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Ecological and Anthropogenic Factors Shaping Fish Survival in Streams of the Kashmir Himalaya

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Abstract

The Himalayas harbor one of the most diverse assemblages of freshwater hill stream fishes, shaped by steep environmental gradients such as altitude, temperature, and flow rate. This review synthesizes current knowledge on how these gradients influence fish diversity, distribution, and physiological adaptations. Unlike earlier descriptive accounts, this paper critically examines the ecological and physiological mechanisms underlying species' responses to environmental stressors, with attention to recent advances in climate and conservation research. The review also highlights urgent conservation challenges—hydropower development, habitat fragmentation, pollution, and climate change—and evaluates ongoing initiatives in the region. Specific recommendations are proposed, including maintaining environmental flows, restoring riparian zones, and developing communityled conservation models. A systematic literature review framework was employed to identify relevant studies from 2000–2025, ensuring comprehensive coverage of both classical and recent works. This study emphasizes the need for integrated research on diversity, physiology, and conservation to safeguard Himalayan hill stream fishes.

Keywords: Hill stream fish, water quality, stream ecology, biodiversity, pollution, climate change

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Introduction

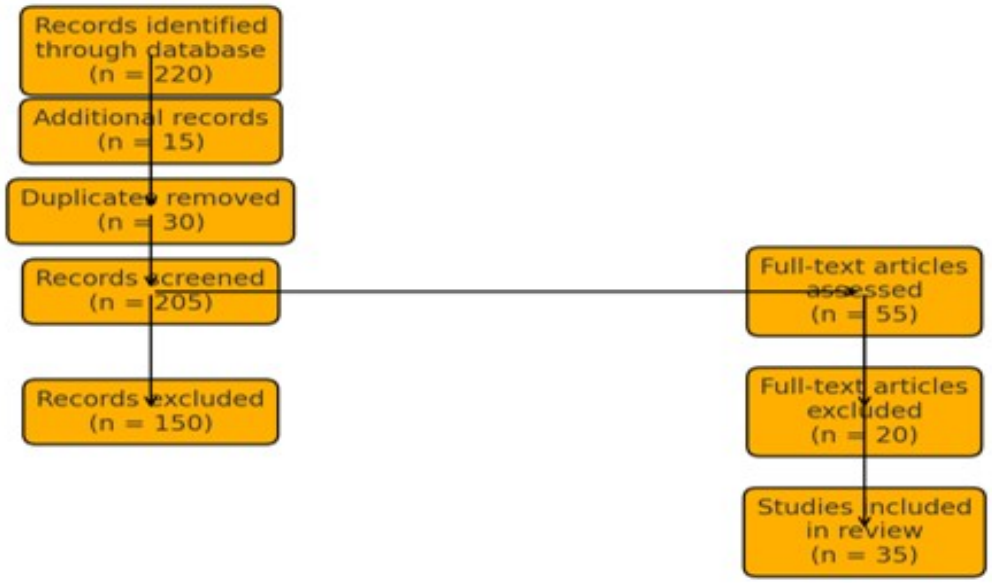
Freshwater fishes are a significant component of aquatic ecosystems, providing ecological and economic benefits (Mehner, 2009). The Himalayan region is home to a diverse array of freshwater fish, particularly in the hill streams. These streams are characterized by high gradients, fast-flowing water, and rocky substrates, which make them a unique and challenging habitat for fish. In the Himalayas, environmental variables like temperature, flow rate, and altitude can have a big impact on the diversity, abundance, richness, and distribution of hillstream fish (Singh 2016). This systematic review of the literature aims to provide an overview of what is currently known about environmental gradients in freshwater hillstream fishes of the Himalayas. The Himalayan region contains a substantial number of freshwater fish species, putting it among the planet's most biologically diversified regions. (Bhatt et al., 2013). The hill streams in the Himalayas are particularly important habitats for these fish, providing a unique environment with distinct environmental gradients. (Sharma and Pandit 2011). These gradients are the consequences of the diverse topography and weather patterns, which vary with elevation, precipitation, temperature, and other factors. The fish fauna of the Himalayan hill streams is adapted to these environmental gradients and have evolved to thrive in an assortment of conditions. (Sharma et al., 2021). The preservation and management of these fish species require a comprehension of the relationships between them and their environment. In this context, environmental gradients refer to the gradual change in abiotic and biotic factors along a spatial or temporal axis. Factors like temperature, oxygen saturation, water flow, substrate composition, nutrient availability, and vegetation cover can be included in these gradients among others. Fish specie's physiology, behavior, and distribution can be significantly impacted by these factors. Considering their habitat preferences and environmental adaptations, the fish fauna of the Himalayan hill streams can be divided into three groups. These include rheophilic species, which are adapted to fast-flowing water and rocky substrates; limnophilic species, which prefer still or slow-moving water with sand or mud substrates; and potamodromous species, which migrate between rivers and streams for breeding or feeding (Jayaram, 2010). Numerous variables, such as temperature, precipitation, altitude, and land use practices, impact the dispersal and abundance of these fish species. The fish populations and their habitats are also significantly impacted by climate change (Reid et al., 2023; Dudgeon, 2023; Su et al., 2021) and human activities including water abstraction, damming, and deforestation (Barbarossa et al., 2021) To sum up, the hill streams of the

