DIVERSITY AND ECOLOGICAL STRUCTURE OF FISHES IN SELECTED STREAMS/RIVERS IN WESTERN GHATS

Thesis submitted to Manonmaniam Sundaranar University
for the degree of
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DECLARATION

I declare that the thesis entitled "**Diversity and ecological structure of fishes in selected streams/ rivers in Western Ghats**" is the rusult of a original study carried out by me under the guidance and supervision of **Dr. M. A. Haniffa**, M.Sc., Ph.D., Reader, Department of Zoology, St. Xavier's College (Autonomous), Palayankottai and **Dr. M. Arunachalam,** M.Sc. Ph.D., Reader, SPK Centre for Environmental Sciences, Manonmaniam Sundanaranar University, Alwarkurichi This work has not been submitted earlier, in full or part for any diploma or degree in this or any other universities. I also declare that no part of the thesis is a reproduction from any other sourcea either published or unpublished, without acknowledgement.

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1. INTRODUCTION

1.1. Biodiversity

The living part of earth comprises of different kinds of fascinating living forms, starting from microscopic organisms to giant whale. Each organism in the environment plays a key role in the maintenance of a sustaining and stable ecosystem. Species present in a given environment, interact with each other leading to diversity of and to new evolutionary pathways which eventually contribute to the formation of new species. This variety and variability of organisms and ecosystems is referred as biological diversity or biodiversity (Kotwal and Banerjee, 1998).

Biodiversity has also been defined as *"The degree of nature's variety"* (McNeely, 1988) ; *"The variety of life and its process"* (Hughes and Noss, 1992) ; *"The variety of ecosystems, which comprises both the communities of organisms within particular habitats and the physical conditions under which they live"* (Wilson, 1992) ; *"The great variety that exists in living organisms (plants, animals and microbes) on earth reflect Biodiversity"* (Jain, 1994) ; *"The variety and variability among living organisms, the ecological complexes in which they occur and the ways in* *which they interact with each other and their environment*" (Johnson, 1995).

Biodiversity can be divided into four hierarchical categories: genes, species, ecosystems and landscape. A more comprehensive definition based on Noss (1983); Norse *et al.* (1986); OTA (1987); Sanderson and Redford (1994), is used herewith, which represents better on the components of biodiversity.

- Genetic diversity refers to the sum total of information in the genes of individual organism of a species, population, variety, subspecies or breed.

- Species diversity is the number and frequency of organisms in a local area, region or at the global scale, *i.e.,* the number of species in a region - its species "richness".

- Ecosystem diversity is related to a community of organisms and their physical environment interacting as an ecological unit. Ecosystem processes such as fire, climate and nutrient cycling that influence the composition, structure and interaction of biotic communities.

- Landscape diversity is the spatial heterogeneity of the various land uses and ecosystems within a larger region measuring from 100 km^2 to 10,000,000 km^2.

1. 2. Values of biodiversity

The public and the scientific community place a high value on the preservation of biological diversity because of its commercial and ecological importance (Carins and Luckey, 1992). In economic terms, ecosystems are fundamental "factors of production". Diversity in genes, species and ecosystems contribute immensely to productivity. In many parts of the world daily lives of people and biodiversity that surround them are closely intermingled. Wild species provide many products such as food, fibre, industrial compounds, fuels and drugs. It is estimated that about 40 % of the annual biological product of the planet is now appropriated for human use (NAGA, 1994). Still now the new crops, new medicines and new industrial products are regularly discovered (Nations, 1988). In addition to this, many important agricultural crops depend on wild germplasm for broadening their genetic base, maintaining yield and enhancing capacity to resist insects and pests (Spears, 1988).

In ecological values, the diversity of organisms serve as some set of ecological services. These include photosynthesis, provision of food and other renewable resources, air and water purification, soil formation and protection, pollination of crops, recycling of nutrients, recharging groundwater and watersheds, operation of the hydrological cycle and buffering floods and droughts. These functions sustain and protect human activities and human well being (Folke *et al.*, 1996; de Groot, 1992; Ehrlich and Ehrlich, 1992). But we have only a poor grasp of ecosystem services.

We must preserve the biodiversity not only for present but also for the future material value to humankind, because each organism has an inherent right to exist in the world (Ehrenfeld, 1978).

1. 3. Biodiversity in India

A very small number of countries mostly located in the tropical belt contains a high percentage of the world's species and high degree of endemism and these are considered as "megadiversity" countries. A dozen countries are identified as megadiversity countries and India is one among them (McNeely *et al.,* 1990). It has two important biodiversity '**hotspot**' areas, Himalayas and Western Ghats (Myers, 1988, 1990) and six plant diversity centres (WWF and IUCN, 1994). India has perhaps the largest array of environmental heterogeneity by virtue of its tropical location, varied physical features, land setting and climatic features. India has the widest variety of biomass in terrestrial as well as in aquatic ecosystems. The geographical area of India is about 329 million ha and its coastline stretches to nearly 7,000 km. The area of the country is only about 2% of world's total landmass. India harbours 5 % of all known species of flora and fauna (Jairajpuri, 1996). The vegetational cover is of rich and varied types, consisting of temperate rain forests to tropical dry forests and a wide expand of grasslands and each habitat supports its own unique group of flora and fauna.

