Fishery Resources and Ichthyofaunal Diversity in the Temperate Himalayas

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Kishor Kunal, Garima, and P. A. Ganie

Abstract

According to some reports, water resources in the Himalayas harbor 268 fish species distributed to 76 genera and 21 families. An updated study by the Zoological Society of India has reported nearly 316 fish species from the Indian Himalayan landscape. Besides, 13 invasive species have been identified, which have been introduced in the Himalayan waters. Ninety-seven of the 316 species found in this area are native to the Indian Himalayan freshwater systems. The fish variety known from the region accounts for roughly 30.8% of India's total freshwater fish species (1027), 62.8% of total genera (188), and 18.6% of the total endemic species (522). The major fishery in the Himalayas mainly comprises of the rainbow trout, snow trouts, mahseers, loaches, garrids, barils, catfishes, and carps.

Keywords

Indian Himalaya · Ichthyodiversity · Fishery resources · Snow trouts · Fish aggregating devices

2.1 Introduction

The literal meaning of Himalaya is "abode of snow." The Himalayas are geologically young and structurally folded mountains that stretch over 4000 km from the east (Myanmar and China) to the west (Afghanistan), with all 14 of the world's

K. Kunal (✉) · Garima · P. A. Ganie
Anusandhan Bhavan, ICAR-Directorate of Coldwater Fisheries Research, Bhimtal, Uttarakhand, India

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highest mountains looming over 8000 m. The Himalayas is a beacon for clouds of moisture that generously bestow its slope with precipitation and, through rapidly growing mountains, create the great rivers of Asia (Zurick and Pacheco 2006). Variation in Himalayan altitudes is greater in the eastern half than in the western half. Rivers are linear systems that show a gradient of characters along their length. The Himalayas has a larger number of rivers that originate from it and possesses a perennial supply of liquescent snows and a substantial number of lakes and reservoirs which have been constructed for different purposes harboring the numerous cold-water fish stock. These mighty rivers are fed by copious rainfall, large glaciers, and extensive snow fields. Streams, originating from the Himalayas, are very peculiar in their characteristics by virtue of their fast-flowing waters, high altitude, low water temperatures, and heterogeneous substrates due to snowmelt or glacier-fed water (Rajput et al. 2013).

"Rhithron" is the steep and turbulent upper course, and "potamon" is the wide, flat, lower course with less water flow rate. Rhithron course of rivers falls in the Himalayan region. River streams of the Himalayas can generally be categorized under three subsystems: collecting system, transporting system, and dispersing system. Stream order depends on the drainage density of the region. Drainage channels of similar flow inputs are identified with the same stream order. Streams of the same order join together and form a higher-order stream. The stream order varies from first order onward, based on their connection with tributaries. Higher stream order or stream with high flow concentration results in lesser fluctuations in physicochemical parameters and supports higher diversity/population (Whiteside and McNatt 1972). The rivers and streams of the Himalayas flow through deep valleys and gorges until they exit the mountains. Enormous power potential of the Himalayan reservoirs is still underutilized. Several sites in the Himalayan region can house hydroelectric plants, either by utilizing waterfalls at many places or by constructing dams at other places. Most of the lakes found in the Himalayan region are of glacial origin. Glacial lakes are widespread in glacierized basins at high elevations. When glacial ice, moraines, or natural depressions impound water, they form glacial lakes. There are many different types of such lakes, ranging from meltwater ponds on glacier surfaces to enormous lakes inside valleys dammed by a glacier in the main valley. They are formed when glaciers dug out a basin, which was later filled with snowmelt. Fishery resources of the Himalayas comprised of both endemic and exotic fishery resources.

2.2 Ichthyodiversity

The altitudinal regime mainly influences the weather condition in this region. The low temperature is a major factor determining the profile of organisms dwelling in the drainage. Fish are important sources of protein for people residing in hills and mountains and provide them livelihood by making income through it. The cold-water rivers and hill streams are renowned for their waterfalls, torrential stream flow, substratum comprising with bedrock boulder sand, rapids, cascades and deep pools. The distribution of fishes is greatly affected by the slope, flow rate, types of

substrata, and availability of food. According to some old reports, these water resources harbor 268 fish species belonging to 76 genera and 21 families in the country of which 203 are recorded from the Himalayas and 91 from the Deccan Plateau (Sehgal 1999).

