***Review Article***

Himalayan Coldwater Fisheries in India: Status, Challenges and Opportunities

Abstract:

The exploitation of fishery resources in upland Himalayan regions mainly comes from capture fisheries. The fish production through culture practices is gaining momentum. At present, the total fish production from upland areas is about 3 % of the total inland fish production of India, which is very meagre to the total fish production. The cold water fishes adapted to Indian climatic conditions to live between 5°to 20°temperature. The high-altitude upland water of mountains and the spring water at low altitude in temperate regions remain cooler than the rest of the water body, supporting cold water fishery. These 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. The aquaculture production potential of the cold water sector has not been exploited to its fullest extent. As far as cold-water fisheries are concerned, very few hill states like Kashmir valley, Himachal Pradesh, and other mountain regions of India are underexplored. The hill states are endowed with natural lakes and reservoirs that could be better utilized under culture-based capture fisheries program. An overview is presented on the cold water resources of India with reference to the cultivation of viable species in the hill region of India. Various initiatives have been taken to promote the cold water fishery by DCFR and various other government agencies, and entrepreneurs.

Keywords: Cold water, valuable germplasm, rivers, sustainable, income generation, biodiversity, DCFR.

**Introduction**

“The Himalayan region, encompassing countries such as India, Nepal, Bhutan, and China, is renowned for its extraordinary environmental diversity and hosts a remarkable array of flora and fauna. This geographical area holds significant importance for both economic and ecological reasons, as it shelters some of the rarest and most valuable cold-water fish species globally” (Petr & Swar, 2002; Swar & Craig, 2002). “The Himalayan fisheries resources present abundant opportunities for cultivating and preserving coldwater fish species well adapted to the region’s extreme environmental conditions. The primary distribution of cold water resources in the area includes upland streams, rivers, high and low-altitude lakes, and reservoirs scattered across various hill states. These resources play a vital role in supporting the diverse coldwater fish fauna found in the Himalayas. Preserving and sustainably utilizing these resources is of paramount importance to maintain ecological balance and support the economic well-being of the region’s communities” (Sarma and Mohan, 2024). “Considering the vast resources available, there is immense potential to draw economic benefit for the prosperity of the people residing in temperate zone of the Himalayan region through a multifold increase in fish production by horizontal expansion, intensification, diversification, and sustainable management of existing natural resources. This would be helpful to reduce the gap between demand and supply. Though the present aquaculture in the Himalayan region is a traditional and rural practice, reforming has been done for the fisheries sector in temperate zone through awareness and technological advancement, which may also require the vertical and horizontal expansion of this sector toward commercial practice and export avenues” (Pandey & Pandey, 2023).

Methods Adopted:

Extensive reviews were made to understand the cold water fishery system practiced in India in various parts of the country and globally. The culture and the cropping adopted to suit different water bodies with climatic conditions are studied. A strategy suggested for the adoption of a culture system for increasing production and productivity by addressing various challenges in the grow-out conditions. The schemes and programs about aquaculture and allied sectors beneficial to the farming community are projected with an emphasis on the introduction of new crops, introduction of technological innovations, farm and pond management, and crop diversity. Information gathered on data classification and grouping ecological aspects, natural resource management, organic farming, and biodiversity. Qualitative descriptive methods were used to discuss the issues and relationships, and compared findings to understand the comprehensive and holistic approach in sustainable aquaculture practices. Literature selection relevant to the research topic, data reliability, and topic-related journals, books, and research reports were referred.

Detailed Review:

“The Himalayan states of India are endowed with abundant amounts of highly oxygenated freshwater suitable for culturing rainbow trout. The high forest range of the Himalaya is covered with diverse forest flora and fauna, with luxury fishes sustaining with wide diversity harboring cold water fishes” (Singh, 2019). “With the increasing pressure of a globalized economy and under the effects of a changing climate, biological invasions have become a frequent feature of marine and freshwater environments. Global fisheries and aquaculture are therefore required to adjust to these changes, with the dual aim of reducing the negative ecological consequences caused by these species and making the most of that might bring changes in the ecosystem for prospective aquaculture development in cold water fisheries” (FAO, 2024). In India, the cold water fisheries primarily focus on breeding and rearing fish species adapted to colder water temperatures, typically in high-altitude regions like the Himalayas, are the habitats for several cold-water rivers and streams suitable for fish farming.  The water bodies of the Himalayan region harbor diverse kind of fish fauna different fish species in the Himalayan and the peninsular region of the country, of which indigenous mahseer, snow trout, exotic trout, and common carp are commercially important. It is reported that out of 1300 species, about 36 species of freshwater fishes are endemic to the Himalayan region. The present exploitation of fishery resources in upland regions mainly comes from capture fisheries, and fish production through culture practices is gaining momentum by growing salmonids in fish farms across the globe. “The present annual rainbow trout production in India is nearly 842 tons from 62 government trout farms and 660 private trout production units distributed across the states of Jammu and Kashmir, Himachal Pradesh, Sikkim, Arunachal Pradesh, and Uttarakhand using raceway culture systems” (Singh and Biju Sam Kamalam, 2017). The introduction of rainbow trout in India in the early 20th century is fast fast-growing and most remunerative industry that provides livelihood and food security to the hill population. For seed and feed production, there are 32 government-affiliated rainbow trout hatcheries with a production capacity of 13 million eyed ova and 3 well-equipped feed mills with an installed capacity of nearly 10 tons per day. The ICAR-Directorate of Coldwater Fisheries Research is making concerted efforts to expand and intensify rainbow trout production in coordination with state fisheries departments. As a conservative measure, adequate remedies are taken to minimize land and water usage in trout culture by giving focus on genetic improvement programs. In progressive development spatial decision support system has been employed to generate GIS-based site suitability to map the resources of trout culture and genetic variability in different rainbow trout. The stocks have been characterized using DNA markers and rainbow trout brood banking and triploid production have been attempted. A comprehensive disease surveillance and measures taken on the development of diagnostic methods with cost-effective feed formulation with better feed conversion ratio for sustainable feed management with on-farm trials. The fish seed transportation is being scientifically optimized, involving the cluster farming modules and introducing culture chains and technical know-how by sharing knowledge to facilitate high returns on investment.