Himalayas are vital habitats for a diverse range of freshwater fish species. Understanding the environmental gradients that exist in these habitats and how they influence the distribution and ecology of these fish species is crucial for their conservation and management in the face of ongoing environmental change

Methods

The review entailed a systematic method for searching and synthesizing published literature pertaining to Himalayan hill stream fishes. Searches were carried out on Scopus, Web of Science, and Google Scholar engines employing a set of keywords such as "Himalayan hill stream fishes," "fish diversity Himalaya," "physiological adaptation cold-water fish," and "climate change freshwater fish." The studies selected had a publishing date between 2000 and 2025, and articles targeted were published literature in the form of books and government and non-government organization reports. Inclusion criteria included studies revolving around diversity and conservation patterns or physiological aspects of hill stream fishes. Exclusion criteria included grey literature, studies from non-Himalayan regions, and studies without a fisheries perspective. About 35 articles were short-listed for the review.

Fig.1: PRISMA Flow Diagram for Literature Selection



Environmental Gradients in the Himalayas

The Himalayas are a complex and diverse region, characterized by a broad variety of environmental gradients. The significant environmental gradients include altitude, which ranges from a few hundred meters to over 8000 meters. The temperature gradient in the Himalayas is also steep, with temperatures ranging from tropical to alpine (Sherpa., 2014). The Stream flows vary greatly in velocity. with some having fast-flowing water and others having slow-moving pools. The Himalayas, located in South Asia, are home to a diverse range of ecosystems, from the subtropical forests of the foothills to the alpine tundra at high elevations. These ecosystems are organized along environmental gradients, which are defined by changes in altitude, temperature, precipitation, and other environmental factors.

The altitudinal gradient is the most important environmental gradient in the Himalayas. As altitude increases, temperatures decrease, and precipitation patterns change. (Akhtar et al., 2008). The formation of different vegetation zones, including subtropical forests, temperate forests, and alpine vegetation, is attributed to this gradient (Lomolino, 2001) Another important environmental gradient in the Himalayas is the precipitation gradient. The southern slopes of the Himalayas receive more rainfall than the northern slopes, which are located in the rain shadow of the mountain range. (Ives, 2004). This gradient is responsible for the formation of different ecosystems, including subtropical forests, dry forests, and high-altitude deserts. The temperature gradient is equally crucial in the Himalayas, with temperatures varying based on altitude, latitude, and season. In the lower elevations, temperatures are warm and humid, while at higher elevations, temperatures are cooler and drier. The variations in temperature are the reason for the formation of different ecosystems, including subtropical forests, temperate forests, and alpine tundra (Salick et al.,2014). In summary, the Himalayas exhibit a gradient of human impact, whereby the high-altitude regions remain mostly unaffected, while lower elevations and valleys experience increased levels of human activity and development. The

region's sustainable development and biodiversity protection are significantly impacted by this gradient. Overall, the environmental gradients in the Himalayas are complex and interconnected, with altitude, precipitation, temperature, and human activity all contributing to The emergence of different ecosystems and patterns of biodiversity (Kattel, 2022). Understanding these gradients is crucial for effective conservation and management of the region's natural resources.(Tickner et al., 2022; Grill et al., 2024)