Variation in Himalayan altitudes is greater in the eastern than in the western part. Such variations might have established greater ichthyodiversity toward the east than the west (Menon 1962). According to an updated study of fish diversity and distribution in the Indian Himalayan landscape, roughly 316 fish species with valid names are found in the Indian Himalayan freshwater ecosystems/habitats (Chandra et al. 2018). Thirteen invasive species have been identified in the Himalayan landscape waters, some of which have become established. There are 118 recognized genera and 38 families in the fish fauna, which are divided into 13 orders (Gopi et al. 2018). Ninety-seven of the 316 species found in this area are native to the Indian Himalayan freshwater systems. The fish variety known from the region accounts for roughly 30.8% of India's total freshwater fish species (1027), 62.8% of total genera (188), and 18.6% of the total endemic species (522) (Gopi et al. 2017).

The headwater zone is dwelled by species of loaches (e.g., *Nemacheilus stolickai* and *N. gracilis*) and catfishes (e.g., *Glyptosternum reticulatum*, which are rheophilic in nature). Further, where the headwater streams join, the large stream zones are formed which are inhabited by species like *Nemacheilus* spp. and *Diptychus maculatus*. The upper and intermediate stretches of this zone are inhabited by different rheophilic species of snow trouts. The slow-moving meandering zone is inhabited by fish species like snakeheads, homalopterid fishes (*Homaloptera* spp.), catfishes, mahseers, and *Barilius* spp. (Petr and Swar 2002).

The order "Cypriniformes" makes up the major ichthyodiversity in the Himalayan waters, accounting for around 54.7% of all species (173 species). There are 92 species of catfish (Siluriformes) identified from this region (29.1%). Cyprinidae, with 111 species, is the most species-rich family, followed by Nemacheilidae (42 species), which together account for 35.1% and 13.3% of the ichthyodiversity recorded from the Indian Himalayan region (Gopi et al. 2018). Snow trouts belong to family Cyprinidae, subfamily Schizothoracine. Seven genera and 15 species of snow trout are found in the sub-Himalayan regions of India. Two major genera of snow trout are *Schizothorax* and *Schizothoraichthys*. Due to declining catch of snow trout in different rivers and streams, IUCN has listed them as vulnerable species. Most common species found in India are *Schizothorax richardsonii*, *S. kumaonensis*, *S. niger*, *S. esocinus*, *S. progastus*, *Shizopyge curvifrons* and *Diptychus maculatus*. In Ladakh streams, five species of snow trout, *D. maculatus*, *Schizopygopsis stolickai*, *Schizothorax labiatus*, *Schizothorax richardsonii*, and *Ptychobarbus conirostris*, are found (Gopi et al. 2018). In Himachal Pradesh, the most dominant species is *S. richardsonii*. In northeast, the Himalayan streams are dominated by snow trouts, such as *S. richardsonii*, *S. esocinus*, and *S. progastus*. *S. richardsonii* and *S. plagiostomus* were found to be the dominant species in the Kameng drainage, whereas *S. progastus* and *S. richardsonii* dominated in the Siang drainage of Arunachal Pradesh. Maximum species of *Schizothorax* spp. and *Schizothoraichthys*

are endemic to Kashmir and Ladakh. *Schizothorax progastus* is mainly found in the eastern part of the Himalayas. *Schizothorax richardsonii* is the most dominant species and found almost all along the Himalayas. Maximum species of snow trout prefers lacustrine habitat.

The family Sisoridae is the most diverse among catfishes, with 41 species accounting for 13.0% of the region's total fish diversity, followed by Bagridae and Erethistidae (15 species each). The family Cyprinidae (Cypriniformes) has the highest generic abundance (40) in the Himalayan freshwater systems, accounting for 33.9% of all fish genera. Twelve genera (10.2%) of the fish genera recorded in the region belong to the Sisoridae (Siluriformes) family.