Globally, the importance of mountains are recognized as the largest repositories of biological diversity. The mountain regions are characterized by the presence of cold waters, many of which harbor fish and support largely subsistence fisheries. The species are typically abundant in high-altitude regions such as the Himalayas and other colder parts of the country. Trout, a cold water fish species, highly cultured fish in India, high valued, known for its delicate flavor, and is a popular game fish among anglers. The cultivation and fish catch have created employment opportunities for the rural population and contributed to the conservation of cold-water fish species. However, habitat destruction and overfishing are the major challenges in cold-water fisheries culture. The fishing is also affected due to limited availability of quality broodstock, lack of proper infrastructure for hatcheries, transportation, and inadequate funding support. In addition to this, climate change has resulted in affecting the socioeconomic development of local communities in conservation and breeding. These aspects need to be addressed to sustain the stakeholders, including the government, fish farmers, and conservation organizations (Singh and Akthar, 2015).

In India, Himachal Pradesh is one of the principal areas where cold-water fisheries are highly dominated, in several cold-water rivers and streams are ideal for fish farming. The other regions of India, including Jammu & Kashmir, Uttarakhand, Sikkim, and Arunachal Pradesh, are also suitable for cold water fisheries. The Himalayas, which have a total area of 594400 km2, stretch between Nanga Parbat (8,126 m) in the west and Namcha Barwa (7756 m) in the east for nearly 2500 km. The Siwaliks, the lesser-known Himalaya and the Greater Himalaya, are also supporting the exploitation of fishery resources, mainly cold water species and capture fisheries, gaining importance. The available resources are under tremendous stress and affect the biodiversity of fish germplasm. The widespread consequences of climate change impact biodiversity, water resources agriculture, human health, and further stress the ecosystem due to anthropogenic pressures like overfishing, habitat loss, and species diversification (Kushi Patel et.al, 2024). These species are now reported under the threatened category under the classification of listed species by the IUCN. Among Schizothoracines, the important dominant fishery of the river system followed by cyprinids  are parallel and longitudinal mountain belts of different widths that run from south to north, each with its own geological history and distinctive physiographic features (Singh et.al, 2014; Sehgal, 1999). In the country, these water resources supported 272 fish species, 21 families, and 76 genera, of which 203 have been linked to the Himalayas and 91 to the Deccan Plateau. Fish farming makes a small contribution to the overall output of freshwater fish in the Indian Himalayas. In the Indian Himalayas, practically every facility built for fish production generates fish for stocking into streams and lakes (Gowhar et al, 2023).

 The states have taken initiatives to boost cold water fisheries with financial aid for the construction of fish farms and the acquisition of supplies to meet the demand for fish with essential inputs. The fish species most frequently farmed in cold water fisheries include mahseer, brown trout, and rainbow trout (Sehgal, 1999). However, lack of market access, insufficient technical know-how, and inadequate infrastructure have hindered the growth of cold-water fisheries in these areas. The northern and northeastern parts of India are native to many cold-water fisheries (Dash et. al, 2023). These fisheries sustain a wide range of fish species that are acclimated to cooler water temperatures. There are 19 significant rivers that drain the Himalayas; the Indus and Brahmaputra are the longest, with a mountain catchment area of roughly 160000 km2 (Singh, 2015). The riverine system in the Indus system and the catchment area is around 110000 km2 and travels across extensive valleys before emerging from the mountains. The distribution and abundance of different species of Coldwater fisheries are influenced by several physical, chemical, geochemical, and biological parameters of various water bodies, including water temperature, dissolved oxygen, velocity, turbidity, substratum, trophic status, and food availability. The flow velocity of rivers, substratum type, water temperature, and the accessibility of food are responsible for the distribution of fish species (Bandyopadhyay and Gyawali, 1994). In cold-water aquatic habitat temperatures and oxygen levels in hill streams support a variety of fishes in the North-eastern states extensively. Among them, a few species are known for their use in sports as ornamental fish, and the majority are known as food fish. Coldwater fisheries play a significant role in India's fisheries industry, which has a large scope for expansion for exclusive economic growth highlighting global warming issues on the changing pattern of biodiversity and impact on the fish production system. (Sharma, 2023). “The major obstacles in the rapid development and expansion of cold-water fish production is totally dependent on suitable food, sport and ornamental value extending from north western to mountainous region covering various states of India, viz., Jammu and Kashmir, Himachal Pradesh, Uttaranchal, Sikkim, Arunachal Pradesh, Nagaland, Manipur, Mizoram, Tripura, Meghalaya and hills of Assam and West Bengal”.