According to Kotwal and Banerjee (1998) the plant wealth of India is about 45,000 species i.e. 12 % of global wealth of flowering plants and nearly 33% of these are endemic ; remaining includes 5,000 species of algae, 1,940 species of lichens, 23,000 species of fungi, 2,843 species of bryophytes and 1,012 species of pteridophytes. These plant wealth alone has contributed to the world nearly 167 economic plants (Zeven and de Wet, 1982).

There are 75 National Parks and 421 sanctuaries with a total area of over 10 million ha. These include 13 Biosphere Reserves and 23 Tiger Projects. The faunal wealth of India is about 81,000 species, which includes 57,000 species of insects, 5,000 species of molluscs, 372 species of mammals, 1,228 species of birds, 428 species of reptiles, 204 species of amphibians and 2,546 species of fishes (Kotwal and Banerjee, 1998). Very little estimates are available about India's marine life. According to Gopal (1997) about 16,500 species or more than 20% of the total fauna in India is aquatic and majority of these are freshwater.

1. 4. Freshwater biodiversity

The biodiversity in the inland aquatic environment has received much less attention. The activities on the preservation of aquatic biodiversity seems to lag behind than in terrestrial environment. The threat to terrestrial organisms such as mammals, birds and plants are due to disappearing habitats such as rain forests, which have attracted much attention but the same cannot be paid to aquatic habitats and aquatic organisms, within them that face imminent extinction (Beverton, 1992; Moyle and Leidy, 1992; Wilcove and Bean, 1994; Abramovitz, 1995).

The Myer's (1988, 1990) "Megadiversity" analysis is mostly based on terrestrial vertebrates, butterflies and higher plants and did not include any aquatic organisms into account. The ten countries with the richest freshwater fish fauna in world - wide are listed by Kottelat and Whitten (1997) and India is one among them. Indian subcontinent is singularly blessed with remarkable aquatic resources harbouring one of the richest fish fauna in the world. The total area of inland aquatic ecosystem in India is estimated as 18 million ha which is only about 5.3 % of the total land area (Gopal, 1997).

Freshwater habitats are inhabited by different groups of animals and plant communities in different ways. The general types of organisms in each habitat are similar between the different parts of country, but the faunal assemblages are distinct. Human communities depend on freshwater biodiversity for a variety of resources. The various habitat types provide a wide range of resources and services such as transport, supply of clean water and energy. Among the organisms, fishes are the best - known species of aquatic organisms and they are the only major food source harvested from natural populations. Indeed many of the world's poorest people depend on freshwater biodiversity for their animal protein needs. Furthermore, fishes exist at or near the top of the food chain and can serve as indicators of a balanced aquatic ecosystem (Karr *et al.,* 1986). However, the biodiversity in freshwater environment has started attracting some attention in recent years; for example the issue related to biodiversity in wetlands are being addressed by the Ramsar Bureau (Hails, 1996) and the protection of aquatic biodiversity was addressed in the World Fisheries Congress (Philipp *et al.*, 1995).

Freshwater biodiversity is a component of 'wetlands' such as marshes, peatlands, estuaries, floodplains, swamps and lakes with less environmental heterogeneity. They have attracted considerable conservation attention because of their ornithological importance. Other freshwater habitats such as rivers, streams, springs and headwaters of streams have limited ornithological value and therefore attracted relatively little concern (Kottelat and Whitten, 1997). These habitats are heterogeneous, with high altitude, high flow, usually high dissolved oxygen due to continuous agitation of water with various physical substrates and different forms of rock substrates. Many of the fishes and invertebrates living in these habitats have adaptations such as suckers, flattended depressed bodies and horizontally expanded well developed fins to resist the threat of being swept away by the current. The energy flow mainly depends upon the allochthonous materials input and transported organic matter from adjacent riparian habitats. The riparian corridor along the stream stretch not only provides food, but also shelter and cover to fishes (Armantrout, 1990b). The chaotic nature of these habitats results in a variety of microhabitats and they harbour diverse fauna of localised species. The fauna of these habitats are known to have a very high degree of endemism. For example the most riverine endemic fish species live in headwater streams and often in very short stretches of rivers (Kottelat and Whitten, 1997; Groombridge, 1992). These freshwater habitats are one of the least well known habitats and hundreds of species probably still await discovery (Kettelat and Whitten, 1997).

1. 5. Current condition of the aquatic habitats

The aquatic systems provide water for many uses. They interact with the landscape to create variety of habitats. Water of mountain streams to lakes may look homogeneous but actually they are separated by variety of environmental factors such as temperature, depth, current and substrates into a great variety of habitats. Each habitat has its own unique community of fishes and other organisms which adapt to the various features of that habitat. Although the diversity of habitats and species remain impressive, the quality of habitat and variety of species have declined as a result of major changes in landscapes by human activities (Armantrout, 1995). Conditions at any point in a basin are a summary of all activities upstream in the basin (Arthington and Welcomme, 1995). The types of changes are many, but involved primarily in habitat alteration, removal of riparian corridor, diversion of water, changes in water quality, over-exploitation of resources and the introduction of exotic species. For most changes we do not know the longterm effects and many of which will not be fully apparent for years or decades (Armantrout, 1995). As a result most larger river systems of the world are now modified or degraded to some degree (Arthington and Welcomme, 1995), although very few of the world's largest rivers retain their original functional integrity (Karr, 1993).

