Garra hughi

Indoreonectes keralensis

REPORT OF SURVEY ON FISHES IN MUNNAR LANDSCAPE TARGETING THE CONSERVATION OF FRESH WATER HABITAT & THREATENED SPECIES

Conducted as part of:

PROTECTION OF FRESH WATER ECOSYSTEMS FOR THE CONSERVATION OF THREATENED SPECIES IN MUNNAR, WESTERN GHATS, INDIA.
Project Code: 2023A-41

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Conducted by:
TROPICAL INSTITUTE OF ECOLOGICAL SCIENCES (TIES)
Ecological Research Campus, Velloor P O.,
Pampady, Kottayam, Kerala.India.
Tel.: 0481 2957050; 9497290339; 9633723305
E mail: tropicalschool@gmail.com; info@ties.org.in
www.ties.org.in

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Implemented as part of the project: Protection of Fresh water Ecosystems for the Conservation of Threatened Species in Munnar, Western Ghats, India.
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Implemented by : Tropical Institute of Ecological Sciences (TIES)

Project Lead:
Dr. Abraham Samuel K.

Co-lead:
Dr. G. Prasad
Dr. C.P.Shaji
Dr. Punnen Kurian

Project Team:

Nihal Hussain T.P.
Praful V. Panicker
Bechu Punnen Abraham
Neethu Nair M. N.
Sarath Babu N.B.
Anoopa Mathews

Design & Lay out:
Jijo TIES

Published by: TIES

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Disclaimer: The findings and conclusions presented are generalized insights derived from the collective responses of the community members who participated in the survey. The information is used solely for the purpose of understanding and improving community conditions and should not be construed as reflecting the views or conditions of any specific individual or group.

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I. Introduction

This report on the "Protection of Freshwater Ecosystems for the Conservation of Threatened Species in Munnar, Western Ghats, India" provides a comprehensive analysis of two critically endangered fish species, Garra hughi (Endangered) and Indoreonectes keralensis (Vulnerable). These species, native to the pristine freshwater ecosystems of Munnar, face significant threats from environmental degradation, including habitat loss, pollution, and the impact of human activities such as agriculture and deforestation.

The report details the objectives, methodology, transect information, and survey findings of the conservation project aimed at assessing the population status, habitat quality, and ecological requirements of these species. In addition to monitoring environmental parameters and identifying key threats, the project emphasizes sustainable conservation practices, habitat restoration, and community involvement to protect these species and their habitats for future generations.

Two surveys were conducted as part of the study, with comparisons and recommendations provided to strengthen the findings and guide future conservation efforts. Through this work, the project seeks to develop targeted strategies that will protect these threatened fish species and preserve the ecological integrity of Munnar's freshwater ecosystems.

II. Background

The project titled "Protection of Freshwater Ecosystems for the Conservation of Threatened Species in Munnar, Western Ghats, India" aims to focus on the conservation of two threatened fish species, Garra hughi (Endangered) and Indoreonectes keralensis (Vulnerable), both of which have been identified in previous studies conducted in Munnar. The primary objective of the project is to assess and monitor the status of these species, including their population dynamics, habitat quality, and the environmental factors that pose a threat to their survival, which could potentially lead to their extinction.

The project aims to identify key habitats where these species are found, evaluate their ecological needs, and assess the environmental pressures they face, including habitat degradation, water pollution, and climate change. Special attention will be given to monitoring the threats that are most detrimental to their populations, such as chemical runoff from plantations, agricultural activities, and deforestation.

A central goal of the project is the sustainable protection of the freshwater ecosystems that these species inhabit. This includes creating strategies for habitat restoration, implementing conservation practices that reduce the impact of human activity on their environments, and promoting responsible land and water management. In addition, the project will prioritize community engagement and education, raising awareness about the importance of these species and their ecosystems. By involving local communities, stakeholders, and authorities in conservation efforts, the project aims to foster a sense of responsibility and collective action toward safeguarding these threatened species and their habitats for future generations. Through these efforts, the project strives to achieve long-term conservation outcomes and ensure the continued survival of Garra hughi and Indoreonectes keralensis in the Western Ghats.

Garra hughi is a benthopelagic fish species native to pristine mountain streams, where it displays unique life cycle and dietary adaptations. As juveniles, typically ranging from 15 to 35 mm in standard length, they are omnivorous, feeding on a variety of food sources such as earthworms, aquatic insect larvae (particularly chironomids and ephemeropterans), and algae. These young fish are found in cleaner waters near stream banks, pools, and small puddles, demonstrating a flexible dietary strategy that allows them to exploit available resources.

As G. hughi matures, it shifts its feeding habits, becoming primarily herbivorous, feeding mainly on algae, and adopts a benthic lifestyle close to the streambed in the swift currents. This shift reflects an adaptation to its environment, where it relies on algae and other plant material for sustenance. The species' ability to adjust its diet and habitat preference ensures its survival in mountain streams, contributing to the ecosystem's balance.

Indoreonectes keralensis is a small freshwater fish species native to the Western Ghats, particularly in Kerala. This loach species is adapted to fast-flowing, cool mountain streams, with its streamlined body and barbels aiding in foraging for invertebrates and detritus on rocky substrates. Its small size and coloration provide effective camouflage in its natural habitat, offering protection from predators.

Ecologically, I. keralensis plays a crucial role in nutrient cycling by consuming invertebrates and organic matter, helping to maintain the health of its aquatic ecosystem. The presence of this species is an indicator of good water quality and stream health. However, it faces conservation challenges due to habitat degradation caused by deforestation, agricultural runoff, and pollution. Conservation efforts are necessary to protect the species and ensure the preservation of its habitat in the Western Ghats.

III. Methodology

Preliminary studies have been conducted to gain a deeper understanding of the habitats, morphology, and previously recorded locations of Garra hughi and Indoreonectes keralensis. In addition to these initial investigations, specific sites deemed suitable for fish transects were identified and documented through photographs. Priority was given to studying higher altitudes, with careful attention also given to representing various mean sea levels during the survey. With the support of fish experts and research assistants, a comprehensive fish survey was carried out using a variety of sampling techniques, including visual surveys, netting, and trapping, to capture and identify the species present. Aquariums were used on site to take better photographs of the fishes and released on the field itself.

Biometric measurements of the captured specimens, along with detailed habitat assessments, were conducted to evaluate environmental factors such as water quality, which are crucial for understanding the health of the ecosystem. All survey activities were conducted with strict adherence to ethical guidelines to minimize any impact on the fish populations and their habitats. The captured specimens were carefully identified and photographed before being released unharmed back into their original habitats.

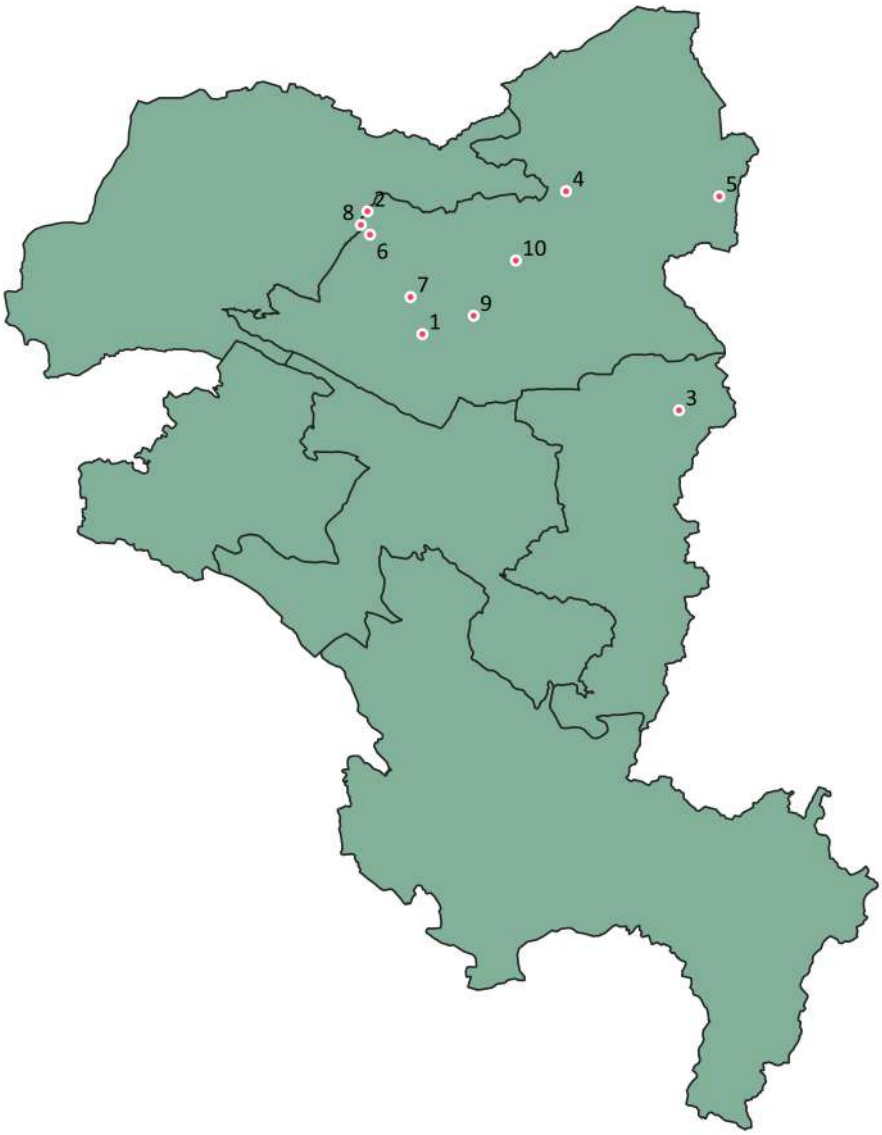
In addition to collecting biological data, the survey documented the population status and distribution of the species within a 1 km transect radius. These findings are essential for gaining insights into the species' abundance, spatial distribution, and potential threats to their survival. The data collected from the survey will form the basis for developing targeted conservation strategies that aim to protect these threatened species and preserve the ecological integrity of Munnar's freshwater ecosystems. Ultimately, the goal is to ensure the long-term survival of Garra hughi and Indoreonectes keralensis while maintaining the health of their natural habitats.

