Ecology and Conservation of Mahseer Fish in Northeast India: Challenges and Solutions for Fisheries Science

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Abstract
The freshwater ecosystems of Northeast India contain Mahseer fish *(Tor species)* as their essential biological components which sustain biodiversity and provide fisheries benefits and generate local income. Habitat destruction and overfishing together with pollution and climate change consequences have severely depleted their populations. This research investigates Mahseer's ecological value and determines their survival threats by developing conservation solutions that unite habitat improvement with sustainable fishing practices and community collaboration, as well as regulatory measures. The main goal is to assess Mahseer species conservation levels across Northeast India while developing scientific and policy-based strategies to protect these species for future generations. Literature reviews and field data collection methods with stakeholder interviews serve this study to assess threats against Mahseer populations and develop suitable solutions for conservation. Research confirms habitat fragmentation from dam building, joined by uncontrolled fishing and hydrological changes caused by climate change, remains the principal threat. Research indicates that Mahseer conservation will benefit from the combination of creating sanctuaries along with catch-and-release practices and knowledge exchange with traditional communities and breeding program development. Research demonstrates that scientists together with policymakers and local communities should prioritize working alongside one another for developing sustainable conservation plans. The future survival of Mahseer in Northeast India depends heavily on improved legal controls and more money for conservation efforts as well as climate-adapted conservation techniques.

Keywords: Mahseer conservation, fisheries management, habitat restoration, climate change, biodiversity, sustainable aquaculture

1. Introduction

1.1*Background on Mahseer Fish (Tor Species) and Their Ecological Significance*

South and Southeast Asia hold the Mahseer fish (Tor genus) as one of their most vital freshwater fish species both from an ecological and economic perspective. Tiger fish is a common name for fish that belong to these families because of their impressive physical characteristics, including their size, strength and endurance (Pinder et al., 2019). Mahseer species are very adaptable to freshwater ecosystems from high mountain rivers and streams in the Himalayan foothills to reservoirs and lakes of India. Of the known species, the golden mahseer *(Tor putitora)* and the chocolate mahseer (*Neolissochilus hexagonolepis*) are the most important as they are of conservation concern and are economically important (Sarma *et al*., 2022).

Figure 1: Lateral view of *Tor putitora*, (Yousaf et al., 2021).

Mahseers play a very important role ecologically in maintaining riverine ecosystem balance. They are omnivorous species, which consume aquatic plants, invertebrates, and smaller fish, and thus contribute to the food web, Gupta *et al*. (2020. This highlights how their movement through river systems contributes to seed dispersal and sediment mixing, which are important for keeping aquatic biodiversity intact. In addition, their population health serves as an indicator of the overall condition of freshwater habitats and thus, they are a key focus for conservation biology (Pinder, 2020).

Yet, they are important ecologically for the catchments where they occur but their populations are declining due to habitat degradation, overfishing, and climate change-induced hydrological alterations (Dash *et al*., 2020). Different approaches for mahseer species protection, implementing breeding programs alongside habitat restoration efforts, and regulatory enforcement, according to Sharma et al. (2019). There exists a requirement to identify detailed ecological knowledge about mahseer species coupled with clarified threats and proven management approaches for efficient species conservation.

1.2 *Importance of Mahseer Fish in Northeast India's Freshwater Ecosystems*

Northeast India is a biodiversity hotspot that contains numerous freshwater fish species, including several Mahseer species. The Brahmaputra and Barak river basins provide Mahseer with its optimal habitat because these waters remain cold and contain high oxygen levels (Kechu et al., 2021). The golden mahseer (Tor putitora) stands as one of the most important species of this area because the International Union for Conservation of Nature (IUCN) has classified it as "Endangered." The species maintains ecological significance combined with cultural and economic importance because local communities consider it sacred while the fishery activities support subsistence fisheries.

The native communities in Northeast India rely on Mahseer fish for their survival and economic growth because it functions as their main dietary source. Tourism relies heavily on this species because anglers and conservationists from across the world come to experience it. Tourism based on Mahseer angling functions as a sustainable conservation method in all regions of Arunachal Pradesh, Meghalaya and Nagaland according to Dash et al. (2021). The mahseer population in Northeast India suffers from the combination of uncontrolled fishing practices and construction of dams alongside tree removal that damages habitats (Pandey and Radhakrishnan, 2022).

Climate change has worsened existing problems because it changes river flow patterns and heats water while disrupting fish breeding activities. According to Yadav et al. (2020), the research shows that mahseer reproduction and their offspring survival suffer from changes in water temperature resulting in population decline. The introduction of foreign fish species in Northeast Indian rivers has resulted in a decrease of mahseer numbers as these species compete for resources and transform the ecosystem structure (Gupta et al., 2020). Scientific knowledge and community involvement and policy-based solutions should unite to develop regional conservation approaches for resolving these issues.

1.3 *Objectives and Scope of the Review*

The main objective of this review is to provide a detailed study about mahseer species ecology while exploring their conservation challenges and management practices in Northeast India. The study of mahseer species conservation needs becomes essential because they support both ecological and economic systems to maintain healthy freshwater biodiversity in the region. The review aims to:

1. Researchers need to understand the ecological value along with geographic range and conservation condition of mahseer species existing in Northeast India.
2. The study assesses primary threats facing mahseer populations as it develops preservation and fisheries management approaches to maintain their survival.