Freshwater Hill Stream Fishes of the Himalayas:

The Himalayan region is home to a diverse array of freshwater fish, particularly in the hill streams. (Johal *et al.,* 2002). The swiftmoving, rocky substrates of these Brooks are suitable for the adaptation of hill stream fish. These fish are capable of maneuvering through the water with ease because of their streamlined body and small size (Chan, 2001). Some of the Himalayas' most prevalent hillstream fish species include Schistura, Nemacheilus, and Barilius species.

The Northwest Himalayas are home to a diverse range of freshwater hill stream fishes that are adapted to the unique ecological conditions of this region. (Sivakumar, 2008). Some of the most notable species found in this area include (Jayaram, 1999).

Snow Trout (Schizothorax richardsonii): This species is most commonly found in the Northwest Himalayas. This fish lives in chilly water, a cold-water fish that is found in fast-flowing streams and rivers with rocky bottoms. Snow Trout has a unique coloration, with a bluish-black back and silvery-white sides.

Golden Mahseer (Tor putitora): The Golden Mahseer is a prized game fish found in the Northwest Himalayas. It is a powerful, huge fish that is well-known for its combative nature. ability and aggressiveness. Golden Mahseers prefer to live in clear, fastflowing rivers and streams with rocky bottoms.

Himalayan Catfish (Sperata seenghala): The Himalayan Catfish is a large predatory fish that is spotted in the Northwest Himalayas. It is renowned for its impressive size and strength and can grow up to 1.5 meters in length. Himalayan Catfish prefer to live in deep pools in fast-flowing rivers and streams.

Brown Trout (Salmo trutta): The Brown Trout is a non-native species that was introduced to the Northwest Himalayas in the beginning 1900s. It's currently well-established in many rivers and streams in the region. Brown trout prefer to live in cool, clear water with a moderate current.

Chirruh Snow trout (Schizothorax esocinus): In the Northwest Himalayas, this species can be found in high-altitude streams as well as rivers. It's a tiny, relatively unknown fish that is prized by local anglers for its delicate flesh and subtle flavor. These are just a few of the many species of freshwater hill stream fishes noticed in the Northwest Himalayas. (Bhatt and Manish, 2023) The region's unique ecology and geography provide a rich and diverse habitat for fish, making it an ideal destination for anglers and researchers alike.

Table 1. Comprehensive list of hill stream fishes in kashmir & related himalayan streams

Scientific Name	Common/Local Name	Family	Habitat Type	Source(s)
Schizothorax plagiostomus	Khont / Buche Asla	Cyprinidae	Lotic	7, 8, 9, 15
Schizothorax esocinus	Chhurru	Cyprinidae	Lotic	7, 8, 9
Schizothorax labiatus	Chush	Cyprinidae	Lotic	7, 8, 9
Schizothorax curvifrons	Satter gad	Cyprinidae	Lotic	7, 8, 9
Schizothorax niger	Ale gad	Cyprinidae	Lentic	7, 9
Schizothoraichthys progastus	Chuchhe Asla	Cyprinidae	Lotic	15
Crossocheilus diplochilus	Tetther	Cyprinidae	Lotic	7, 8, 9
Crossocheilus latius	Buduna	Cyprinidae	Lotic	15
Garra gotyla gotyla	Buduna	Cyprinidae	Lotic	15

