Debajit Sarma
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Aquaculture and Conservation of Inland Coldwater Fishes

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Dedicated
to the memory of
Late Dr P. C. Mahanta
In recognition of his exemplary contributions
to the field of Indian Fisheries and
Aquaculture and unwavering advocacy for
sustainable and responsible aquaculture
practices

Foreword

The aquatic environments of the world, particularly the coldwater habitats, are facing unprecedented challenges, both natural and anthropogenic. Climate change, habitat degradation, and overfishing have placed immense pressure on native fish populations, threatening their survival and the health of the ecosystems they inhabit. Amidst these pressing concerns, aquaculture has emerged as a critical tool not only for meeting the growing demand for fish but also for conserving and restoring fragile coldwater fish species.

I am delighted to see that the enlightening and all-encompassing volume titled *Aquaculture and Conservation of Inland Coldwater Fishes* has delved into the intricate and vital convergence of aquaculture and the conservation of inland coldwater fish species, offering a profound exploration of the challenges, innovations, and solutions that shape the future of these aquatic ecosystems. Through a collaborative effort of esteemed experts in the fields of aquaculture and fisheries conservation, the book has provided a much-needed light on the myriad of issues and opportunities surrounding inland coldwater fishes. The authors have demonstrated their perseverance in the protection and enhancement of these unique and ecologically important species. By bridging the worlds of science, policy, and practice, they have created a resource that promises to be invaluable to students, researchers, policymakers, and practitioners alike. Within the pages, one will find a wealth of knowledge covering a diverse array of topics. The book presents a deep dive into the aquaculture of coldwater fish and the critical importance of conservation efforts. This volume is not just a compendium of information, but also a call to collective action. It urges us to acknowledge the interconnectedness

of all life in our aquatic ecosystems and compels us to protect these fragile and invaluable resources for future generations. As we face the critical juncture of climate change and dwindling resources, the book offers us a roadmap to responsible aquaculture practices and the preservation of our planet's aquatic biodiversity. This book serves as both an educational tool and a source of inspiration, reminding us that we have the power and responsibility to shape a future where our coldwater fish thrive in their natural habitats while sustaining the needs of a growing human population.

I commend the authors and editors for their dedication in bringing this essential work to fruition. Going through the books encourages us to absorb the knowledge, engage in the discourse, and embrace the challenge of safeguarding our inland coldwater fishes, recognizing that their survival is inextricably linked to the future well-being of our planet.

Joykrushna Jena

Krishi Anusandhan Bhawan - II
New Delhi, India

Preface

Aquatic ecosystems, particularly those in inland coldwater regions, have long captivated the imagination of scientists, conservationists, and aquaculturists. These environments, characterized by pristine rivers, crystal-clear lakes, and breathtaking mountain landscapes, play host to some of the most charismatic and ecologically significant fish species of the world. However, these extraordinary habitats and the species they support are facing unprecedented challenges, from the warming effects of climate change to habitat destruction, overfishing, and pollution. *Aquaculture and Conservation of Inland Coldwater Fishes* stands as a testament to the urgent need for both the protection and sustainable management of these unique ecosystems and their inhabitants. It is a culmination of the collective efforts, wisdom, and expertise of researchers, practitioners, and policymakers who are committed to preserving these invaluable resources for future generations.

This book is a journey of exploration and discovery, investigating into the intricate web of interactions that defines the world of inland coldwater fishes. It weaves together the science of aquaculture with the art of conservation, highlighting the delicate balance required to ensure the survival of these remarkable creatures while meeting the global demand for fish products. In the pages that follow, readers will find a diverse and multidisciplinary collection of chapters that traverse the landscapes of inland aquaculture, fisheries science, ecology, and resource management. Our contributing authors have drawn from their rich reservoir of experiences and knowledge to create a resource that is both informative and inspirational. This book serves as an introduction to a critical discourse that looks into the intricate relationship between aquaculture and the conservation of inland coldwater fishes. It seeks to illuminate the multifaceted challenges and opportunities that emerge as humanity grapples with the dual imperative of feeding a growing global population and safeguarding the ecological health of our freshwater ecosystems. At the same time, readers will also explore the dynamics of aquaculture, a practice that has seen remarkable growth in recent decades and has the potential to alleviate the pressure on wild fish populations. This discourse will draw upon the collective wisdom of scientists, conservationists, aquaculture practitioners, policymakers, and indigenous communities, who have devoted their efforts to finding the delicate balance between these competing imperatives. By offering a diverse range of perspectives, we aim to provide a comprehensive understanding of the issues at hand, the progress made, and the path forward.

As we embark on this exploration, let us be reminded of the profound responsibility we bear as stewards of the environment. In the quest to nourish our bodies, let us also nourish the ecosystems that sustain us. This book *Aquaculture and Conservation of Inland Coldwater Fishes* challenges us to find innovative solutions and forge partnerships that can ensure the long-term survival of fishes and the habitats they call home. This journey is both a call to awareness and a testament to the power of collective action. It invites researchers, students, policymakers, industry professionals, and concerned citizens to embrace their roles as custodians of our freshwater habitats and the extraordinary coldwater fish that call them home. Together, we can strive for a future where the vibrant inland ecosystems of coldwater fishes thrive, even as we meet the ever-growing demand for nutritious and sustainable food.

We hope that this book serves as a guiding light, illuminating the path toward a future where the conservation and sustainable management of these species are central to our values and practices. We are confident that this effort will inspire understanding, empathy, and tangible actions that may lead us toward a more harmonious coexistence with our precious inland coldwater fisheries resources.