The paper integrates modern research results with conservation rules and operational norms to describe sustainable conservation structures which preserve environmental equilibrium while addressing social, economic factors. The paper evaluates habitat restoration together with hatchery programs and community-driven conservation approaches to protect mahseer populations in Northeast India (Renjithkumar et al., 2022).

2. Taxonomy and Species Diversity of Mahseer in Northeast India

2.1 *Overview of Mahseer Species Found in the Region*

The Cyprinidae family Tor species maintains its presence in South and Southeast Asian freshwater ecosystems with a specific abundance found in Indian territory. The rivers, lakes and streams of Northeast India support numerous mahseer species. The main mahseer species present in this region include golden mahseer (Tor putitora), deep-bodied mahseer (Tor tor), Assam mahseer (Tor progenius) and chocolate mahseer (Neolissochilus hexagonolepis) as reported by Pinder et al. (2019). The different species within this group demonstrate unique body designs alongside specific choices of habitats and ecological survival strategies.

The rivers of Arunachal Pradesh, Assam and Meghalaya support the sole natural habitat of the golden mahseer (Tor putitora) species. The large species attains high value in recreational and commercial fisheries because of its golden yellow body and extended form (Sharma et al., 2019). This deep-bodied species belongs to the Tor tor group yet stands apart from T. putitora because of its stronger body structure and preference for rocky riverbeds and pools. Tor progenius or Assam mahseer holds ecological importance because it inhabits the smaller tributaries and hill streams of the Brahmaputra basin as per Kechu et al. (2021).

The chocolate mahseer (Neolissochilus hexagonolepis) exists primarily between Nagaland and Arunachal Pradesh and parts of Meghalaya. Tor putitora exceeds other species in size while local fisheries depend on this species to generate

revenue and conservationists use it for breeding programs as well as aquaculture activities (Sharma et al., 2019). The different species function as indicators of freshwater aquatic biodiversity that show both the health and state of aquatic ecosystems throughout this area.

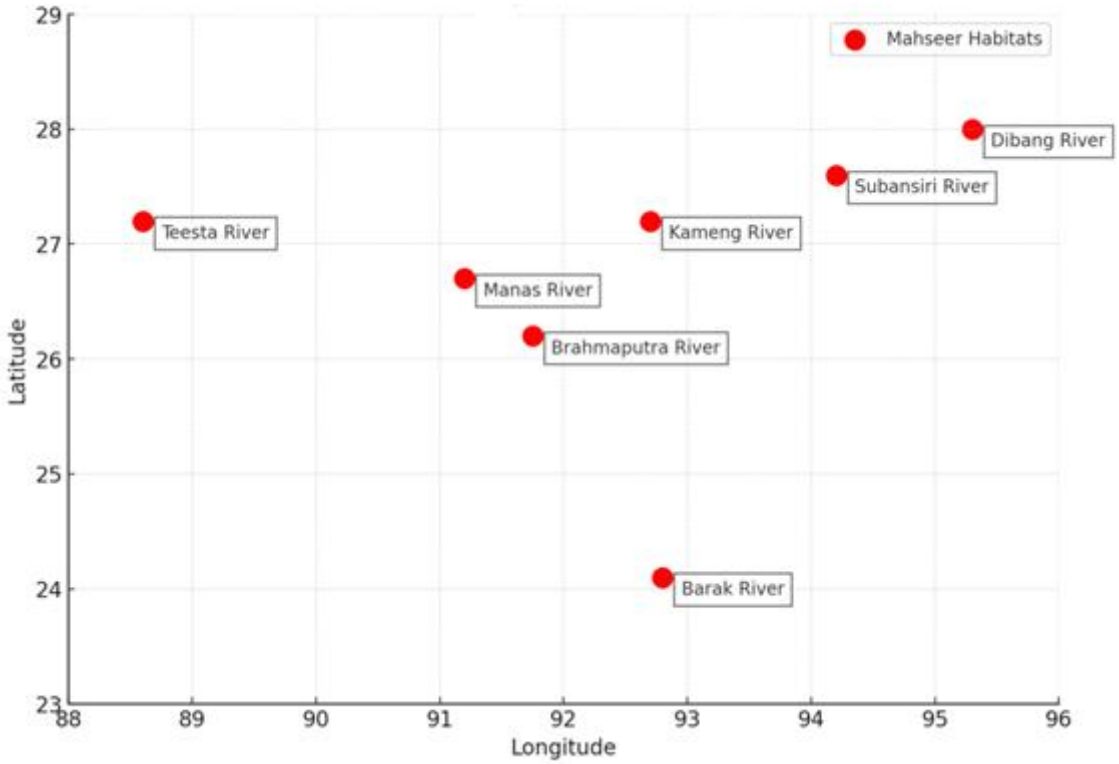

Figure 2: Mahseer Distribution Map in Northeast India

2.2 *Morphological and Genetic Diversity*

The various mahseer species inhabiting Northeast India display wide morphological distinctions that include body shape together with fin structure alongside their scale pattern and coloration characteristics. Tor putitora features a stretched body plan together with a big head and forked tail while Tor tor shows deep body proportions to create its strong appearance (Sarma et al., 2022). The chocolate mahseer (*Neolissochilus hexagonolepis*) achieves camouflage against rocky river substrates because it has dark coloration and hexagonal scales (Sharma et al., 2019).