Transect Details

SL. NO.	LOCATION NAME	MSL	START COORDINATES	END COORDINATES
1	PEECHADU RIVER	990m	10°02'32"N 76°57'57"E	10°02'29"N 76°58'14"E
2	AANAKULAM	330m	10°09'39"N 76°54'43"E	10°09'35"N 76°54'40"E
3	SHANTHANPARA	1049m	9°58'07"N 77°13'03"E	9°58'07"N 77°13'08"E
4	VAGUVURRAI STREAM	1361m	10°10'49"N 77°06'24"E	10°10'41"N 77°06'27"E
5	VATTAVADA (UMANKADAVU)	1632m	10°10'31"N 77°15'25"E	10°10'46"N 77°15'23"E
6	PERUMBANKUTH	460m	10°08'18"N 76°54'52"E	10°08'16"N 76°54'53"E
7	VIRIPARA	1043m	10°04'41"N 76°57'15"E	10°04'39"N 76°57'16"E
8	KARINTHIRI AARU	340m	10°08'52"N 76°54'20"E	10°08'37"N 76°54'04"E
9	LETCHMI ESTATE	1500 m	10°03'36"N 77°00'58"E	10°03'27"N 77°01'25"E
10	NALLATHANNY (PERIYAVURRAI)	1505m	10°06'48"N 77°03'27"E	10°06'30"N 77°03'29"E

Table 1. Transect details

Map Showing Fish Transect



1. Peechadu

Peechadu Aaru flows through Kurisupara, a small town within the Pallivasal Grama Panchayath. The stream runs alongside the Kallar-Mankulam road, surrounded by cardamom plantations, residential areas, and homestays. The area includes instances of greywater being discharged into the stream, and the riparian forest is significantly diminished due to land encroachment and construction. Peechadu receives water from the Letchmi Estate and several smaller streams originating in the Kallar Valley hills, eventually merging with the Kallar Stream and Ambazhachal before joining the Periyar River. Situated at an altitude of 990 meters above mean sea level, Peechadu Aaru hosts diverse fish species and functions as a medium-sized stream, integrating first, second, and third-order streams within the region's altitudinal range.

Figure 1. Peechad River

2. Aanakulam

Anakulam, known as the land of wild elephants, is home to water bodies enriched by mineral-rich springs that seep through the rocks of the riverbed. This area is nourished by two tributaries of the Periyar River, the Idacholayaar and Nallatanniyaar. A unique feature of this region is the frequent visits of elephant herds to drink from these mineral-rich waters. The streams here, including those originating from Edamalakudi and Kozhiyilakudi at an altitude of approximately 1500 meters above mean sea level, descend to about 330 meters above sea level, supporting a variety of fish species. The transect traverses the forested landscapes of the Malayattoor and Mankulam Forest Divisions, where the presence of indigenous tribal communities and diverse wildlife plays a significant role in the ecological dynamics of the streams.

Figure 2. Aanakulam

3. Santhanpara

The Santhanpara transect encompasses the Panniyar River, a major tributary of the Periyar River. The Panniyar River is fed by its tributaries—Uchilkuthipuzha, Mathikettan Puzha, Chemmannar, and Nander Puzha—all originating from the hills of Mathikettan National Park. The river flows through Ponmudi Dam and Kallarkutty Dam before merging with the Periyar River. Located near Santhanpara town at an altitude of 1049 meters above mean sea level, the area is surrounded by extensive cardamom plantations, which increase the likelihood of chemical runoff into the water. The aquatic system faces significant threats from algal blooms and plastic pollution, exacerbated by the region's growing population. Additionally, riparian forests have largely been replaced by plantations, further impacting the river ecosystem.

Figure 3. Santhanpara

4. Vaguvurrai

The stream originates northeast of the Anamudi Hills (approximately 2000 meters above mean sea level) near Munnar, close to the Lakkam Waterfalls. These waterfalls are part of the Eravikulam Stream, which flows through the Eravikulam National Park and serves as a significant tributary of the Pambar River. The Pambar River eventually merges with the Chinnar River to form the Amaravathi River in Tamil Nadu. The transect is located near the Sri Kaliyamman Temple in Lakkom, surrounded by forests and tea plantations. However, pollution from tourists, local vendors, and waste from a nearby tea factory often finds its way into the Pambar River via roadways. This third-order stream, situated at an altitude of 1361 meters above mean sea level, flows along steep terrain adjacent to the Gundumalai Hills.

Figure 4. Vaguvarrai stream

5. Vattavada (Umankadavu)

The transect features a third-order stream originating from Pampadum Shola, which flows into the Chilanthoyaar, Ten Aaru, and eventually the Amaravathi River. While the stream traverses forested areas, it also passes through Vattavada town, where it collects polluted sewage and drainage water, effectively turning it into a drainage channel rather than a freshwater stream. The water shows significant contamination, impacting its ecological integrity. Located at an altitude of 1632 meters above mean sea level, the stream supports a limited aquatic population due to its altitudinal constraints. Additionally, agricultural runoff is a significant concern in the area, given Vattavada's prominence in agriculture.

Figure 5. Umankadavu

6. Perumbankuthu

Situated along the Mankulam Aaru at an altitude of approximately 460 meters above mean sea level, this transect collects water from various sources, including the Letchmi Hills, Nakshatrakuthu, and Panniyaarkuthu, before flowing into the Karinthiri Aaru and ultimately joining the Periyar River. The transect culminates in a striking steep waterfall, offering a dramatic end to its flow. It is bordered by Reserve Forest on one side and plantations on the other, creating a unique ecological interface. Despite its rich biodiversity, the area faces significant challenges from agricultural runoff and plastic pollution, which threaten the integrity of its natural systems.

Figure 6. Perumbankuthu

7. Viripara

Located at an elevation of 1043 meters above mean sea level in the Viripara Forest Area, this second-order stream originates at the base of the Letchmi Hills. It flows towards the Mankulam Aaru, eventually merging with the Karinthiri Aaru before joining the Periyar River. The stream is characterized by a gentle flow and is surrounded by well-preserved riparian forests, contributing to its ecological significance. However, the waterbody faces potential threats from chemical runoff, which poses a risk to its health and biodiversity.

Figure 7. Viripara

8. Karinthiri Aaru

Situated at an elevation of 340 meters above mean sea level near Anakulam, this area serves as a river basin, receiving water from the Anakulam Aaru and Mankulam Aaru. These streams converge to form the Karinthiri Aaru, which eventually joins the Periyar River. The region is enriched with thriving riparian forests and diverse aquatic life, making it ecologically significant. However, pollutants from the upstream lower-order streams accumulate in this basin, posing environmental concerns. During the rainy season, the area experiences a substantial increase in water flow, highlighting its role in managing seasonal hydrological dynamics.

Figure 8. Karinthiri River

9. Letchmi Estate

Located at an elevation of 1500 meters above mean sea level, this third-order stream is surrounded by eucalyptus forests and tea plantations. It collects water from the Letchmi Hills before joining the Muthirapuzhayar, which eventually merges with the Periyar River. The transect faces challenges from chemical runoff, primarily due to the surrounding plantations. The area features an extensive grassland riparian zone, with domestic animals frequently grazing nearby. Natural forests are absent, as the entire landscape has been converted into plantation land. The riverbed is sandy, and several first-order streams feed into the Letchmi stream along its course.

Figure 9. Mankulam River

10. Nallathanni (Periyavurrai)

The transect is located at an elevation of 1505 meters above mean sea level, near the Periyavurrai Bridge along the Munnar-Marayoor road. The area is characterized by expansive grasslands, with no natural forest cover present. Nearby, there are layams (traditional houses) and factories situated close to the stream. The stream collects water from the Anamudi Hills and flows towards the Muthirapuzha River, ultimately joining the Periyar River. The stream is wide and has a slow flow, with grassland vegetation both along the riparian zone and within the stream itself. In 2018, the area experienced a devastating flood that drastically altered the ecosystem.

Figure 10.Nallathanni

Figure 11. Fish survey at Vattavada. Fish Specialist C.P. Shaji and Bechu Punnen, Project Assistant

IV. First Survey

The first phase of the survey (Pre-Monsoon) covered four transects situated at the extreme ends of the study perimeter, including locations such as Vattavada, Santhanpara, Nallathanni, and Vaguvurrai. The survey team comprised Dr. C.P. Shaji (Fish Expert), Dr. Punnen Kurien (Project Lead), Mr. Nihal Hussain T.P., Mr. Praful V. Panicker (Project Officers), and Mr. Bechu Punnen Abraham (Project Assistant). Conducted on February 10th and 11th, 2024, the survey benefited from water levels that were conducive for data collection.

1. Vattavada Umankadavu

The downstream section of the survey area did not reveal the presence of any fish species. However, moving upstream into the forested riparian zone, the team identified a critically endangered fish species, Horalabiosa arunachalami, which is endemic to the Western Ghats. Unfortunately, only a single specimen was observed during the survey, and it was carefully photographed to aid in accurate identification. The species density within the transect was notably low.
Although Horalabiosa arunachalami is not a focus species of this project, its critically endangered IUCN status underscores its ecological significance. The team decided to document the finding for potential use in future studies and prioritized this transect for closer monitoring and additional consideration in subsequent surveys.

Place	Vattavada, Umankadavu	10-02-2024, 02.30 PM
Sl. No.	Fishes	Phase 1
1	Horalabiosa arunachalami	1
	Fish Density	1

2. Vaguvurrai

In the upstream region, only one fish species, Garra hughi, was observed, while no species were reported in the downstream area. The upstream area features a pool region formed after a steep water flow descending from the hills. Garra hughi, an endangered species and a key focus of the project's conservation efforts, is endemic to the Western Ghats. The fishes were found clinging to rocks in shaded areas, avoiding the strong water currents. Detailed assessments of the population, photographs, and riparian conditions were recorded. A total of 16 individuals were documented during this survey phase. Additionally, follow-up visits to the Vaguvurrai transect were conducted on June 22 during water sample analysis, during which the fish counts were noted to be 6 individuals, respectively.