India has a unique fish fauna, especially in the southern peninsula, which collided with the northern portion of the country to bring with it a separate, more ancient fish fauna. The combination of different origins and a wide variety of habitats have led to create a highly diverse fish fauna. Recently the Conservation Breeding Specialist Group of the Species Survival Commission (IUCN) have assessed the current status of the freshwater fish taxa in India (CAMP, 1998). They listed 327 native fish taxa ; of which 45 are currently considered critically endangered, 91 endangered, 81 vulnerable, 66 lower risk - near threatened, 16 lower risk - least concern and 26 data deficient. They have also listed the species *Gymnocypris biswasi* is extinct and *Osteobrama belangeri* is extinct in the wild.

No major river basin in India and very few smaller drainages remain unaltered (Dudgeon, 1992). Extensive historical documentation is available on fish species in India (Day, 1875-78; Jayaram, 1981, 1999; Talwar and Jhingran, 1991) and is still continuing by the Zoological Survey of India with less information on habitats. However, the current status of much of the aquatic habitats and associated fish communities are unknown.

1. 6. Recent advances in stream ecology

Sound management of aquatic resources, requires a better understanding of the condition of fish communities, their habitat requirements and the factors influencing them. In different ecoregions, the number of species occupying a particular type and size of habitat should reflect the historical factors affecting the number of species available for colonization (Angermeier and Schlosser, 1989). In lotic environment, the diversity, community structure and species assemblages are influenced by biotic and abiotic variables (Minns, 1989) such as water current, depth, substrates, nutrients and riparian cover, which determine the success or failure of fish species and assemblages in the range of streams within the spatial distribution limits (Ricklefs, 1987).

Habitat structure has been identified as a major determinant in distribution and abundance of fishes from earlier time (Shelford, 1911). Later the zonation concept was developed by Huet (1954) where he explained the fish community in longitudinal succession with environmental characteristics. The environmental variation may have a significant impact on both assemblage structure and resource availability. The influence of habitat structure and complexity on fish assemblage structure has been tested mostly in North American streams (e.g. Gorman and Karr, 1978; Schlosser, 1982, 1985, 1987; Capone and Kushlan, 1991) and Australian streams (Bishop and Forber, 1991; Pusey *et al.*,1993). Angermeier and Schlosser (1989) have examined the relative importance of habitat area, habitat volume, habitat heterogeneity and number of individuals as determinant of the species richness in a habitat patch. The influence of riparian vegetation (Ross, 1986; Cummins *et al.*, 1989; Grefory *et al.*, 1991), benthic organic matter (Cummins, 1975; Naiman and Sedell, 1979; Newbold *et al.*, 1981a, b) in functional organization in stream community have been documented. Horwitz (1978) has proposed the stream order concept where the spatial heterogeneity associated with upstream versus downstream. The number of species increases in parallel with the stream order, which is attributable to an increase in habitat diversity and stability. Further more Vannote *et al.*, (1980) have proposed the River Continum Concept to explain the downhill movement of nutrients and organic matter from the riparian zone to the stream. With increase in stream order for each type of stream, the pressure on aboitic factors gradually decreases as spatial heterogeneity and stability improve. However, the number of species in the same stream order does not grow according to latitude. Moreover, human impact had now become a factor which modifies the spatial structure of fish community, for example marked changes in flow regime and the water quality (Bovee, 1982).

In contrast to the zonation and continum concept, Zelewski and Naiman (1984) have presented a model based on the functional relation between the abiotic and biotic factors as a mode of regulating fish communities in different geographical zones. Schlosser (1991) has proposed that the emerging field of landscape ecology offers new opportunities for understanding interrelated characteristics of landscape elements. It focuses on three interrelated characteristics of the environment; structural characteristics of landscape elements; the flow of water, organic matter, nutrients and species and the impact of natural and anthropogenic changes in structural and functional relationship of landscape elements over time. Among the structural and functional relationship of landscape, the total habitat or macro and microhabitat availability and/or diversity are the primary factors (Grossman, 1982; Facey and Grossman, 1990, 1991; Hill and Grossman, 1993) and competition and predation are the secondary factors (Schlosser, 1982, 1987) limiting the species in the assemblage. The microhabitat availability and use, spatiotemporal changes in the microhabitat use and size related microhabitat use of fishes have been well studied (Moyle and Vandracek, 1985; Grossman and de Sostoa, 1994a,b). Recently Grossman *et al.* (1998) assessed the relative effects of environmental variation, habitat limitation, predator abundance and microhabitat use and microhabitat overlap in an assemblage of stream fishes in North Carolina streams in United States.

Most of the information on fish assemblages and community structures are available from temperate streams. Meagre information is available on the assemblage structure of fishes in south Indian streams (Arunachalam *et al.*, 1988, 1997) and in Sri Lankan streams (De Silva *et al.*, 1980; Kortmulder, 1987; Kortmulder *et al.*, 1990).