The mahseer population shows its intra-species diversity through genetic studies, which result from both geographical separation and hydrological variations and local adaptations (Sharma et al., 2019). Through combined DNA barcode and microsatellite research scientists demonstrated that genetics form distinct patterns between populations that demonstrate restricted genetic exchange across river systems (Yadav et al., 2020). The maintenance of mahseer sub-population genetic diversity requires specific conservation strategies because habitat fragmentation and hatchery-based interventions endanger genetic diversity.

2.3 *Distribution and Habitat Preferences*

The Northeast Indian Mahseer species lives in flowing rivers and high-altitude freshwater ecosystems that need water that remains clear and contains plenty of oxygen. The Brahmaputra and Barak rivers along with their tributaries host numerous mahseer populations as per Dash et al. (2020). Tor putitora finds its habitat in big rivers with cold water streams while Tor tor and Tor progenies live in rivers with moderate flow rates that contain deep pools (Sharma et al., 2019).

The natural life cycle of Mahseer fish depends on their seasonal migration patterns for successful spawning events that occur during the monsoon season. Mahseer fish populations together with their migration patterns have declined because human activities like dam construction, deforestation, and water contamination (Pandey and Radhakrishnan, 2022). Implementation of mahseer habitat conservation programs should focus on their specific environmental needs for sustainability purposes.

3. Ecological Role of Mahseer in Riverine Ecosystems

3.1 *Contribution to Ecosystem Balance and Nutrient Cycling*

Ecological stability of freshwater ecosystems requires Mahseer fish to maintain their preservation. Mahseer fish feed on aquatic plants and insects combined with crustaceans and detritus allowing them to regulate trophic relationships in their habitat (Pinder et al., 2019). The fish species Mahseer establishes an essential position within aquatic food webs because it consumes algae and organic matter and regulates both algae population growth and recycles ecosystem nutrients.

The feeding habits of fish generate positive outcomes that improve water quality of riverbeds while maintaining diverse substrate composition (Gupta et al., 2020). Mahseer fish in Northeast Indian hill streams fulfill an essential role through their behavioral activities that affect sediment deposition rates together with organic matter decomposition in steep gradient rivers.

3.2 *Interactions with Other Aquatic Species*

The preservation of the Freshwater ecosystem ecological stability requires the Mahseer fish because they maintain its stability. The feeding behaviors of Mahseer fish consist of consuming aquatic plants and insects as well as crustaceans and detritus which allow them to maintain trophic relationships in their habitat (Pinder et al., 2019). The natural ecological operations in riverine ecosystems depend on Mahseer because they consume algae and organic matter to regulate excessive algal growth while participating in nutrient cycles.

Mahseer fish feeding behavior creates positive effects that improve riverbed water quality and maintain substrate diversity (Gupta et al., 2020). Mahseer fishing behavior maintains vital importance for the high gradient rivers and hill streams of Northeast India because this behavior controls sediment accumulation while decomposing organic matter.

3.3 *Importance as an Indicator Species for Freshwater Health*

The Mahseer fish acts as an indicator species that reveals both environmental health status and population abundance of their aquatic ecosystem (Sharma et al., 2019). The decline in mahseer fish numbers serves as a warning sign that water quality deteriorates alongside disrupted ecological balance since these fish demonstrate high sensitivity to environmental factors (Pinder, 2020).

Based on the studies, several indicators show that mahseer populations decrease when human activities result in rising pollution and sedimentation and habitat fragmentation in Indian waters (Dash et al., 2021). Recruitment rates of mahseer decrease due to elevated pollutant levels of pesticides and heavy metals and industrial effluents in their spawning grounds (Renjithkumar et al., 2022).

The ecological sensitivity of mahseers makes them serve as flagship species for conservation programs, which enables their protection to safeguard freshwater biodiversity. The northeast Indian region implements mahseer conservation strategies through sanctuaries and breeding programs and habitat restoration efforts to protect both mahseer species and their entire aquatic environment (Pandey and Radhakrishnan, 2022).