Mumbai, Maharashtra, India — Debajit Sarma
Bhimtal, Uttarakhand, India — Suresh Chandra
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Editors and Contributors

About the Editors

Debajit Sarma is presently working as Head, Division of Aquaculture, ICAR-Central Institute of Fisheries Education (ICAR-CIFE), Mumbai. He worked as a Principal Scientist at ICAR-Directorate of Coldwater Fisheries Research (ICAR-DCFR), Bhimtal, Nainital, Uttarakhand, India, 263136, for more than 12 years. He also worked as a Director (Acting) at ICAR-DCFR for 3 years. He was awarded Fellow of Academy of Environmental Biology, AEB Gold Medal, Fellow of Zoological Society of India, Dalela Oration Award, Eminent Scientist Award, IBRF Excellence Award, Scientist of the Year-2017, VRP Sinha Award, CFSI Honours and "Certificates of Appreciation" from the Department of Fisheries, Govt. of Mizoram; Govt. of Sikkim; Govt. of Nagaland; Assam Bhorelli Angling and Conservation Association, Assam; Jasingfaa Aqua-tourism Centre, Assam; Guamco Society, Arunachal Pradesh; Gauhati University, Assam and Rajiv Gandhi University, Itanagar, Arunachal Pradesh for his outstanding contribution in the field of Aquaculture and Fisheries Science. His area of research interest is Aquaculture and Conservation. He has standardized the hatchery management and seed production technology of golden and chocolate mahseer in India. Dr. Sarma has noteworthy contribution of establishing mahseer hatchery and eco-tourism centers in India and the concept of "Mahseer Watching" is well recognized. Dr. Sarma is also having expertise on evaluation of nutrient profiling of coldwater fishes. He is having in his credit 104 research papers in peer-reviewed international and national journals and 160 research/technical articles including books, book chapters, manuals, and bulletins.

Dr. Sarma is the Editor of three important international/national research journals and has been reviewer for several national and international peer-reviewed journals. He is also serving as the Visiting/Adjunct Faculty of more than 10 reputed Universities in India. He has successfully completed more than 20 research projects funded by different scientific organizations developing package of practices for the benefit of multiple stakeholders. During the tenure of 25 years of service, he has guided 1 National Post-Doctoral Fellow, 10 Ph.D., and 12 M.Sc. students as Major Supervisor. He has organized 15 national seminars/symposia in the capacity of organizing secretary and also conducted 50 national HRD program as course Director/Coordinator benefiting 10000 fish farmers and officers. He has participated and presented papers in several international seminars and training programs abroad in various capacities. Dr. Sarma is the Founder Secretary and former President of Coldwater Fisheries Society of India (CFSI).

Suresh Chandra is currently working as a Principal Scientist (Fish Pathology) at Directorate of Coldwater Fisheries Research, Bhimtal, Uttarakhand, under the aegis of the Indian Council of Agricultural Research, New Delhi. He has 35 years of research experience in freshwater and coldwater aquaculture development and extension. He has received numerous accolades and awards, including the ICAR-CIFA's Best Extension Worker Award, the Krishakbandhu Team Award, the Young Scientist Award, and the Distinguished Service Award. As a team member, he was associated with the development of a medicine popularly known as CIFAX, which had been commercialized for four times. His area of research interest is fish health, extension, and aquaculture. As a team member, he has standardized the hatchery management and seed production technology of four indigenous fish species in India, along with the commercial seed production of rainbow trout (*Oncorhynchus mykiss*). To his credit, he has published 70 research papers in peer-reviewed international and national journals and 110 research and technical articles, including books, book chapters, manuals, and bulletins. Dr. Chandra has edited three important books. He has been actively involved in more than 19 research projects funded by different scientific organizations,

including two international projects, and developed packages of practices on fish farming for the benefit of multiple stakeholders in rural areas of the country.

Sumanta Kumar Mallik is presently working as a scientist at ICAR-Directorate of Coldwater Fisheries Research, Bhimtal, Nainital, Uttarakhand, India, 263136. His area of research interest is aquaculture and fish health management. Mr. Mallik has published 32 research publications in peer-reviewed international and national journals along with 25 research/technical articles and bulletins in his credit. He is also serving as a reviewer for several national and international peer-reviewed journals.

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1 Himalayan Fishery Resources: Treasury of Coldwater Fishes for Sustainable Aquaculture

Debajit Sarma and Dinesh Mohan

Abstract

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 coldwater fish species globally. The Himalayan fisheries resources present abundant opportunities for cultivating and preserving coldwater fish species well adapted to the region's extreme environmental conditions. In India alone, the coldwater fisheries resource spans an extensive hilly area covering 533,604 km^2, extending from Jammu and Kashmir in the west to Arunachal Pradesh in the east. This region constitutes approximately 16.2% of India's total geographic area and is inhabited by 4% of the country's population. The primary distribution of coldwater 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. This chapter provides an overview of Himalayan fisheries resources, their potential for aquaculture and conservation, and the challenges in ensuring their sustainable management.

