundings, helps in the growth of fisheries resources through protection and preservation for its future scope and aspiration of better fishing.

   Game and sport fishing, is one of the most fascinating outdoor physical activities, which satisfies diverse tastes and pursuits. It is one of the major sources of recreation to millions of tourists around the world. There are about 20 millions anglers in USA, 3 million in Japan and 4 million in UK. Their numbers are increasing with each passing day.

2. **Fish Watching:** Like bird watching, fish watching also has scope for its expansion. Moving shoals of different size, color and shaped fishes always provide joy to the visitors particularly to children. Many of the religiously protected water bodies in the hills like Mattan in Jammu & Kashmir, Renuka lake in Himachal Pradesh; river stretch of Ganga at Haridwar and Rishikesh, Gomati river at Baijnath, Naldamayanti tal in Uttarakhand are some examples of fish watching spots, which attracts thousands of tourists. Similar spots need to be developed near tourist sites for visitors.

## NUTRITION IN COLDWATER AQUACULTURE

Aquaculture has made tremendous progress world over particularly in Asian countries like China and India. The increase in yield has been manifold during last few decades. The fisheries sector occupies an important place in the socio-economic development as well as nutritional security of Indian upland region. Successful and sustainable aquaculture depends on the provision of nutritionally adequate, environmental friendly and economically viable artificial feeds. Feed is the major operational input, and feed costs normally range from 50-70 % of the operational expenditure in culture systems. Therefore, minimizing the feed cost is the most effective way of increasing the profitability of aquaculture venture. In view of this, artificial feeds should scientifically formulated, optimally processed and judiciously supplied considering the specific nutritional needs of the cultivated species and the intensity of culture operations. The management of successful aquaculture depends on feeding the required quantity of feed to the fish. In this context, *ad-libitum* feeding is receiving more attention. Over feeding leads to water pollution since it have deleterious effects on the environment and on the hygiene of the fish farm. It also leads to economic losses. On the other hand, fish should not be under fed so that the quality as well as quantity of produce will be decreased. Therefore, nutrient and energy supply to maximize production and profitability and minimize pollution and economic loss is an important aspect of fish nutrition research. The calculations of the optimum ration level with optimum nutrient and energy should be the ultimate concept related to the fish feeding strategy (Sarma *et al.*, 2012).

**Major obstacles in coldwater fish nutrition** (Akhtar *et al.*, 2010)

1. Low temperatures of upland regions results in lower metabolic rate which in turn leads to reduced nutrient utilization as well as feed intake and ultimately poor growth.
2. Low natural productivity of coldwater resources leads to more dependent on supplemental feeds.
3. Non-sustainable availability of local feed ingredients ultimately resulting in higher feed cost.
4. Lower temperature limits mass culture of live food organisms.

## COLDWATER FISH IN HUMAN NUTRITION (Sarma *et al.*, 2013)

Fish plays a major role n human nutrition. Importance of fish as a source of high quality, balanced and easily digestible protein is now well understood. Besides, it is also a well-known source of polyunsaturated fatty acids specially, omega-3 fatty acids such as eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) which play a central role in the physiology of living system. Regular consumption of omega-3 fatty acids significantly lowers triglycerides and often raises high density lipoproteins levels, thereby diminishing the risk of heart/cardiovascular diseases. Fish is also known to be a good source of several other nutrients like macro and micro minerals and vitamins and hence, it is being accepted as a healthy food. Fish is a rich source of calcium and phosphorus and calcium deficiency in children produces decreased growth rate, negative calcium balance of calcium from bones. Phosphorus is very essential for the formation of bone and teeth. Other micro mineral like copper, iodine, manganese, cobalt, zinc, fluoride, selenium etc are vital for maintaining the physiological functions of the body. Vitamin A, D and E as well as thiamin, riboflavin and niacin are abundantly found in fish and are important in normal vision, skeletal growth and many other physiological functions including immunity and disease resistance.

## Nutritional Significance of Coldwater Fishes

Coldwater fishes namely rainbow trout, snow trout, golden mahseer, chocolate mahseer and common carp etc are important food in the rural and urban upland population in India. Most of the population residing in hilly areas are fish eaters. They are widely accepted as healthy food because of their richness in amino acid, fatty acids, vitamins and minerals. Coldwater fishes like trout and mahseer contain high PUFA compared to other fresh water fishes. The DHA and selenium content are also higher in them.