4. Conservation Status and Threats

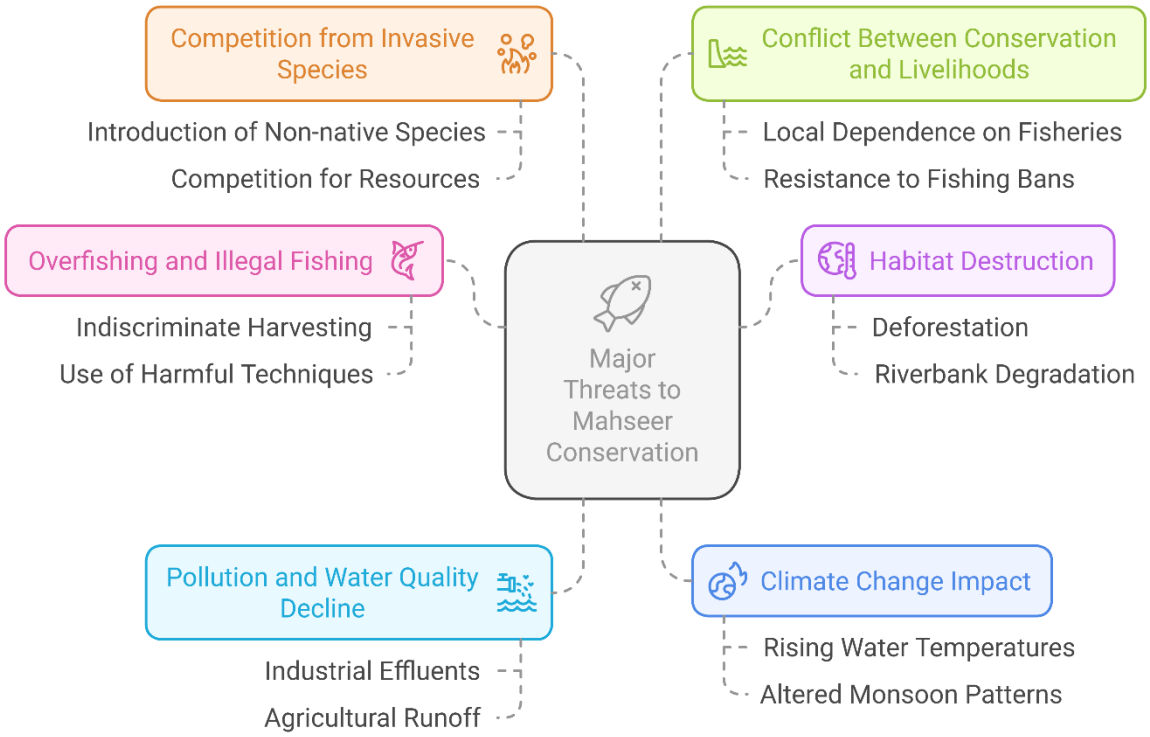

Figure 3: Major Threats to Mahseer Conservation

4.1 *Anthropogenic Threats*

*4.1.1 **Overfishing** and Illegal Fishing Practices*

The Mahseer species in Northeast India faces it's main threat from overfishing activities and illegal fishing practices. The rivers of many regions allow uncontrolled exploitation of mahseer because the species serves as both game fish and

commercial species and food source (Pinder et al., 2019). The natural fish populations become exhausted from overfishing, which disrupts ecological balance and destroys vital species genetic diversity required for species survival. Many Mahseer populations face severe impacts from improper fishing practices that consist of dynamite fishing combined with fine mesh nets and chemical poisoning (Sarma et al., 2022).

The population of mahseer declines when illegal fishers target immature individuals that have not yet reached maturity. The Northeast Indian states face a problem of indiscriminate Mahseer fishing because law enforcement is weak and community-driven fisheries management is nonfunctional. The mahseer populations face serious threats in the Brahmaputra and Barak river basin because proper regulations are not in place and suitable alternative income options are unavailable (Gupta et al., 2020).

4.1.2 Habitat Destruction Due to Deforestation and Dam Construction

The Mahseer species demonstrates high sensitivity to habitat changes while Northeast Indian deforestation and dam building projects have proven destructive to its population numbers. Deforestation in the river catchment areas leads to an increase in soil erosion and sedimentation, which in turn affects the physical and chemical properties of the rivers. Higher sediment levels create multiple water quality problems that reduce oxygen levels and expose vital spawning areas, thus causing reproductive failure (Kechu et al., 2021).

The existence of mahseer populations faces its most severe threat from hydropower projects, together with major dam construction activities. The construction of infrastructure projects generates three major impacts: it breaks down river habitats and disrupts migration routes, and disrupts natural flow patterns vital for breeding (Pandey and Radhakrishnan, 2022). The Tipaimukh Dam project concerns fisheries conservationists because it poses potential risks to river ecology and aquatic biodiversity distribution (Choudhury and Dey Choudhury, 2021). The failure to establish fish migration passages and habitat conservation measures during these projects will lead to severe population declines of mahseer fish stock.

4.1.3 Pollution from Industrial, Agricultural, and Domestic Sources

Water pollution has become an increasing threat to mahseer population numbers in Northeast India. Water quality deteriorates because of heavy metals, pesticides and plastics, which enter the water from industrial waste and agricultural runoff and domestic sewage sources (Sharma et al., 2019). Major mahseer populations located in the Brahmaputra and Barak rivers face damage because of human-made pollutants (Dash et al., 2021).

The agricultural sector in Northeast India pollutes rivers through eutrophication and aquatic habitat oxygen depletion because of overusing fertilizers and pesticides (Yadav et al., 2020). Mahseer populations face disease risks because urban wastewater discharges with untreated sewage and industrial chemicals affect their health (Gupta et al., 2020). The management of pollution sources and waste management systems requires improvement to maintain suitable water conditions for mahseer.

4.2 ***Climate Change Impacts***

4.2.1 Changes in Water Temperature and Flow Regimes

The unpredictable changes in water temperature together with hydrological patterns caused by climate change have severely affected mahseer populations throughout Northeast India (Pinder, 2020). The Mahseer species require cold water to survive, but the temperature increases from global warming and deforestation-related microclimatic changes have affected their metabolic rates, oxygen needs and stress tolerance abilities (Dash et al., 2020).

In addition, the monsoon intensity and precipitation patterns have changed, causing irregularity in the river flow regime. Sudden floods, sedimentation surges, and riverbank erosion destroy spawning and nursery habitats because of increased rainfall variability (Pandey and Radhakrishnan, 2022). However, mahseer populations are negatively impacted by prolonged dry spells and low water levels during non-monsoon seasons, which decreases the habitat availability of available food to feed the mahseer (Borah, 2021).