Only seven families out of 38 exhibit a species diversity of ten species or more in family-specific dominance. They are classified into the following orders: Cyprinidae (111 species), Nemacheilidae (42 species), Sisoridae (41 species), Bagridae (15 species), Erethistidae (15 species), Cobitidae (13 species), and Channidae (10 species); and they account for approximately 78.2% of the total fish species. Four families have 2 species in 1 or 2 genera, whereas 15 families have 1 genus with 1 species each. There are 46 species in 21 families with only 1 genus each, among which the Channidae family has the most species (10 species), followed by Badidae (7 species), and Psilorhynchidae (5 species). Each family has an average of >8 species diversity of fishes known from the Indian Himalaya (Gopi et al. 2018).

Comparing all the genera, the genus *Glyptothorax* of family sisoridae is the most diverse genera with 20 species, followed by genus *Garra* of family cyprinidae also with 20 species. The genus *Schizothorax* (12 species), genus *Barilius* (8 species), genus *Psilorynchus* (5 species) of cyprinidae family, and genus *Triplophysa* (10 species), genus *Aborichthys* (7 species) of Nemacheilidae family are the other genera with diverse species. The genera *Pseudolaguvia* (7 species) (Erethistidae family), *Mystus* (5 species) (Bagridae family) in order Siluriformes, and the *Badis* (7 species) (Badidae family) and *Channa* (6 species) (Channidae family) in order Perciformes are also species-rich groupings in India's Himalayan freshwater systems. There are more than two species under each genus on an average. In comparison with the west, the Indian Himalayan fishes have a greater diversity in the east. Fishes of the genus *Aborichthys*, *Erethistoides*, *Olyra*, and others can be found in the Brahmaputra drainage system and are not found elsewhere in the Himalayas.

The genera *Semiplotus* and *Balitora* are found up to the Gandak drainage system, whereas *Pseudecheneis* and *Neolissochilus* are found up to the Kosi drainage system. The genus *Psilorhynchus* is widely distributed, extending all the way to the Jumna. *Schizothorax*, *Schistura*, *Paracanthocobitis*, *Indotriplophysa*, *Glyptothorax*, *Garra*, *Gagata*, *Botia*, *Bagarius*, *Amblyceps*, and other genera are found throughout the Himalayan region. Even beyond the Himalayas, genera like *Silurus*, *Schizothorax*, *Schizopygopsis*, *Schizopyge*, *Triplophysa*, *Indotriplophysa*, *Glyptothorax*, and *Garra* can be found. The western Himalayas lack certain fish species found in the Assam hill streams and the Brahmaputra drainage. In Myanmar, Southern China, and Southeast Asia, the same genera or closely related forms are found at the same time (Malay Peninsula).

2.3 Major Fisheries in the Himalayas

Fishes are not only source of high-quality protein, but they are also used for recreational purposes or sport fisheries. The beauty of fish makes them attractive and provides the ornamental value to it. The different fishes of Himalayas fall in two main categories: (1) subsistence fishery and (2) recreational fishery. The exotic species which were introduced in water bodies were mainly for the recreational purpose. The overall fish production in Himalayan streams remains low due to particular environmental condition, so commercial fishery is very limited. Low temperature causes low metabolic activities which result in low biological productivity and small size, while in few lentic waters bodies, large sizes also exist. There are few fishing methods which are commonly used in mountain streams such as cast net, drag net, stake net, bag net, noose trap, and harpoons. Tough terrain of the Himalayas and absence of standardized fishing crafts and gears to operate in cold-water streams are mainly responsible for the same.

The upstream part of the reservoir mainly comes under cold-water, while near the dam, comparatively higher temperatures exist due to stagnant water. To allow the smooth passage of fishes across the dam or avoid hindrance in the migration of fishes, installation of fish passes facilitates this migration.