**Table 7: Proximate composition of important coldwater fishes** (Das *et al.*, 2012)

| Species | Crude protein | Crude ash | Crude fat | Moisture |
|---|---|---|---|---|
| Golden mahseer | $20.00^{c} \pm 1.000$ | $1.45^{b} \pm 0.045$ | $6.15^{d} \pm 0.006$ | $72.38^{b} \pm 0.024$ |
| Rainbow trout | $19.44^{bc} \pm 0.07$ | $1.37^{b} \pm 0.08$ | $5.18^{c} \pm 0.22$ | $74.00^{c} \pm 0.30$ |
| Snow trout | $17.05^{a} \pm 0.72$ | $2.88^{d} \pm 0.59$ | $6.15^{d} \pm 0.74$ | $70.12^{a} \pm 0.98$ |
| Chocolate mahseer | $18.75^{b} \pm 0.11$ | $1.21^{a} \pm 0.09$ | $3.33^{a} \pm 0.27$ | $76.20^{e} \pm 0.56$ |
| Common carp | $17.5^{a} \pm 0.48$ | $2.33^{c} \pm 0.21$ | $4.54^{b} \pm 0.56$ | $75.05^{d} \pm 0.32$ |
| **P value** | **0.01** | **0.01** | **0.01** | **0.01** |

Coldwater fish species manifest as high quality nutrient source in terms of well balanced essential amino acids, n-3 & n-6 PUFA, micro and micro minerals and vitamins. Being a rich source of n-3 PUFA and other nutrients, coldwater fish consumption could ensure nutritional security and reduce the risk of cardiovascular as well as nutritional deficiency diseases among Indian upland population.

## COLDWATER FISH DISEASES IN INDIA: STATUS AND STRATIGIES

Fish pathogens can have detrimental effect on aquaculture production. Incidence of diseases in coldwater aquaculture sector has been a matter of grave concern and due to the lack of a facility for disease diagnosis this work remained unattended for quite a while. At this point of time DCFR, Bhimtal realized to set up a Fish Health Section to develop procedures for the identification of important fish pathogens. We initiated the surveillance program in 2008 for the identification of fish pathogens of coldwater and in this endeavour our teams have collected samples from the cold desert of Laddakh in Kashmir to Arunachal Pradesh and came across different pathogens of coldwater fish. Pathogenic microorganisms like virus, bacteria, fungi and fish parasites are the causative agents for fish diseases. Our preliminary work shows the evidence of parasitic, fungal, bacterial and viral infections that are being discussed below (Pande *et al.*, 2012).

**Table 8: Mineral composition of coldwater fishes (Sarma *et al.*, 2011)**

| Species | Sodium | Potassium | Calcium | Iron | Manganese | Zinc | Selenium |
|---|---|---|---|---|---|---|---|
| Golden mahseer | $234.33^{d}\pm4.04$ | $1252.0^{c}\pm8.54$ | $405.66^{b}\pm16.26$ | $1.28^{b}\pm0.04$ | $0.16^{b}\pm0.02$ | $1.19^{a}\pm0.03$ | $0.74^{b}\pm0.05$ |
| Rainbow trout | $208.00^{c}\pm9.00$ | $1447.00^{e}\pm7.55$ | $359.33^{a}\pm12.01$ | $5.17^{e}\pm0.02$ | $0.19^{d}\pm0.01$ | $1.79^{c}\pm0.02$ | $1.66^{d}\pm0.03$ |
| Snow trout | $146.00^{b}\pm2.06$ | $1159.00^{b}\pm5.99$ | $413.00^{c}\pm6.43$ | $0.68^{a}\pm0.34$ | $0.35^{e}\pm0.09$ | $2.71^{d}\pm0.23$ | $1.03^{c}\pm0.31$ |
| Chocolate mahseer | $105.00^{a}\pm5.02$ | $808.00^{a}\pm7.47$ | $1172.00^{e}\pm21.26$ | $1.87^{d}\pm0.02$ | $0.09^{a}\pm0.02$ | $1.59^{b}\pm0.05$ | $1.87^{e}\pm0.05$ |
| Common carp | $404.00^{e}\pm5.02$ | $1266.00^{d}\pm8.37$ | $508.00^{d}\pm4.65$ | $1.37^{c}\pm0.01$ | $0.18^{c}\pm0.02$ | $4.77^{e}\pm0.03$ | $0.43^{a}\pm0.05$ |
| P value | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |

**Table 9: Fatty acid composition of coldwater fishes (Sarma *et al.*, 2013)**

| Species | ΣSFA | ΣMUFA | ΣPUFA | Σn-3 | Σn-6 | Σn-3/ Σn-6 |
|---|---|---|---|---|---|---|
| Golden mahseer | $52.91^{d}\pm0.16$ | $28.05^{b}\pm0.08$ | $18.35^{a}\pm0.06$ | $8.68^{a}\pm0.03$ | 9 $.67^{b}\pm0.05$ | $0.90^{b}\pm0.01$ |
| Rainbow trout | $34.51^{a}\pm0.09$ | $35.88^{d}\pm0.15$ | $31.39^{d}\pm0.17$ | $13.62^{c}\pm0.08$ | $17.77^{d}\pm0.12$ | $0.77^{a}\pm0.01$ |
| Snow trout | $42.73^{b}\pm0.12$ | $37.14^{d}\pm0.18$ | $19.43^{b}\pm0.09$ | $16.18^{d}\pm0.06$ | $3.25^{a}\pm0.02$ | $4.98^{d}\pm0.03$ |
| Chocolate mahseer | $44.25^{b}\pm0.20$ | $23.90^{a}\pm0.07$ | $31.22^{d}\pm0.14$ | $21.49^{e}\pm0.14$ | $9.73^{b}\pm0.04$ | $2.21^{c}\pm0.01$ |
| Common carp | $46.13^{c}\pm0.09$ | $31.22^{c}\pm0.12$ | $25.00^{c}\pm0.16$ | $11.13^{b}\pm0.06$ | $13.87^{c}\pm0.08$ | $0.80^{ab}\pm0.01$ |
| P value | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |

## Parasitic Infections

Fish samples of rainbow trout, snow trout, *Barrelius*, mahseer, and common carp collected from different coldwater bodies including capture and culture environments demonstrated the presence of ecto and endo parasites. The parasitic diseaseses that can be recorded from different water bodies are ich or ichthyopthiriasis, trichodiniasis, whirling disease, costiasis, argulosis and dactylogyrosis (Mallik *et al.*, 2010).

These results show that there is a major problem of parasitic infection in coldwater fishes, which has to be dealt with in order to enhance the production. Parasites like *Dactylogyrus*, *Argulus sps* and *Epistylish* are a cause of concern, as they occur in warm waters. Their presence in coldwater regions may perhaps be an indicator of climate change. It is also possible that these pathogens might have been accidently introduced along with fish like carps that were earlier bought for stocking from other reservoirs or farms located elsewhere (Pande *et al.*, 2012).

## Fungal Infections

Fungal infection is more prominent in the ponds having stagnant water than the running water raceways. Hatchery water is also prone for the fungal infection. Infection can be observed in the muscles, gills and fins of rainbow trout, common carp and mahseer. Pathogenic fungi that can be commonly observed are *Saprolegnia parasitica* and *Saprolegnia diclina.* They can be identified having cottony appearance, elongated zoosporangia and pear shaped primary sporangium. Temperature variation has a significant effect on the development of fungal infection. Most epizootics occur when temperatures are below the optimum range. However, during incubation of trout eggs it can be observed that higher temperatures increase the chances of infection. Dead eggs are more susceptible to the fungal attack during incubation as *Saprolegnia* is a saprophyte. It is observed that under captivity snow trout is more susceptible to *Saprolegnia* than rainbow trout. (Pande *et al.*, 2012).

## Bacterial Infections

Although incidence of a major outbreak of bacterial disease in coldwater bodies has not been observed, but signs of bacterial diseases like tail rot, fin rot, gill rot, exophthalmia and aeromonasis are common. These diseases are generally caused by group of *Aeromonands* and *Pseudomonands*. The bacteria in group of *Aeromonands* and *Pseudomonands* are ubiquitous in all the fresh water bodies and opportunistic. When fishes are in stress, they get infected therefore good management practices have to be adapted to minimize the chances of infection (Pande *et al.*, 2012).