Habitat structure and resources in Western Ghats streams vary in different ecoregions of Tamil Nadu, Kerala and Karnataka. They are regulated by various degree of biotic and abiotic factors. The present study therefore aims to explain the fish assemblages, habitat structure, microhabitat availability and usage in fifteen different streams in the Western Ghats of Tamil Nadu, Kerala and Karnataka of Peninsular India.

1. 7. Objectives of the present study

1. To study the species richness and distribution of fishes in different streams/rivers and river basins.

2. To describe the fish assemblage structure in 15 different streams/rivers using macrohabitat and microhabitat approaches.

3. To assess the habitat heterogeneity and environmental variables in study streams in relation to the fish diversity in different streams.

4. To assess the macrohabitat and microhabitat requirements and preferences of the dominant cyprinids in the study streams.

5. To examine the feeding habits and feeding ecology of cyprinids in the study streams.

6. To identify the man-made stressors on fish habitats in the study streams.

Study Area

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2. STUDY AREA

2. 1. Biogeography of Western Ghats

Western Ghats region is identified as one of the "hot spot" areas for biodiversity (Myers, 1990). It is also considered as mega endemic centre for plant diversity (WWF and IUCN, 1994; Nayar, 1996). It is a chain of hills of 1600 km in length running parallel to west - coast of Peninsular India (between 8° and 21° N latitudes) from the mouth of river Tapti in Gujarat to Kanyakumari in Tamil Nadu (Fig. 1). The more or less continuous hill ranges have a major discontinuity in the Palghat Gap at around 11° N (30 km). The biogeographical province of Western Ghats covers 160,000 km^2 of which about 100,000 km^2 forms mountainous terrain. The Western Ghats straddle the Indian states of Tamil Nadu, Kerala, Karnataka, Maharashtra and southern Gujarat. The narrow coastal strip that separates the hill chain from the Arabian sea in the west varies in width from 30 to 60 km. Hills are generally of elevations between 600 and 1000 m. However, the highest hill peaks of Anaimudi (2695 m) and Doddabetta (2636 m) are found only in the Nilgiris and Anaimalais. The

