"SPATIAL PATTERNS OF FRESHWATER FISH DIVERSITY AND COMMUNITY STRUCTURE IN THE STREAMS OF THE PALANI HILLS, SOUTHERN WESTERN GHATS, INDIA"

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Abstract

Freshwater stream ecosystems of the Western Ghats support remarkable fish diversity and endemism but are increasingly threatened by habitat degradation and anthropogenic disturbances. The present study investigated the diversity, distribution, and environmental determinants of freshwater fish assemblages in streams of the Palani Hills, Southern Western Ghats, India. Fish sampling was conducted across 23 stream sites representing varying elevational gradients and habitat characteristics between January and December 2019. Different environmental variables were assessed to determine their influence on fish distribution. A total of 16 fish species belonging to 13 genera, 7 families, and 6 orders were recorded. The family Cyprinidae dominated the assemblage, accounting for approximately 73% of the total species composition. Diversity indices revealed greater species richness and abundance in downstream low-elevation streams compared to upstream high-altitude streams. Jaccard similarity and beta diversity analyses indicated moderate faunal similarity among downstream stream systems. Multivariate analysis of variance (MANOVA) demonstrated that elevation, water temperature, conductivity, total dissolved solids, salinity, and dissolved oxygen significantly influenced taxa richness. Principal Component Analysis (PCA) identified longitude, canopy cover, and substrate composition as important environmental determinants of fish assemblages. The findings emphasize the ecological importance of habitat heterogeneity and environmental gradients in structuring stream fish communities of the Palani Hills. Conservation strategies focusing on riparian vegetation, habitat restoration, and regulation of anthropogenic disturbances are essential for sustaining freshwater biodiversity in the region.

Keywords: Freshwater fishes, Palani Hills, Western Ghats, Fish diversity, Stream ecology, Environmental variables, Freshwater conservation

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1. Introduction

Freshwater ecosystems are among the most biologically diverse yet highly threatened habitats on Earth, supporting a disproportionate share of global biodiversity despite occupying less than 1% of the Earth's surface (Reid *et al.,* 2019). Rivers and streams play critical ecological roles in maintaining nutrient cycling, ecosystem productivity, hydrological balance, and aquatic biodiversity. However, freshwater ecosystems are increasingly threatened by anthropogenic disturbances including habitat fragmentation, pollution, deforestation, invasive species, hydrological alterations, and climate change, resulting in substantial biodiversity loss worldwide (Tickner *et al.,* 2020). Freshwater fishes constitute an ecologically important component of aquatic ecosystems and contribute significantly to trophic dynamics, nutrient cycling, and ecosystem functioning. Owing to their sensitivity to environmental disturbances, fish assemblages are widely regarded as indicators of ecosystem integrity and habitat quality (Moyle & Cech, 2004). Environmental variables such as elevation, stream flow, water temperature, dissolved oxygen, substrate composition, canopy cover, and riparian vegetation strongly influence fish diversity and distribution in stream ecosystems (Teresa & Casatti, 2017).

The Western Ghats of India, recognized as one of the world's biodiversity hotspots, harbor exceptional freshwater fish diversity and endemism (Myers *et al.,* 2000). More than 320 freshwater fish species have been documented from the region, many of which are endemic to specific river systems and hill streams (Dahanukar *et al.,* 2011; Raghavan *et al.,* 2021). Nevertheless, freshwater habitats of the Western Ghats are increasingly threatened by urbanization, tourism, land-use changes, habitat degradation, and climatic variability, leading to population declines in several freshwater taxa (Molur *et al.,* 2011). Previous studies have demonstrated that environmental heterogeneity and habitat complexity significantly influence stream fish assemblages in the Western Ghats (Arunachalam, 2000; Johnson & Arunachalam, 2009). However, comprehensive information regarding freshwater fish diversity and habitat relationships in the Palani Hills remains limited despite increasing anthropogenic pressure in the region.

The Palani Hills, situated in the southern Western Ghats of Tamil Nadu, contain ecologically important stream ecosystems characterized by substantial elevational gradients and habitat heterogeneity. Understanding fish diversity and environmental drivers in these stream systems is crucial for biodiversity conservation and sustainable watershed management. Therefore, the present study aimed to assess the diversity and distribution of freshwater fishes in streams of the Palani Hills and evaluate the influence of environmental variables on fish assemblage patterns.