4.2.2 Effects on Breeding Patterns and Population Dynamics

Some of the Mahseer species have specific temperature and flow requirements for successful spawning which have been observed to be disrupted by climate change. According to studies, fluctuating temperatures delay spawning, decrease egg viability, and increase larval mortality (Yadav *et al*., 2020). Furthermore, altered monsoon patterns impact migratory behavior, and mahseers are unable to reach their optimal breeding sites (Renjithkumar *et al*., 2022).

Such long-term climate-driven changes in population dynamics may potentially lead to lowered recruitment rates and localized experiences of extinction and genetic bottlenecks in the mahseer population across Northeast India (Gupta *et al*., 2020). Because these threats cannot be eliminated, conservation must also integrate temperature-regulated conservation zones, habitat restoration, or artificial breeding programs into fisheries management strategies, adaptation to climate change.

5. Challenges in Conservation and Fisheries Management

5.1 Lack ***of Scientific Data and Monitoring Programs***

Mahseer conservation faces one of the biggest challenges, i.e., lack of complete scientific data, besides the absence of long-period quality monitoring programs. However, many rivers of Northeast India are understudied, and population

assessments of mahseer species are limited, as there is a lack of research funding and logistical constraints (Pinder *et al*., 2019). With no accurate data on population trends, genetic diversity, and habitat conditions, we cannot implement as impactful policies as we could on conservation (Kechu *et al*., 2021).

5.2 *Inadequate Policy Implementation and Enforcement*

Despite the presence of several laws and conservation policies, there is little enforcement thereof, which has continued to contribute to habitat degradation and overfishing of freshwater resources and thereby biodiversity in India. Despite being included in the list of protected species under the Wildlife Protection Act (1972), mahseer continues to be illegally fished and habitat destroyed due to poor surveillance and lack of inter-agency coordination (Dash *et al*., 2021). Moreover, community-led conservation efforts are not supported by the government and lack financial resources, making them less effective (Pandey and Radhakrishnan, 2022).

5.3 *Socio-Economic Factors Influencing Conservation Efforts*

Mahseer fisheries are important for the subsistence and livelihood of local communities in Northeast India and hence conservation efforts are difficult. Overfishing persists in fishing communities because they lack other income sources despite conservation awareness programs according to Sharma et al. (2019). The commercial fisheries and tourism businesses primarily focus on present economic returns that threaten mahseer fish populations according to Dash et al. (2020).

5.4 *Conflicts Between Conservation and Livelihood Needs of Local Communities*

A key barrier to successful mahseer population conservation exists because of the competition between fish protection and local economic needs. Local communities and fishery people oppose conservation policies that ban fishing because these policies lack alternative income sources (Pinder, 2020). Sustainable eco-tourism together with community-led fisheries management and alternative livelihood programs should be promoted according to Dash et al. (2021).

The establishment of balanced conservation-livelihood practices requires structured collaborative models that unite local participants with intervention entities and state representatives. Strategy implementation for conservation purposes such as catch-and-release angling programs together with mahseer sanctuaries and regulated aquaculture represents viable methods to harmonize conservation measures with community well-being (Gupta et al. 2020).

Table 1: Conservation Challenges and Proposed Solutions for Mahseer Fish

Challenge	Description	Proposed Solution	Implementation Strategy
Overfishing and Illegal Fishing	Unregulated fishing, use of destructive methods, and catching juveniles	Implement strict fishing regulations and catch-and-release policies	Enforce seasonal fishing bans, use barbless hooks, and introduce licensing for fishing activities
Habitat Destruction	Dam construction, deforestation, and mining, leading to habitat fragmentation.	River restoration projects and riparian buffer zone management	Promote afforestation along riverbanks, integrate fish migration passages in dam designs
Pollution and Water Quality Decline	Industrial, agricultural, and domestic waste contaminating water bodies	Improve waste management and regulate industrial discharge	Strengthen monitoring of pollution levels, implement wastewater treatment systems
Climate Change Effects	Rising temperatures and altered monsoon patterns affecting breeding cycles	Climate-resilient conservation strategies	Establish Mahseer refugia, research thermal tolerance
Conflict Between Conservation and Local Livelihoods	Dependence of local communities on Mahseer fisheries	Community-based fisheries management and alternative livelihoods	Introduce eco-tourism, promote aquaculture and Mahseer-friendly livelihood options
Lack of Scientific Data and Monitoring	Insufficient long-term population studies and genetic assessments	Establish regular population monitoring and genetic diversity studies	Use eDNA analysis, satellite tracking, and acoustic telemetry to track Mahseer's movement

6. Conservation Strategies and Solutions

Successful Mahseer species preservation in Northeast India requires complete ecological, social and policy-based conservation interventions. Multiple conservation interventions emerged throughout the region because habitat destruction and overfishing and pollution and climate change threats continue to increase. This strategy implementation through habitat restoration features together with sustainable fishery management and community participation and genetic conservation with policy changes aims at ensuring the lasting survival of Mahseer populations and their aquatic habitats.