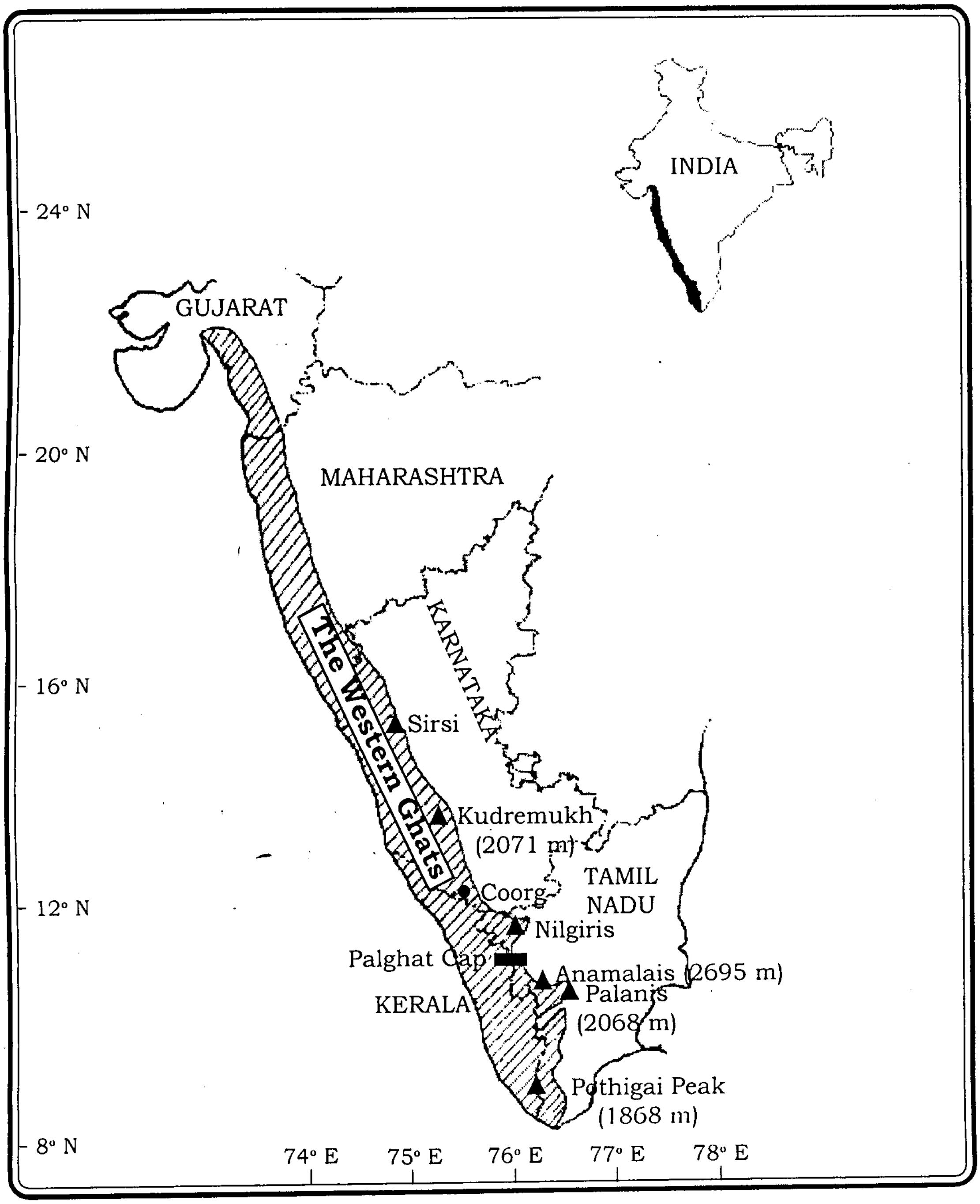

Figure 1. Map of the Western Ghats, the boundary of states and the location of the major ecoregions.

Nilgiris and Palani hills are spurs from the main hill chain which extend the Western Ghats eastwards to the latitude of 78 °E (Fig. 1).

The western side of the Western Ghats is on the threshold of southwest monsoon and receives much rainfall and the eastern side lies in the rain shadow area of the Peninsula. The annual rainfall varies from 2350 mm in north to 7450 mm in the south. The wettest season generally lies between June and October. The rainy season in the southern part is however, often prolonged locally due to premonsoon and winter showers. The dry period in southern parts of 13° N are the shortest (2 - 5 months) while in the north it varies from 5 to 8 months. Mean temperature pattern ranges from 20° C to 24° C, but very often it shoots beyond 30° C during summer (April - May).

The rainfall patterns of south-west and north-east monsoons make the Western Ghats the important watershed of the Peninsula (Nair and Daniel, 1986), with their several streams and rivers. Torrential and perennial hillstreams are more common in the south due to higher elevation and spates of both monsoons. The four major rivers flowing to the east are Godavari, Krishna, Cauvery and Tamiraparani, while the river Bharathapuzha, Periyar and Malampuzha in Kerala flow towards the west. There are numerous quick flowing streams and riveulets arising on the western slope are discharging into the Arabian sea. In the present study fifteen streams covering major river basins represented from Tamil Nadu, Kerala and Karnataka states. The summary of the study sites and their characteristic features are given in Table 1.

2. 1. 1. Stretch of Western Ghats in Tamil Nadu

Tamil Nadu part of Western Ghats is found between Kanyakumari in the south to Nilgiris (8° - 12° N) in the north and covers about 400 km length of east facing mountain valleys. The west-facing regions are shared by Kerala state. The two important ecoregions are Nilgiris and Pothigai hills.

Pothigai hill, a part Agasthyamalai Biosphere Reserve (proposed), is located in the Tirunelveli and Kanyakumari districts of Tamil Nadu, between latitudes 8° 20' - 8° 50' N and longitudes 77° 05' - 77° 40' E (Fig. 2). The highest point is Pothigaimudi peak reaching 1868 m (Davis *et al.*, 1995). These hills form a very compact block of reserve forests comprising Papanasam, Singampatti, Kalakad, Mundanthurai, Sivasailam, Kadayam and Sengaltheri (Hendry *et al.*, 1984). These forests have important water catchment areas and they are drained by several small perennial streams which join to form major east flowing river systems such as Tamiraparani and Nambiyar in Tirunelveli and Tuticorin districts and one west flowing river called Chittar-II, in Kanyakumari district (Fig. 2). There are five major reservoirs in this region, which are used to produce hydropower, drinking water supply, irrigation purposes and industrial use. Four study sites were selected in this region, three in east flowing streams namely

Thalayanai (Manimuthar river basin, sub basin of Thamiraparani river basin), Karaiyar (Tamiraparani river basin) and Hanumannadhi (Chittar river basin, sub basin of Thamiraparani river basin) from Tirunelveli district and one in a west flowing stream namely Samikuchi stream (Chittar-II river basin) from Kanyakumari district (Fig.2).

Another important ecoregion in Tamil Nadu is the Nilgiri Biosphere Reserve lying between borders of Kerala, Karnataka and Tamil Nadu states (10° 45' - 12° 15' N lat. and 76° 00' - 77° 15' long. E). This area covers 5520 km^2 in the Nilgiri hills (Davis *et al.*, 1995). The highest peak in the Nilgiri hills, Doddabetta (2636 m), is excluded from the Biosphere Reserve. On the east, the Nilgiri slopes down to Coimbatore plains. The eastern portion is drained by tributaries of Moyar and Bhavani rivers (Fig. 2) which ultimately join the major east flowing river Cauvery (Davis *et al.*, 1995). The Nilgiris and Palanis are spurs from the main hill chain which extend from the Western Ghats eastwards to a longitude of 78° E (Daniels, 1992). The area is subjected to the influence of both south-west and north-east monsoons. Many types of vegetation can be found from tropical evergreen rain forest to grasslands. This area is rich in floral and faunal diversity and high degree of endemism and hence the area is considered as Regional Centre for Endemism (Davis *et al.*, 1995). A study site therefore was selected in the upstream of Moyar (Cauvery river basin) from Nilgiri district of Tamil Nadu (Fig.2).