## Viral Infections

Viral infections in fish can lead to mass mortality but it is observed that infected fish upon survival can carry the infection for quite a long while. Therefore viral diseases have to be closely monitored as the country suffered severe mass mortalities. Samples have been collected from the difficult terrains of Kargil and Drass Sectors in Laddakh, Kashmir Valley, Himachal Pradesh, Uttarakhand, Sikkim and Arunachal Pradesh and have been analysed for the presence of important fish viruses like infectious pancreatic necrosis virus, infectious hematopoietic necrosis virus, viral hemorrhagic septicaemia and epizootic hematopoietic necrosis virus. Isolation of the said viruses is carried out in fish cell lines. Five cell lines namely BF-2, CHSE-214, EPC-2, FHM, and RTG-2 are being maintained for this purpose. Once a consistent cytopathic effect is observed the viruses can be confirmed by serological assays or RT-PCR followed by nucleotide sequencing. Fish showing darkening of the body, abnormal swimming movements with ataxia are sampled and dissected. Upon post-mortem, spleen, liver, intestine, heart, muscle, kidney, ovarian fluid along with the eggs or and brain are collected from the infected fish.

Based on the signs, the disease is quite difficult to diagnose as the post-mortem signs can be similar for different viral infections. The signs resemble classical behavioural changes as reported in IPN and IHN infected trout for example, anorexia, corkscrew swimming motion interspersed with ataxia. It has been documented that affected fish exhibit a variety of external signs of disease such as darkened pigmentation of skin, abdominal swelling, mild or moderate exophthalmia, and paleness of gills and sometimes hemorrhages in ventral areas and fins. Internally, lumen of the stomach and intestine is devoid of feed but characteristically contain a clearly pathognomic yellowish cohesive mucous. In some infected fish, pyloric caeca and anterior adipose tissue are flecked with petechiae and body cavity containing ascetic fluid. For confirmative diagnosis, the samples from such fish are transported to the laboratory where virus isolation can be done in cultured fish cells (Pande *et al.*, 2012).

## Current Diseases Status

The mass mortality of stocks of rainbow trout was recorded in the year 2003 in Himachal Pradesh. The causative agent was suggested as a possible irridoviral infection. As the country was lacking diagnostic facility, the agent could not be isolated and characterized. In the year 2009 there was a mass mortality of brown and rainbow trout in state trout farm Bairangna (Uttarakhand). Mortality of fingerlings and brood stocks of rainbow trout and brown trout weighing 530g to 2500g was recorded in the incident. After this outbreak, a cell culture facility was immediately set up and screening of samples started to enable isolation of fish viruses from trout farms. In the year 2010, mass mortality of *Schizothorax plagiostomus* in stretches of Upper Siang River at Yingking and Mariyang circle, Arunachal Pradesh, was attended by the scientists of DCFR. Tissue samples were screened for cytopathic effect in cultured fish cells. Presently, surveillance of viral diseases in trout is being regularly conducted from the difficult terrains of Leh-Ladakh, Himachal Pradesh, Uttarakhand, Sikkkim and Arunachal Pradesh. The characterization and identification of the suspected viruses is under progress. However, preliminary findings suggest the presence of aquabirna-like virus and rhabdoviral infections that requires confirmation. In addition to this, fish that are asymptomatic carriers of viral infection are also being tested. In one of the mass mortality observed in rainbow and brown trout, stray snow trout specimens that were present in the rearing system appeared healthy. However, samples collected from such specimens showed cytopathic effect in cultured cells, which may suggest that snow trout may act as "carrier" of the disease.