**Cold Water Ecosystem Diversity:**

The present exploitation of fishery resources in upland regions mainly comes in the form of capture fisheries, and fish production through culture practices is gaining momentum. Coldwater fish farming is practiced in various countries, with a focus on species like trout, salmon, and char. In Asia, countries like India, China, and Vietnam have significant cold-water fish farming industries, with a focus on species like trout and salmon. Countries like Norway, Scotland, and Ireland have well-established Coldwater fish farming industries, with a focus on species like salmon and trout. The United States and Canada have significant coldwater fish farming industries, with a focus on species like salmon and trout. Climate change is affecting Coldwater fish populations, making it essential to develop resilient and adaptable breeding programs. The disease management challenge in Coldwater fish farming requires effective attention as a strategy for health management measures, giving major emphasis on water resources for the country's food security and economic growth.  In the Himalayan mountain ranges influence of climate change is very high, and the monsoons deviate to the tropical and subtropical zone (below 38° N latitude), protected by the high Himalayan mountain ranges against the cold winds from the north. The mean daily temperature during the summer drops to 20 °C, that deviate changes in altitude, the key determinant factor for cold water conditions in the Himalayan belt. (Johri et al.,1989. In the Himalayan region, the lakes and reservoirs differ greatly along the altitudinal gradient in their origin, mixing pattern, salinity, trophic status, and total biodiversity, including fish diversity. The cold water fisheries sector confined in the Himalayan region holds vast potential of rivers and streams (Jammu and Kashmir, Himachal Pradesh, Uttarakhand, Sikkim, and Arunachal Pradesh) and Lakes and reservoirs (Dal Lake, Manasbal Lake, and Tehri Dam), Rivers (Ganga, Brahmaputra, and Indus). The key fish species includes Trout (Rainbow, Brown, and Brook), Mahseer (Golden and Silver), Snow Trout, Catla, and various carp species. 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 is one of the major game fishes of Himalaya’s. The practice involves breeding and rearing of fish species that are adapted to colder water temperatures, typically found in high-altitude regions such as the Himalayas (Sharma et.al 2018). Trout, a cold water fish species, is the most commonly cultured fish in India. Trout farming in Jammu and Kashmir, Mahseer conservation in Uttarakhand, Snow Trout cultivation in Sikkim, and Arunachal Pradesh have achieved great success. “Climate change has already affected the trends of some important biological processes, resulting in changes in primary production and fish distribution. Climate change affects primary production and fish stock distribution have negative implications for food security in many tropical countries” (FAO, 2015). Thus, the major challenges in Indian fisheries are habitat degradation and fragmentation, overfishing and poaching, climate change and water pollution, inadequate infrastructure and resources, and limited awareness and training among fishermen (Kaur and Tewari, 2023). “The region is vast, uneven, and versatile, inhabiting rich biological floral and faunal diversity. These areas are broadly divided into eastern Himalaya, central Himalaya, and western Himalaya, each of these having different physiographic and faunal diversity” (Singh, 2015)

The Culture of cold water fish in the Indian Himalayas has largely concentrated on the production of stocking material in rivers and streams, and some lakes. Species viz carps, mahseer, snow trout, brown and rainbow trout dominated for fish seed production, and to a much lesser extent for table size fish production. The most common exotic species sustaining are rainbow trout, brown trout, carp, and the indigenous fish mahseer’s (*Tor putitora* and *Tor tor*), and schizothoracines (*Schizothoraichthys esocinus,* including the species introduced Chocolate mahseer (*Neolissocheilus hexagonolepis), Labeo dero, Labeo dyocheilus, and O. belangari and Semiplotus semiplotus*. *Labeo dero, L. dyocheilus* are mid-distance cold water migrant fish degree centigrade with a desirable growth. *S. progastus, Schizothorax richardsonii, S. niger* and *S. curvifrons* reported in culture system. (Sarma et al., 2012). Among these, *Tor putitora, S. progastus,* and *S. richardsonii* are preferred for fisheries because of their wide range of distribution in the Himalayan region. However, the productivity is affected due to climate change in fisheries through its impact on flow regimes of streams, phonological changes, food chain, and micro habitat. Thus, cold water fisheries development in India holds immense potential for economic growth and food sustainability.

India’s diverse natural resource base, wide climatic diversity, are conducive to conserving and rearing different fish species, for high-value fish and growing interest in eco-tourism and angling in different altitudinal regions of the country. These issues are addressed by ensuring the sustainability and promoting science and literacy in cold water fisheries for sustainable aquaculture development. In the Indian subcontinent, cold water fishes generally dominate the Himalayan and sub-Himalayan zones in the north and watersheds draining the southern slope of the Deccan plateau (Sunder et al., 1999). “Coldwater fisheries occupy an important place in fisheries sector of India. The country’s Himalayan region is bestowed with vast and varied cold water/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 in the high altitude” (Mahanta and Sarma, 2010). “Among these, some species are known for sports purposes, a few of them have potential ornamental value and the majority of them contribute little to the overall freshwater fish production. The commercial fishery is dependent on the stocking of lakes and reservoirs with fry and fingerlings. The fish hatcheries in the Himalayas have been raising fry and fingerlings of brown and rainbow trout, and fry and fingerlings of common carp for stocking. Now, some hatcheries started producing seed for stocking the indigenous mahseers and Schizothoracines decline in seed production” (Sehgal, 1999; Sarma et al., 2012).

**Coldwater Fisheries Resources:**

The cold-water/hill fishery resources in India are spread from the Northwestern to Northeastern Himalayan region and some parts of the Western Ghats, encompassing about ten Himalayan states. India's cold water fisheries are mainly confined to: Himalayan rivers and streams (Jammu and Kashmir, Himachal Pradesh, Uttarakhand, Sikkim, and Arunachal Pradesh) and Lakes and reservoirs (Dal Lake, Manasbal Lake, and Tehri Dam), Rivers (Ganga, Brahmaputra, and Indus). The Key Fish Species includes Trout (Rainbow, Brown, and Brook), Mahseer (Golden and Silver), Snow Trout, Catla, and various carp species. Mahaseer, Snow trout, and Indian hill trout are the principal cold water fish species inhabiting the mountain waters of India. The mahaseer fishery of cold water is one of the major game fishes of the Himalayas. The practice involves breeding and rearing of fish species that are adapted to colder water temperatures, typically found in high-altitude regions such as the Himalayas. Trout, a cold-water fish species, is commonly cultured in India to bring more and more high-value fish species, either under monoculture or polyculture with diversification. These efforts are encouraging for entrepreneurship developmentthat need to be introduced in the mainstream of aquaculture practice withstandardization of breeding, seed production protocol. The seed rearing and grow-out technology also neednutrition, physiology, and health management. Various composite fish culture practices in small ponds are considered a good production system in the upland waters. The introduction of indigenous species for aquaculture after breeding, feeding, and culture protocol was introduced in hill aquaculture as a new candidate species by DCFR.