Place	Vaguvurrai	11-02-2024, 12.30 PM	22-06-2024, 01.30 PM
Sl. No.	Fishes	Phase 1	Phase 2
1	Garra hughi	16	6
	Fish Density	16	6

Table 3. Fish Density of Vaguvurrai

3. Nallathanni (Periyavurrai)

The transect exhibited poor riparian conditions and a low water column. Only one species, Poecilia reticulata, an exotic species, was recorded in the area. No native fish species were observed within the transect. Approximately 35 individuals of Poecilia reticulata were spotted. Despite being classified as a medium stream, no other fish species were found in this transect.

Place	Nallathanni, Periyavurrrai	11-02-2024, 10.30 AM
Sl. No.	Fishes	Phase 1
1	Poecilia reticulata	35
	Fish Density	35

Table 4. Fish Density of Nallathanni (Periyavurrai)

4. Santhanpara

The transect features a healthy water column and supports two distinct fish species: Poecilia reticulata, an exotic species, and Haludaria fasciata, which is endemic to the region. Although the species densities vary, the potential for competition between them is notable. The transect recorded a total fish density of 39 individuals, with the fishes predominantly observed near the rocky surfaces within the stream.

Place	Santhanpara	11-02-2024, 03.30 PM
Sl. No.	Fishes	Phase 1
1	Haludaria fasciata	27
2	Poecilia reticulata	12
3	Lepidocephalichthys thermalis	16
4	Rasbora dandia	14
	Fish Density	39

Table 5. Fish Density of Santhanpara

V. Second Survey

The second survey was conducted on December 7th and 8th, 2024, during the post-monsoon phase. This phase focused on exploring seven transects, with the primary objective of locating Indoreonectes kerelensis. To optimize the likelihood of finding this species, the survey concentrated mainly on first- and second-order streams. Additionally, other transects were surveyed to analyze altitudinal variations in fish diversity and to build a comprehensive database on the ichthyofauna of the Munnar Territorial Division. The survey was carried out by the same team of experts, ensuring consistency in methodology and expertise. The surveyed locations included Vaguvurrai, Letchmi Estate, Santhanpara, Anakulam, Karinthiri Aaru, Perumbankuthu, Viripara, and Peechadu. These diverse sites were selected strategically to capture a wide range of ecological conditions, contributing valuable data to the ongoing conservation and biodiversity documentation efforts.

1. Letchmi Estate

The transect was located within the Letchmi tea plantations and is classified as a third-order stream. The surrounding area is dominated by plantations, limiting access to the water body. Upstream, Indoreonectes kerelensis, a vulnerable and endemic fish species included in the conservation project, was observed along with numerous tadpoles in the water. A significant population of Indoreonectes kerelensis was found near shaded riparian grass areas. Downstream, an excessive presence of tadpoles was also noted, accompanied by Poecilia reticulata, an exotic species. The coexistence of these species raises concerns about potential competition, which could disrupt the natural aquatic ecosystem. The transect recorded a total diversity of 24.

Place	Letchmi Estate	07-12-2024, 12.00 PM
Sl. No.	Fishes	Phase 1
1	Indoreonectes keralensis	16
2	Poecilia reticulata	8
	Fish Density	24

Table 6. Fish density of Letchmi Estate

2. Anakulam

The transect exhibited a rich diversity of fish species within the stream, with Anakulam reporting the highest species diversity and abundance. The species identified included Haludaria fasciata, Dawkinsia filamentosa, Devario malabaricus, Rasbora dandia, Tor khudree, Garra mullya, Salmostoma acinaces, Barilius gatensis, and Poecilia reticulata. Among these, Barilius gatensis, Devario malabaricus, and Haludaria fasciata are endemic to the Western Ghats, while the others are cosmopolitan and commonly found in various regions. The fishes were predominantly observed on pebbles along the riverbed and in shaded areas near forested regions, highlighting the ecological importance of these habitats for sustaining aquatic biodiversity.

Place	Anakulam	08-12-2024, 09.30 AM
Sl. No.	Fishes	Phase 1
1	Haludaria fasciata	35
2	Dawkinsia filamentosa	18
3	Devario malabaricus	47
4	Rasbora dandia	16
5	Tor khudree	7
6	Garra mullya	38
7	Salmostoma acinaces	45
8	Barilius gatensis	5
9	Poecilia reticulata	20
	Fish Density	**231**

Table 7. Fish Density of Anakulam

3. Karinthiri Aaru

The transect encompasses a significant confluence of two large streams, creating an ecologically rich habitat. A total of five fish species were identified in this area, with a notable overall density of 143 individuals. The fishes were predominantly observed along rocky substrates and sandy riverbeds, highlighting the habitat's structural diversity.
The species documented include Haludaria fasciata (Melon Barb), Devario malabaricus, Rasbora dandia, Barilius gatensis, and Salmostoma acinaces. Among these, Haludaria fasciata, Devario malabaricus, and Barilius gatensis are endemic to the Western Ghats, underscoring the area's importance as a refuge for native biodiversity. This transect exemplifies the dynamic interplay of habitat features that support both endemic and widespread fish species.

Place	Karinthiri Aaru	08-12-2024, 11.30 AM
Sl. No.	Fishes	Phase 1
1	Haludaria fasciata	43
2	Devario malabaricus	25
3	Rasbora dandia	15
4	Barilius gatensis	33
5	Salmostoma acinaces	27
	Fish Density	143

Table 8. Fish Density of Karinthiri Aaru

4. Perumbankuthu

The transect revealed the presence of four fish species, three of which are endemic to the Western Ghats. Notably, Travancoria jonesi was observed in significant numbers, clinging to the rocky surfaces. The transect recorded a total density of 72 individuals. However, the area experiences substantial human activity, including river crossing, rafting, and bathing, which contribute to the degradation of the riparian environment. Signs of pollution were evident along the stream's edges. The stream itself features a high water column and flows over a predominantly rocky substrate, providing unique habitat conditions for the aquatic species present.

Place	Perumbankuthu	08-12-2024, 01.00 PM
Sl. No.	Fishes	Phase 1
1	Travancoria jonesi	17
2	Haludaria fasciata	29
3	Devario malabaricus	14
4	Rasbora dandia	12
	Fish Density	72

Table 9. Fish Density of Perumbankuthu

5. Viripara

The transect is a second-order stream characterized by a well-preserved forested riparian zone. Stepwise water pools formed between rocks provide ideal habitats where fish were observed. The species identified include two endemics, Indoreonectes keralensis (Vulnerable) and Horalabiosa arunachalami (Critically Endangered), along with Poecilia reticulata, an exotic species. This combination is ecologically concerning, as the coexistence of native and exotic species poses potential risks to the natural balance of the waterbody.

Place	Viripara	08-12-2024, 02.30 PM
Sl. No.	Fishes	Phase 1
1	Indoreonectes keralensis	8
2	Poecilia reticulata	12
3	Horalabiosa arunachalami	6
	Fish Density	26

Table 10. Fish Density of Viripara

6. Peechadu

The transect recorded a fish density of 103 individuals, with four species identified in the area, including two endemic to the region. The stream features a well-maintained riparian zone and a sandy riverbed, offering favorable conditions for aquatic life. However, nearby point-source pollution poses a significant threat, potentially leading to a decline in both fish populations and overall density within the stream if left unaddressed. Preserving the water quality is crucial to maintaining the ecological balance and supporting the endemic species in this habitat.

Place	Peechadu	08-12-2024, 03.00 PM
Sl. No.	Fishes	Phase 1
1	Haludaria fasciata	36
2	Rasbora dandia	24
3	Puntius vittatus	15
4	Devario malabaricus	28
	Fish Density	103

Table 11. Fish Density of Peechadu

7. Santhanpara

The transect now supports four fish species, showing an increase in density compared to previous observations. Among these, two are endemic to the region, and one is an exotic species. Notably, no threatened species were identified in this area, in contrast to findings from earlier studies conducted in Santhanpara. This shift highlights the dynamic nature of species composition and population trends, emphasizing the importance of continuous monitoring to understand ecological changes and their implications for conservation.

Place	Santhanpara	07-12-2024, 03.00 PM
Sl. No.	Fishes	Phase 2
1	Haludaria fasciata	24
2	Poecilia reticulata	18
3	Devario malabaricus	34
4	Rasbora dandia	22
	Fish Density	98

Table 12. Fish Density of Santhanpara (Second Survey)

8. Vaguvurrai

The transect was initially surveyed to confirm the presence of Garra hughi at the site. A follow-up survey was conducted on September 9, 2024. Observations from the revisit indicate a noticeable decline in the species' density compared to earlier visits.