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Keywords

Himalayan fisheries · Coldwater · Aquaculture · Capture fisheries · Diversity

1.1 Introduction

The Himalayan region stands out as one of the most environmentally diverse areas on the planet, boasting an immense variety of flora and fauna. Some of the rarest and most expensive coldwater fish species in the world, which are crucial for both economic and ecological reasons, are found in this area (Singh et al. 2014). Coldwater fish species with the potential for aquaculture and conservation can be found in abundance in the Himalayan fisheries resources. The Himalayan area, which encompasses nations like India, Nepal, Bhutan, and China, has a variety of fisheries resources (Pandey et al. 2023). Coldwater fish species, which are adapted to the region's extreme environmental conditions, make up the majority of the region's fish fauna. India's coldwater fisheries resource covers a hilly area of 533,604 km, spanning 200–400 km from north to south and across a distance of 2500 km from Jammu and Kashmir in the west to Arunachal Pradesh in the east. This area makes up roughly 16.2% of the nation's total geographic area and is home to 4% of the entire population. Between Nanga Parbat (8126 m) in the west and Namcha Barwa (7756 m) in the east, the Himalayas, which have a surface area of 594,400 km^2, span approximately 2500 km from west to east. The western and northern boundaries of this mountain range are formed by the Karakoram Mountains and the high plateau of Tibet, respectively. Four parallel and longitudinal mountain bands of varying breadth can be differentiated from south to north are the Siwaliks, Lesser Himalaya, Greater Himalaya, and Trans-Himalaya (Sehgal 1999).

The Himalayas are drained by 19 major rivers; the Indus and Brahmaputra are the longest, and each has a catchment area of mountains that is about 160,000 km^2 (Singh 2015). Of the remaining 17 rivers, five are a part of the Indus system, of which the Beas and the Sutlej have a combined catchment area of 80,000 km^2 and the Ganga, Yamuna, Ram Ganga, Kali-Sharda, Karnali, Rapti, Gandak, Bhagmati, and Kosi are a part of the Ganga River system, which drains an approximate area of 150,000 km^2 altogether (Singh 2015). There are five rivers that feed into the Ganga; Bhagirathi, Mandakini, Alaknanda, Dhauliganga, and Pindar. From Bhutan and India, more numbers of rivers also enter. With a catchment area of around 11,0000 km^2, the Brahmaputra is also known as Yarlung Zangbo Jiang or Tsangpo in China (Bandyopadhyay and Gyawali 1994). Before they leave the mountains, the majority of these rivers go through extensive valleys. Most of the upland streams, rivers, high- and low-altitude lakes, and reservoirs that are dispersed among the several hill states are the primary forms in which the coldwater resources are distributed (Raina and Petr 1999).

1.2 Major Divisions of the Indian Himalayan Region

The Indian Himalayan region is a huge and varied area that almost entirely encloses northern region of India. Based on their physical, cultural, and ecological characteristics, it can be roughly split into three main divisions (Fig. 1.1): the Eastern Himalayas, Central Himalayas, and Western Himalayas (Jana 1998).