 The present Himalayan aquatic resources and their fish diversity are summarized in Table 1.

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| Table 1. Aquatic resources and their fish diversity in the Indian Himalayan Region (IHR) (Based on GIS-based mapping and field data). |
| Sr. No  | State  |  Lakes (ha)  | Reservoirs (ha)  | Rivers (Km) | Fish Species Diversity (No.) |
| 1. | Jammu & Kashmir  | 137275.3 | 4087.3 | 10893.5 | 21 |
| 2. | Himachal Pradesh  | 27.2 | 31320.2  | 10464.3 | 62 |
| 3. | Uttarakhand | 212.0 | 16864.0 | 10657.8 | 83 |
| 4. | Sikkim | 1004.5 | -------- | 1771.5 | 47 |
| 5. | Arunachal Pradesh  | 2792.7 | ------- | 12351.0 | 167 |

Source: Singh (2019).

**Sustenance of Himalayan water Fisheries:**

“In Himalayan water, the 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.). Considering the long streams and rivers, natural lakes and reservoirs, both natural and manmade and brackish water lake resources in the high altitude the brown trout spread to other sections of the Himalayas in Kashmir region. The rainbow trout (*Salmo gairdneri irideus*)” (Sehgal, 2012; FAO, 2024). “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 landlocked variety of Atlantic salmon (*Salmo* *salar*) from North America have been transplanted trout in Kashmir valley. The exotic brown trout (*Salmo trutta*) has established itself in some areas of the Himalayas the recreational fishery based on *Tor putitora*, called golden mahseer, and other species of mahseers and trouts, for the livelihood of locals”. (Raina and Petr, 1999).

**Fisheries of North West Himalayan Streams**

The Valley region of Kashmir has great potential for fresh water habitats of both lentic (flowing) and lotic (stagnant) nature spread throughout the valley, forming tributaries of the river Jhelum that flows through the valley. These streams harbor a number of indigenous Schizothorax fish species. In most of the streams important fishery resource of the valley, not much is known about the ecology of the fish of these habitats sustain. The fish fauna of the high altitude waters of the valley of the Kashmir lakes, rivers and springs comprise species of the genus Schizothorax, Cyprinus, Glyptothorax, Tryplophysa, etc. The subsistence and commercial fisheries exploit the larger fish, such as the cyprinids, *Schizothorax plagiostomus* and *Schizothoraichthys esocinus*, as well as *Crossocheilus diplochilus.* The common carp, introduced in Kashmir Himalaya, is now a very common fish in the Kashmir Valley lakes and the Jhelum River. The Wular and Dal Lake are much shallower and are almost entirely carpeted with flowering plants in the vicinity of Srinagar, large swamps exist on the western side of Dal. These swamps are extensively canalized and are cultivated by the mooring of rafts, called floating gardens, laden with mud and manure, on which green vegetables can be grown. “The two fish species viz; *Cyprinus carpio specularis* and *C. carpio communis*, introduced in 1956, have been well established as they thrive in waters rich in nutrients and organic matter. The present-day fish catch of these lakes comprises more than 80% of the carp. This has been reported on the ichthyofauna of the region” (Das and Subla, 1970).

**Fish Diversity in Kashmir Valley**

The distribution pattern of Himalayan fish to inhabit the torrential streams studied by Hora (1955) and Menon (1962) reported the evolution of schizothoracines appeared during the first interglacial period. The main factors which influence fish life in the Himalayan streams are: current velocity, fluctuation in water discharge, water temperature and dissolved oxygen level, substratum, shelter from the current, and food availability, mostly by organisms clinging to and growing on rock and stone surfaces in fast current. Schizothoracines and brown trout remain active in the near-zero temperature that prevails in streams of the Lesser and Greater Himalayas during December and January. A drought condition during 1972 in Kashmir resulted in trout killing due to the sharp rise of temperature in the Vishav River, a tributary of the Jhelum in Kashmir Valley (Sehgal, 1970) and cope up with the steep fall in temperature in winter months schizothoracines migrate from headwaters to lower altitudes where they represent a sizeable part in fish catches in large rivers and their tributaries. The rise in temperature in Kashmir streams from near-freezing level to 10-17°C during May and June induces *S. plagiostomus* and *S. curvifrons* to spawn. (Singh et al, 2017)

**Biodiversity and Climate Change:**

“Salmonid species were introduced in the Himalayas between 1905 and 1969 from Europe, North America and Canada: brown trout, rainbow trout, eastern brook trout (Salvelinus fontinalis), splake (a hybrid between lake and brook trouts), and the land-locked variety of Atlantic salmon (*Salmo salar*). Among these, brown trout is now well established, with a number of self-sustaining populations in the streams of the Himalayas. Rainbow trout has failed to establish itself in the stream ecosystem, but it is cultured in fish farms. Reports of a sharp increase in common carp catches in Lake Dal, with the once-abundant schizothoracine species having been virtually ousted” (Das and Subla 1970). It is believed that the endemic schizothoracines are fast losing their ground in Kashmir lakes due to the higher fecundity of common carp and its habit of spawning in confined waters. By contrast, schizothoracines undergo breeding migration for spawning in turbulent streams, and they also have a lower fecundity than carp. In the Jhelum River in Kashmir, schizothoracines represented 78% of the total catch during 1980-82 (Sunder and Subha, 1984a). In Gobindsagar Reservoir, common carp contributed 22- 35% to the total catch between 1975 and 1984, but with the increase in silver carp, there was a decline in common carp (Kumar, 1988). Due to their high fecundity, silver and common carps have monopolized the whole water body and undertake detailed investigations on the biology of the two species in selected waters to further clarify the silver carp-common carp-mahseer-schizothoracines inter-relationships.