2. 1. 2. Stretch of Western Ghats in Kerala

Kerala part of Western Ghats lies between the latitude of 8° 18' - 12° 48' N and longitude of 74° 52' - 77° 52' E and covers about 500 km length of west facing mountain valleys. The state is bounded by Karnataka in the north, Tamil Nadu in the south and Arabian sea in the west (Fig. 1). The mountain region consists of a series of hilly ranges covered with dense forest vegetation. The eastern border of Kerala is bounded by an almost unbroken mountain chain with major hills like Anamalai, Choolamalai, Elamalai, Amruthamalai etc., The hill chain is interrupted in north by a 30 km wide 'Palghat Gap' at around 11° N and south of this gap lies the Anamalai range of hills with the highest peak (Anaimudi - 2695 m) in Peninsular India.

Kerala is a warm, humid, tropical climate state with an average rainfall ranges from 1016 mm to 7620 mm in hilly areas and relative humidity ranges from 75 - 92 % (Sreekumar and Nair, 1991). The state receives precipitation both during south-west and north-east monsoons. A major portion of annual precipitation is received from south-west monsoon between June and September. March and April are the hottest months. Many torrential and perennial hill streams are the main sources for 44 rivers of which 3 are east flowing. Among the west flowing rivers Bharathapuzha is the largest one in the state which originates from Anamalai hills and drains into the Arabian sea. Periyar is the second largest river in Kerala originates from the Sivagiri hills. Other important rivers include Manjeswar, Manimala, Achankoil, Kallada, Meenachil, Pamba, Karamana, Neyyar, Beyurpuzha and Chalakudi. The important east flowing rivers are Kabini, Bhavani and Pambar. They take their origin from Nilgiri Biosphere Reserve in Wynaad district and drains into the major east flowing river Cauvery. Five study streams were selected from this region covering four major river basins such as Vamanapuram, Achankoil (south Kerala), Periyar (central Kerala) and Kabini (north Kerala) (Fig. 3).

2. 1. 3. Stretch of Western Ghats in Karnataka

Karnataka part of Western Ghats lies between the latitude of 11° 12' N and 18° 12' N, which runs north to south for about 640 km with an average width (east to west) of 50 - 65 km (Fig. 1). This region is mainly forested and hilly. This sector forms the Archean series of the rocks and its highest point is Kudremukh (2071 m) in Chikmagalur district. The state receives rainfall during the south-west (June - September) and north-east (October - November) monsoons. Agumbe receives the highest rainfall (7090 mm) in the state (Prasad and Malhotra, 1984) and the Western Ghats have also created a rain-shadow area to the east. The vegetation ranges from tropical wet evergreen, deciduous (666 - 1000 m) to scrub type, as in other parts of Western Ghats (Nayar, 1996).

A large number of rivers transverse the narrow strip of land between the ridge of Western Ghats and the coast. The ridge also divides east flowing and west flowing rivers. The major west flowing rivers are Kali, Gangavali-Bedti, Aghanashini and Sharavati. These rivers, although having independent basin are clubbed together into a single basin (Irrigation Department, 1983). This basin with a relatively small catchment area, yields about 57 % of the surface waters of the state (Prasad and Malhotra, 1984).

The eastern slope of Western Ghats drains a number of streams and rivers, which forms major river basins called Cauvery and Thungabhadra. Kodagu district has the maximum yield (75 %) of surface water for Cauvery river (Prasad and Malhotra, 1984). Five study streams were selected from this region covering four river basins of Cauvery, Thunga, Aghanashini and Bedti (Fig. 4).

2. 2. Detailed study site descriptions

Name of the study streams, river basins, altitude, stream gradiant, air temperature, mean channel width and the riparian cover are given in Table 1.

Site 1. Samikuchi (S1)

Samikuchi stream is one of the tributaries of Chittar-II river (west flowing) in Kanyakumari district of Tamil Nadu. It originates from the western slope of Maramalai hills of Western Ghats and it is impounded upstream and the reservior is called Perunchani. Sampling site (Fig. 2) is located in the unregulated stram above the reservior near Government

Rubber Factory, Keeriparai at an attitude of 150 - 650 m MSL. (lat. 8° 25' N and 77° 25' E long). It is a third order stream with a maximum width of 15 m, the stream bed comprising mostly of bedrocks, boulders and cobbles. Water temperature is 26 ± 2°C. The riparian vegetation is formed of old growth overstory and midstory trees which provide cover of 50%. In addition to forest cover there are about 400 ha of rubber plantation by Government Rubber Corporation.

Site 2. Thalayanai (S2)

Thalayanai is one of the tributaries of the east flowing river Tamiraparani in Tirunelveli district of Tamil Nadu. It originates from Sengaltheri region of Kalakad Mundanthurai Tiger Reserve and drains into Manimuthar reservoir. Sampling site is located (Fig. 2) just above the reservoir (1 km from the confluence point) at an altitude of 300 m MSL. (lat. 8° 35' 45'' N and long. 77° 25' 45'' E). It is a third order stream with a maximum width of 12 m, the stream bed comprising mainly of bedrock, boulders and sands. Water temperature is 28 ± 2°C. Riparian vegetation is mainly of old growth overstory and midstory tree canopy which forms a cover range of 60 - 70 %. This stream habitat is well protected by Tamil Nadu Forest Department under Kalakad Mundanthurai Tiger Reserve. It has less access to human activities.