2. Materials and Methods

2.1 Study Area

The study was conducted in the Palani Hills, Southern Western Ghats, Tamil Nadu, India, located between 10°11′–10°31′ N latitude and 77°21′–77°54′ E longitude. The region is characterized by tropical montane climate, elevational gradients, perennial and seasonal streams, and diverse riparian vegetation. Climate is influenced by southwest and northeast monsoons, resulting in seasonal variation in stream hydrology.

2.2 Sampling Sites

A total of 23 stream sites distributed across varying elevational gradients were selected for the present study. Elevation ranged from 265 m at Aathupalam Stream to 2184 m at Suicide Point Stream. Stream systems represented different habitat types, substrate conditions, and stream morphology. The selected sites included Aathupalam, Moolaiyaru, Gurusadi, Perumal, Silver Cascade downstream, Fairy Falls, Suicide Point, Pillar Rock, Kozhikode, Sothuparai, Sellumbu, Kumbakkarai, Manjalar, Maruthanathi, Aathur, Kombaikadu, Virupachi, Shanmuganathi, Thalaiyuthu, Amaravathi, Kuthiraiyaru, Palar, and Thalakuthu Falls.

2.3 Fish Sampling

Fish sampling was conducted from January to December 2019. Fishes were collected using hand nets, scoop nets, cast nets, and traditional fishing methods depending on stream size, water depth, and habitat characteristics. Sampling was performed across different mesohabitats including pools, riffles, and marginal vegetation zones. Collected specimens were identified based on external morphological characteristics using standard taxonomic keys (Jayaram, 1999, 2010; Menon, 1999). Updated taxonomic nomenclature was adopted following recent ichthyological classifications.

2.4 Physico-Chemical Analysis

Environmental variables recorded at each stream site included latitude, longitude, elevation, atmospheric temperature, water temperature, pH, conductivity, total dissolved solids (TDS), salinity, dissolved oxygen (DO), stream width, water depth, current velocity, canopy cover, substrate composition, and riparian vegetation. Water quality parameters were measured using portable water quality meters, whereas stream morphology and habitat variables were measured directly in the field.

2.5 Data Analysis

Fish diversity and ecological analyses were carried out using PAST software version 3.16. Diversity indices including Shannon–Wiener diversity, Simpson diversity, Evenness, Margalef richness, and Chao-1 richness estimator were calculated. Faunal similarity among stream sites was estimated using Jaccard similarity index. Beta diversity indices including Whittaker, Harrison, Cody, Routledge, Wilson–Shmida, Mourelle, Harrison-2, and Williams indices were calculated to evaluate species turnover. Multivariate Analysis of Variance (MANOVA) was performed to determine the significance of environmental variables influencing taxa richness. Principal Component Analysis (PCA) was used to identify major environmental gradients affecting fish distribution patterns.

3. Results

3.1 Environmental Characteristics of Stream Sites

The environmental characteristics of the 23 stream sites exhibited considerable spatial variation across the Palani Hills (Tables 1–3). Sampling sites were distributed across elevations ranging from 265 m at Aathupalam Stream to 2184 m at Suicide Point Stream, indicating substantial altitudinal heterogeneity. Atmospheric temperature varied between 18.6°C and 34.3°C, whereas water temperature ranged from 17.1°C to 27.1°C. Cooler water temperatures were consistently recorded in high-altitude streams such as Fairy Falls, Suicide Point Stream, and Pillar Rock Stream.

The pH of stream water ranged from 6 to 8, reflecting slightly acidic to alkaline conditions. Conductivity values varied considerably among sites, with the highest value recorded at Kuthiraiyaru Stream (512 µsec) and the lowest at Perumal Stream (28.6 µsec). Total dissolved solids ranged between 20.3 and 362 ppt, while salinity varied from 18.6 to 248 ppm. Dissolved oxygen concentration ranged between 6.8 and 12.6 mg L^{-1}, with high-elevation streams generally exhibiting greater oxygen concentrations. Stream habitat characteristics also varied markedly among sampling locations. Stream width ranged from 2.1 to 16 m, while water depth varied from 13 to 76 cm. Current velocity ranged between 1.2 and 14.6 sec/m. Substrate composition included bedrock, boulders, cobbles, pebbles, sand, and mud, with upstream streams predominantly characterized by rocky substrates and downstream systems exhibiting greater substrate heterogeneity.