Garra annandalei	Buduna	Cyprinidae	Lotic	15
Triplophysa marmorata	Araguran	Nemacheilidae	Lotic	7, 8, 9
Triplophysa kashmirensis	Araguran	Nemacheilidae	Lotic	8, 9
Glyptothorax kashmirensis	-	Sisoridae	Lotic	7
Glyptosternon reticulatum	-	Sisoridae	Lotic	8
Schistura corica	Stone loach	Nemacheilidae	Lotic	15
Schistura rupecola	Bhote gadelo	Nemacheilidae	Lotic	15
Acanthocobitis botia	Baghe / Natwa	Nemacheilidae	Lotic	15
Lepidocephalus guntea	Guntea	Cobitidae	Lotic	15
Botia lohachata	Baghi (Y-loach)	Botiidae	Lotic	15
Cyprinus carpio communis	Punjabe gad	Cyprinidae	Lentic	7, 8, 9
Cyprinus carpio specularis	Punjabe gad	Cyprinidae	Lentic	7, 8, 9
Carassius carassius	Gang gad	Cyprinidae	Lentic	9
Puntius conchonius	Rosy barb	Cyprinidae	Lentic	9
Gambusia holbrooki	-	Poeciliidae	Lentic	9
Barilius barna	Poti	Cyprinidae	Lotic	15
Barilius bendelisis	Gurdi	Cyprinidae	Lotic	15
Barilius vagra	Faketa	Cyprinidae	Lotic	15
Raiamas bola	Bhutte / Chalwa	Cyprinidae	Lotic	15
Esomus danricus	Dedhawa	Cyprinidae	Lotic	15
Brachydanio rerio	Zebra fish	Cyprinidae	Lotic	15
Glossogobius giuris	Bulla	Gobiidae	Benthic	15

Altitude Gradient and Fish Diversity:

The altitude gradient in the Himalayas has an immense impact on the distribution and abundance of freshwater hillstream fish. Fish diversity decreases with altitude, with fewer species found in higher elevations, as revealed by ecological studies on fish diversity. This pattern is thought to be owing of the decreasing temperature and oxygen levels at higher elevations, which makes it harder for fish to survive. However, some species, such as the snow trout (Schizothorax richardsonii), are biologically adapted to the highaltitude cold water streams and are found at elevations of over 5000 meters. The altitude gradient refers to the change in environmental conditions that occur as elevation increases. Environmental variables like temperature, precipitation, and vegetation cover undergo significant change with the increase in altitude (Mittelbach et al., 2007). The diversity and distribution of plant and animal species can be significantly impacted by these changes. The altitude gradient is a term used to explain the association amid fish species richness, of different fish species, and elevation in the setting of fish diversity. Studies have demonstrated that the species richness decreases at higher elevation. This trend is attributed to changes in water temperature, dissolved oxygen levels, and habitat availability. At lower elevations, water temperatures are generally warmer, and dissolved oxygen levels are higher, providing suitable conditions for a greater diversity of fish species. As elevation increases, water temperatures become colder, and dissolved oxygen levels decrease, creating less suitable conditions for some fish species. Additionally, habitat availability can also influence fish diversity along the altitude gradient. At higher elevations, the accessibility of suitable habitats such as deep pools and riffles may be limited, which can further reduce fish species richness. While there are some broad patterns, there are exceptions. The occurrence of cold-water-adapted species can increase the richness of fish species at higher elevations in some cases. Furthermore, fish diversity throughout the altitude gradient may be significantly impacted by human activities like building dams and deforestation. Fish diversity patterns in freshwater ecosystems are affected by altitude gradient, and understanding these patterns is crucial is essential for effective conservation and management of fish populations.

Temperature Gradient and Fish Diversity:

Freshwater fish diversity in the Himalayas is affected by the environmental gradient of temperature. Research has shown that as the temperature rises, the diversity of fish increases., with more species found in streams that experience higher temperatures (O'Gorman et al., 2016). This pattern is thought to be owing of the increased availability of food and habitat in warmer streams. However, some species, such as the snow trout, are adapted to the cold temperatures found in high-altitude streams and are found at temperatures below 10°C. Temperature gradient refers to the change in temperature over a distance or space. The diversity and distribution of fish species can be significantly impacted by temperature gradients in aquatic ecosystems (Bennett et al., 2009). Since fish are ectothermic creatures, the warmth of their surroundings affects their body temperatures. The preferred temperatures of various fish species can have an impact on their growth, survival, and behavior. In general, fish species tend to be more diverse in areas with a broad variety of temperatures, for instance near the equator, or areas with significant temperature gradients, such as mountain streams (Jobling 2010). These areas offer a variety of microhabitats with different temperatures, allowing for a greater range of species to thrive. Fish diversity is typically lower in regions with more consistent temperatures, such as huge lakes or the deep ocean. This is because there are fewer distinct microhabitats for different species to occupy that vary in temperature. Fish species migration patterns can also be impacted by temperature variations. For example, in response to warming waters, some species may move to higher latitudes or higher elevations to maintain their preferred temperature range. Overall, temperature gradient is a significant factor to consider when studying the diversity and distribution of fish species in aquatic ecosystems.