Site 3. Karaiyar (S3)

Karaiyar is a tributary of the Tamiraparani river in Tirunelveli district of Tamil Nadu. It originates from Kannikatti region of Kalakad Mundanthurai Tiger Reserve and extends up to Karaiyar reservoir. Sampling site (Fig. 2) is located 4 km from the Karaiyar dam site (lat. 8° 40' 00'' N and long. 77° 20' 15'' E) on the way to Kannikatti Forest Rest House (near Katalamalai estate). It has an altitude of 300 m MSL. It is a third order stream with a maximum width of 10 m, the stream bed comprising mainly bedrocks, boulders and sand. Water temperature is 27.5 ± 2°C. Riparian vegetation is formed of old growth forest mostly overstory canopy providing a cover range of 70 - 80 %. It is also a well protected area under Kalakad Mundanthurai Tiger Reserve.

Site 4. Hanumannadhi (S4)

Hanumannadhi is a tributary of Chittar river, which forms a sub-basin of Tamiraparani river in Tirunelveli district of Tamil Nadu. It originates from the Shenkottai range of hills and joins with the main river near a place called Thayarthoppu. Sampling site is located (Fig. 2) near a village called Mekkarai (lat. 9° 05' N and long. 77° 20' E). The altitude range is 200 - 300 m MSL. It is a third order stream with a maximum width of 12 m, the stream bed mainly comprises boulders and cobbles. Water temperature is 26 ± 2°C. Riparian vegetation is completely altered and were replaced by plantation such as arecanut and silk cotton trees. Very poor natural vegetation exists along the stream banks and with less cover (20 %). Most of the stream habitats are open.

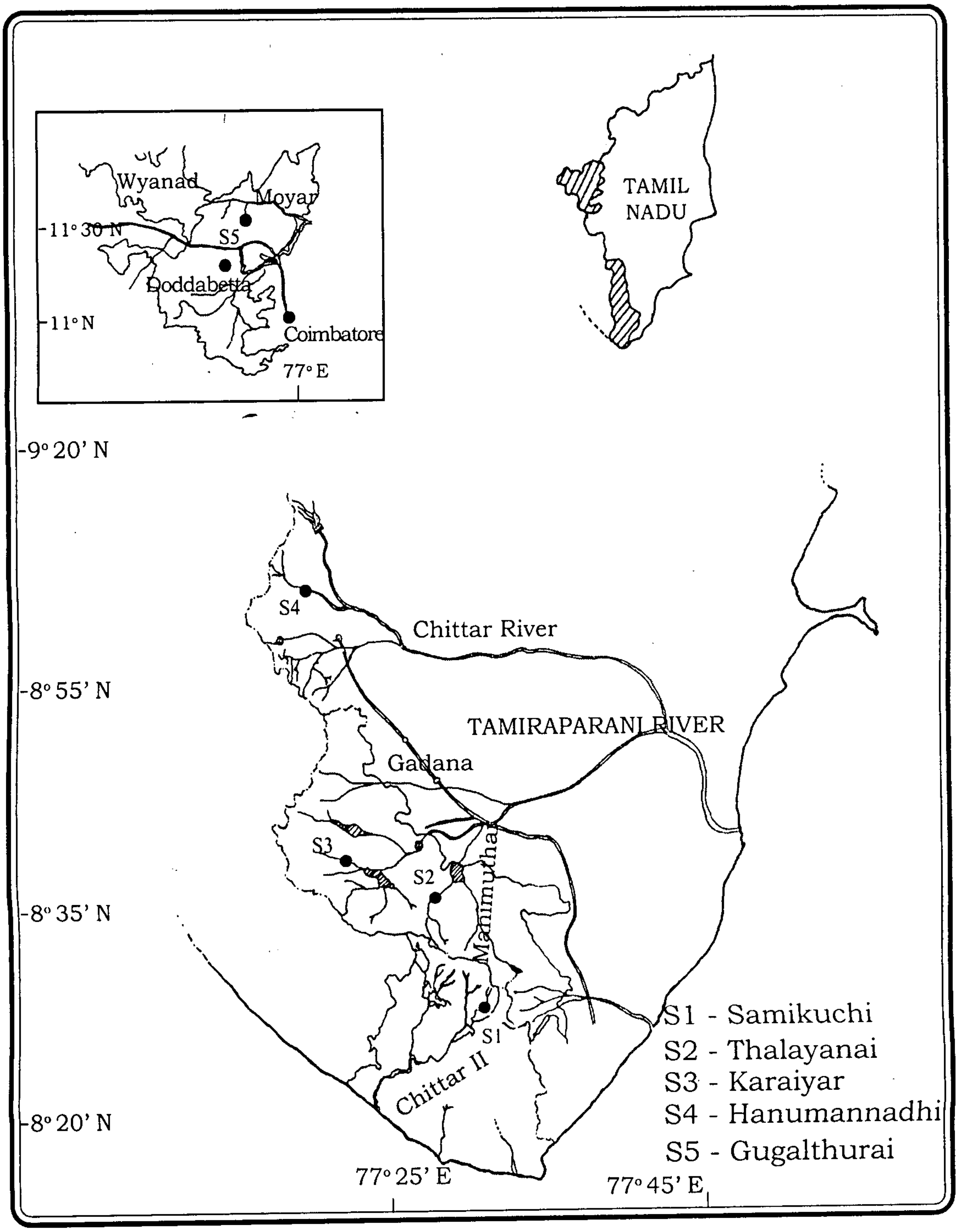

Figure 2. Map showing the study streams in Tamil Nadu part of Western Ghats.