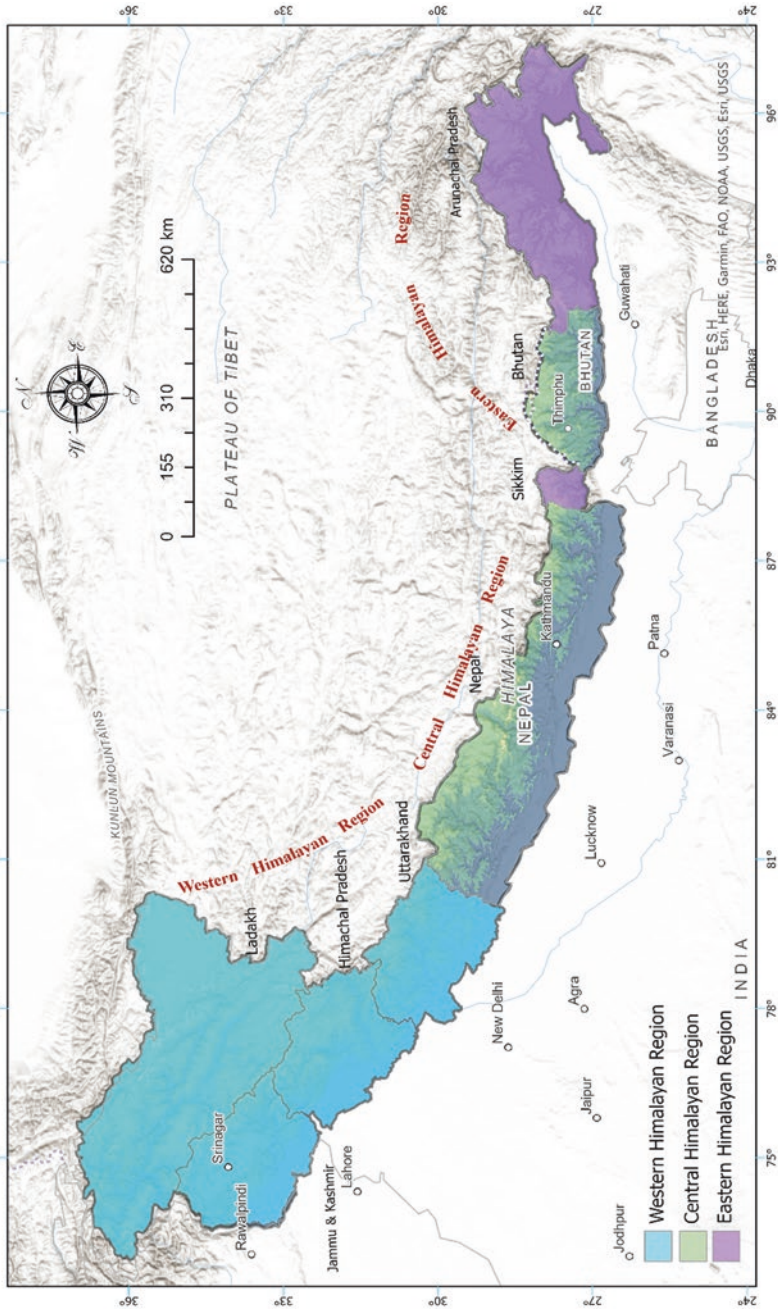

Fig. 1.1 Major divisions of the Indian Himalayan Region

1.2.1 Eastern Himalayas

The Eastern Himalayas stretch from Arunachal Pradesh, the easternmost state of India, to the westernmost region of Bhutan. The area is distinguished by lofty peaks, wide valleys, and thick woods. It is home to a wide variety of plants and animals, including the red panda and the clouded leopard, both of which are endangered. The area features a variety of indigenous populations, including the Monpas, Sherdukpens, and Lepchas, as well as immigrant communities from Nepal and Bhutan, adding to its cultural diversity. The Brahmaputra and its tributaries receive a significant amount of water from the Eastern Himalayas (Bisht 2008).

1.2.2 Central Himalayas

The states of Uttarakhand, Himachal Pradesh, and a portion of Jammu and Kashmir are all covered by the Central Himalayas. This area is well-known for its glaciers, rocky landscape, and high-altitude deserts. Numerous significant pilgrimage destinations, including Kedarnath, Badrinath, and Amarnath, are located there. Due to the fact that the area is the origin of numerous significant rivers, including the Ganga and Yamuna, it is also significant environmentally. The Bhotias, Gaddis, and Kinnauris are just a few of the indigenous groups that call the Central Himalayas home (Sati 2020).

1.2.3 Western Himalayas

From the most northern state of Jammu and Kashmir to the most eastern state of Uttarakhand, the Western Himalayas are present. Sleek mountains, wide valleys, and alpine meadows define the area. It is home to a number of significant national parks, including the Great Himalayan National Park, Hemis National Park, and Nanda Devi National Park. The Gujjars, Baltis, and Ladakhis are among the indigenous communities in the Western Himalayas, and there are also migratory communities from Tibet and other parts of Central Asia. Due to its role as the source of numerous significant rivers, including the Indus and the Sutlej, the area is also pertinent environmentally (Chakraborty and Chakraborty 2021).

The ecological, cultural, and economic health of the Indian Himalayan region as a whole, as well as its three main divisions, is dependent on these interrelated divisions. A wide variety of coldwater fisheries resources can be found in the Himalayan region (Mahanta et al. 2012; Singh et al. 2018). The two main categories of these resources are native and immigrant fish species. The term "indigenous fish species" refers to fish species that are native to the Himalayan region and have spent thousands of years adjusting to the local environmental circumstances (Sugnnan 1995; Sarma et al. 2012a, b). These fish species include the Himalayan trout (*Salmo trutta fario*) and snow trout (*Schizothorax* spp.), the Indian carp (*Catla catla*), the golden mahseer (*Tor putitora*), among others. Local anglers respect these fish much, and

they are a significant source of food and revenue for the area's communities. On the other hand, exotic fish species are those that have been brought into the Himalayan region from other regions of the globe. These fish species include the common carp (*Cyprinus carpio*), brown trout (*Salmo trutta fario*), and rainbow trout (*Oncorhynchus mykiss*) among others; these fish species were initially introduced to the area primarily for recreational fishing; and they have now taken root in many of the rivers and streams in the area (Cucherousset et al. 2021).

It is a challenging task to manage these coldwater fishing resources while juggling the demands of regional residents, recreational fishermen, and conservation initiatives (Dey and Chandra 2019). Concerns about the effects of exotic fish species on native fish populations and the environment as a whole have grown in recent years (Bhattacharya and Choudhury 2017). In the Himalayan region, initiatives are being made to create sustainable management techniques that support the preservation of both native and invasive fish species.

1.3 Ichthyofauna of the Indian Himalayan Region

The distribution of fish species in Himalayan streams is influenced by the amount of flow, the kind of substrate, the water temperature, and the food availability. The species distribution in the higher reaches of the stream/river is distinct from that of the mid and lower sections of the stream, where flow is moderate and water current is mild (Singh 2006; Mahanta and Sarma 2010; Vishwanath 2011). A variety of fish species can be found in the freshwater systems of the Indian Himalayas, which are an ideal habitat for temperate or coldwater species. However, a sizable number of species discovered in the peripheral habitats of the area in the sub-Himalayan belt, or even in other nearby or distant Indian biogeographic zones or areas, show the region's high species richness (Chandra et al. 2019). The Great Himalayan uplift in earlier geological history and the succeeding biogeographical evolution led to different zoogeographic affinities between freshwater fish in the Indian Himalaya and the Palaearctic, Indo-Chinese, and Southeast Asian (Malayan) sections (Jayaram 1977; Mani 1974). In total 316 fish species have been found in this region, and 97 of those are endemic to the freshwater systems of the Indian Himalaya. The fish diversity that has been discovered in the area represents a representation of around 30.8% of India's total freshwater fish species (1027), 62.8% of its total genera (188), and 18.6% of its total endemic species (522) (Gopi et al. 2017).