**Loss of breeding grounds**:

Deforestation over the last few decades and significant quantities of eroded soil entering the upper reaches of the streams caused loss of native species’ breeding grounds. The exotic species did not suffer much on this account as their population in the streams was regularly reinforced by the government agencies by releasing fry and fingerlings raised in the farms. Extraction of sand and gravel, where the native fish feed and breed, has also been cited as a reason for the dwindling fish population. The use of herbicides, pesticides, and fertilizers for agriculture and horticulture has picked up enormously in recent years. The local fish species are most sensitive to the pollutants and affecting the larvae and juveniles. The rapid melting of glaciers in spring due to the impact of climate change is also a factor in the decline of native fish. It is seriously noted that the fishery of Himalaya is suffering from anthropogenic stress (Singh and Akthar, 2015). The spawning affected during the spring season, the streams are generally full of water because of the melting of snow, and the broods of migrating fish try to go as upstream as possible and lay eggs in shallow areas having sandy or gravelly bottoms. But the water recedes once the melting stops, causing shallow areas to dry up. The fingerlings of the fish get trapped in pools of leftover water and ultimately perish after finding no access to the main stream

 **Conservation Measures:**

The indiscriminate fishing affecting  the conservation of valuable fish species. Therefore, the potential areas need identification for integrated aquaculture, stock diversification for sustainable enhancement measures in lakes and reservoirs including the development of ornamental fish and promotion of fishery based eco­tourism at suitable sites (Vishwanath et al., 2011). It is felt that improving the surveillance along the rivers and lakes to protect fish stocks involves voluntary agencies in conserving the stocks. In the Kashmir Himalaya, construction of dams on various rivers is likely to affect the schizothoracines. The stretches of streams and rivers, pools and temple springs in the states of Kashmir, Himachal Pradesh and Uttar Pradesh act as cold water fish sanctuaries in the Himalayas. The trout fishery in rivers and lakes is regularly stocked with yearlings’ production in hatcheries in different streams to better regulate sport and recreational fishing and to determine stocking rates, ecological parameters involving water quality and status of benthic population in different streams having productive potential need assessment with focus on fisheries development and conservation (Sehgal, 2012). Trout is introduced 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. This was, due to no availability of a cool room in the ship, all the eggs perished on way to India. (Shakir Ahmad Mir et.al, 2023). The swim up fry from these eggs were successfully reared up to adulthood and the first spawning of the brown trout was done in winter season at Harwan near Srinagar Kashmir transported successfully and well 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).

**Exploitation cold water resources for aquaculture:**

The cold water resource availability status of potentiality suitable culture areas for development and scientific management for the cold water fisheries in North East India has abundant water resources and is home to several major rivers, including the Brahmaputra and Ganga river systems, which have numerous tributaries. These rivers are fed by snowmelt and glaciers, making them cold water resources. The Eastern Himalayas have numerous glaciers that store cold water. These glaciers feed rivers and streams, maintaining water flow during dry seasons (FAO, 2024). These cold water resources are essential for the region's ecosystem and support agriculture, industry, and domestic water needs. Cold water resources depend on the evaluation of water resources for sustainable aquaculture typically sustaining fish between 10 °to 20°, enriched water quality and adequate water flow and application of remote sensing technology to assess water bodies sites for cultivation. DCFR, Bhimtal has developed GIS GIS-based decision support system based on the spatial database on physicochemical parameters. (Sarma et al, 2018). Among the exotic species, *Tor putitora*, *S. progastus* and *S. richardsonii* are preferred because of their wide range of distributionin the Himalayas. Rainbow trout can also bepropagated artificially, which is important for its production as food fish with artificial feed withstand temperatures of up to 26.6°C for short periods. The snow trout or mountain barbel (*Schizothorax richardsonii*) is widely distributed in the Indian Himalayas, from Ladakh in the North West Himalayas, undertakes migration during winter months when the temperature reaches near freezingpoint. Thus, trout farming has immense scope in the Himalayan and some peninsular regions where a sufficient quantity of quality water is available (Akthar et al*.,* 2017). The aquaculture facilities is based on the availability of water required in springs and glacier-fed streams. The abundant availability of water resources in Nepal has huge potential for fish farming. The yield and water resources availability for fish production and opportunities have resulted shown steady growth in fish production in the last 15 years. The fish yield increased by more than 2000 kilograms per hectare and the majority of the fish productioncomes from the Eastern Terai region, with some hilly districts developing themselves as a good hub for rainbow trout, addressing the problems faced by the farmers and bringing self-sufficiency in fish production (Karki, 2016).Some specific cold water resources in North East India include Arunachal Pradesh, Meghalaya, Nagaland, and Assam have abundant surface water resources, including rivers and wetlands, abundant with a large number of cold water species, are highlighted in Fig.1.

Fig 1. Fish species of North East India.