The fishes which inhabit the Himalayan rivers are rheophilic in nature which prefer and thrive well in the fast-flowing water. Menon (1954) reported that the different morphological characteristics of fishes enable them to inhabit the torrential streams. Water temperature plays significant role in distribution of fishes, such as exotic trout and the endemic Schizothoracines. These fishes can only tolerate temperature below 20°C and fall in the category of cold stenothermic species. In order to cope up with the change in temperature, fishes migrate across upstream and downstream. The cylindrical body shape of fishes enhances the swimming capacity as in snow trout. Loaches possess adhesive organs on the ventral surfaces for attaching themselves to the rock. Adhesive organs also vary among the different species based on requirement. *Schizothorax* spp. which belong to the subfamily Schizothoracine under family Cyprinidae is prime/predominant group of fishes, followed by mahseer which is one of the important sport fishes. Major fisheries of the Himalayas are comprised of (1) snow trout (*Schizothorax* and S*chizothoraichthys*), (2) mahseer (*Tor* and *Neolissochilus*), (3) loaches (*Nemacheilus*), (4) garrids (*Garra*), (5) barils (*Barilius*), (6) carps, and (7) exotic species (*Oncorhynchus* sp.). Other fish species, such as *Bagarius bagarius*, *Chagunius chagunio*, *Clupisoma garua*, and *Puntius* (*Barbus*) *chilinoides*, also have a promising future from a fisheries perspective in addition to the ones mentioned above.

2.3.1 Snow Trout Fisheries

The capture fisheries in cold-water is mainly based on schizothoracines. Two major genera of snow trouts are *Schizothorax* and *Schizothoraichthys*. Due to declining

catch of snow trout in different rivers and streams, the IUCN has listed them in Vulnerable species. Most common species found in India are *S. richardsonii*, *S. kumaonensis*, *S. niger*, *S. esocinus*, *S. progastus*, *Shizopyge curvifrons* and *Diptychus maculatus.* Twenty-eight species of snow trouts have been recorded in the Himalayan region of which 15 have been reported from Indian sub-Himalayan region. It is considered a delicacy among the various local populace. Only subsistence or artisanal methods of fishing are used for capturing these fishes. Snow trouts are commercially important food species found in upland area. Snow trout is mainly found in numerous snow-fed and glacier-fed streams, lakes, and spring. Most cold-water lakes are perennial which contain water throughout the year, and some are seasonal which contain water only during the rainy season or particular months. Snow trouts live in just a discrete way on stretch of stream of hilly regions. They require low temperature, clear water, ample of food, places to hide from predators, and clean pebbles to lay their eggs. Snow trouts cannot survive in polluted water as their physiology gets affected. Increased tourism in hilly region has affected the population of snow trout and more or less exotic carp has replaced this native fish Region spreading between 21°57′–37°5′ N latitudes and 72°40′–97°25′ E covering 250–300 km on stretches over 2500 km from Jammu and Kashmir to Arunachal Pradesh. Snow trout is found in almost 12 states of India, including Arunachal Pradesh, Himachal Pradesh, Jammu and Kashmir, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim, Tripura, Uttarakhand, and hills of Assam and West Bengal in mountain regions. It does not form the fisheries of commercial importance but is caught by local fishermen mainly in rivers. Presently, farming of native species of snow trout is not very successful in hilly regions, but cultivable traits have been identified in few species.

The following is a list of 15 snow trout species recorded from Indian Himalayan region:

Genus *Diptychus* Steindachner, 1866
- *D. maculatus* Steindachner, 1866

Genus *Schizopyge* Heckel, 1847
- *S. curvifrons* Heckel, 1838

Genus *Schizopygopsis* Steindachner, 1866
- *S. stolickai* Steindachner, 1866

Genus *Schizothorax* Heckel, 1838
- *S. niger* Heckel, 1838
- *S. esocinus* Heckel, 1838
- *S. huegelii* Heckel, 1838
- *S. intermedius* McClelland and Griffith, 1842
- *S. kumaonensis* Menon, 1971
- *S. labiatus* McClelland, 1842
- *S. microcephalus* Day, 1877
- *S. molesworthi* Chaudhuri, 1913
- *S. nasus* Heckel, 1838
- *S. plagiostomus* Heckel, 1838