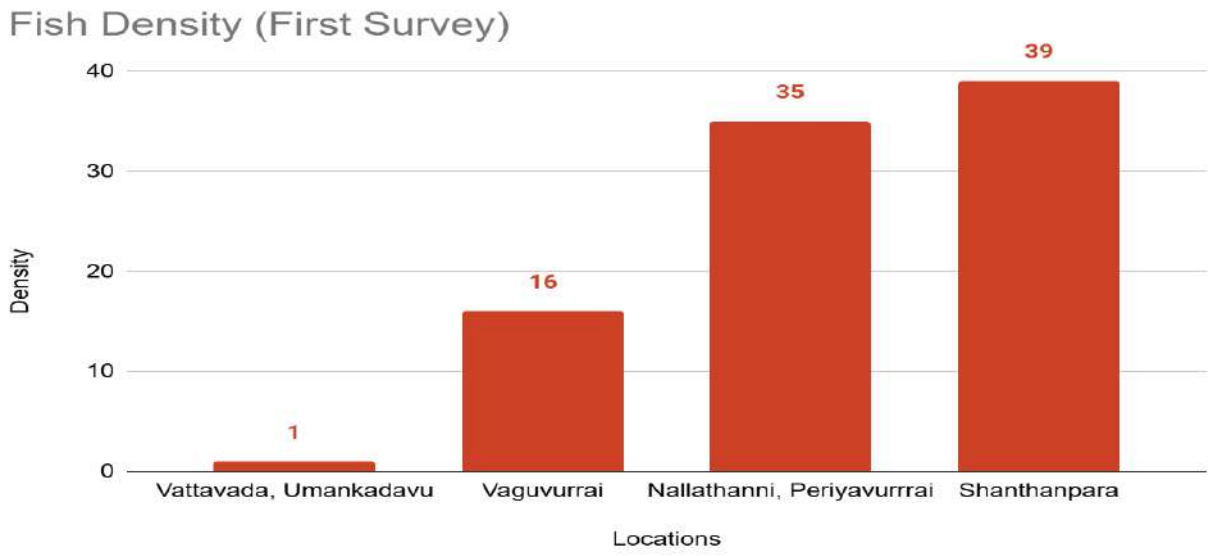
Place	Vaguvurrai	09-09-2024, 12.45 PM
Sl. No.	Fishes	Phase 3
1	Garra hughi	7
	Fish Density	7

Table 13. Fish Density of Vaguvurrai

6. Comparison Studies

6.1. Fish Density

Determining fish density across various locations is essential for understanding the ecological dynamics and health of aquatic ecosystems. This study provides critical insights into habitat preferences, resource availability, and the influence of environmental factors such as altitude and stream size on fish populations. By identifying areas of high and low density, it is possible to pinpoint biodiversity hotspots and habitats requiring conservation focus. Additionally, monitoring density helps track the survival of endangered species, such as Garra hughi, within their natural habitats and evaluate their interactions with other species. These findings are instrumental in guiding effective management strategies and ensuring the long-term sustainability of aquatic ecosystems.



Graph 1. Fish Density of first survey

6.1.1. First survey

The initial survey revealed significant variation in fish density across different locations. The lowest density was observed in Vattavada and Umankadavu, with only one individual recorded. In contrast, Vaguvurrai had a density of 16 individuals, while Nallathanni and Periyavurrrai exhibited higher numbers, with 35 individuals documented. The highest density was recorded in Shanthanpara, where 39 individuals were observed.

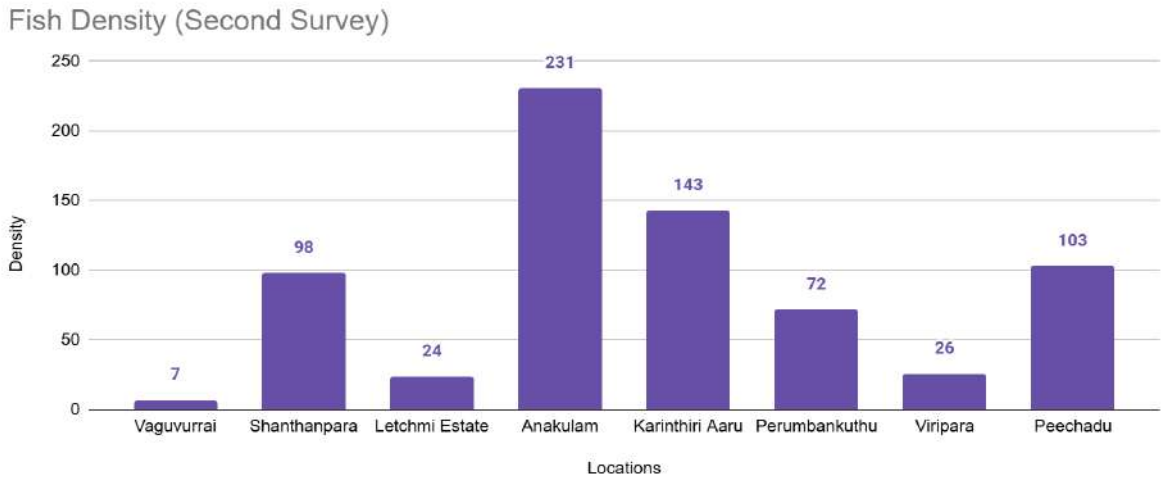
Vattavada, being a small-order stream located at higher altitudes with limited resources, supports lower fish diversity. However, it is noteworthy that this site harbors a critically endangered species thriving in its natural habitat, free from competition with other fish species. Santhanpara, on the other hand, is part of a larger mainstream waterbody with greater fish diversity. This location provides a more resilient habitat, supporting the survival of various species.

6.1.2. Second Survey

The second survey of fish density revealed notable variations across the surveyed locations, providing valuable insights into the ecological dynamics of each site. The highest fish density was observed in Anakulam, with 231 individuals, making it a significant biodiversity hotspot. Karinthiri Aaru also demonstrated a high density of 143 individuals, highlighting its potential as a key habitat for sustaining fish populations. Peechadu and Santhanpara followed, with densities of 103 and 98 individuals, respectively, indicating their capability to support diverse aquatic life.

In contrast, Vaguvurrai recorded the lowest density, with only 7 individuals, suggesting possible limitations in habitat suitability or resource availability. Other sites such as Viripara (26 individuals), Letchmi Estate (24 individuals), and Perumbankuthu (72 individuals) exhibited moderate densities, reflecting varying ecological conditions and habitat quality.A scientific comparison shows that mainstream

locations such as Anakulam and Karinthiri Aaru exhibit significantly higher fish densities, likely due to their larger water volumes, better connectivity, and resource richness. Smaller streams like Vaguvurrai, on the other hand, show limited density, potentially influenced by their altitude, size, and resource constraints. These findings emphasize the importance of location-specific factors in shaping fish population dynamics and provide a foundation for targeted conservation efforts.



Graph 2. Fish density of second survey

6.1.3. Comparison of both surveys

Observations from two consecutive surveys revealed a notable increase in fish diversity during the second phase, attributed to the expansion of surveyed locations from 4 to 8. Although the surveys were conducted during pre-monsoon and post-monsoon periods, fish availability and population densities were significantly higher after the monsoon season. Mean sea level variations during each survey also influenced fish density.

In contrast, multiple visits to Vaguvurrai revealed a decline in fish density, likely due to decreased water column depth resulting from unpredictable rainfall patterns. As a habitat for the endangered Garra hughi, this lower-order stream is particularly vulnerable to drought conditions exacerbated by climate change. However, the absence of competing fish species in this habitat is a positive note.

Similar challenges were observed in Viripara, Vattavada, and Letchmi Estate, where small stream habitats face comparable threats. The endemic Indorronectes kerelensis, for instance, faces competition from introduced guppy species, posing a notable threat to its survival and ecosystem balance. In contrast, Horalabiosa arunachalami remains unaffected by competition until exotic species are introduced. In Perumbankuthu, the endangered Travancoria jonesi coexists with three other species, benefiting from a relatively stable habitat with adequate water column depth and river width.

Comparative analysis revealed that Anakulam, Karinthiri, Santhanpara, and Peechadu exhibit the highest fish densities, attributed to their mainstream habitats, which accumulate diverse fish species and support increased population densities. This study highlights the importance of considering environmental factors, such as mean sea level and rainfall patterns, when assessing fish diversity and population dynamics in freshwater ecosystems.

The observed increase in fish diversity and population density during the post-monsoon phase can be attributed to the enhanced water flow and nutrient influx, creating a conducive environment for fish growth and survival. Additionally, the reduced water column depth during the pre-monsoon phase may have limited fish habitat and increased competition for resources, leading to decreased fish density. The

findings suggest that hydrological variability plays a crucial role in shaping fish community dynamics in freshwater ecosystems.

6.2. Fish Diversity

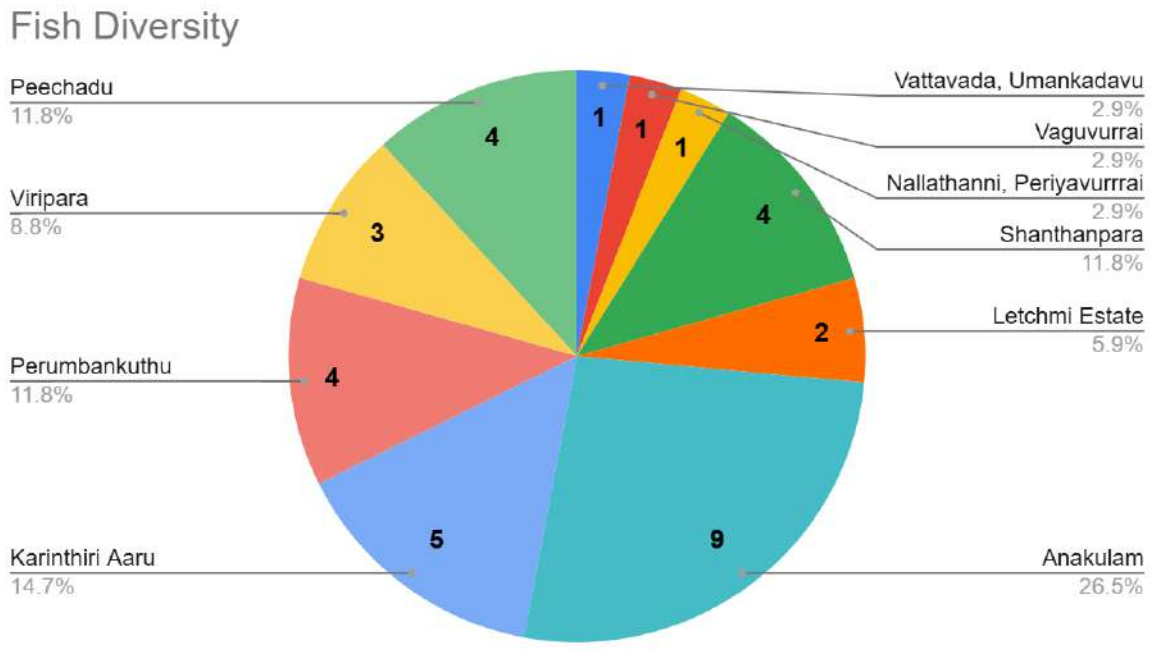
Studying fish diversity is crucial for understanding the health and resilience of freshwater ecosystems, as changes in fish populations can indicate broader environmental issues. Investigating fish diversity also informs conservation efforts, enabling targeted protection of vulnerable species and habitats. Furthermore, understanding fish diversity can provide valuable insights into ecosystem function, nutrient cycling, and the overall biodiversity of aquatic ecosystems.