Table 1. Geographic and Physical Characteristics of Stream Sites in the Palani Hills

Stream Number		Latitude (N)	Longitude (E)	Elevation (m)	Atmosphere Temperature (°C)	Water Temperature (°C)
1	Aathupalam stream	10º09′83″2	77º41′50″9	265	31.3	25.6
2	Moolaiyaru stream	10º16′17″1	77º36′64″9	1186	27.7	18.7
3	Gurusadi stream	10º16′81″8	77º33′80″2	1386	25.7	19.7
4	Perumal Stream	10º16′03″4	77º32′61″2	1572	23.5	17.3
5	Silver cascade down stream	10º14′68″6	77º30′99″1	1624	22.2	18.1
6	Fairy falls	10º13′62″2	77º28′13″6	2028	18.7	17.1
7	Sucide point stream	10º12′93″2	77º28′61″9	2184	18.6	17.1
8	Pillar rock stream	10º13′27″2	77º28′45″9	2160	18.8	17.1
9	Kozhikode stream	10º23′73″9	77º54′59″3	1081	27.4	19.6
10	Sothuparai stream	10º07′88″2	77º28′18″3	373	25.5	23.6
11	Sellumbu stream	10º12′25″6	77º32′94″6	445	26.4	22.4
12	Kumbakkarai stream	10º10′55″6	77º32′10″6	364	24.2	21.5
13	Manjalar Stream	10º11′70″3	77º38′12″6	292	27.8	23.5
14	Maruthanathi stream	10º12′93″8	77º45′55″9	270	24.5	25.3
15	Aathur stream	10º17′46″1	77º50′96″0	283	29.8	24.5
16	Kombaikadu stream	10º19′87″2	77º49′00″7	325	27.3	25.9
17	Virupachi stream	10º27′96″0	77º41′67″1	277	25.4	24.2
18	Shanmuganathi river	10º27′34″3	77º29′48″0	303	25.1	24.5
19	Thalaiyuthu stream	10º31′19″9	77º25′64″2	329	31.7	24.3
20	Amaravathi river	10º29′04″2	77º21′69″8	311	32.7	25.1
21	Kuthiraiyaru stream	10º24′82″4	77º23′37″7	356	34.3	26.1
22	Palar stream	10º23′07″4	77º29′10″8	315	29.6	27.1
23	Thalakuthu falls	10º26′53″1	77º40′94″2	330	25.1	23.1

Table 2. Physico-Chemical Characteristics of Stream Sites

Stream Number.		pH	Conductivity (µsec)	Total dissolved Solids (	Salinity (ppm)	Dissolved oxygen (mg L^{-1})

				ppt)		
1	Aathupalam stream	7	297	208	142	8.2
2	Moolaiyaru stream	6	56.5	40	37.6	10.4
3	Gurusadi stream	7	63.3	45.1	34.1	9.4
4	Perumal Stream	6	28.6	20.3	18.6	11.7
5	Silver cascade down stream	7	171.4	122	82.3	10.2
6	Fairy falls	7	45.1	32.1	25.3	9.3
7	Sucide point stream	6	31.1	22.2	19.5	12.6
8	Pillar rock stream	6	52.9	37.6	28.7	10.5
9	Kozhikode stream	7	29.1	20.7	19.6	11.8
10	Sothuparai stream	6	87.5	62.2	45.9	9.7
11	Sellumbu stream	7	124.9	67.1	88.6	10.8
12	Kumbakkarai stream	7	92.2	65.5	47.3	10.5
13	Manjalar Stream	7	102.2	72.8	52.6	8.9
14	Maruthanathi stream	7	495	352	240	7.3
15	Aathur stream	7	212	154	104	10.3
16	Kombaikadu stream	7	141.4	101	70.8	11.7
17	Virupachi stream	8	383	272	184	8.3
18	Shanmuganathi river	8	492	349	238	6.8
19	Thalaiyuthu stream	7	124.9	88.8	62.9	9.1
20	Amaravathi river	7	144.8	103	72.1	11.2
21	Kuthiraiyaru stream	8	512	362	248	8.7
22	Palar stream	7	174.1	124	86.1	9.5
23	Thalakuthu falls	8	344	244	165	10.8