S. progastus McClelland, 1839
S. richardsonii Gray, 1832

2.3.2 Mahseer Fisheries

Mahseer is a large-bodied potamodromous freshwater fish with substantial economic and recreational value. It is considered indigenous to Asian rivers. As it is the most tenacious combatant among freshwater sport fish and is consequently regarded as the indisputable king of Indian freshwaters, the mahseer is the most sought-after game fish among anglers in India. The existence of such a mighty game fish in Indian water is depicted in the writings of King Someswara (1127 AD) in Vedic times in his Matsya Vinoda on account of the angling of mahseer with rod and line. As per different resources presently, there are 47 valid species of mahseer around the world belonging to the genera *Tor*, *Naziritor*, and *Neolissochilus* (Nautiyal et al. 2013). In India, 14 valid species of mahseer have been recorded among which *T. putitora* (Hamilton, 1822) (golden mahseer), *T. tor* (Hamilton, 1822) (tor barb), *T. khudree* (Sykes, 1839) (the Deccan or Yellow mahseer), *N. hexagonolepis* (McClelland, 1839) (the Copper mahseer), and *N. chelynoides* (McClelland, 1839) (Black mahseer) are the most common species. *T. putitora*, known as golden mahseer in India, is a significant sport fish. When the southwest monsoon precipitation causes streams to swell, that is when it migrates from the lower reaches of the river to the middle ones to spawn. This species has suffered significant poaching, and dams and weirs that have prevented fish movement have caused more harm. Deforestation of mountains has increased soil erosion, which has resulted in high siltation of streams and rivers, compromising the fundamental biological requirements of this species. The copper mahseer, *N. hexagonolepis*, is a valuable food and sport fish.

If the tourism industry is developed to the expected level, starting with identifying the potential areas, followed by the formulation of effective policies and guidelines for entrepreneurship development, and supported by ancillary services, India has tremendous potential for mahseer recreational fisheries in many states. The country's ecotourism industry focused on fishing, and fish watching has both beneficial indirect and direct effects on mahseer conservation. Mahseer, in this sense, has been designated as the "state fish" in many (7) states of India and possesses all the necessary characteristics to be designated as the "national freshwater fish" for its spectacular color, fighting prowess, and size.

The following are valid *Tor* species found in India (Nautiyal et al. 2013):

1. *Tor putitora* (Hamilton, 1822)
2. *Tor tor* (Hamilton, 1822) Tor barb
3. *Tor khudree* (Sykes, 1839) The Deccan or yellow mahseer
4. *Tor progenius* (McClelland, 1839) The Jungha mahseer
5. *Tor kulkarnii* (Menon, 1992)

6. *Tor barakae* (Arunkumar and Basudha, 2003)
7. *Tor macrolepis* (Heckel, 1838)
8. *Tor remadevii* (Madhusoodana Kurup and Radhakrishnan, 2011)
9. *Neolissochilus hexagonolepis* (McClelland, 1839) The copper mahseer
10. *Naziritor chelynoides* (McClelland, 1839)
11. *Neolissochilus hexastichus* (McClelland, 1839)
12. *Neolissochilus dukai* (Day, 1878)
13. *Neolissochilus spinulosus* (McClelland, 1845)
14. *Neolissochilus wynaadensis* (Barbados) (Day, 1873)

2.3.3 Loach Fisheries

The fish superfamily Cobitoidea includes loaches. They are freshwater fish that live in rivers and creeks all over Eurasia and northern Africa. They are benthic (bottom-dwelling) (Kottelat 2012). Loaches are one of the most varied groups of fish, and the 1249 species of Cobitoidea that are now recognized belong to around 107 genera and nine families (Fricke et al. 2022; Nelson et al. 2016). Some loaches are important food fish, especially in East and Southeast Asia, where they are a common sight in markets.