6.2.1. Fish Diversity in different locations

Upon examining the fish diversity data from various locations, it is evident that Anakulam boasts the highest fish diversity with 9 species, followed closely by Karinthiri Aaru and Perumbankuthu with 5 and 4 species, respectively. In contrast, Vattavada, Umankadavu, Vaguvurrai, and Nallathanni, Periyavurrai exhibit remarkably low fish diversity, with only 1 species recorded at each location. The remaining locations, including Santhanpara, Letchmi Estate, Viripara, and Peechadu, display moderate fish diversity, ranging from 2 to 4 species.

A comparative analysis indicates that mainstream habitats, such as Anakulam and Karinthiri Aaru, exhibit elevated fish diversity, likely attributed to enhanced water flow and nutrient availability. Conversely, smaller streams and habitats, including Vattavada and Vaguvurrai, display reduced fish diversity, potentially resulting from restricted habitat and resource

limitations. These results underscore the significance of habitat characteristics in influencing fish community composition and stress the importance of conservation initiatives aimed at preserving and restoring habitats that support high levels of fish diversity. Factors such as water quality, habitat availability, anthropogenic impacts, and proximity to natural water sources play crucial roles in shaping these patterns. Conservation efforts are necessary for low-diversity areas, while high-diversity locations require strategies to sustain and protect their aquatic ecosystems.



Graph 3. Fish Diversity in different locations

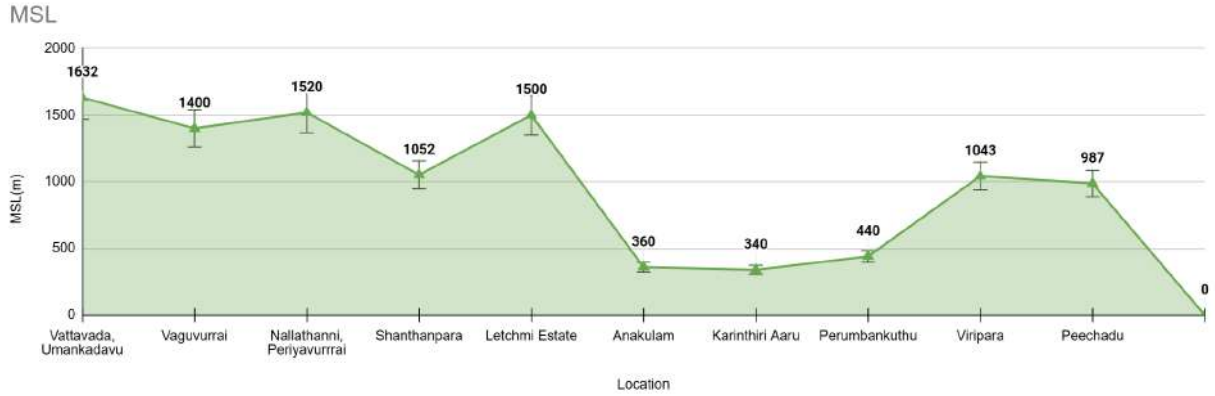
6.2.2. Distribution of each fish species

A comparative analysis of the distribution of various fish species across different locations reveals notable patterns. Four species, namely Devario malabaricus, Haludaria fasciata, Poecilia reticulata, and Rasbora dandia, exhibit a relatively wide distribution, being found in 5 locations each. In contrast, five species, including Garra hughi, Garra mullya, Puntius vittatus, Tor khudree, and Travancoria jonesi, are found in only one location, highlighting their limited geographic range. The remaining species, such as Barilius gatensis, Dawkinsia filamentosa, Horalabiosa arunachalami, Indoreonectes keralensis, and Salmostoma acinaces, exhibit an intermediate distribution pattern, being found in 2 locations each. These findings emphasize the importance of conservation efforts tailored to the specific distribution patterns and habitat requirements of each species.

Graph 4. Distribution of each fish species

6.3. Distribution of fishes on basis of MSL

The distribution of fish species based on Mean Sea Level (MSL) highlights how altitude influences aquatic biodiversity, with specific species adapted to varying elevations. Low-altitude regions may host species that thrive in warmer, nutrient-rich waters, while high-altitude areas are often home to cold-water species with unique adaptations. Understanding fish distribution relative to MSL is crucial for conservation planning, as it helps identify elevation-specific habitats that require protection against environmental changes.



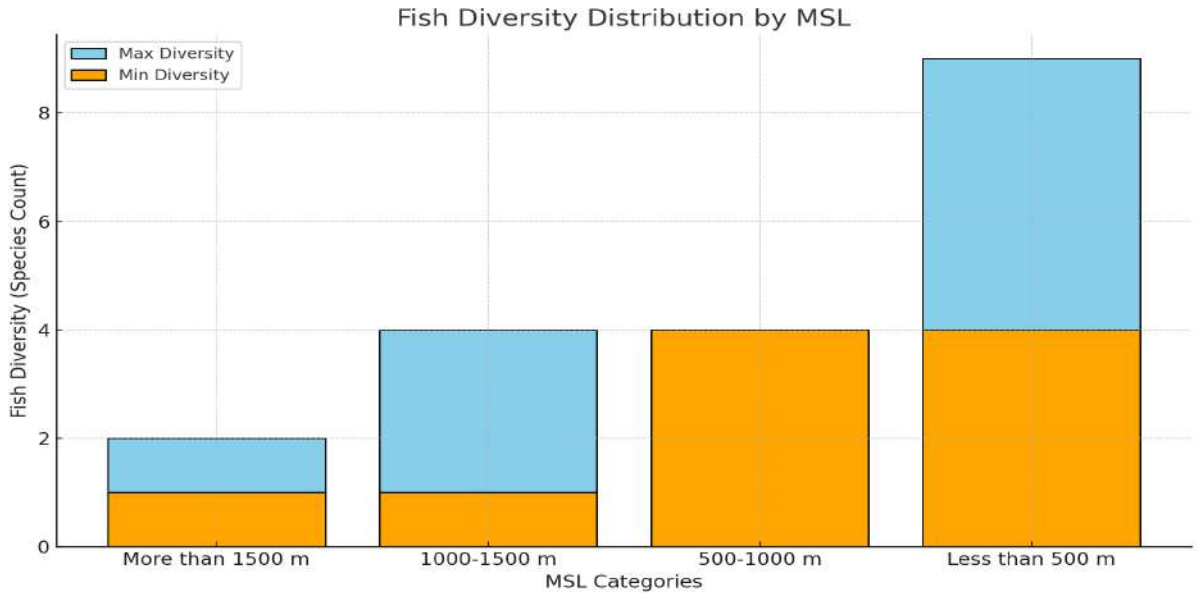
Graph 5. Distribution of fishes on basis of MSL

6.3.1. Fish Diversity on basis of MSL

The distribution of fish diversity across different MSL (Mean Sea Level) categories reveals distinct ecological patterns. High-altitude regions above 1500 meters exhibit low diversity (1–2 species) due to harsh environmental conditions such as cold temperatures, low oxygen levels, and limited nutrient availability, which restrict species to highly specialized ones like Garra hughi and Travancoria jonesi. In mid-altitude areas (1000–1500 meters), diversity increases slightly (1–4 species) as these transitional zones offer moderate environmental conditions, allowing species like Barilius gatensis and Dawkinsia filamentosa to thrive. Lower mid-altitude regions (500–1000 meters) show stable diversity (4 species) with optimal conditions, including better nutrient availability and larger streams supporting species like Haludaria fasciata and Rasbora dandia. The highest diversity (4–9 species) is observed in low-altitude areas below 500 meters, where nutrient-rich waters, diverse habitats, and human influences like aquaculture provide ideal conditions for a wide range of species, including native and introduced ones like Poecilia reticulata. These patterns emphasize the need for altitude-specific conservation strategies, as high-altitude species are vulnerable to environmental changes, while low-altitude habitats require protection from human-induced threats.

MSL	Fish Diversity
More than 1500 m	1-2
1000-1500 m	1-4
500-1000 m	4
Less than 500 m	4-9

Graph 6. Fish Diversity based on MSL



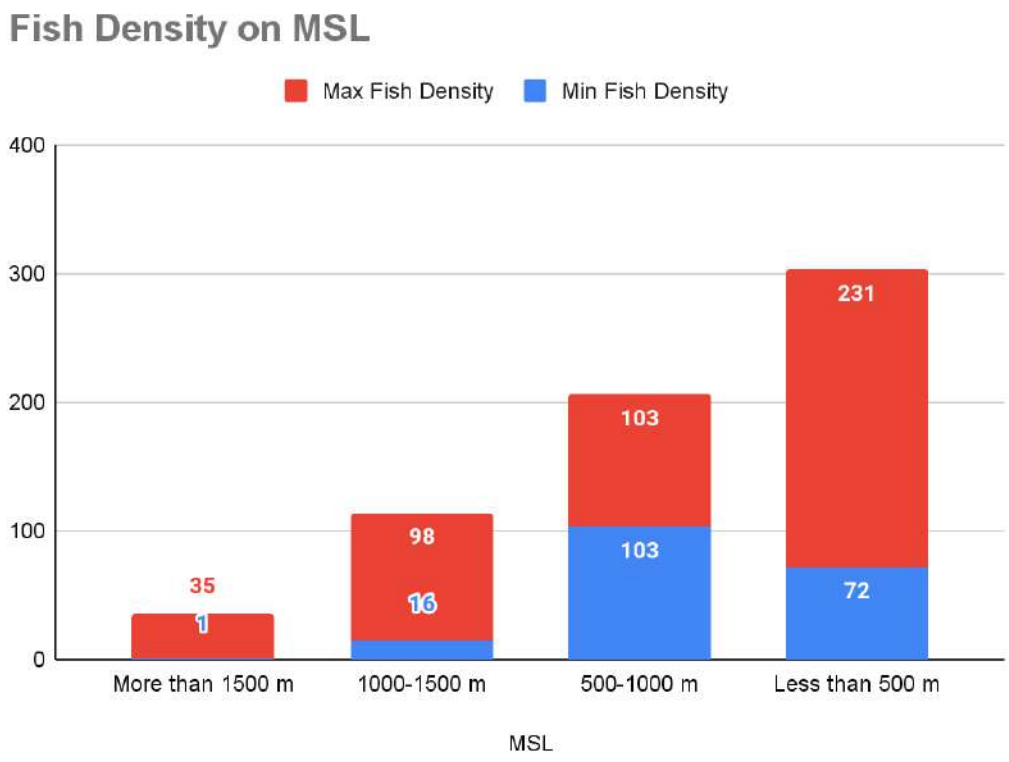
Graph 7. Fish diversity distribution by MSL