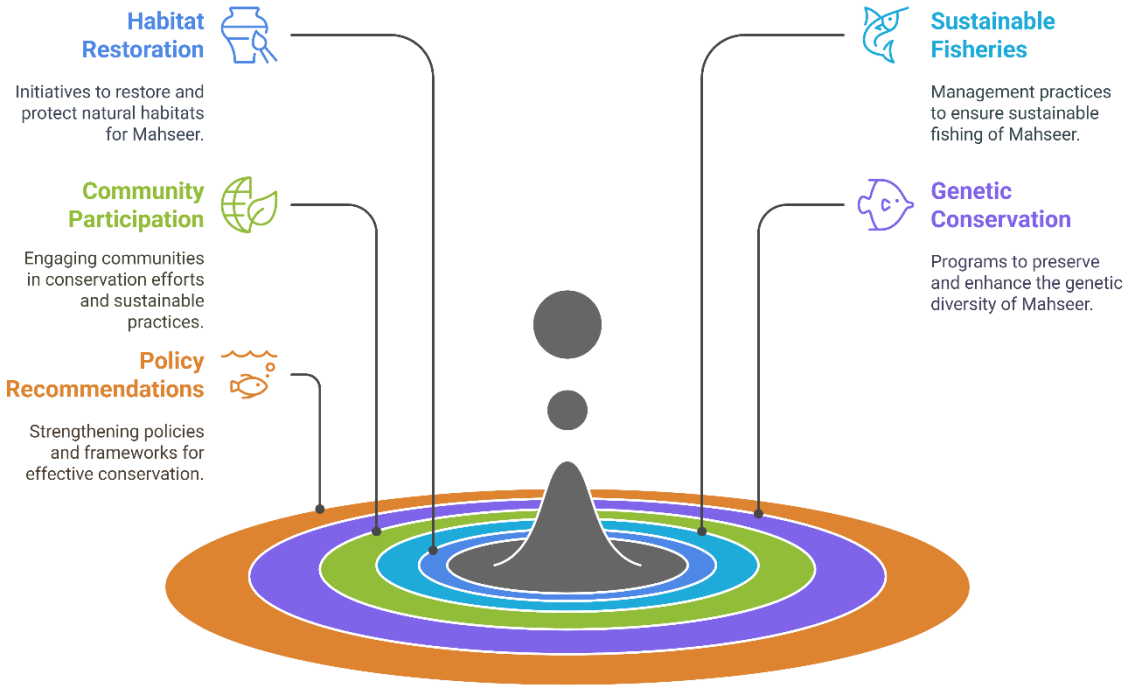

Figure 4: Conservation Strategies for Mahseer

6.1 *Habitat Restoration and Protection*

6.1.1 River Conservation Initiatives

The protection of Mahseer depends on rivers that contain clean water with abundant oxygen while flowing freely, and river conservation serves as the essential component for this protection. The Neidan organization has a background of launching multiple river conservation projects throughout Northeast India for habitat restoration and water quality enhancement (Panja et al., 2021). The challenges of deforestation and erosion receive solutions through efforts that include restoring fish breeding areas and stabilizing riverbanks and planting trees near water bodies (Laskar et al., 2019).

For example, the Mahseer Conservation Program in Meghalaya has taken steps to protect the key Mahseer habitats through habitat mapping, a conservation awareness program, and the inclusion of local stakeholders (Dash *et al*., 2020). However, research has shown the need for conservation-driven hydropower projects, that make sure fish migration routes are not disturbed by fish ladders and bypass channels (Sahoo *et al*., 2022).

6.1.2 Riparian Buffer Zone Management

Mahseer populations benefit from sites where riparian buffer zones – vegetated areas along rivers – stop litter from eroding soil, moderate water temperature, and generally improve the quality of the habitat. The destruction of riparian vegetation due to agriculture, logging, and urbanization has had a great effect on Mahseer spawning sites and food availability in Northeast India (Borah, 2021).

In Arunachal Pradesh and Nagaland, community-based initiatives have highlighted reforestation along the riverbank to compensate for the loss of habitat and to ensure the natural flow of water (Kundu *et al*., 2019). Policies that protect Mahseer's buffer zones surrounding major rivers such as Brahmaputra and Barak will strengthen their ability to withstand environmental disturbances (Ali and Siva, 2022).

6.2 *Sustainable Fisheries Management*

6.2.1 Implementation of Catch-and-Release Policies

The practice of catch and release angling proves to be the most efficient way for sustaining Mahseer populations. Sport fishing has become a popular activity across Northeast India, and when used appropriately, it is an important tool for conservation (Wangchuk and Wangmo, 2022). Scientific research shows that properly managed catch and release programs can serve as an alternative to destructive fishing practices because Mahseer species can heal from capture stress (Dash et al., 2021).

The Mahseer population needs stable management through size restrictions and barbless hook rules and seasonal fishing prohibition to lower death rates (Debnath, 2022). The enforcement of these regulations requires local fishing communities to participate in conservation programs (Majumdar, 2022).

6.2.2 Establishment of Mahseer Sanctuaries and Protected Areas

Mahseer sanctuaries are now increasingly recognized as key conservation tools for protecting the key habitats that people and mahseer require to breed and feed in. Commercial fishing has been restricted and conservation-based tourism

promoted in Mahseer sanctuaries in Meghalaya, Arunachal Pradesh, and Mizoram which has proved effective in maintaining the fish populations (Dash *et al*., 2020).
Aquatic biodiversity conservation has been incorporated as a part of the wildlife protection plan of the Dampa Tiger Reserve in Mizoram which ensures protection of Mahseer populations from overfishing and habitat destruction (Zirkunga and Lalronunga, 2020). Such initiatives can be expanded across vulnerable river systems of Northeast India to further enhance Mahseer conservation (Kalbande *et al*., 2022).