In the aquarium industry, loaches are very common. The clown loach (*Chromobotia macracanthus*), the kuhli loach (*Pangio kuhlii*), and the dwarf chain loach are a few of the more well-known types (*Ambastaia sidthimunki*). Additionally, gastromyzontid and botiid loaches occasionally enter the market (Ng and Tan 1997). Only the Cobitidae family of loaches had been described at the start of the twentieth century, and it was largely acknowledged by taxonomists. The early 1900s saw the discovery of the Balitoridae and Gastromyzontidae by the American ichthyologist Fowler and the Indian ichthyologist Hora. Up until 2002, Nemacheilidae and later Botiidae were classified as subfamilies of the Cobitidae family (Fowler 1905; Hora 1932). Recent reports suggest a record of at least 57 species of loaches, belonging to 14 genera and 3 families (Cobitidae, Balitoridae, Nemacheilidae) from the Indian Himalayan region. Out of 57 species, 24 are endemic to India (Gopi et al. 2018).

2.3.4 Garrid Fisheries

Garra is a genus of fish in the family Cyprinidae. These fishes are inhabitants of rivers, lakes, small ponds, and small muddy streams in hilly or mountainous regions. The fishes are example of the sucker-mouthed barbs, log suckers, and other cyprinids, commonly kept in aquaria to control algae. Cylindrical body; slightly depressed head; heavily tuberculated or tubercleless blunt snout; inferior mouth; semicircular, thick, and fleshy lips; fimbriated upper lip; lower jaw covered by thick labial fold; and lower lip with a mental adhesive disc consisting of semicartilaginous pad are some of the important characteristics of these fishes. The garrids hide under

and among stones and vegetation and are bottom dwellers, feeding on aufwuchs. The garrids are widely distributed from sub-Saharan Africa to Borneo through the Arabian Peninsula, Southern Asia, and Southern China (Zhang and Chen 2002). More than 200 species of this group have been reported worldwide (Yu et al. 2016), and more than 31 species have been recognized from NE India (Roni and Vishwanath 2018).

2.3.5 Baril Fisheries

Indian hill trout, also known as *Barilius bendelisis* (Hamilton), is an important fish under the genus *Barilius*. It is a member of the family Cyprinidae, subfamily Danioninae, and it lives in shallow, chilly, and clear water (Gurung et al. 2005). Its pointed head, compressed body, blue/black vertical bands on the side of the body, and origin of the dorsal fin inserted behind the midsection of the body are distinguishing features (Talwar and Jhingran 1991). This fish is an upland water fish that can be found in a number of Southeast Asian nations, including India, Bangladesh, Nepal, Myanmar, Pakistan, Thailand, and Sri Lanka (Talwar and Jhingran 1991; Fricke et al. 2022). This species is widely found in India throughout the Himalayan foothills in the Ganga and Brahmaputra drainages. *Barilius bendelisis* inhabits both lentic and lotic water bodies which are not quite suitable for subsistence of other carp species, playing a significant role in the capture fisheries of the Himalayan regions of Arunachal Pradesh (Sahoo et al. 2009).

2.3.6 Carp Fisheries

Indian major carps and exotic carps make up the majority of the carp species, caught in the Himalayas. However, from an Indian perspective, the fishery also includes species of the subfamily Cyprininae that live in streams, lakes, and rivers that get snowfall water.

Rohu (*Labeo rohita*) is the most well-known main carp in the highlands in India. Common carps, silver carps, and grass carps are examples of exotic carps. The primary source of these carps is cultured fisheries. The rohu is a sizable, silvery fish with a prominently arched head and a classic cyprinid form. A large portion of northern, central, and eastern India's rivers contain rohu. The species is omnivorous and exhibits distinct feeding preferences at various life stages. It consumes mostly zooplankton in the beginning of its life cycle, but as it grows, it consumes an increasing amount of phytoplankton. As an adult or juvenile, it is an herbivorous column feeder that consumes primarily phytoplankton and submerged vegetation. It appears to feed by sieving the water based on the modification of its thin, hairlike gill rakers. *Cyprinus carpio*, the common carp, is a native of Asia and Eastern Europe. To increase the fish supply, common carp were introduced to Kashmir in 1959. Since that time, this fish has gained significant commercial importance in Kashmir Valley. Additionally, it dominates wetlands found on the Jhelum River floodplain. *C. carpio*