The Cypriniformes (173 spp.) comprises around 54.7% of the species in the Himalayan waters. The fish fauna of the Himalayas is closely related to that of Indo-China and Southeast Asia. The genera of the local fishes, are closely connected to those in Southeast Asia. He postulated that the fish fauna of the Himalayas was mostly from the east, most likely from the Yunnan region, and that because of suitable ecological conditions, it was able to spread to the west as far as Africa. With about 54.7% of the species (173 spp.), the Cypriniformes accounts majority of the variety in the Himalayan waters. From this region, 92 species (31.9%) of catfishes (Siluriformes) have been identified. The largest fish family, Cyprinidae, contains 111 species, followed by

Nemacheilidae, which has 42 species (Kunal et al. 2023). These two families make up 35.1% and 13.3%, respectively, of all the fish species that have been identified in the Indian Himalaya region (Sharma and Sharma 2014). The Sisoridae family of catfishes is the most diverse, with 41 species, and accounts for 13.0% of the total fish variety in the area. It is followed by the Bagridae and Erethistidae families, each of which has 15 species. The family Cyprinidae (Cypriniformes), which comprises 40 of the total fish genera found in the freshwater systems of the Himalayas, or around 33.9% of them, exhibits the highest level of generic abundance. Twelve genera (10.2%) of the total number of fish genera in the region are members of the Sisoridae (Siluriformes), the second-most prevalent family (Chandra et al. 2019).

1.4 Fish Diversity in Major River System of Himalaya

With a variety of fish species found in its rivers, streams, and high-altitude lakes, the Indian Himalayan region is a treasure trove of coldwater fish diversity. Since coldwater fish are accustomed to live in waters that are cooler than those commonly found in tropical areas, they have unique environmental requirements in order to survive and flourish. The Himalayan mahseer (*Tor putitora*), often known as the golden mahseer, is one of the most recognizable coldwater fish species found in the Indian Himalayan region. It is a big, strong fish with a maximum length of 2 m and a weight of more than 50 kg (Sehgal 1999). Because of its toughness and strength, the species is highly prized by fisherman. It is a crucial cultural and economic resource for nearby people and is found in swift-moving rivers and streams in the area. The Indian Himalayan region is home to the snow trout (*Schizothorax* spp.), another significant coldwater fish species. The area is home to multiple species of snow trout, which are normally found in high-elevation lakes and streams. The vivid red, orange, and gold scales on snow trout are well renowned for their stunning appearance, which is especially striking during the spawning season. They are a common target for fishers and a significant source of food for the neighborhood. The Indian Himalayan region is also home to the coldwater fish species brown Trout (*Salmo trutta fario*), rainbow trout (*Oncorhynchus mykiss*), and *Barilius* spp. (Gurumayum and Tamang 2017). In the late 1800s, the brown trout, an imported species, was first brought to the area. It is frequently observed in cool, clean streams, and is distinguished by its ferocious feeding habits. As an imported species, rainbow trout are generally found in lakes and streams at high altitudes. They are prized by anglers and renowned for their aerial leaps and stunning coloration. Fast-moving streams are home to the *Barilius* spp., often known as hill trout, which is a vital source of food for nearby people. In addition to these species, the Indian Himalayan region is home to a number of additional coldwater fish species, such as catfish (Siluriformes), carp (Cyprinidae), and *Garra* spp. The *Garra* spp. are small, bottom-dwelling fish that inhabit fast-moving streams. They are distinguished by their distinctive feeding strategy, in which they use specialized mouthparts to scrape algae off rocks.

In general, the Indian Himalayan region is home to a wide variety of coldwater fish species, many of which are significant to local populations on both cultural and economic level. However, a number of concerns, including habitat loss, overfishing, and climate change, affect these fish species. To ensure the survival of these species and their habitats for future generations, the protection of both is crucial (Sarkar et al. 2020).

The major Himalayan River system (Fig. 1.2) includes the Ganga Brahmaputra and Indus river systems. The rivers flowing across the Himalayas form sizable basins. There are many rivers that flow through the mountains. Plains generate large meanders and a variety of depositional characteristics, such as floodplains, river bluffs, and levees. Day (1878, 1889) conducted the initial study on Indian fishes using scientific methods, and he published the results in two volumes. The waterways in the Himalayan region are home to a wide range of fish species. Seventeen percent of the fish species known to exist in India's entire fish fauna were discovered in the Himalayan region, which serves as a center for the origin and evolution of biotic forms (Ghosh 1997). Out of the approximately 258 coldwater fish species (both indigenous and exotic) reported from Indian uplands, 17 members of the snow trout family have been identified. These fish are also known locally as Asela and Sela in Uttarakhand, Gulgali in Himanchal, and Koushargad in the Kashmir Himalayas (Sunder et al. 1999).

1.4.1 Fish Diversity of the Ganga River System

The Ganga River system is the largest river system in India. There are at least 265 different fish species in a single ecosystem. It has tributaries of the Ganga and Yamuna rivers. The total length of the Gangetic River system is 12,500 km. Its total catchment area is 97.6 million ha, or 9.71 lakh km^2. It is a significant river system on the planet. This system is home to the richest freshwater fish fauna in India, with species ranging from mahseers and torrential fish of the foothills to cultivable Gangetic carps, Hilsa, and other species; snow trout, catfish, mahseer, and smaller *Barilius* inhabit the Ganga rivers head waters in the upper Himalaya. The primary feeding fishes include Mahseers, *Tor putitora*, *Tor tor*, *Acrossocheilus hexagonolepis*, *Bagarius bagarius*, and *Labeo dero* up to an elevation of 1067 m. The fisheries in the plains are of carps, catfishes *Wallago attu*, *Hilsa ilisha*, and *Pangasius*, *Notopterus* and the prawn species *Macrobrachium malcolmsonii* and *Palaemon lamarrei* (Bhattacharjya et al. 2017).