An Institutional project was initiated by DCFR, Bhimtal in 2008 to investigate and document the fish diseases in coldwater environment. Occurrences of various parasites, bacterial and fungal diseases have been recorded. In 2009, argulosis was observed in stocks of Indian snow trout, *Schizothorax richardsonii* and Golden Mahseer, *Tor putitora* being reared in cage culture unit in Bhimtal Lake (Uttarakhand). Prevalence was recorded 67.9 % & 25.0% in stock of *Schizothorax richhardsonii* (size 45-55mm, weighing 25-55g) & *Tor putitora* (60- 120mm, weighing 80-220g) respectively. The incidence of *Argulus* infection was intriguing in coldwater bodies, as water temperature doesn't provide a favourable environment for larval development of the parasite. *Schizothorax richardsonii* stocks (mean length ranged from 15.53 ± 0.20 to 16.86 ± 0.08, and mean weight 24.70 ± 0.05 to 26.73 ± 0.06) reared in high altitude raceways were monitored periodically from April-December 2009 for parasite infection at Experimental Fish Farm, Chhirapani, Champawat, Uttarakhand. Presence of pinhead sized white and slightly yellow spots (0.4 to 0.8 mm) were observed on dorsal body surface and caudal fins of sampled fishes during month of April. The causative agent was identified as a ciliate parasite, *Ichthyopthirius multifiliis*. The marked hyperplasia of gill epithelium was associated with presence of trophonts stage of this ciliate in the gill tissue. A thermophilic infection pattern was noted with maximum prevalence of 84.80 ± 1.83 in month of July followed by a decline in December (21.99 ± 2.13). Similarly, in 2011 mature trophonts of the ciliate *Ichthyopthirius multifiliis* were observed in the stock of rainbow trout, when mucus scraps of 75% of trout stock assessed. The size of the stock in length and weight was varied from 90 -150mm &150 – 300g respectively. There was no mortality of infected fishes observed in both the cases. Infection of stock (5 -10%) due to *Trichodina sp.* was observed in fingerlings of *Tor putitora*, *Cyprinus carpio, Schizothorax richardsonii* & *Oncorhyncus mykiss* during the study period. Occurrence of whirling movement (possibly a whirling disease) in 45 % of fry of *Oncorhyncus mykiss* at Experimental Field Station, Chhirapani, Champawat, Uttarakhand and trout farm, Shergaon (15%), Arunachal Pradesh have been recorded during breeding of trout in 2009-10 (Pandey *et al.*, 2012; Mallik *et al.*, 2012). Cataract induced eye diseases in stock of *Oncorhyncus mykiss* (25%) & *Tor putitora* (10%) were observed at Champawat and Bhimtal during 2010-11. The reason for this infection may be either bacterial or parasitic that is being explored. Large scale trout loss has been observed at Champawat farm due to eye infection. But it is reported that generally cataract induced eye disease occurs due to infection by *Diplostomum sp* or fish fed with zinc deficient diet (Mallik *et al.*, 2010).

Bacterial diseases like tail rot, fin rot and gill rot and hemorrhagic septicaemia are commonly observed in mid altitude carp farming systems during 2008-2011. Common carp stocks (0.3- 1.2 kg) at Fish farm, DCFR, Bhimtal, Paatiblock, Champawat, Uttarakhand, State fish farm, Ghagas, Bilaspur, Himachal Pradesh, State fish farm, Kangra, Himachal Pradesh, were observed with above said diseases. It was observed that brood stock of common carp (2-3%) at Kangra, were also suffering from protruding eye disease (exophthalmia). Bacterial gill disease was recorded in stock of *Tor putitora* (2%). Symptoms of tail rot and fin rot were also observed with *Tor putitora* and *Schizothorax richarsonii* at Bhimtal and Champawat.

## GENOMICS RESEARCH IN COLDWATER FISHERIES

The coldwater fishes adopted to live between $5^{0}$C to $20^{0}$C temperature. The upland water at high altitudes of mountains and the spring water at low altitude in temperate regions remain cooler than the rest and the cold water fishes flourish in these region. Such water bodies comprising several hill streams, rapids, pools, lakes and reservoirs are abundantly found in the Himalayan region and in the Deccan plateau region of peninsular India. These are either fed by melting snow and the springs as in north or by the rain water as in Deccan plateau (Barat *et al.*, 2012).

During recent years, there has been growing realization for development of cold water fisheries in India, since the production from cold water is negligible in comparison to total inland catch. The trout hatchery established in Kashmir is one of the potential sources from where the brown trout have been transplanted to the upland waters of Jammu, Kashmir, Kullu, Simla, Kangra, Nainital, Shilong and Arunachal. Other hatcheries constructed at Nilgiris and Kerala. Mahaseer, Snow trout and Indian hill trout are the principle cold water fish species inhabiting the mountain waters of India. Mahaseer fishery of cold water: It is one of the major game fishes of Himalayas. However, it has not received attention as exotic fishes in India. The main reason may be, lack of proper breeding strategies of those fishes.