6.3 *Community Participation and Indigenous Knowledge Integration*

6.3.1 Role of Local Communities in Conservation Efforts

Aquatic ecosystems have been known for a long time in Northeast India and Indigenous communities have a long history of knowledge of the same; their participation is indispensable for the success of conservation initiatives. Traditional fishing methods related to sustainable fish harvesting and contributing to the balance of the ecosystem are practiced by many tribal groups (Everard *et al*., 2021). Introducing indigenous ecological knowledge with scientific conservation programs can improve the outcome of management strategies (Sharma, 2020).
States like Assam and Nagaland have implemented community-led fisheries co-management programs where Mahseer conservation programs are integrated with local livelihood needs (Borah, 2021). Local populations have been positive about locally managed conservation areas (LMCAs) where communities have been leading in habitat protection and the management of sustainable fisheries since the inception (Nur *et al*., 2022).

6.3.2 Promotion of Eco-Tourism and Sustainable Fishing Practices

Mahseer conservation can be promoted while creating livelihoods for local communities through eco-tourism (Lahiri *et al*., 2021). Their contribution to conservation awareness and economic incentives for the conservation of fish populations is being developed through angling tourism, contributing towards the conservation of Mahseer in Meghalaya and Arunachal Pradesh (Dash *et al*., 2021).
In some parts of Northeast India, there have been implemented programs that join regulated recreational fishing by bringing together conservation education and habitat restoration projects, but have yet to attract policy support and infrastructure development to achieve broader success (Pownkumar *et al*., 2022).

6.4 *Genetic Conservation and Breeding Programs*

6.4.1 Hatchery-Based Conservation and Stock Enhancement Programs

To support wild populations, Mahseer hatchery programs have been established to produce juveniles for restocking efforts (Jaafar *et al*., 2021). Mahseer recovery in some river systems of Uttarakhand and Arunachal Pradesh has been achieved through successful hatchery-based interventions (Dash *et al*., 2021).
Nevertheless, genetic homogenization and reduced fitness of hatchery-raised fish, emphasize the importance of genetic surveillance to prevent the wild genetic diversity from being compromised through hatchery-based interventions (Sharma *et al*., 2019).

6.4.2 The Potential of Selective Breeding for Species Restoration

In response to climate change and habitat loss, the resilience and adaptability of Mahseer populations under the stress of mild temperature, low oxygen, and potential pollution are increased through selective breeding programs (Renjithkumar *et al*., 2022). The research of genetic markers and hybridization techniques can facilitate the Mahseer conservation strategy by identifying resilient strains for reintroduction in degraded habitats (Kumar *et al*., 2020).

7. Policy Recommendations for Effective Conservation

7.1 *Strengthening Legal Frameworks and Enforcement*

The Wildlife Protection Act (1972) is just one of the existing conservation laws that need better enforcement and stricter penalties for illegal fishing and habitat destruction (Borah, 2021). Effective protection requires such state-level regulations to be harmonized with national conservation policies (Sharma *et al*., 2019).

7.2*Inter-State and International Cooperation for Enhancing Transboundary River Conservation*

The many Mahseer habitats are also international, and India, Bhutan, and Nepal need to work together to protect them (Wangchuk and Wangmo, 2022). Transboundary Mahseer populations can be protected by cross-border conservation initiatives such as joint monitoring programs and information sharing and information-sharing agreements (Choudhury and Dey Choudhury, 2021).

7.3 *Funding and Research Support for the Mahseer Conservation Projects*

Scientific research, habitat restoration, and community engagement programs require sustained funding (Ali and Siva, 2022). To develop long-term conservation strategies, government agencies, research institutions, and nonprofit organizations must work together with adequate financial resources (Kundu *et al*., 2019).

Table 2: Policy Recommendations for Mahseer Conservation

Policy Recommendation	Description	Implementation Strategies	References
Strengthening Legal Frameworks and Enforcement	Improve enforcement of existing laws like the Wildlife Protection Act (1972) and introduce stricter penalties for illegal fishing and habitat destruction.	Increase patrols in Mahseer habitats, impose higher fines, and conduct awareness campaigns for local fishing communities.	Borah, 2021; Sharma *et al*., 2019
Enhancing Inter-State and International Cooperation for Transboundary River Conservation	Enhance bilateral agreements between India, Nepal, and Bhutan for shared river conservation, ensuring coordinated management strategies.	Create cross-border conservation treaties and establish a joint scientific monitoring network.	Wangchuk and Wangmo, 2022; Choudhury and Dey Choudhury, 2021
Funding and Research Support for Mahseer Conservation Projects	Allocate long-term funding for Mahseer research, habitat restoration, and breeding programs to prevent species decline.	Engage government, private sector, and NGOs in funding collaborative research and conservation efforts.	Ali and Siva, 2022; Kundu *et al*., 2019
Establishing Mahseer Conservation Zones	Create legally protected Mahseer conservation zones where fishing is restricted and habitat restoration is prioritized.	Designate specific river stretches as Mahseer sanctuaries, with periodic population monitoring and habitat restoration.	Dash *et al*., 2021; Kalbande *et al*., 2022
Integrating Indigenous Knowledge into Conservation Planning	Incorporate traditional ecological knowledge of indigenous communities into conservation strategies to enhance effectiveness.	Conduct workshops and collaborative conservation programs with indigenous groups to document and apply traditional practices.	Everard *et al*., 2021; Sharma, 2020
Developing Sustainable Mahseer Fisheries Management Plans	Develop policies that balance fisheries management with conservation, including size limits, closed seasons, and sustainable catch quotas.	Introduce eco-certification programs for Mahseer fisheries to promote responsible fishing practices.	Debnath, 2022; Majumdar, 2022
Strengthening Community-Based Fisheries Governance	Empower local communities to co-manage fisheries resources through participatory decision-making and benefit-sharing mechanisms.	Provide incentives and alternative livelihood programs to fishing communities to encourage sustainable practices.	Nur *et al*., 2022; Lahiri *et al*., 2021
Regulating Hydropower Projects to Minimize Ecological Disruptions	Regulate hydropower dam operations to allow ecological flow for migratory fish species and reduce habitat fragmentation.	Require environmental impact assessments for all new hydropower projects and introduce fish ladders where needed.	Sahoo *et al*., 2022; Renjithkumar *et al*., 2022
Monitoring and Controlling Invasive Fish Species	Implement monitoring programs to prevent invasive fish species from outcompeting Mahseer and disrupting native ecosystems.	Ban the release of non-native fish species and establish rapid-response teams to control invasive populations.	Jaafar *et al*., 2021; Kumar *et al*., 2020
Implementing Climate-Resilient Conservation Strategies	Adapt conservation policies to climate change by establishing thermal refugia and ensuring adequate water flow in dry seasons.	Develop climate models to predict habitat shifts and integrate climate adaptation measures into river management plans.	Panja *et al*., 2021; Pownkumar *et al*., 2022