1.4.2 Fish Diversity of the Brahmaputra River System

The whole length of the Brahmaputra riverine system is 4023 km. It emerges from an enormous glacier near Mansarovar lake. There are 51 million acres in the 187,110 km^2 catchment area of this river in all of India. It has a variety of fish species in its upper reaches, which are home to torrential streams of limited

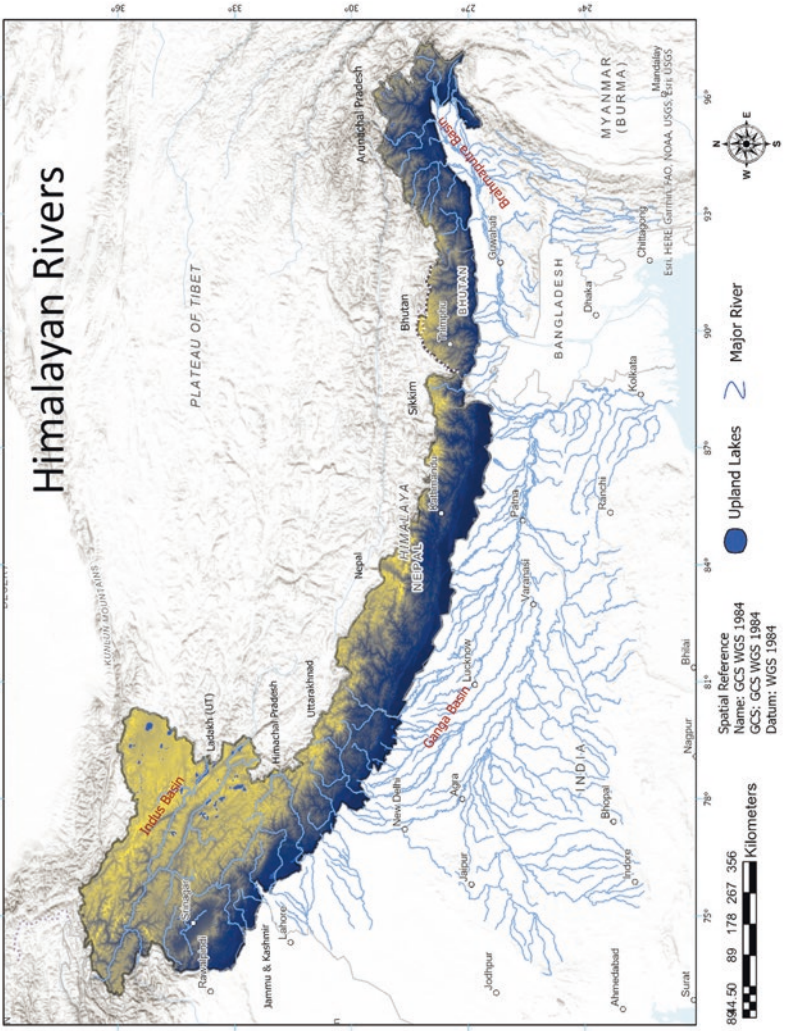

Fig. 1.2 Major riverine systems of India

commercial significance, while its middle and lower reaches are the habitat of several species of carps, catfishes, and air-breathing fishes, including anadromous Hilsa (high-economic value). Fish from 126 different species and 26 different families can be found in this system. Commercial significance is acknowledged for 41 of these. Catfish (mainly *Wallago attu*) and major (especially Rohu) and minor carps prevail in the commercial catches of the upper, middle, and lower parts, while catfish and other forms of catch make up the majority of the commercial catch in the lower middle length. The Himalayas are home to a variety of species, including *Tor* spp., *Glyptothorax* spp., *Balitora* spp., *Noemacheilus* spp., *Schizothorax* spp., *Lepidocephalichthys* spp., and *Gagata* spp. *Labeo gonius*, *Wallago attu*, *Puntius sarana*, *Notopterus notopeterus*, *N. chitala*, *Mystus seenghala*, *Clupisoma garua*, and *Eutropiichthys vacha* are some of the prominent fishes found in this system (Sarkar and Pal 2018).