var. specularis, *C. carpio var. communis*, and *C. carpio var. nudus* are the three different types of common carp. They are frequently regarded as invasive species since they have entered aquatic environments legally or occasionally illegally all over the world. Although common carps like huge quantities of sluggish or standing water and soft, vegetative sediments, they are exceedingly resilient and can easily adapt to most environments. Though larger carp may live alone, they are typically found in small schools. Their natural habitat consists of fresh or brackish water with a pH range of 7.0–9.0 and a temperature range of 5.0–35.0 °C. The common carp is a fish that may be eaten and is very well-liked by anglers. *Hypophthalmichthys molitrix*, commonly known as silver carp, was introduced into Indian waters from China. Among both native and foreign fish, it grows the quickest. It is a plankton-eating fish that is not predatory. The grass carp (*Ctenopharyngodon idella*) is a native resident of Chinese waters. This fish was brought to India from Hong Kong for the first time in 1959 and is now widely distributed throughout the nation. It grows well and is a nice fish that Indians enjoy. They consume up to three times as much food as they do every day. Small lakes and backwaters with an abundance of freshwater flora are ideal for them. Aquatic vegetation are the main source of food for the species' adults. They consume higher aquatic plants and submerged terrestrial flora as well as debris, insects, and other small invertebrates.

In the mid-hill region, there is a lot of room for exploiting local fish species for aquaculture. The following species could be candidates for mid-hill aquaculture in India: *Chagunius* spp., *Cirrhinus reba*, *Labeo pangusia*, *L. dyocheilus*, and *L. dero*, including endemic minor carp, pengba, and *Osteobrama belangeri*.

2.3.7 Exotic Species

Mitchell introduced the first species of exotic trout into the waterways of the Indian Himalayan region in 1900. The western Himalayas were introduced to common carps in 1959. Silver carps were unintentionally introduced in this area in 1971. Biologically, silver carps appear to have an edge over Indian major carp. Approximately 14 foreign fish species have been introduced, according to some fringe literature, into the IHR. The important exotic fish species of the region are *Carassius auratus*, *C. carassius*, *Ctenopharyngodon idella*, *Cyprinus carpio communis*, *C. carpio nudus*, *C. carpio specularis*, *Gambusia holbrooki*, *G. affinis*, *Hypophthalmichthys molitrix*, *H. nobilis*, *Oncorhynchus mykiss*, *Osphronemus goramy*, *Salmo trutta fario*.

Brown trout (*Salmo trutta fario*) and rainbow trout (*Oncorhynchus mykiss*) were introduced to the Indian subcontinent from Europe largely to promote sport fishing or leisure angling. It is necessary to create and scale up brown trout breeding and culture technology for the ecological conditions of the Himalayas. It is a viable ecotourism candidate species.

In the Indian Himalayan regions, rainbow trout, *O. mykiss*, has established itself as a top cultivable cold-water species and is currently raised commercially. There have been independent attempts to introduce rainbow trout to India's northwestern

and peninsular regions. The largest trout farming operation in Asia was started in 1984 with the help of the EEC (European Economic Council) at Kokernag, in the Indian state of J&K. In Himachal, trout farming began in 1991 with help from Norway (Indo-Norwegian project). Rainbow trout farming on a commercial scale began in the early 1990s on various fish farms in India's Himalayan area. Presently, there is a well-established farm with modern RAS (Recirculatory Aquaculture System) facility and state of the art hatchery facility at ICAR-Directorate of Coldwater Fisheries Research, Champawat, which maintains quality brooders and produces quality seeds of Rainbow trout to cater to the needs of the sector. Indian trout production continues to be centered in the Northwestern Himalayan region (Jammu and Kashmir and Himachal Pradesh). Majority of India's trout output comes from the northwest (81.2%), with very modest amounts coming from the northeastern, central, and southern highland regions. India now produces 602.0 tons of rainbow trout annually, up from just 147.0 tons in 2004 (309% increase). During this time, the growth rate of trout output maintained 31.0% annually. Over the same time frame, the total number of ova produced increased from 1.8 to 10.17 million (450% increase) (Pandey and Ali 2015).