Table 3. Stream habitat characteristics of 23 sampling sites at Palani hills (CV-Current velocity, CC-Canopy cover, BR-Bedrock, BS-Boulders, CS-Cobbles, PS-Pebbles, SD-Sand, RV-Riparian vegetation)

Stream Number.	Stream order	Stream width (m)	Water depth (cm)	CV (sec/m)	CC (%)	Stream substrates (%)						RV (no.)
						BR	BS	CS	PS	SD	Mud	
1	4	16.0	27	2.4	open	0	0	0	20	70	10	3
2	4	7.4	37	4.5	50	80	0	0	5	15	0	4
3	3	2.8	18	2.1	80	65	20	10	5	0	0	5
4	3	2.1	23	2.3	open	0	30	30	20	20	0	3
5	4	5.7	16	2.2	90	0	0	30	40	20	10	2
6	3	2.3	19	1.9	ope	70	0	5	20	5	0	2

					n							
7	3	2.6	16	3.8	open	60	0	10	20	10	0	2
8	3	4.3	37	2.3	open	70	0	0	10	20	0	1
9	3	2.3	18	2.2	60	50	10	10	20	10	0	2
10	4	8.3	23	3.7	open	45	20	10	20	5	0	5
11	4	5.4	27	1.8	30	50	15	10	5	20	0	3
12	4	6.2	42	1.6	40	30	20	20	15	15	0	2
13	4	9.3	33	2.6	open	0	5	5	20	70	0	2
14	4	5.7	49	3.2	50	60	5	10	15	10	0	3
15	4	10.8	33	2.3	open	0	10	5	5	70	10	3
16	4	6.4	16	1.4	40	0	0	20	60	20	0	2
17	4	8.6	21	1.2	open	0	5	15	40	30	10	2
18	4	3.4	76	14.6	open	10	20	15	15	30	10	2
19	3	5.4	46	4.3	open	0	0	5	10	80	5	1
20	4	8.7	52	1.2	open	65	5	5	10	15	0	4
21	4	9.3	41	4.1	open	0	5	0	10	75	10	2
22	4	7.6	45	5.7	open	0	15	30	40	15	0	2
23	3	4.7	13	3.2	open	0	20	20	20	30	10	3

3.2 Fish Diversity and Composition

A total of 16 freshwater fish species belonging to 13 genera, 7 families, and 6 orders were recorded from the 23 stream sites surveyed in the Palani Hills (Table 4). The family Cyprinidae was dominant and accounted for approximately 73% of the total fish assemblage (Figure 1).

Table 4. Checklist of Freshwater Fish Species Recorded from the Palani Hills

S. No	Scientific Name	Family	Order	IUCN Status
1	*Channa striata*	Channidae	Anabantiformes	Least Concern
2	*Barilius gatensis*	Channidae	Cypriniformes	Least Concern
3	*Devario aequipinnatus*	Channidae	Cypriniformes	Least Concern
4	*Devario malabaricus*	Channidae	Cypriniformes	Least Concern
5	*Garra mullya*	Channidae	Cypriniformes	Least Concern
6	*Haludaria fasciata*	Channidae	Cypriniformes	Least Concern
7	*Puntius bimaculatus*	Channidae	Cypriniformes	Least Concern
8	*Puntius chola*	Channidae	Cypriniformes	Least Concern
9	*Puntius dorsalis*	Channidae	Cypriniformes	Least Concern
10	*Rasbora microcephalus*	Channidae	Cypriniformes	Least Concern
11	*Oreochromis niloticus*	Cichlidae	Cichliformes	Exotic/Invasive
12	*Cobitis biwae*	Cobitidae	Cypriniformes	Not evaluated
13	*Schistura denisonii*	Nemacheilidae	Cypriniformes	Data Deficient
14	*Schistura nilgiriensis*	Nemacheilidae	Cypriniformes	Near Threatened
15	*Chanda nama*	Ambassidae	Perciformes	Least Concern
16	*Macrognathus*	Mastacembelidae	Synbranchiformes	Least Concern

	malabaricus			

Fish diversity varied considerably among stream sites. Aathupalam Stream (Site 1), Shanmuganathi River (Site 18), and Palar Stream (Site 22) exhibited the highest taxa richness, whereas high-altitude streams such as Gurusadi Stream, Perumal Stream, Fairy Falls, and Pillar Rock Stream supported lower species richness (Figure 2).