1.4.3 Fish Diversity of the Indus River System

The Indus, Jhelum, Chenab, Ravi, Beas, and Sutlej are merely some of the rivers that flow through the northwest Himalayas. In its lower levels, this system supports a variety of native carp and catfish, while in its upper reaches, it supports exotic rainbow and brown trout. The world's richest sport fishing rivers, Kashmir's trout streams bring tourists from all over the world. *Schizopygopsis stoliczkee*, *L. gonius*, *Rita buchanani*, *Sisor rabdophorus*, *Exostoma stolicizkae*, *Trichogaster* sp., and *Nemacheilus* spp. are the predominant fish present in the Indus. The prevalent fishes present in the river Jhelum comprise *Schizothoraichthys* spp. and six species of *Schizothorax*, *Diptychus maculatus*, *Cyprinus carpio*, *Labeo dero*, *Crossocheilus diplochilus*, *Salmo trutta fario*, *Glyptosternum reticulatum*, *Botia birdi* and *Nemacheilus gracilis*, and *Nemacheilus kashmirensis*. The important fishes found in the river Ravi are *Amblypharyngodon mola*, *Barilius bendelisis*, *Carassius carassius*, *Catla catla*, *Cirrhina mrigala*, *C. reba*, *Cyprinus carpio, Labeo* spp., *Tor tor*, *Mastacembelus armatus*, *Channa* spp., *Trichogaster fasciatus*, *Clarias batrachus*, *Heteropneustes fossilis*, *Mystus* spp., *Ompok bimaculatus*, *O. padba*, *Rita rita*, and *Wallago attu*. The following fish species are the most prevalent ones in the river Beas: *Xenetodon cancila*, *Gadusia chapra*, *Amblypharyngodon mola*, *Barbus* spp., *Carassius* spp., *Catla catla*, *Chela* spp., *Cirrhina mrigala*, *C. reba*, *Cyprinus carpio*, *Labeo* spp., and *Danio devario*. *Tor tor*, *Nemacheilus binotatus*, *Oxygaster gora*, *Puntius species*, *Rasbora daniconius*, *Mastacembelus armatus*, *Channa* species, *Trichogaster fasciatus*, *Clarias batrachus*, *Heteropneustes fossilis*, and *Notopterus* species are a few examples. From the Sutlej River, a total of 70 species have been identified. The most widespread species among them are *Wallago attu*, *Clarias batrachus*, *Heteropneustes fossilis*, *Mystus* spp., *Rita rita*, *Eutropiichthys vacha*, *Notopterus notopterus*, *N. chitala*, *Puntius* spp., *Colisa fasciatus*, *Esomus danricus*, and *Chela laubuca* (Kaur et al. 2022).

Five species were recorded from the Nainital lake. Hora (1937a, b) identified 17 fish species from several families from the Kumaon hills. The lower sections of the

Nandhaur, Kalaunia, and Kosi rivers, which are near to Khairna, were the river sites, where he made the most of his collections. Menon (1949, 1950) identified 23 species of fish from the lake and streams in Nainital. He also collected fish from the Kosi River (Khairna) and the Almora basin. In two books by Menon (1954, 1962), fish from the Himalayas are listed at the length. This collection was inspired by the Assam Mountains, the Nepal Himalayas, the Punjab Himalayas, and the Kumaon Himalayas. The Indian Himalaya to the east has a greater variety of fish than the Indian Himalaya to the west. The Brahmaputra drainage system is home to fish from the genera *Aborichthys*, *Erethistoides*, Olyra, and others, although the remainder of the Himalayas are devoid of them. While *Neolissochilus* and *Pseudecheneis* are found up to the Kosi drainage, the spread of the genera *Balitora* and *Semiplotus* reaches the Gandak drainage system. The range of the genus *Psilorhynchus* extends to the Jumna. The Himalayas' whole range is covered by the genera *Amblyceps*, *Bagarius*, *Botia*, *Gagata*, *Garra*, *Glyptothorax*, *Indotriplophysa*, *Paracanthocobitis*, *Schistura*, and *Schizothorax*, among others. Even outside of the Himalayas, there can identify genera like *Garra*, *Glyptothorax*, *Indotriplophysa*, *Triplophysa*, *Schizopyge*, *Schizopygopsis*, *Schizothorax*, and *Silurus*. Further highlighting the evidence of catfishes of the species *Silurus* and *Bagarius* found in colder, deeper waters at the foot of slopes of upper Siwalik rocks was done by Hora and Menon (1953).

1.5 Status of Upland Fisheries Resources

The Himalayan region's upland coldwater fisheries resources are very important to the local populations and play a significant part in the region's ecosystem. Numerous high-altitude rivers and streams in the Himalayan region are home to cold-water fish species including trout and snow trout. These fish species are highly prized for their advantages in the economy, leisure, and ecology (Singh and Sarma 2018; Bhattacharjya et al. 2017).

The Himalayan region's upland coldwater fisheries resources are significant for a variety of reasons, including their economic impact. Due to the fact that they are captured and sold both locally and in close-by urban areas, these fish are an important source of money for the surrounding communities. Similar to this, thousands of people living in hilly locations in Nepal depend on cold-water fisheries resources for their livelihoods (Bista et al. 2017).

Additionally, the Himalayan region's upland coldwater fisheries resources offer both locals and visitors leisure possibilities. Anglers, in particular, enjoy trout fishing and are prepared to pay large rates for permits and access to desirable fishing grounds (Agrawal et al. 2013). The biodiversity and ecological balance of the area are enhanced by coldwater fisheries in addition to offering recreational opportunities. Fish populations are crucial elements of freshwater ecosystems and serve as indicators of the quality of the water.

However, there are a number of issues affecting upland coldwater fisheries resources in the Himalayan region, such as habitat deterioration, pollution, and

overfishing (Bista et al. 2017). These resources are also anticipated to be impacted by climate change, since increasing temperatures may alter the range and quantity of coldwater fish species (Pandey et al. 2019; Sarma and Shahi 2019). To maintain the long-term sustainability of these resources, it is crucial to implement sustainable management practices. In conclusion, the Himalayan region's upland coldwater fisheries resources are crucial for the local population, the economy, and the environment. To maintain these resources' long-term vitality, however, sustainable management strategies and conservation initiatives are required.