**Source: (Sarma et al., 2018).**

**Culture of Schizothoracines**

In India, the culture of Schizothoracines is still in its experimental stage, like the mahseer group of cyprinids. It 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 species viz; *Tor putitora, S. progastus and S. richardsonii* have adversely affected the schizothoracine fishery in the lake environment of the Kashmir valley lakes. While in the Jhelum River, the presence of the common carp had no impact on schizothoracines with collection and artificial fertilization of eggs from *Schizothorax planifrons, S. curvifrons and S. plagiostomus*. The larval rearing and induced breeding in snow trout *Schizothorax niger* has been reported successful with tha aopplication of ovatide(Wani,2014). The fish spawning from Lake Wular supports fishermen who depend on fishing for their livelihood and women contribute to the production, marketing and management of fish. The conservation efforts were made by conducting awareness camps to combat illegal fishing and protect the lake ecosystem in the hilly region (Sehgal, 1974).

**Culture of Common Carp**

The Common Carp (*Cyprinus carpio*) is a widely cultivated fish species in the Himalayas, including India. The German phenotype of Common Carp is known for its fast growth rate and desirable traits. 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 stocking of lakes and reservoirs. The breeding programs for Common Carp in the Himalayas focus on selecting desirable traits like fast growth rate, disease resistance, and adaptability to local conditions. There is a growing demand for Common Carp in the Himalayan region, driven by increasing consumer preference for fish as a protein source, and it minimizes environmental impacts while optimizing production. “Common carp are produced in fish farms of the State Fisheries Departments of Himachal Pradesh, Uttaranchal, North Bengal, Arunachal Pradesh, Meghalaya, Manipur, and Nagaland. It is successfully bred in cement tanks, in rectangular cloth containers fixed in ponds (hapas), and in earthen ponds. The growth performance of these Hungarian strains and the existing local strain of scale carp (Bangkok strain) has been evaluated and recorded the highest growth in Hungarian mirror carp under a polyculture system in India, followed by Hungarian scale carp” (Mahanta et al., 2010, Sarma, D et al., 2018). “The breeding of these two improved strains has been done successfully and released at Champawat center and the seeds of F1 generation (named as Champa1 and Champa2 respectively) have been adopted to other hill states to assess its culture and growth potential on experimental field trial basis to help in improving hill aquaculture production in near future” (Srivastava et al., 2010).

**Fish Farming in Polyhouse System:**

Cold water fish culture in polyhouses is an innovative approach being explored in India, particularly in the northeastern region. Polyhouse fish culture has been shown to increase fish growth rates, with one study demonstrating a 34.6% higher final weight and 34.8% greater daily weight gain compared to traditional outdoor systems. Polyhouse systems have also reported a 16.1% better survival rate, likely due to controlled water temperature and quality. Polyhouse fish culture can lead to higher biomass production, with a reported 56.5% increase in total fish biomass. Emphasis is given on ornamental fish breeding in aquarium tanks, and techniques used to breed ornamental fish in aquarium contribute to the fish industry supporting aquaculture in cold water species (Zaidi et al, 2018). Suitable fish species, namely *Neolissochilus hexagonolepis* (Chocolate Mahseer) have been successfully cultured in polyhouse ponds in Meghalaya, demonstrating promising results. Species like trout and salmon could potentially be cultured in polyhouses, given their adaptability to cold water conditions. Pond-Based Aquaculture Production System (PPAS) has shown promise in cultivating cold water fish, maintaining an average 2.4°C higher water temperature than outdoor systems. Polyhouse systems provide a controlled environment, allowing regulation of water temperature, quality, and other parameters to optimize fish growth. Polyhouse fish culture needs refinement of technology to make it more accessible to farmers in India. “At DCFR’s Champawat farm during winters (November to February) ascertained 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 the Lesser Himalayas. The ponds covered with polyhouse revealed a drastic increase in temperature in the covered area marginally higher growth rate recorded over the control ponds” (Vishwanath et al*.*, 2011).

**Mahseer Conservation and Breeding:**

Mahaseer breeding programs have been successful using artificial propagation techniques, including induced breeding with pituitary extract or ovaprim/ovatide. The Tata Power Company's Mahaseer hatchery in Lonavla has developed a simple and effective breeding process, producing over 8.1 million fry and fingerlings in the last 30 years. The induced breeding aspects in golden mahseer *T. putitora* have been well elaborated (Joshi et al, 1988). Successful cross-breeding of mahaseer species has been achieved, producing F1 and F2 generations. In India, under conservation efforts, Rajasthan government has designated around a 300-hectare area surrounding Badi Lake as a Mahaseer Conservation Reserve, providing a safe habitat for the species. Mahaseer ranching programs aim to rehabilitate the species in natural waters, supplementing wild fish stocks with hatchery-reared juveniles and fingerlings. The stripped eggs are collected in the plastic trays and the milt is spread over the eggs 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). A tremendous success in brood stock management of golden and chocolate mahseer in the pond environment and seed has been produced from the pond-raised brooders. The distribution of Mahseer seed to distant places, Mahseer eggs are being transported in moist cotton by air. Fertilized eggs after the water hardening process were placed between the layers of moist cotton in 23 layers and then kept in plastic boxes. As the minimum hatching period is 70 hours, sufficient time is available to transport the eggs over long distances (Sarma et al., 2009). The breeding and propagation of Himalayan golden Mahseer is well established to examine the coldwater fish diversity for sustainable development. The issues and priorities attempted to conserve the threatened species in North East India for production and productivity increase (Singh, 2018., Singh and Sarma, 2017). The cryopreservation protocol for mahaseer milt has been developed, allowing for gene banking and conservation of endangered mahaseer populations. This has paid attention to Conservation Awareness by education of local communities and stakeholders to save mahseer from extinction the brood stock is obtained from natural grounds in rivers, lakes and reservoirs.