6.3.2. Fish Density on basis of MSL

The data provided outlines the fish density at different depths in the ocean, measured in terms of both minimum and maximum values. At depths greater than 1500 meters, fish density ranges from 1 to 35 fish per unit area, reflecting relatively lower concentrations of fish in the deep ocean. Between 1000 and 1500 meters, fish density increases, with values ranging from 16 to 98 fish per unit area, indicating a higher presence of marine life at these mid-depths. At depths between 500 and 1000 meters, fish density significantly rises, with a constant value of 103 fish per unit area, suggesting a more consistent and abundant fish population in this range. In waters less than 500 meters deep, fish density varies from 72 to 231 fish per unit area, showing the highest variability and abundance of fish, likely due to the greater availability of nutrients and habitats in shallower waters. Overall, the data suggests that fish density generally increases as the depth decreases, with the most variable and abundant populations found in the shallowest waters.

MSL	Fish Density
More than 1500 m	1-35
1000-1500 m	16-98
500-1000 m	103
Less than 500 m	72-231

Table 14. Fish density based on MSL



Graph 8. Fish Density on basis of MSL

6.3.3. Fish Availability on basis of MSL

The distribution of fish species across different MSL (Mean Sea Level) categories highlights the adaptation of various species to specific altitudinal ranges. The majority of species, such as Barilius gatensis, Dawkinsia filamentosa, Garra mullya, Salmostoma acinaces, Tor khudree, and Travancoria jonesi, are found at low altitudes below 500 meters, likely due to the favorable conditions of warm, nutrient-rich waters. Species such as Devario malabaricus, Haludaria fasciata, Poecilia reticulata, and Rasbora dandia inhabit a broader range from 300 to 1500 meters, demonstrating adaptability to varying elevations. In higher altitudes, between 1000 and 1700 meters, species like Garra hughi, Horalabiosa arunachalami, and Indoreonectes keralensis are present, adapted to colder, oxygen-rich, and faster-flowing waters. Meanwhile, Puntius vittatus is specifically found at mid-altitudes (500–1000 meters), possibly reflecting habitat preferences for transitional environments. This distribution underscores how environmental factors such as temperature, oxygen levels, and habitat structure influence fish biodiversity along the altitudinal gradient.

Scientific Name	MSL
Barilius gatensis	Less than 500 m
Dawkinsia filamentosa	Less than 500 m
Devario malabaricus	300-1500 m
Garra hughi	1000-1500 m
Garra mullya	Less than 500 m
Haludaria fasciata	300-1500 m
Horalabiosa arunachalami	1000-1700 m
Indoreonectes keralensis	1000-1500 m
Poecilia reticulata	300-1500 m
Puntius vittatus	500-1000 m
Rasbora dandia	300-1500 m
Salmostoma acinaces	Less than 500 m
Tor khudree	Less than 500 m
Travancoria jonesi	Less than 500 m

Table 15. Fish Availability on basis of MSL

Figure 13. Sampling at Periavarai Bridge.

7. Consolidated Report

7.1. Checklist

A total of 14 fish species were recorded from the transect around Munnar, comprising threatened, endemic, and exotic species. Notably, the majority of these species belonged to the family Cyprinidae, with additional representatives from Nemacheilidae, Poeciliidae, and Balitoridae. The distribution of these species varied, with some exhibiting cosmopolitan abundance, while others were restricted to specific areas or middle terrain, showcasing adaptations to local environmental conditions.

The dominance of Cyprinidae in this region can be attributed to their adaptability to diverse aquatic environments and their ability to thrive in various water conditions. The presence of endemic species highlights the unique biodiversity of this region and emphasizes the need for conservation efforts to protect these species and their habitats. Furthermore, the occurrence of exotic species underscores the potential risks associated with invasive species and the importance of monitoring and managing their populations to prevent adverse ecological impacts.

Fish Checklist				
Sl. No.	Scientific Name	Family	Common Name	Locations
1	*Barilius gatensis (Valenciennes, 1844)*	Cyprinidae	River - Carp Baril	Anakulam, Karinthiri Aaru
2	*Dawkinsia filamentosa (Valenciennes, 1844)*	Cyprinidae	Blackspot Barb	Anakulam
3	*Devario malabaricus (Jerdon, 1849)*	Cyprinidae	Malabar Danio	Santhanpara, Anakulam, Perumbankuthu, Karinthiri Aaru, Peechadu
4	*Garra hughi (Silas, 1955)*	Cyprinidae	Cardamom Garra	Vaguvurrai
5	*Garra mullya (Sykes, 1839)*	Cyprinidae	Mullya Garra	Anakulam
6	*Haludaria fasciata (Jerdon, 1849)*	Cyprinidae	Melon Barb	Santhanpara, Anakulam, Perumbankuthu, Karinthiri Aaru, Peechadu
7	*Horalabiosa arunachalami (Johnson and Soranam 2001)*	Cyprinidae	Garra Arunacha-lami	Umankadavu (Vattavada), Viripara
8	*Indoreonectes keralensis (Rita, Banarescu & Nalbant, 1978)*	Nemacheili-dae	Kerala Loach	Viripara, Letchmi Estate
9	*Poecilia reticulata (Peters,1859)*	Poeciliidae	Guppy	Viripara, Letchmi Estate, Nallathanni, Shanthanpara, Anakulam
10	*Puntius vittatus (Day, 1865)*	Cyprinidae	Green Stripe Barb	Peechadu
11	*Rasbora dandia (Valenciennes, 1844)*	Cyprinidae	Common Rasbora	Santhanpara, Anakulam, Perumbankuthu, Karinthiri Aaru, Peechadu
12	*Salmostoma acinaces (Valenciennes, 1844)*	Cyprinidae	Silver Razorbelly Minnow	Anakulam, Karinthiri Aaru
13	*Tor khudree (Sykes,1839)*	Cyprinidae	Deccan Mahseer	Anakulam
14	*Travancoria jonesi (Hora, 1941)*	Balitoridae	Travancore loach	Perumbankuthu

Table 16. Checklist of fishes

Figure 14. *Devario malabaricus*

Figure 15. *Garra hughi*

Figure 16. *Indoreonectes keralensis*

Figure 17. *Rasbora dandia*

Figure 18. *Haludaria fasciata*

Figure 19. *Poecilia reticulata*

Figure 20 *Travancoria jonesi*

Figure 21 *Dawkinsia filamentosa*

Figure 22 *Tor khudree*

Figure 23 *Barilius gatensis*

Figure 24 *Puntius vittatus*

Figure 25 *Salmostoma acinaces*

7.2. Endemic Fishes

The Western Ghats' unique geography and climate have created isolated habitats that have allowed these endemic fish species to evolve independently. As a result, they possess distinct characteristics that set them apart from other fish species found in different parts of the world.

Conservation efforts are essential to protect these endemic fish species and their habitats. The Western Ghats are facing numerous threats, including habitat destruction, pollution, and invasive species, which can have devastating impacts on native fish populations. By conserving the Western Ghats' ecosystems, we can help ensure the long-term survival of these unique and fascinating fish species.

The study of these endemic fish species also provides valuable insights into the evolutionary history and biodiversity of the Western Ghats. By examining the phylogenetic relationships and ecological adaptations of these species, scientists can gain a better understanding of the complex interactions between species and their environments, ultimately informing conservation strategies and management practices.

Endemic Fishes to the Western Ghats	
Sl. No.	Fishes
1	*Barilius gatensis (Valenciennes, 1844)*
2	*Devario malabaricus (Jerdon, 1849)*
3	*Garra hughi (Silas, 1955)*
4	*Haludaria fasciata (Jerdon, 1849)*
5	*Horalabiosa arunachalami (Johnson and Soranam, 2001)*
6	*Indoreonectes keralensis (Rita, Banarescu & Nalbant, 1978)*
7	*Travancoria jonesi (Hora, 1941)*

Table 17. Endemic Fishes to the Western Ghats

7.3. IUCN Status of Fishes

The IUCN status of 14 fish species in the region reveals a concerning picture, with four species facing significant threats to their survival. Garra hughi and Travancoria jonesi are listed as Endangered (EN), while Horalabiosa arunachalami is Critically Endangered (CR), and Indoreonectes keralensis is Vulnerable (VU). These species are at risk due to habitat destruction, pollution, and other human activities, highlighting the need for urgent conservation efforts to protect them. In contrast, the remaining 10 species, including Barilius gatensis, Dawkinsia filamentosa, and Devario malabaricus, are listed as Least Concern (LC), indicating that they are currently not considered threatened. However, continued monitoring and conservation efforts are necessary to ensure the long-term survival of all these species.