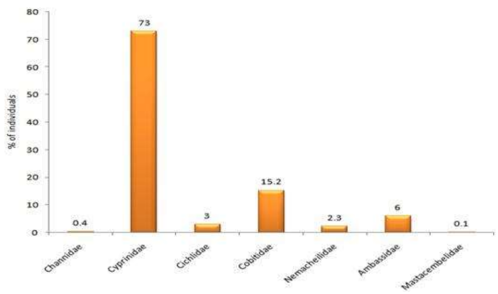

Figure 1. Percentage composition of freshwater fish families recorded from streams of the Palani Hills

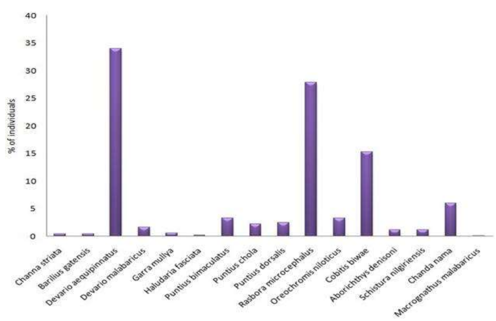

Figure 2. Distribution of fish taxa richness across 23 sampling sites in the Palani Hills.

3.3 Diversity Indices

Alpha diversity indices indicated considerable variation in fish assemblages among sampling sites (Table 5). Taxa richness ranged from one to seven species across stream systems. Shannon–Wiener diversity (H′) values ranged from 0 to 2, with the highest value recorded at Aathupalam Stream (Site 1), indicating greater species richness and evenness. Similarly, Simpson diversity values suggested higher diversity in downstream stream habitats. Margalef richness index ranged from 0 to 1.8, while Chao-1 estimates ranged from 1 to 10, indicating greater richness in downstream habitats than upstream systems. High-altitude streams generally exhibited lower diversity values due to restricted habitat availability and reduced environmental heterogeneity.

Table 5. Diversity Indices of Fish Assemblages Across 23 Stream Sites in Palani hills

Stream Number	Taxa richness (S)	Dominance (D)	Simpson (1-D)	Shannon (H′)	Evenness (□/□	Margalef richness	Chao-1 estimator
1	7	0.3	1	2	1	1.8	10
2	2	0.6	0	1	1	0.3	2
3	1	1	0	0	1	0	1
4	1	1	0	0	1	0	1
5	1	1	0	0	1	0	1
6	1	1	0	0	1	0	1
7	2	0.6	0	1	1	0.9	2
8	1	1	0	0	1	0	1
9	2	0.9	0	0	1	0.3	2
10	5	0.3	1	1	1	1.6	6
11	3	0.5	1	1	1	1.1	4
12	3	0.4	1	1	1	0.9	3
13	4	0.3	1	1	1	0.8	4
14	5	0.2	1	1	1	1.5	5
15	3	0.5	1	1	1	0.5	3
16	1	1	0	0	1	0	1
17	2	0.7	0	0	1	0.3	2
18	7	0.5	0	1	0	1.3	7
19	2	0.8	0	0	1	0.5	2
20	2	0.9	0	0	1	0.2	2
21	5	0.7	0	1	0	0.8	5
22	7	0.6	0	1	0	1.2	8
23	4	0.5	0	1	1	1	5

3.4 Beta Diversity and Similarity Analysis

Faunal similarity among stream sites was evaluated using Jaccard similarity index (Table 6). The analysis revealed comparatively high similarity between Site 1 and Site 10, Site 10 and Site 14, Site 12 and Site 20, Site 14 and Site 18, and Site 17 and Site 21. These highly similar sites were predominantly located in downstream or low-elevation regions and shared similar environmental characteristics. In contrast, low similarity values were observed among several upstream and downstream sites, indicating substantial variation in fish assemblages across elevational gradients. Beta diversity indices further confirmed moderate turnover in fish assemblages among stream systems.

The Whittaker index value was 4.18, indicating moderate species replacement among sites. Similarly, Harrison (0.19), Routledge (0.51), Wilson–Shmida (14.7), Mourelle (0.66), Harrison-2 (0.05), and Williams (0.56) indices collectively suggested moderate faunal similarity and ecological variation among stream habitats. Differences in altitude, substrate composition, temperature, and water quality may contribute to this variation in species assemblages.