**Constraints in Cold Water Fishery:**

Cold water fish culture in India faces several constraints that impact the growth and sustainability of this industry. Cold water fish culture requires specific water temperature and quality conditions, which can be challenging to find in suitable quantities. Rising water temperatures and changing precipitation patterns can impact the growth and survival of cold-water fish species. India faces difficulty in the availability of quality bloodstock, a significant constraint in cold water fish culture, affecting the productivity and sustainability of farms. Further, the lack of modern hatchery infrastructure and technology can hinder the production of high-quality fish seed. There are economic and social constraints in setting up cold water fish farms, requiring significant initial investment in infrastructure, equipment, and technology. The fish, having limited market access for cold water fish products, may face challenges in reaching markets, particularly in regions far from production areas. Disease outbreaks can be a significant challenge in cold water fish culture, requiring effective management strategies. Providing suitable feed and nutrition for cold-water fish species. The sustainable growth and development of cold-water fish culture will be promising by solving major hurdles concerning the development of cold water fisheries sector in India (Mahanta and Sarma, 2010; Akhtar et al., 2013). The major constraints reported are low level of production /slow growth rate, lack of infrastructure for aquaculture, less availability of seed for culture, climate change and global warming issues. The lack of a well-established hatchery technology for Mahseer and for the rearing of its seed is a major obstacle in introducing Mahseer ranching. The Directorate of Coldwater Fisheries Research, ICAR, India has taken a 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 is 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 introduced generations and may serve as natural sanctuaries. These kinds of efforts can be suggested wherever mahseer exists (Sarma et al., 2012; Akhtar et al.,2013). The conservation and rehabilitation of endangered mahseers are of national importance by stocking material through artificial propagation is important to stock those water bodies which are having facility for natural breeding and nursery grounds (Akhtar et al., 2010). The low natural productivity of cold-water resources leads to more dependence on supplemental feeds and availability of local feed ingredients, ultimately resulting in higher feed cost, as lower temperature limits mass culture of live food organisms.

**Disease and health management:**

Disease management is crucial in cold-water fish farming to prevent losses and ensure the health and well-being of fish. Here are some key aspects of disease management in cold water fish: Disease Prevention is the primary step to save the husbandry. Providing a balanced diet and proper feeding practices can help boost the immune system of fish and reduce the risk of disease. Observing clinical signs such as lethargy, loss of appetite, and abnormal behavior can help identify diseased fish. Laboratory testing, such as microbiology, histopathology, and molecular diagnostics, can help confirm the diagnosis of diseases. Medications such as antibiotics and antifungals can be used to treat bacterial and fungal diseases in cold water fish. Probiotics can be used to promote a healthy gut microbiome and boost the immune system of fish. The strategies that combine multiple control methods can help manage diseases effectively with vaccination protocol by regular monitoring and surveillance help detect diseases early, allowing for prompt action to be taken. By implementing effective disease management strategies, cold water fish farmers can reduce the risk of disease outbreaks and promote the health and well-being of their fish. The fish health sector develops procedures for the identification of important fish pathogens. The dead eggs are more susceptible to the fungal attack during incubation, as Saprolegnia is a saprophyte observed under captivity snow trout is more susceptible to Saprolegnia than rainbow trout. The group of Aeromonads and Pseudomonads bacteria are ubiquitous and get infected in fresh water bodies and opportunistic when they get infected; therefore, good management practices have to be adapted to minimize the chances of infection (Pande et al., 2012). Implementing biosecurity measures such as quarantine, disinfection, and sanitation can help prevent the introduction and spread of diseases. Maintaining good water quality can help reduce stress on fish and prevent disease outbreaks.

**Promotion of Ecotourism:**

Ecotourism can be a valuable opportunity for promoting sustainable cold water fisheries.

Ecotourism can support conservation efforts by promoting the value of intact ecosystems and the species that inhabit them. Ecotourism can provide alternative livelihoods for local communities, reducing dependence on fishing and promoting sustainable use of resources. Ecotourism can raise awareness about the importance of cold water fisheries and conservation needs. Ecotourism can generate income for local communities. These days fishery-based eco-tourism is an emerging potential area for employment generation. Species like valuable mahseer and rare Indian exotic trout fishes available in cold-water regions are in high demand among anglers. The revenues from fishing licenses support fish and wildlife management agencies at all levels of government, and the expenditures from recreational fishing contribute to the local and regional economy. (Sarma et al., 2012). The activities include guided fishing trips that can promote sustainable fishing practices and provide opportunities for visitors to experience cold water fisheries, wildlife photography, or simply observing fish in their natural habitat can promote appreciation for these ecosystems and can also involve cultural experiences, such as learning about local fishing traditions and practices.

**Socio-economic Development**

The cold water fisheries sector contributes significantly to food security, employment and sustainability. Fisheries have a great potential in generating rural income and providing food security to the rural population in the upland regions of India. However, climate change impacts are occurring as a result of gradual warming and related physical changes as well as socio-economic pressures on natural ecosystems, thus modifying the distribution of fisheries, including cold water species. There is a need to adopt appropriate strategic plans so that hill aquatic resources and aquaculture activities can contribute substantially to fisheries and aquaculture in remote hilly regions. The Socio-Economic aspects of cold water fisheries can help promote sustainable livelihoods and economic development. The government's effective policy and regulatory frameworks can help support the growth and sustainability of cold water fisheries by addressing these issues through R&D, and the cold water fisheries sector can become more sustainable, productive, and resilient. The linkages between ICAR research institutes, fisheries departments of hill states, agricultural universities, non-governmental organizations and central agencies such as the National Fisheries Development Board for promoting research, extension and capacity building need strengthening for future development.