2.4 Concerns

Overfishing of stock has resulted in overexploitation of different stocks and is posing threat of extinction of few species. There are mainly two types of overfishing: (1) growth overfishing and (2) recruitment overfishing. Destructive fishing methods which most likely include the usage of poison and explosives to stun the fishes are practiced in few Himalayan rivers especially in higher altitude. Usage of destructive fishing methods results in indiscriminate killing of different species and different sizes of fish, have also harmed the fishery resources significantly. Catchment area management is very important for maintaining the quality of water in resources like rivers, reservoirs and lakes. Agricultural practices in the catchment cause the entry of different inorganic and organic compound which consequently deteriorates the environmental condition for fishes. Fish stocks have been impacted by the increasing use of river water for a variety of purposes, including irrigation, hydropower generation, urban and industrial uses, and the input of pollutants (Petr and Swar 2002). The fast-flowing water of Himalayan rivers (lotic) does not allow the aquatic vegetation and bloom to cause a problem, such as in lentic water bodies like lake, in which the macro- and microscopic plant grows immensely and decreases the depth on deposition at bottom. The size of Wular Lake and Dal Lake of Jammu and Kashmir has been reduced significantly due to eutrophication. The nutrient requirement responsible for proliferation of plant is fulfilled by the runoff from agricultural land and other anthropogenic activities. Hailstorm and sediment load also result in fish kill in the rivers. Heavy tourism exists on the few lakes and reservoir which also causes the introduction of pollutants in the water bodies. Dams block rivers, preventing fish and other aquatic animals from migrating. This isolation of ecosystems has an impact on the genetic makeup of populations. Additionally, it

causes a patchy area and poor conditions for the mahseer or other fishes downstream of the dam due to the low water level that develops. The runoff of hot water from the dam helps in providing the favorable condition for fish growth, or sometimes increased temperature of water put detrimental effects on fishes by putting impact on their physiology. Species like *Schizothorax*, *Ptychobarbus* and *Gymnocypris* are unusual and more prone to extinction. It is also evident that indigenous species like *Schizothorax* and mahseer may suffer if common carp is introduced in pristine streams or water sources.

2.5 Management

If fisheries are to become a more dynamic source of food in the area and fully contribute to the reduction of poverty in mountain nations, there must be a better integration of fisheries development within the overall ecosystem and rural development approach, taking into full consideration the ecological, social, and economic values of fisheries in relation to biodiversity conservation, agriculture, and hydroelectric power generation. Traditional fishing methods which do not harm the ecosystem and are selective in nature should be encouraged. Noose and line is one such gear used for capturing snow trout. Fish aggregating devices (FAD) is a man-made object used to attract fish. FADs attract fish for numerous reasons that vary by specie and help in making the harvest of fish more efficient and responsible. Ranching by which artificial recruitment of different fish species into their natural habitat has helped in improvement and enhancement of production as well as in conservation of stock. The waste produced by anthropogenic activities should be managed properly to avoid its detrimental effects on water resources and its biodiversity.

2.6 Conclusion

The Himalayas has a larger number of rivers, streams, and lakes fed by copious rainfall, large glaciers, and extensive snow fields. The variation in Himalayan altitudes is greater in the eastern half than in the western half. Such variations might have established greater ichthyodiversity toward the east than the west. The rich diversity of the Himalayas is facing threat for their existence due to various concerns, such as overfishing, illegal trades, anthropogenic activities, and competition from introduced exotic species. Species diversification for aquaculture and proper conservation measures for vulnerable and threatened species are of prime concern today.

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