Flow Rate Gradient and Fish Diversity:

In the Himalayas, the flow rate is another significant environmental gradient that affects the diversity of freshwater fish. According to studies, fish diversity increases as the flow rate does, with faster-moving streams possessing a higher species diversity (Bhat et al., 2012) This pattern is believed to be because of the increased availability of food and oxygen in fast-flowing streams. However, some species, like hill stream loach (Homaloptera spp.), are adapted to slow-moving streams and are found in pools and eddies. The velocity gradient indicates the rate at which water flows within a particular body of water. This gradient can be impacted by a number of things, such as the size and shape of the body of water, the quantity of precipitation in the area, as well as the existence of man-made structures such as dams or levees. Contrarily, fish diversity describes the variety of distinct fish species that can be found in a given body of water. Many factors could impact it, including the temperature, the amount of dissolved oxygen in the water, the quality of the water, and the existence of predators or rivals.Fish diversity and flow rate gradient have a complex relationship (Vander Sleen and Albert, 2022). Higher flow rates are often thought to be connected with more diverse and dynamic ecosystems since swift-moving water is linked to faster-moving fish. This is because high rates of flow can produce a range of distinct microhabitats in the water that may be occupied by various fish species. However, the connection between flow rate gradient and fish diversity is not always straightforward. For example, in some cases, extremely high rates of flow can limit fish

diversity, as certain species may not be able to tolerate the fast-moving water. Similarly, in some bodies of water, low flow rates may be associated with high fish diversity, as slower-moving water may create more stable and hospitable conditions for certain species. Fish diversity and flow rate gradient have a complex and multifaceted relationship that is influenced by a wide range of factors. Additional research is necessary to fully understand this link and its implications for aquatic ecosystems.

Impacts of Environmental Gradients on Fish Physiology:

Fish physiology may additionally be significantly impacted by environmental gradients (Barletta and Dantas, 2016 and Dudgeon, 2023) For example, cold temperatures in the Himalayas. can slow down the metabolic rate of fish, leading to reduced growth rates and activity levels. (Awas et al., 2020). Low oxygen levels at high elevations can also lead to reduced growth rates and lower survival rates in fish. Increased oxygen demand in fish can be caused by elevated flow rates, which have the potential to lead to higher metabolic rates and energy expenditure. Environmental gradients, which reflect alterations to the surrounding environment over time or space, can have significant impacts on fish physiology. Several of the key environmental gradients that can affect fish physiology include temperature, salinity, oxygen levels, and pH. (Zhao et al., 2019). Fish physiology can be significantly affected by temperature gradients. Fish are ectothermic, which indicates that their body temperature is based on their environment. Temperature changes have the potential to impact metabolic rates, growth rates, and reproductive success (Edds, 1993). For example, a few varieties of fish are adapted to living in cold water environments and have lower metabolic rates and slower growth rates than species that live in warmer waters. Salinity gradients can also possess a significant impact on fish physiology. Fish are osmoregulatory, meaning they must regulate the concentration of salts and other solutes in their body fluids to maintain proper cell function. (Buf et al., 2001) Changes in salinity can affect the osmotic balance of fish, causing dehydration or water overload. For example, certain fish species have evolved to live in in freshwater environments and have specialized mechanisms for regulating salt concentrations, while others are designed to survive in saltwater environments and have mechanisms for excreting excess salt (McCormick, 2011). Oxygen levels can also impact fish physiology. Fish require oxygen to survive, and changes in oxygen levels can affect respiratory function, metabolism, and behavior. For example, in areas with low oxygen levels, fish may exhibit reduced activity levels, decreased growth rates, and altered feeding behaviors. Finally, changes in pH can also impact fish physiology. Fish have specific pH requirements for survival, and changes in pH can affect fish's capacity to maintain proper acid-base balance. For example, in areas with low pH, fish may exhibit decreased reproductive success and impaired immune function. Fish physiology can be significantly impacted by environmental gradients, which can affect metabolic rates, growth rates, reproductive success, and other important physiological processes. As a result, understanding how fish respond to changes in their environment is critical for conservation and management efforts Conservation Implications.