**Research and Development:**

Research and development (R&D) in cold water fisheries and aquaculture can address various issues in cold water fishery promotion viz; bloodstock development and seed production. Therefore, developing healthy and disease-resistant bloodstock is crucial for sustainable cold water fisheries. The seed production techniques can help increase the availability of high-quality fish seed. Disease and health management can be addressed with effective diagnosis methods to treat and help reduce losses in cold water fisheries. Research in vaccination and health management strategies can help prevent disease outbreaks. In feed and nutrition, developing nutritionally balanced feeds can improve fish growth and health and optimization of feed management practices can help reduce waste and improve water quality. Recirculating aquaculture systems (RAS) can help improve water quality and reduce waste in cold water fisheries. In India, there is a large potential to improve and conserve indigenous and exotic species in the region. The National Research Centre on the Directorate of Coldwater Fisheries Research DCFR-ICAR is supporting research to enhance fish production, support local communities, and contribute to the country's food security. The exotic species of trout introduced to Indian waters, with species *like Salmo trutta fabrio, Oncorhynchus mykiss* (rainbow trout) and *Oncorhynchus nakrii Cyprinus Carpio* cultivated in Kashmir and northeastern India showing good success in induced breeding, can be cultured commercially in Trans-Himalayan Countries like India, Nepal, Bhutan, and Pakistan have significant cold-water fisheries resources. This include species like Schizothorax and exotic species like trouts in hills are a valuable fishery both for food, sport. However, to manage these ecosystems, they can contribute to fishery development on a sustainable basis. The efforts have been made to improve fisheries management practices, including habitat conservation and sustainable fishing practices. With proper management and conservation practices, cold water fisheries can be developed sustainably, supporting the long-term health of fish populations and ecosystems.

**Challenges and Opportunities**

Cold water fish culture in polyhouses is an innovative approach being explored in India, particularly in the northeastern region. Polyhouse fish culture has been shown to increase fish growth rates, with one study demonstrating a 34.6% higher final weight and 34.8% greater daily weight gain compared to traditional outdoor systems. Polyhouse systems have also reported a 16.1% better survival rate, likely due to controlled water temperature and quality. Some of the species have been successfully cultured in polyhouse ponds in Meghalaya, demonstrating promising results. By seeing success, species like trout and salmon could potentially be cultured in polyhouses, given their adaptability to cold water conditions. Pond-Based Aquaculture Production System (PPAS) has shown promise in cultivating cold water fish, maintaining an average 2.4°C higher water temperature than outdoor systems. With a controlled environment, allowing for regulation of water temperature, quality, and other parameters to optimize fish growth, while playhouse fish culture shows promise, further research and development are needed to refine the technology and make it more accessible to farmers in India.

For achieving the goal, the priority attention is given to

* Resource mapping of the fishery resources in the mountain/hill region for the integrated development of the cold-water sector.
* To develop the riverine and lacustrine fisheries, it is necessary to go for a stock enhancement programme through ranching.
* Develop a legal framework to stop all types of destructive fishing methods.
* Declare the breeding grounds of the fish need special protection zones as ‘No fishing Zone’ or ‘Protected Area’.
* Balanced strategy for lakes, for tourism and fishery development.
* 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 resources and conservation of biodiversity.

**Summary:**

Cold water fisheries in India are primarily located in the Himalayan region, where the water temperature and quality support the growth of cold water fish species. It supports Trout a popular cold water fish species in India, with several species being farmed and stocked in rivers and lakes. Mahaseer is another important cold water fish species in India, known for its sporting and food value. Initiatives were made in several hatcheries with their establishments in the Himalayan region to produce high-quality fish seed for stocking and farming in several states, including Jammu and Kashmir, Himachal Pradesh, and Uttarakhand. India is second second-largest producer of fish and offers a vast potential for aquaculture, which is growing at an annual growth rate of over 8%, contributing significantly to the economy and nutrition of millions of people with freshwater species. The overall key species contributing to about 80-90% of the freshwater aquaculture production in India. Considering a vital role in the hill region in supplementing protein requirement to poor people in the Himalayan region can support a good source of income in cultivable lands in hills overexploiting natural resources. At high altitudes, we have tremendous scope for the development of low-volume, high-value species such as trout, especially the rainbow variety. The National Fisheries Policy (2020) is promoting sustainable fisheries management, increasing fish production, and improving the livelihoods of fishers. Emphasis is given on cold water species in breeding new varieties and aquaculture to fulfill the goal of blue revolution. In conclusion, trout and mahseer cultivation in states like Himachal Pradesh, Jammu & Kashmir, Uttarakhand, Sikkim, and Arunachal Pradesh has been the major focus of growth of cold-water fisheries in India. Overall, cold water fisheries development in India has huge potential to support sustainable livelihoods, promote conservation and contribute to India’s food security.

Strategic approach for Promotion and Development:

To promote cold water fisheries in India at commercial scale india need to give focus on Species Selection and Breeding, Identify and breed suitable cold water fish species, such as rainbow trout and Mahseer, to improve growth rates, disease resistance, and adaptability.

For aquaculture Development need is felt to establish aquaculture farms and hatcheries in suitable locations, ensuring proper water quality management and biosecurity measures.

Introduce Training and Capacity Building programme to provide training and capacity-building for local communities, farmers, and fisheries professionals on cold water fish farming, management, and conservation.

Set up infrastructure development by investing in cold storage facilities, transportation networks, and markets, to support the growth of cold water fisheries.

Promote Research and Development by conducting research on cold water fish biology, ecology, and aquaculture, and develop innovative technologies and practices to improve the sector's sustainability and productivity.

Implement Policy and Regulatory Framework to promote sustainable cold water fisheries development, including guidelines for aquaculture, conservation, and management

Data sharing is not applicable in this article as no new data were created or analyzed in this review article.

Declaration: The review has not been published previously/ under publication consideration elsewhere.

Ethical statement: This being a review paper and as such the clearance of ethical committee was not required.

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