Sl. No.	Scientific Name	IUCN Status
1	*Barilius gatensis (Valenciennes, 1844)*	LC
2	*Dawkinsia filamentosa (Valenciennes, 1844)*	LC
3	*Devario malabaricus (Jerdon, 1849)*	LC
4	*Garra hughi (Silas, 1955)*	EN
5	*Garra mullya (Sykes, 1839)*	LC
6	*Haludaria fasciata (Jerdon, 1849)*	LC
7	*Horalabiosa arunachalami (Johnson and Soranam 2001)*	CR
8	*Indoreonectes keralensis (Rita, Banarescu & Nalbant, 1978)*	VU
9	*Poecilia reticulata (Peters,1859)*	LC
10	*Puntius vittatus (Day, 1865)*	LC
11	*Rasbora dandia (Valenciennes, 1844)*	LC
12	*Salmostoma acinaces (Valenciennes, 1844)*	LC
13	*Tor khudree (Sykes,1839)*	LC
14	*Travancoria jonesi (Hora, 1941)*	EN

Table 18. IUCN Status of Fishes

Eutrophication at Santhanpara

7.4. Issues Faced

7.4.1. Alterations in Habitat

Fish populations in Munnar are highly dependent on specific habitat conditions, including clean water, adequate flow, and natural vegetation cover. Habitat alterations, such as deforestation, dam construction, and water diversion, disrupt these conditions. Dams fragment rivers, blocking migration routes and preventing fish from reaching spawning grounds. Sedimentation from soil erosion caused by deforestation clogs fish gills, reduces light penetration, and suffocates aquatic vegetation that forms the base of the food chain. These changes can lead to declines in fish populations and the loss of endemic species.

Munnar is highly vulnerable to natural disasters such as floods and landslides, which can only be mitigated to a limited extent. However, the damage caused by anthropogenic activities, such as habitat alterations, can be effectively addressed through the enforcement of strict laws, penalties, and regulations to curb such practices. Implementing and upholding these measures is an urgent necessity to control the unchecked human activities threatening Munnar's fragile ecosystems.

7.4.2. Climate Change

Erratic rainfall patterns, temperature changes, and prolonged droughts significantly impact fish. Heavy rainfall increases sediment and pollutant runoff, degrading water quality and reducing oxygen levels critical for fish survival. Rising water temperatures can exceed the tolerance limits of many native fish species, affecting their metabolic rates, reproduction, and survival. Droughts reduce the availability of water, causing overcrowding and increasing competition for limited resources. Moreover, climate change disrupts breeding cycles and spawning seasons, leading to reduced recruitment in fish populations.

The consequences of disrupting ecosystems through harmful human activities contribute significantly to climate change. Mismanagement and unscientific practices in treating ecosystems lead to extreme climatic variations, affecting not only wildlife but also having severe repercussions on humans themselves.

7.4.3. Waste Dumping and Pollution

Pollution from chemical runoff, untreated sewage, and waste dumping directly impacts fish health and survival. Pesticides and fertilizers from plantations can cause acute toxicity in fish or disrupt their reproductive systems, leading to population declines. Eutrophication from nutrient runoff creates oxygen-deprived zones, or "dead zones," where fish cannot survive. Accumulated heavy metals and microplastics can enter the food chain, causing bioaccumulation and harming both fish and predators, including humans who consume them. Pollution also damages the natural aesthetics and ecological function of water bodies, indirectly affecting fish habitats.

Plantations are frequently treated with heavy doses of pesticides and weedicides, often without regulation or sufficient intervals between applications. This practice leads to pollution of both the atmosphere and water bodies. Sudden rainfall washes these chemicals into streams, causing eutrophication and contaminating drinking water sources. The lack of proper mitigation measures exacerbates the situation, posing severe risks to aquatic life, including diseases and significant disruptions to their ecosystems.

7.4.4. Exotic Species Competition

The introduction of non-native fish species poses a significant threat to Munnar's native fish populations. Exotic species often outcompete native fish for food, breeding areas, and habitat. Aggressive invaders can also prey on native fish, reducing their numbers. Additionally, exotic species may carry diseases and parasites that native fish have no immunity against, leading to widespread mortality. This competition disrupts the delicate ecological

balance, pushing many native fish species toward endangerment or extinction.

Exotic species are often introduced into ponds for recreational purposes or food production. However, during floods, these species can escape from the ponds and enter natural rivers, disrupting local ecosystems. This alters habitats, affects predator-prey dynamics, and challenges the natural predators of the region. The guppy species, for example, has become increasingly common in Munnar, highlighting the need for special care to address these sensitive issues and protect threatened fish species.

7.4.5. Tourism and Recreational Activities

The popularity of Munnar as a tourist destination brings pressure on its freshwater habitats. Boating, fishing, and other recreational activities can disturb fish habitats, cause physical damage to aquatic ecosystems, and introduce pollutants such as fuel and plastic waste into water bodies. Unregulated tourism also leads to habitat degradation, noise pollution, and increased stress on aquatic life.

Uncontrolled tourism, exceeding Munnar's carrying capacity, is a significant issue, leading to increased pollution, particularly plastic waste. The lack of proper waste disposal methods and limited provisions for segregated waste management further exacerbate the problem. As a result, fish are forced to migrate to areas where human impact is minimal.

7.4.6. Mining and Quarrying Activities

Sand mining and quarrying in and around Munnar's rivers and wetlands disturb sediment patterns and destroy fish habitats. These activities increase turbidity in water, reducing light penetration and affecting photosynthesis in aquatic plants that many fish species depend on for food. Furthermore, mining alters water flow, erodes riverbanks, and disrupts the natural spawning grounds of fish.

Sand mining is prevalent even in the small streams of Munnar. Despite excess sand accumulation from floods, sand is extracted from rivers under the pretext of managing this surplus. While quarry activities are more limited, waterlogging in quarries remains a significant concern in Munnar.

7.4.7. Hydroelectric Projects

The construction and operation of hydroelectric dams in Munnar significantly impacts fish. Dams block migration routes, change natural water flow, and alter the thermal and chemical characteristics of rivers. Sudden release of water from reservoirs during power generation creates rapid changes in water levels and flow rates, which can harm fish populations and their habitats.

Although several dams have existed in Munnar for the past 50 to 100 years, the proposed construction of new dams in areas like Chilanthiyar and Mankulam raises significant concerns about the potential impact on the local ecosystem. Biodiversity within these reservoirs is already limited, with exotic species such as catfish being bred in these controlled environments. When the dam shutters are opened, these non-native species can pose a direct threat to the indigenous fish populations, further disrupting the natural balance of the ecosystem. The introduction of new dams could exacerbate these issues, leading to further ecological degradation.

7.4.8. Urbanization and Land-Use Changes

The expansion of urban areas and agricultural plantations in Munnar has led to increased encroachment on wetlands and riparian zones. These areas are critical for fish breeding and shelter. Urban runoff introduces contaminants, including oils, heavy metals, and untreated sewage, into water bodies, further degrading fish habitats.

Encroachment along the riparian zones of streams is widespread in Munnar, and this is a major factor contributing to the decline in fish populations. Additionally, road construction near streams disrupts natural water flow and habitats. Landfilling of wetland areas for homestay developments is also a

growing concern, as it poses a significant threat to fish and their ecosystems.

7.4.9. Diseases and Pathogens

Changes in water quality and temperature, as well as the introduction of exotic species, can increase the prevalence of diseases and parasites in fish populations. Native fish may lack immunity to new pathogens, leading to outbreaks that can decimate entire populations. Poor water management practices exacerbate these risks.

Epizootic Ulcerative Syndrome (EUS) was reported in Garra mullya from Anakulam, a disease that can spread rapidly through contaminated water. Environmental factors such as low water temperatures, heavy rainfall, and prolonged periods of cold can exacerbate EUS outbreaks. These conditions create an ideal environment for the disease to flourish, potentially impacting other fish species as well. The rapid spread of EUS poses a serious threat to aquatic biodiversity, highlighting the need for effective monitoring and management to prevent further outbreaks.

7.4.10. Lack of Effective Conservation Measures

Inadequate enforcement of environmental regulations and lack of awareness about sustainable practices contribute to the degradation of freshwater habitats. Without comprehensive management and conservation efforts, these cumulative threats can lead to irreversible damage to fish populations and their ecosystems.

There is a significant lack of awareness within the community about the threats faced by fish species in Munnar. The absence of proper education regarding the importance of conserving threatened species further exacerbates the issue. Local authorities have yet to take meaningful action or prioritize this knowledge, which contributes to the ongoing challenges. Addressing this gap in awareness and fostering greater understanding of the region's vulnerable aquatic species is a crucial issue that must be resolved to ensure effective conservation efforts.

7.5. Inference on Threatened Fishes in Munnar

Four species have been identified in Munnar under three conservation categories: Horalabiosa arunachalami (Critically Endangered), Garra hughi (Endangered), Travancoria jonesi (Endangered), and Indoreonectes keralensis (Vulnerable). Among these, Cardamom garra and Kerala loach were the primary focus of the project. It was unfortunate to discover the presence of the other species, which underscores the importance of conserving freshwater ecosystems. These species face numerous threats, and taking appropriate measures to address these challenges will not only help protect them but also ensure the well-being of other aquatic species in the region.

a. *Garra hughi*

The species thrive in a relatively good environment of Vaguvurrai but are surrounded by tea plantations, which pose a significant risk due to chemical runoff. Additionally, the transect intersects the State Highway, contributing to pollution from vehicular emissions. One of the primary issues is the unscientific dumping of waste near the transect, which contaminates the nearby water bodies. Another pressing concern is climate change, with unpredictable rainfall patterns that affect the stability of the ecosystem. As a hilly area, Munnar is also highly susceptible to landslides, which further exacerbate these risks.

To address these challenges, a multifaceted approach is needed. Strict regulations should be enforced to limit chemical runoff from plantations, with sustainable farming practices promoted to minimize environmental impact. Proper waste management systems, including waste segregation and recycling, must be implemented, and waste dumping near sensitive areas should be strictly prohibited. Efforts should also be made to monitor and predict climate patterns more effectively, using modern tools to enhance preparedness for extreme

weather events. Additionally, improving infrastructure, such as reinforcing slopes and providing early warning systems for landslides, can help mitigate these natural risks. Environmental education and community involvement are crucial to ensure that locals understand and actively contribute to conservation efforts.

b. *Indoreonectes keralensis*

The species was identified in two crucial locations: Letchmi Estate and Viripara, both supporting significant populations. However, several factors threaten their survival. Streams in both areas originate from and pass through tea plantations, resulting in chemical runoff that compromises water quality. Additionally, water levels in these streams are low, and Munnar's worsening climatic conditions further exacerbate the challenges. Viripara benefits from well-preserved riparian zones with forest cover, offering suitable habitats for the species, while Letchmi is dominated by grasslands with minimal shade, making it less conducive for breeding. Though tourist activity is limited in both locations, human habitation near the transect raises concerns about potential habitat degradation.