To manage any biological resources effectively it is necessary to identify the level of genetic variation within and among population. Genetic diversity or variation and its measurement have vital importance in interpretation, understanding and management of populations and individuals. The amount of intra-specific genetic variation is now widely accepted as a key parameter to determine populations to prioritize for protection purposes. Loss of genetic diversity within populations might be associated with inbreeding depression, which in turn results in reduced fitness and ultimately jeopardizes the population persistence. Genetic diversity is influenced by selection, mutation, migration, population size, and genetic drift and understanding how each of these factors influences the genetic diversity of a population is critical to the conservation of species. It is theoretically possible to observe and exploit genetic variation in the entire genome of organisms with DNA markers. Allozymes, mitochondrial DNA, RFLP, RAPD, AFLP, microsatellite, SNP, and EST markers are the popular genetic markers employed in fisheries and aquaculture. For many important species of the Indian cold water region such as *Schizothorax richardsonii, S. esocinus, S. niger, S. progastus, S. plagiostomus*, *Tor putitora* and *Garra* etc additional informative loci are required for population genetics studies and for long-term endeavours such as genome mapping, localization of quantitative trait loci and the implementation of marker-assisted selection (Barat *et al.*, 2012).

## Population Genetics and Species Characterization

Recent times most genomic and genetic studies were carried out using few molecular tools to detect population structure of natural populations of fishes. In recent past the conventional marker approach to study population was allozymes. However, the limited number of loci and low variability of allozymes limits the statistical power of the resulting data. Mitochondrial DNA (mtDNA) was the first widely used DNA marker and has provided many insights into the population structure analysis. we studied the seven geographically isolated population of *Tor putitora* (Jia Bhoreli river at Bhalukpong, Arunachal Pradesh, Satluj river at Bhakara, Himachal Pradesh, Beas river at Jogindernagar, Himachal Pradesh, Kosi river at Ramnagar, Uttarakhand, Walwhan dam, Lonavla, Maharashtra, Chenab river at Anji, Jammu & Kashmir and Ravi river at Basoli, Jammu & Kashmir during April 2009 to January 2012) for morphological (Truss morphometric and length and weight) and molecular analysis (Mt-DNA- Cyto b and ATPase 6/8 gene) & microsatellite). 348 individuals of *Tor putitora* were collected from six geographically isolated location of India. (Barat *et al.*, 2012)

## Functional Genomics

**Few genes found to be specific for coldwater regions were identified** under a NAIP funded program. The main aim of NAIP project entitled "Bioprospecting of genes and allele mining for abiotic stress tolerance" was to identify candidate genes associated with resistance to cold stress conditions and thus provide **the physiological and genetic basis for new marker-assisted selection strategies**. Under this project a large body of physiological and genetic data is being generated for this species.

Fish population with reference to coldwater requires genotyping of species from natural population of aquaculture importance and for that it requires a large number of loci. These loci might be SNPs, microsatellites, mtDNA, RAPD etc. DCFR had so far tried to develop genetic markers with an approach to population structure analysis for making a suitable molecular breeding practice. However, this approach still seems to be very little. With the discovery of next generation sequencing a full genome sequence provides many resources to better understand the genetics and molecular mechanisms affecting change in gene frequency or gene expression. Whole genome or whole transcriptome using high throughput sequencing technologies can be applied to many coldwater fishes to yield genome wide information. (Barat *et al.*, 2012)

## MAJOR CONSTRAINTS IN COLDWATER FISHERIES DEVELOPMENT IN INDIA

Several constraints such as low productivity of upland waters, comparatively slow growth rate in almost all fish species, low fecundity in fishes and poor landing and marketing facility have been seen as major obstacles in the rapid development and expansion of coldwater fish production. The major hurdles concerning the development of coldwater fisheries sector in India may be summarized as (Mahanta and Sarma, 2010; Akhtar *et al.*, 2013):

- Low level of production /slow growth rate
- Lack of infrastructure for aquaculture
- Less availability of seed for culture
- Habitat destruction
- Wanton destruction
- Conservation policy
- Lack sound management policy
- Climate change / global warming

## MANAGEMENT ISSUES FOR COLDWATER FISHERIES IN INDIA

The aquatic resources in hills are quite valuable for the development of fishery both for food, sport, recreation and employment but scientific management of these resources is necessary to achieve the objectives. In order to manage these ecosystems, so that they can contribute to fishery development in remote hilly regions on a sustainable basis, the following issues need attention on priority basis.

- Resource mapping of the fishery resources in mountain/hill region for the integrated development of the coldwater sector.
- In order to develop the riverine and lacustrine fisheries it is necessary to go for stock enhancement programme through ranching.
- A legal framework should be formulated to stop all types of destructive fishing method.
- The breeding grounds of the fish need special protection by declaring them as 'No-fishing Zone' or 'Protected Area'.
- A balanced strategy for lakes, for tourism and fishery development is required.
- Development of sport/recreational fishery for tourism and employment generation.
- Education, training and extension support to the hill communities for resource conservation and utilization.
- Promotion of mountain-specific policy formulation and legislation.
- Promoting sustainable use of mountain natural resources and conservation of biological diversity and mountain ecosystems.