Table 6. Similarity matrix for fishes collected from 23 sampling sites of Palani hills

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1	1																						
2	0.1	1																					
3	0.1	0.5	1																				
4	0	0	0	1																			
5	0.1	0	0	0	1																		
6	0	0	0	0	0	1																	
7	0	0	0	0	0	0	1																
8	0.1	0	0	0	0	0	0	1															
9	0.3	0	0	0	0	0	0	0	1														
10	**0.7**	0.2	0.2	0	0	0	0	0.2	0.4	1													
11	0.3	0.3	0	0	0.3	0	0	0.3	0	0.1	1												
12	0.4	0.3	0.3	0	0.3	0	0	0	0.3	0.3	0.2	1											
13	0.1	0	0	0	0	0	0.2	0	0.2	0.1	0	0	1										
14	0.5	0	0	0.2	0	0	0	0.2	0.4	**0.7**	0.1	0.1	0.1	1									
15	0.1	0	0	0	0	0	0	0	0.3	0.1	0	0.2	0	0.1	1								
16	0.1	0	0	0	0	0	0	0	0.5	0.2	0	0.3	0	0.2	0.3	1							
17	0.3	0	0	0	0	0	0	0	1	0.4	0	0.3	0.2	0.4	0.3	0.5	1						
18	0.4	0	0	0.1	0	0.1	0	0.1	0.3	0.5	0.1	0.1	0.2	**0.7**	0.1	0.1	0.3	1					
19	0.3	0	0	0	0	0	0	0.5	0.3	0.4	0.3	0	0.2	0.4	0	0	0.3	0.3	1				
20	0.3	0.3	0.5	0	0	0	0	0	0.3	0.4	0	**0.7**	0	0.2	0.3	0.5	0.3	0.1	0	1			
21	0.2	0	0	0.2	0	0.2	0	0	0.4	0.3	0	0.1	0.3	0.4	0.1	0.2	0.4	**0.7**	0.2	0	1		
22	0.2	0.1	0.1	0.1	0	0.1	0.1	0	0.1	0.2	0	0.1	0.2	0.2	0.1	0	0.1	0.4	0.1	0	0.5	1	
23	0.6	0	0	0	0.3	0	0	0.3	0.5	0.5	0.4	0.4	0.1	0.5	0.2	0.3	0.5	0.4	0.5	0	0.3	0.1	1

3.5 Relationship between Environmental Variables and Fish Richness

MANOVA results demonstrated that environmental variables significantly influenced fish taxa richness (Table 7). Elevation exhibited a significant negative relationship with taxa richness ($R^2 = 0.371$, $p = 0.002$), indicating lower species diversity at higher altitudes. Water temperature showed a strong positive relationship with taxa richness ($R^2 = 0.448$, $p < 0.001$), suggesting favorable thermal conditions in downstream habitats. Similarly, conductivity, total dissolved solids, and salinity positively influenced fish richness.

Table 7. MANOVA Results Showing Relationship between Environmental Variables and Taxa Richness

Variable	t-value	p-value	R^2	Significance
Elevation	-3.52	0.002	0.371	Significant
Water temperature	4.13	0.0004	0.448	Significant
pH	3.06	0.005	0.30	Significant

			9	
Conductivity	3.53	0.001	0.373	Significant
TDS	3.49	0.002	0.368	Significant
Salinity	3.55	0.001	0.375	Significant
Dissolved oxygen	-3.44	0.002	0.360	Significant

Dissolved oxygen showed a negative relationship with taxa richness, indicating that colder oxygen-rich upstream streams supported fewer fish species compared to downstream habitats. Principal Component Analysis (PCA) identified longitude, canopy cover, and pebble substrates as important environmental variables positively influencing fish assemblages (Figure 3). In contrast, elevation, stream width, stream depth, and current velocity exhibited negative relationships with taxa richness. Sampling sites 15 (Aathur Stream), 16 (Kombaikadu Stream), 9 (Kozhikode Stream), 23 (Thalakuthu Falls), and 17 (Virupachi Stream) were identified as ecologically significant sites for fish distribution.