To mitigate these challenges, tea plantations should adopt eco-friendly farming practices, such as organic fertilizers and biopesticides, to reduce chemical runoff. Measures to restore water levels, including rainwater harvesting and catchment area rehabilitation, should be implemented. Riparian zones in Letchmi need enhancement through native tree and shrub planting to create suitable breeding conditions. Sustainable tourism practices must be promoted, with guidelines to minimize habitat disturbances and waste pollution. Community engagement is crucial, involving awareness programs and incentives for sustainable practices in surrounding areas. Additionally, predictive tools for monitoring climatic risks and proactive strategies, such as early warning systems, can help address extreme weather events. Regular monitoring of fish populations and habitat conditions will ensure the effectiveness of these conservation efforts while preserving the broader freshwater ecosystem.

c. *Horalabiosa arunachalami*

The species was identified in two key transects: Vattavada and Viripara. Chemical runoff from plantations and tea estates remains a significant concern in both locations, impacting water quality and threatening the species' habitat. Vattavada faces an additional challenge with high levels of pollution being reported. While the riparian zones in both transects are generally suitable for the species' survival, competition with an exotic species has been observed in Viripara, further straining the ecosystem.

Plantations and tea estates must adopt eco-friendly practices to reduce chemical runoff. Strengthening waste management in Vattavada is vital to address pollution, while controlling exotic species in Viripara through removal and habitat restoration is crucial. Regular monitoring of ecosystems and engaging communities through awareness campaigns will support long-term conservation efforts.

d. *Travancoria jonesi*

The species was found in Perumbankuthu, inhabiting rocky surfaces submerged in water. This location supports a notable population of the species. However, activities such as jeep river crossings, boating, and other tourist recreational pursuits pose significant threats to the habitat. These activities not only contribute to environmental pollution but also present direct physical dangers to the species and their ecosystem.

To address these issues, stricter regulations should be enforced to limit tourist activities such as jeep crossings and boating in sensitive habitats. Implementing eco-friendly tourism practices, including waste management systems and designated activity zones, can help minimize environmental impact. Community engagement and awareness programs should be conducted to promote sustainable tourism and conservation of the species' habitat.

7.6. Inference on Transects with fishes

A closer look at the transects surveyed reveals critical insights into the vulnerabilities and trends of fish populations in these ecosystems. Several endemic and threatened species, such as Horalabiosa arunachalami, Garra hughi, Indoreonectes keralensis, and Travancoria jonesi, are clinging to survival in these habitats. The notable presence of exotic species like Poecilia reticulata in nearly all surveyed transects points to an invasive threat that could severely impact native biodiversity. In areas such as Letchmi Estate and Nallathanni, the dominance of invasive species alongside excessive human activities, such as waste dumping and riparian destruction, is exacerbating ecological imbalances.

Transects such as Anakulam and Karinthiri Aaru exhibited significant species diversity, including Devario malabaricus and Barilius gatensis, which are endemic to the Western Ghats. However, these regions also face threats from pollution, tourism, and unregulated activities like sand mining. Vaguvurrai, which initially supported a stable population of Garra hughi, has shown a sharp decline in density over subsequent surveys, likely due to habitat degradation. Perumbankuthu and Peechadu highlight the dual pressures of human activity and pollution, with notable species such as Haludaria fasciata and Travancoria jonesi being affected.

Climate variability, such as irregular rainfall patterns and prolonged dry spells, poses an overarching risk across all transects. Reduced water flow, combined with pollution and chemical runoff from plantations, is impacting aquatic life directly and indirectly by disrupting breeding cycles and reducing suitable habitats. The data also suggest a correlation between poor riparian management and lower fish densities, as observed in Nallathanni and other heavily impacted areas.

Immediate interventions are required to restore these ecosystems, including riparian restoration projects, strict regulation of agricultural runoff, and habitat-specific conservation measures to protect endemic species. Collaboration between local communities, conservationists, and authorities will be essential to mitigate invasive species, regulate tourism, and ensure sustainable management of these critical aquatic systems.

8. Conclusion

The freshwater ecosystems of Munnar harbor a rich diversity of fish species, with a significant proportion being endemic and a few critically threatened. These species, including Garra hughi, Indoreonectes keralensis, Horalabiosa arunachalami, and Travancoria jonesi, highlight the ecological importance of this region as a biodiversity hotspot. However, this unique aquatic ecosystem is under growing pressure from various anthropogenic activities such as urbanization, agriculture, tourism, and hydroelectric projects. Habitat degradation, pollution, climate change, and the introduction of invasive exotic species exacerbate the challenges for native fish populations.

Conservation of these ecosystems demands immediate, well-coordinated efforts to mitigate threats. Measures like regulating waste disposal, managing tourism sustainably, restoring riparian vegetation, and controlling invasive species are critical. Furthermore, creating targeted conservation plans for the most threatened species and enhancing community participation through awareness programs are necessary to ensure long-term ecological balance.

The future of Munnar's aquatic biodiversity relies on balancing conservation with development. A holistic approach involving local stakeholders, policymakers, and conservationists is vital to preserve these ecosystems. By safeguarding these freshwater habitats, Munnar can continue to support its unique biodiversity and serve as a model for sustainable development in ecologically sensitive regions.

9. Recommendations

9.1. Habitat Conservation

- Protect riparian zones by planting native vegetation.
- Restore wetlands to support aquatic life.
- Promote eco-friendly agricultural practices to reduce chemical runoff.

9.2. Pollution Control

- Implement proper waste management systems.
- Create buffer zones between plantations and water bodies.
- Educate the public about reducing pollution and its impact on aquatic ecosystems.

9.3. Exotic Species Management

- Enforce strict regulations on the introduction of exotic species.
- Remove invasive species through targeted programs.
- Conduct routine monitoring to prevent the spread of invasive species.

9.4. Sustainable Tourism Practices

- Promote eco-friendly tourism activities.
- Designate no-tourism zones in ecologically sensitive areas.
- Educate tourists about the importance of fish diversity and conservation.

9.5. Hydroelectric Projects and Mining Management

- Install fish-friendly infrastructure like fish ladders.
- Regulate water releases to mimic natural flow patterns.
- Prohibit mining activities in critical aquatic habitats.

9.6. Climate Change Adaptation

- Implement rainwater harvesting systems to maintain water levels.
- Ensure adequate stream flow to support aquatic life.
- Establish biodiversity corridors to help species adapt to changing environments.

9.7. Disease and Pathogen Control

- Conduct regular monitoring of fish populations for diseases.
- Improve sanitation practices around water bodies.
- Invest in research to develop effective disease countermeasures.

9.8. Community Engagement

- Involve local communities in conservation initiatives.

- Organize awareness workshops on fish diversity and its importance.
- Promote citizen science programs to engage the public in data collection and monitoring.

9.9. Policy and Governance

- Strengthen and enforce environmental protection laws.
- Conduct regular inspections to ensure compliance with conservation regulations.
- Allocate adequate funds for fish diversity conservation projects.

9.10. Scientific Research and Monitoring

- Conduct biodiversity surveys to identify key species and habitats.
- Develop conservation breeding programs for threatened species.
- Use ecosystem modeling to guide conservation strategies and policymaking.

9.11. Water Quality Improvement

- Monitor water quality parameters regularly (e.g., oxygen levels, pH, and pollutants).
- Install sediment traps in upstream areas to minimize siltation.
- Promote the use of organic fertilizers to prevent water contamination.

9.12. Integration of Traditional Knowledge

- Involve local and indigenous communities to incorporate traditional practices in conservation.
- Document traditional fishing practices that are sustainable and fish-friendly.
- Promote cultural values related to the conservation of aquatic biodiversity.

9.13. Species-Specific Conservation Efforts

- Identify and prioritize endangered and endemic species for targeted conservation.
- Develop genetic diversity studies to understand population health.
- Reintroduce locally extinct species in restored habitats.

9.14. Ecotourism Revenue for Conservation

- Use revenues from ecotourism to fund conservation initiatives.
- Promote fish-watching tours to foster interest in aquatic life.
- Establish partnerships with eco-lodges to support habitat restoration.

By integrating these measures, Munnar can ensure sustainable conservation of fish diversity while balancing ecological health and human activities.

10. Summary

The study documented 14 fish species in Munnar, primarily from the Cyprinidae family, with other species from families like Nemacheilidae, Poeciliidae, and Balitoridae. It highlighted the dominance of endemic species, showcasing their adaptation to the region's unique environmental conditions. In addition to native species, the study noted the presence of invasive exotic species, such as guppies, which pose a threat to local biodiversity. Four species—Horalabiosa arunachalami, Garra hughi, Indoreonectes keralensis, and Travancoria jonesi—were found to be threatened, according to the IUCN Red List, underscoring the need for immediate conservation action.

The population of these target species was closely studied, and a comprehensive database was created to track the fish species based on their mean standard length (MSL). Efforts were made to conserve threatened species, which included conducting awareness programs, placing information boards, organizing exhibitions, workshops, seminars, and even coloring competitions to engage the local community. Habitat and water sampling were carried out in transects to monitor water quality, and a scientific database was established based on these findings.

The study identified several threats to Munnar's aquatic ecosystems, including habitat alteration, climate change, waste dumping, and competition from exotic species. Other significant concerns were tourism, mining, hydroelectric projects, urbanization, and disease outbreaks, all of which harm water quality, disrupt breeding grounds, and degrade ecosystems. Recommendations included adopting eco-friendly agricultural practices, regulating waste and tourism, improving riparian zones, and raising community awareness. Targeted conservation strategies were proposed for the threatened species, particularly Garra hughi and Indoreonectes keralensis, to address their specific habitat challenges and vulnerabilities. These initiatives are essential for safeguarding Munnar's freshwater biodiversity for future generations.

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Ecological Research Campus, K.K. Road, Velloor P.O., Kottayam, Kerala - 686501

Affiliated Research Centre of Mahatma Gandhi University, Kottayam

Tel: +91 481 295 7050, 9497 290 339

info@ties.org.in | www.ties.org.in