Freshwater Hill stream fish in the Himalayas face cumulative impacts of expansion of Hydropower development, habitat destruction (Tickner et al., 2022; Reid et al., 2023; Arthington, 2022) pollution, overfishing, and climate change-induced alterations in water temperatures and discharge. Drawing on recent findings, conservation efforts should shift from general suggestions to specific actions in conservation, in as much as:

Habitat Protection & Restoration: Riparian zone vegetation maintenance, minimizing sedimentation, and restoring impaired stream sections.

Environmental Flow Regulations: Regulate minimum environmental flows in hydropower and irrigation schemes to preserve fish spawning and migration corridors.(Arthington, 2022).

Community-based Conservation: Enable local communities through awareness campaigns and participation in monitoring efforts (e.g., Mahseer sanctuaries).

Climate Change Adaptation: Locate coldwater refugia, construct fish passes, and detect range shifts using eDNA and GIS analysis.

Policy Integration : Enhance the enforcement of laws protecting biodiversity and integrate fish conservation into watershed management strategies.

Existing initiatives like conservation efforts for snow trout in Uttarakhand and the mahseer sanctuaries in Himachal Pradesh offer valuable models for new projects that can simply be scaled up. Future research should continue to focus on complementary research paths that span fish physiology, habitat ecology, and socio-economic aspects. The freshwater hill stream fish of the Himalayas are facing significant threats due to human activities, such as habitat destruction and pollution. To develop effective conservation strategies, it is crucial to comprehend the outcomes of environmental gradients on fish diversity and physiology. The necessity that among the most important conservation implications is the necessity to protect the habitats of hillstream fish in the Himalayas. Human activities, such as deforestation, mining, and dam construction, can significantly alter the natural flow patterns of streams leading to habitat fragmentation and degradation. (Grill *et al.,* 2024; He *et al.,* 2023). The impacts of these modifications,

particularly those that are adapted to specific environmental gradients, can be significant for fish populations. So, management and conservation efforts require emphasis on protecting the natural flow patterns of streams, including maintaining riparian vegetation and reducing sedimentation and pollution. Developing plans to protect fish diversity in the backdrop of climate change is another crucial conservation consequence. Climate change is especially dangerous for the Himalayan region because of rising temperatures and shifting patterns of precipitation. These variations can have noteworthy influences on the distribution and abundance of freshwater fish in the area, especially those who are adapted to specific temperature and flow rate gradients. Therefore, the main goal of conservation efforts must be to create plans for habitat restoration and fish population management that will lessen the influence of climate change on fish populations. Lastly, it's important to promote awareness and education about the importance of freshwater fish conservation in the Himalayas. Hill stream fish are often overlooked in conservation efforts, with a focus on larger, more charismatic species. However, freshwater fish play critical ecological and economic roles in the region, providing food and livelihoods for local communities. Therefore, conservation efforts must focus on promoting awareness and education about the importance of freshwater fish conservation, including the need to protect their habitats and address the impacts of climate change. This may involve interacting with local communities and promoting sustainable fishing practices.

Conclusion

In conclusion, freshwater hill stream fish present in the Himalayas are a distinctive and important part of aquatic ecosystems. Environmental gradients, such as altitude, temperature, and flow rate, have significant impacts on fish diversity and physiology in the region. To formulate viable conservation plans for these species, it is crucial to understand their impacts, which includes protecting their habitats, addressing the consequences of climate change, and promoting awareness and education about the significance of the conservation of freshwater fishes. By prioritizing the conservation of hill stream fish, we can help to safeguard the long-term sustainability of freshwater aquatic ecosystems in the Himalayas and the communities that depend on them.

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