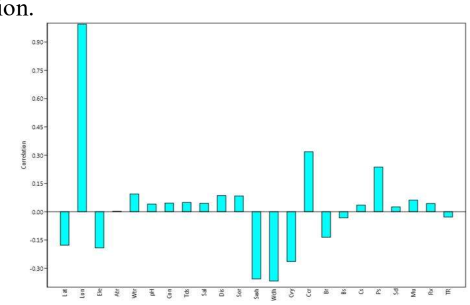

Figure 3. Principal Component Analysis (PCA) ordination showing relationships between environmental variables and fish assemblages.

Figure 4. Representative photographs of freshwater fishes recorded from the Palani Hills..

4. Discussion

The present study demonstrated that freshwater fish diversity in the Palani Hills is strongly influenced by environmental heterogeneity, stream habitat characteristics, and elevational gradients. Similar ecological patterns have been documented in stream ecosystems of the Western Ghats where habitat complexity and physicochemical conditions regulate fish assemblage structure (Johnson & Arunachalam, 2009; Teresa & Casatti, 2017). The dominance of Cyprinidae observed in the present study is consistent with previous investigations conducted in freshwater ecosystems of the Western Ghats (Dahanukar *et al.,* 2011). Cyprinids possess remarkable ecological adaptability and occupy diverse habitat niches due to their feeding plasticity and morphological specialization (Nelson *et al.,* 2016). Their predominance in tropical stream ecosystems reflects favorable habitat conditions and ecological flexibility.

The higher species richness observed in downstream stream systems compared to upstream habitats may be attributed to increased habitat heterogeneity, wider stream channels, moderate thermal conditions, and greater nutrient availability. Similar elevational declines in fish richness have been reported from mountain streams worldwide (Buisson *et al.,* 2008; Terra *et al.,* 2016). High-altitude streams are generally characterized by cooler temperatures, rocky substrates, and reduced habitat complexity, limiting fish diversity. Environmental variables including elevation, water temperature, dissolved oxygen, conductivity, salinity, and total dissolved solids significantly influenced fish assemblages. Water temperature is a key ecological determinant affecting fish metabolism, feeding efficiency, reproductive success, and habitat suitability (Nyanti *et al.,* 2018). Warmer downstream streams generally support greater fish diversity than colder upstream habitats.

Substrate composition and canopy cover also significantly influenced fish distribution patterns. Pebbles, cobbles, and riparian vegetation provide shelter, breeding habitats, and feeding grounds for stream fishes (Gorman & Karr, 1978). Riparian vegetation further regulates stream temperature, sediment input, and nutrient cycling, thereby supporting ecological stability in freshwater ecosystems (Allan & Castillo, 2007). The occurrence of *Oreochromis niloticus*, an invasive exotic species, may indicate anthropogenic influence and ecological disturbance within some stream systems. Invasive fishes may alter native fish assemblages through competition, predation, and habitat modification (Raghavan *et al.,* 2021). Tourism activities, habitat modification, riparian degradation, and stream pollution around Kodaikanal may negatively affect stream biodiversity in the Palani Hills. Anthropogenic disturbances often lead to habitat fragmentation, altered flow regimes, and declining freshwater biodiversity (Tickner *et al.,* 2020). Conservation strategies should therefore prioritize habitat restoration, riparian vegetation protection, and sustainable watershed management.

5. Conclusion

The present study documented 16 freshwater fish species belonging to 13 genera, 7 families, and 6 orders from streams of the Palani Hills, Southern Western Ghats. Cyprinidae represented the dominant fish family, contributing approximately 73% of total species composition. Fish diversity and richness were comparatively greater in downstream low-elevation streams than in upstream habitats. Environmental variables including elevation, water temperature, dissolved oxygen, conductivity, salinity, total dissolved solids, substrate composition, and canopy cover significantly influenced fish assemblages.

The findings highlight the ecological importance of habitat heterogeneity and environmental gradients in structuring stream fish communities. Increasing anthropogenic disturbances may threaten freshwater biodiversity in the Palani Hills, emphasizing the need for conservation measures focusing on habitat restoration, riparian vegetation management, and long-term monitoring of freshwater ecosystems.

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Conflict of Interest

The author declares no conflict of interest.

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Ethical Statement

The study involved non-invasive field sampling and complied with institutional guidelines for biodiversity documentation.

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