8. Future Directions and Research Gaps

However, much more research and technological advancements are needed for the continued conservation of Mahseer populations in Northeast India, splintered from increasing environmental and anthropogenic pressures. Mahseer protection efforts must be prioritized in several key areas for future research and conservation initiatives.

8.1 *Need for Long-Term Ecological Studies and Population Assessments*

Relatively long ecological studies and population assessments are some of the most critical gaps in Mahseer conservation. However, many rivers in Northeast India are understudied, and population dynamics, breeding patterns, and habitat use of Mahseer are not well documented (Borah, 2021). Monitoring of the population size, genetic diversity, and habitat suitability regularly is necessary for the development of effective conservation strategies (Sharma *et al*., 2019).

Moreover, river ecosystems have been altered by climate change and habitat degradation, but the data on how these changes affect Mahseer species are insufficient (Wangchuk and Wangmo, 2022). What is needed for future research is a standardized survey methodology, genetic assessment, and ecosystem health monitoring to ensure the conservation decisions we will make are based on what the science says (Ali and Siva, 2022).

8.2 *Advancements in Technology for Mahseer Tracking and Monitoring*

New opportunities to track and monitor Mahseer populations are emerging through the use of new technologies. Acoustic telemetry, radio tagging, and satellite-based remote sensing can be very helpful in making sense of Mahseer migration patterns, habitat selection and environmental responses (Jaafar *et al*., 2021). These technologies can be used to find critical spawning sites, migratory routes, and seasonal habitat shifts to assist in the management and planning for habitat conservation (Dash *et al*., 2021).

DNA barcoding and eDNA (environmental DNA) analysis can also be used as a further non-invasive method to track their occurrence in different river systems and have some evidence on population structure changes over time, although sampling in widely different locations will be required (Kumar *et al*., 2020). These technologies will improve data accuracy and decision making for Mahseer management (Laskar *et al*., 2019).

8.3 *Exploring Climate-Resilient Conservation Strategies*

The river ecosystems are being significantly altered by climate change therefore, it is necessary to devise adaptive conservation options to attenuate its impacts on the Mahseer populations. Research participants need to conduct thermal refugia identification and hydrological modeling for habitat prediction along with developing climate-resistant breeding programs (Panja et al., 2021).

Habitat restoration efforts would be more effective by focusing on sustaining natural flow patterns and reducing riverbed silting and protecting riverbank ecosystems to establish climate-resistant fish habitats for Mahseer according to Pownkumar et al. (2022). The research team conducted Mahseer physiological studies regarding temperature adaptations and hydrological changes to develop sustainable conservation strategies for population survival under climate change (Renjithkumar et al., 2022).

9. Conclusion

The conservation efforts targeting Mahseer species in Northeast India should be prioritized since they safeguard freshwater ecosystems while helping maintain local community sustainability. The study presents the key threats which endanger Mahseer populations starting with habitat destruction and continuing through overfishing together with pollution and climate change. Different conservation methods including habitat restoration together with sustainable fisheries management and genetic conservation programs are in place yet essential obstacles remain. There exists an immediate need to implement studies with extended time horizons together with modern monitoring equipment and strategies to protect these resources from climate change impacts. Mahseer populations require sustainable outcomes by implementing legal infrastructure improvements alongside boundary-area collaboration and native ecological understanding integration for conservation.

Security for Mahseer in Northeast India requires the active involvement of policymakers with researchers and conservation organizations and local communities. The successful conservation of Mahseer requires policymakers to strengthen their regulations and support conservation funding along with researchers who need to pursue ecological studies supported by technological developments. The stakeholders who live in local communities should receive empowerment through sustainable livelihood programs and eco-tourism initiatives. Scientific success in Mahseer conservation depends on professionals from fisheries science along with personnel from environmental policy and community engagement working together. A sustainable strategy that combines wildlife conservation with economic growth will guarantee Mahseer's continued existence together with protecting the region's diverse aquatic species.

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