One of the most significant coldwater fish species in the Himalayan region is the trout. The rivers and streams in the area are home to several trout species, including brown trout (*Salmo trutta*) and rainbow trout (*Oncorhynchus mykiss*). Anglers and fish growers are interested in these species due to their great commercial and recreational worth. The annual output of trout in the Nepalese Himalayas alone is projected to be over 100 metric tonnes, with an estimated worth of $1.5 million, according to a study by (Shrestha et al. 2013). Mahseer (*Tor* spp.) are a further significant coldwater fisheries resource in the Himalayan region. Mahseer are substantial freshwater fish that are highly appreciated by both local people and anglers for their meat and fighting prowess. In the region's rivers and streams, there are several mahseer species, such as the golden mahseer (*Tor putitora*) and the Himalayan mahseer (*Tor tor*). The golden mahseer is thought to be worth $20 million to the economy of Northeastern India (Choudhury et al. 2003). The Himalayan region is home to numerous carp species, including the common carp (*Cyprinus carpio*) and the mirror carp (*Cyprinus carpio specularis*), both of which are significant food sources for the local populations. Thousands of small-scale farmers are involved in the production of carp for local and regional markets, making carp farming a significant industry in the area. The economy of Nepal is thought to benefit from carp farming to the tune of $5 million yearly (Singh and Sarma 2018; Shrestha et al. 2013).

The importance of these coldwater fishing resources cannot be overstated, as they contribute significantly to the local economy and provide opportunities for sustenance and livelihoods for residents. Nonetheless, challenges such as overfishing, habitat destruction, and the impacts of climate change pose threats to these vital resources. It is imperative to implement sustainable management techniques to ensure the continued survival of these resources for future generations.

This upland region of the country is home to a wide variety of water resources, including rivers, rivulets, streams, lakes, ponds, and reservoirs. The snow-fed Himalayan Rivers are found in the altitudinal range of 200–8000 msl (Raina 2009). In addition, the length of the main highland river is thought to be around 10,000 km in total. Due to topographical and altitudinal changes, mountain slopes, the expansion of river valleys, and flora cover, this area of the country enjoys a range of climates. Fast cascades, deep pools, bedrock, stones, and sand substratum are hallmarks of coldwater rivers and highland streams. A wide variety of fauna inhabits the uplands' numerous and varied water sources (Sehgal 1999; Mahanta and Sarma 2010; Singh and Sarma 2018). A maximum of 258 species, 21 families, and 76 taxa can be found in coldwater fisheries of the country, of which 203 species are found

in this region. The resources of cold water of these areas are home to some of the most favored sport fishes, including the renowned *Neolissochilus hexagonolepis*, deep-bodied mahaseer (*Tor tor*), and golden mahaseer (*Tor putitora*). Apart from these food fishes, other species such as *Semiplotus semiplotus*, *Labeo pangusia*, *L. dero*, *L. dyocheilus*, *Raimus bola*, *Anguilla bengalensis*, *Bagarius yarrelli*, etc. are also drawing market demand and have the potential to encourage leisure fishing in the area. The following species of coldwater fish are important for commerce in India: *Tor tor*, *T. putiora*, *T. mosal*, *T. progeneius*, *T. khudree*, *T. mussullah*, *T. malabaricus*, *Naziritor chelynoides*, *Neolissochilus wynaadensis*, *N. hexagonolepis*, *Schizothorax richardsonii*, *S. plagiosto*, *S. curvifrons*, *S. micropogon*, *S. kumaonensis*, *Barilius bendelisis*, *Semiplotus semiplotus*, *Bangana dero*, *Labeo dyocheilus*, *Crossocheilus periyarensis*, *Osteobrama belangeri*, *Garra lamta*, *Garra gotyla*, *Glyptothorax pectinopterus*, *G. brevipinnis*, *G. stoliczkae*, *Chagunius chagunio*, *Labeo dero*, *L. dyocheilus*, and *Lepidopygopsis typus* (Sehgal 1999; Sunder et al. 1999; Jena and Gopalakrishnan 2012; Sehgal 2012). Many coldwater river segments in Jia Bhoroli, Subansiri (Assam), Kameng, and Siang (Arunachal Pradesh) are described to as "anglers' paradise." Along with the sport fishes, the aquatic groups snow trout, minor carps, major carps, catfishes, bagrids, barils, murrels, and mud eels are extensively used as food fishes in the area. Many of the aquatic species found in the coldwater zone are colorful, intriguing, and have high decorative value. Northeast India is known as a repository for attractive fish species as a result. Approximately 187 of the 203 species mentioned are well known for their aesthetic value.

1.6 Capture Fisheries Resources in Himalayan Waters

There are two main types of fishing in the waterways of the Indian Himalaya: subsistence fishing and sport/recreational fishing. Because of the low fish yield in mountain streams, only very tiny amounts of commercial fishing are conducted there (Sharma et al. 2018). A majority of little fish results from low biological productivity, with the exception of pools where fish have some protection and a place to rest. The temperature of the water is always a crucial limiting factor that impacts the geographic distribution and local occurrence of water within a water system. The subsistence and commercial fisheries in India utilize sisorids (*Glyptothorax* and *Glyptosternum* spp.), garrids (*Garra* spp.), lesser barils (*Barilius* spp.), schizothoracines (*Schizothorax* and *Schizothoraichthys* spp.), and carps (*Labeo* and *Tor* spp.). The remaining genera are insignificant and of little economic importance. The rare brown trout (*Salmo trutta*) has become entrenched in some areas of the Himalayas (Raina and Petr 1999; Sehgal 1999, 2012). In an endeavor to catch the gorgeous mahseer or trout, anglers from all over the world congregate at Indian rivers. There are approximately 3800 km of river and stream sections that include huge mahseers and 714 km of brown trout for fishing in the highland region of our country (Raina and Petr 1999; Singh and Sarma 2018; Sarma et al. 2018a, b, 2019).

For many populations in the Himalayan region, especially those in rural areas, fishing is a significant source of income. For local inhabitants in some places,