## STRATEGIES FOR FURTHER DEVELOPMENT OF FISHERIES IN HILL STATES OF INDIA

At present attention should be directed towards the standardization of technologies for various fish species suitable to hilly cold areas of the region depending on investment potentials. This should also be based on species-based systems, as, a high biodiversity of fish species present in this part of the country. The following points should be considered in order to improve breeding and culture of fish in the hills:

- Imparting training to farmers and entrepreneurs at different levels along with better co-ordination between extension functionaries.
- Development of suitable and specific aquaculture system for micro climatic conditions of the mid and high altitude areas.
- Regular monitoring of reproductive biology of economically important fish species so as to suggest remedial measures for depleting population.
- Conservation and rational exploitation of resources, which are the backbone of fish and fisheries in the region particularly at the high altitude areas.
- Introduction of research programmes aiming at intensification and diversification of freshwater aquaculture in tune with the geomorphological feature of the region.
- Extensive conservation and bio monitoring of all coldwater resources in time and space to assess threat perspectives in relation to biodiversity.
- It is important to explore new candidate fish species for coldwater aquaculture.

## FUTURE PERSPECTIVE

The Hill Area Development is now being focused as priority in the country. But up till now economic upliftment of hill states, due to various climatic, geomorphologic and resource constraints has been very insignificant. The hill regions of our country are bestowed with valuable indigenous fish germplasm and pristine water resources with tremendous range in their thermal regime. The fish can play a vital role in supplementing protein requirement to the poor people located in remote Himalayan region and to provide source of income to a section of people who because of resource constraints in terms of cultivable lands in hills overexploit natural resources. At high altitudes we have tremendous scope for development of low-volume, high-value species such as trout, especially rainbow variety. At 4% growth in farming of rainbow trout, a production of 150 tonnes is possible, which can be enhanced to 200 tonnes at growth rate of 8%. As per the study, our domestic demand has been assessed at 800 tonnes, therefore, steps must be taken to achieve this target. This can further promote feed industry and preservation units at high altitudes. Similarly, sport fishing ancillary units including short and long distance transportation of trout will come into operation. All these will generate avenues for establishment of self-help groups in hill regions. But it will be possible if the seed production centers and table fish production units for trout are de-linked and private sector is involved in fish production while quality seed and feed supply is to be insured through state channels. All the private units should be registered to maintain hygienic standards.

Depending upon the natural aquatic resources in the hills, the fishery, if developed on scientific lines will go a long way in contributing to rural economy in remote hilly zones. It is suggested that fishery development should be initiated based on the available resources involving both exotic and indigenous fishes. There is an immediate need to replenish depleting stock of some of the most important commercial as well as sport fishes. The indiscriminate use of chemicals in orchards/tea gardens may affect catchment's water quality of regional river/stream systems.

The training in coldwater fishery and hill resource management is also an issue to be addressed. Confluence of rivers in north-east and central Himalayas was reported one of the best mahseer angling spots of the world once upon a time. Thus, creation of adequate facilities for anglers for sport fishing is of paramount importance. Similarly, streams in Kashmir and Himachal Pradesh are world famous for brown trout angling/ fishing. Coupled with sport fishery development, the commercial farming through Jhora fishery in sub-Himalayan West Bengal has a good potential of generating rural income and will contribute towards upliftment of socio-economic conditions of local population in this hill region. Establishment of carp hatcheries and farms at lower altitudes is another pre-requisite for hill states to meet demand of local farmers who are engaged in small-scale fish farming. There is tremendous potential for running water fish culture based on exotic carp. This should be encouraged by providing know-how and seed to the farmers to supplement their income. Though some effective efforts have been initiated for development and popularization of fisheries in the hill region of our country, still there is lot to be done. Besides conservation of valuable fish species, a holistic approach required for overall fisheries development includes expansion of fish culture activities in all potential areas, integrated aquaculture, stock diversification, implementation of the sustainable production, enhancement measures in lakes and reservoirs, development of ornamental fish and promotion of fishery based eco-tourism at the suitable sites (Mahanta *et al.*, 2011).

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