Site 5. Gugalthurai (S5)

Gugalthurai stream is a tributary of Moyar river (sub basin of Cauvery river). It originates from eastern slope of Nilgiri Biosphere Reserve and it confluences with Bhavani Sagar Reservoir. Sampling site is (Fig. 2) located near a village called Thengumarada in Nilgiri district of Tamil Nadu (lat. 11° 40' N and long. 76° 45' E). It has an altitude of 600 m MSL. It is a third order stream with a maximum width of 8 m, the stream bed comprising mainly of bedrocks and boulders. Water temperature is 27 ± 2°C. Riparian vegetation mostly of midstory natural forest provides a cover of 60 %. It is a well protected area and less disturbed from human activities, even though local people depend upon this stream for irrigation and fishing activities.

Site 6. Kallar (S6)

Kallar is one of the major tributary of Vamanapuram river. It originates from Chemmunji mottai hills of Tiruvananthapuram district, Kerala and it drains into Anjuthengu kayal after covering a course of 88 km. Sampling site (Fig. 3) is located in Kallar village (5 km from Vithura, on the way to Ponmudi hill resort) at an altitude of 800 m MSL. (lat.8° 45' N and long. 77° 15' E). It is a third order stream with a maximum width of 12 m and the stream bed comprises mainly of boulders, cobbles and sands. Water temperature is 26 ± 2°C. Riparian vegetation is mainly formed of old growth forest which provides stream cover of about 70 %. Major threat in this stream is habitat destruction by local people for sand digging and water extraction.

Site 7. Achankoil (S7)

Several small streams like Pallikondanar, Chittar and Thoraiar originating from Pasukida mettu, Ramakalteri and Rishimalai join to form Achankoil river. It is one of the major sub basins in the west flowing river called Pamba in Kerala. The main river of Achankoil flows in a north-westerly direction before it confluences with the Pamba river at a place called Veeyapuram. Sampling site (Fig. 3) is located 8 km from Achankoil village at an altitude of 600 m MSL. (lat. 9° 10' N and long. 76° 50' E). It is a fourth order stream with a maximum width of 12 m, the stream bed mainly comprises of boulders, cobbles and gravels. Water temperature is 26 ± 2°C. Riparian vegetation is mostly of natural old growth forests with overhanging vegetation (70-80%).

Site 8. Panniyar (S8)

Panniyar is a tributary of the major west flowing river called Periyar. Most of the headwater streams of Panniyar originates from Santhamparai hill regions of Idukki district of Kerala and it is regulated dwon stream and the reservoir is called Ponmudi. Sampling site (Fig. 3) is located between Santhamparai and Pooparai (4 km from Santhamparai village) at an altitude of 912 m MSL. (lat. 9° 45' N and long. 77° 15' E). It is a third order stream with a maximum width of 8 m and the stream bed comprised mainly of large boulders and bedrocks. Water temperature is 17 ± 2 °C. Riparian vegetation is completely altered with cardamom and tea plantations. Scattered old growth forests provide the stream cover about

30 % and the rest of the canopy cover of (60 - 70 %) cardamom plantations extends to the stream side in some areas.

Site 9. Thalipuzha (S9)

Thalipuzha is one of the tributaries of Kabini river (a sub-basins of Cauvery river). It originates from Vellarymalai hills of Wynaad district, Kerala. Sampling site (Fig. 3) is located between Vythiri town and Pookat lake (2 km down from Pookat lake). With an altitude of 750 m MSL. (lat. 11° 30' N and long. 76° 45' E). It is a third order stream with a maximum width of 8 m, the stream bed comprises mostly of boulders and cobbles. Water temperature is 23 ± 2 °C. Stream bank vegetation is altered with sparse growth of small shrubs and bamboo trees on left and on the right bank human settlement, arecanut and orchard plantations are found. Stream cover is less than 50 %.

Site 10. Bavalipuzha (S10)

Bavali is a tributary of a major east flowing river called Kabini. It originates at about 1350 m MSL from Brahmagiri hills in Trirunelli village of Wynaad district, Kerala and it joins with the Kabini river near the border of Karnataka state. Sampling site (Fig. 3) is located just in the boundary line of Karnataka and Kerala states near a village called Bavali (lat. 11° 55' N and long. 76° 45' E). It is a third order stream with a maximum width of 10 m, the stream bed comprises of mostly boulders, cobbles and sand. Water temperature is 23 ± 2 °C. Riparian vegetation mostly of

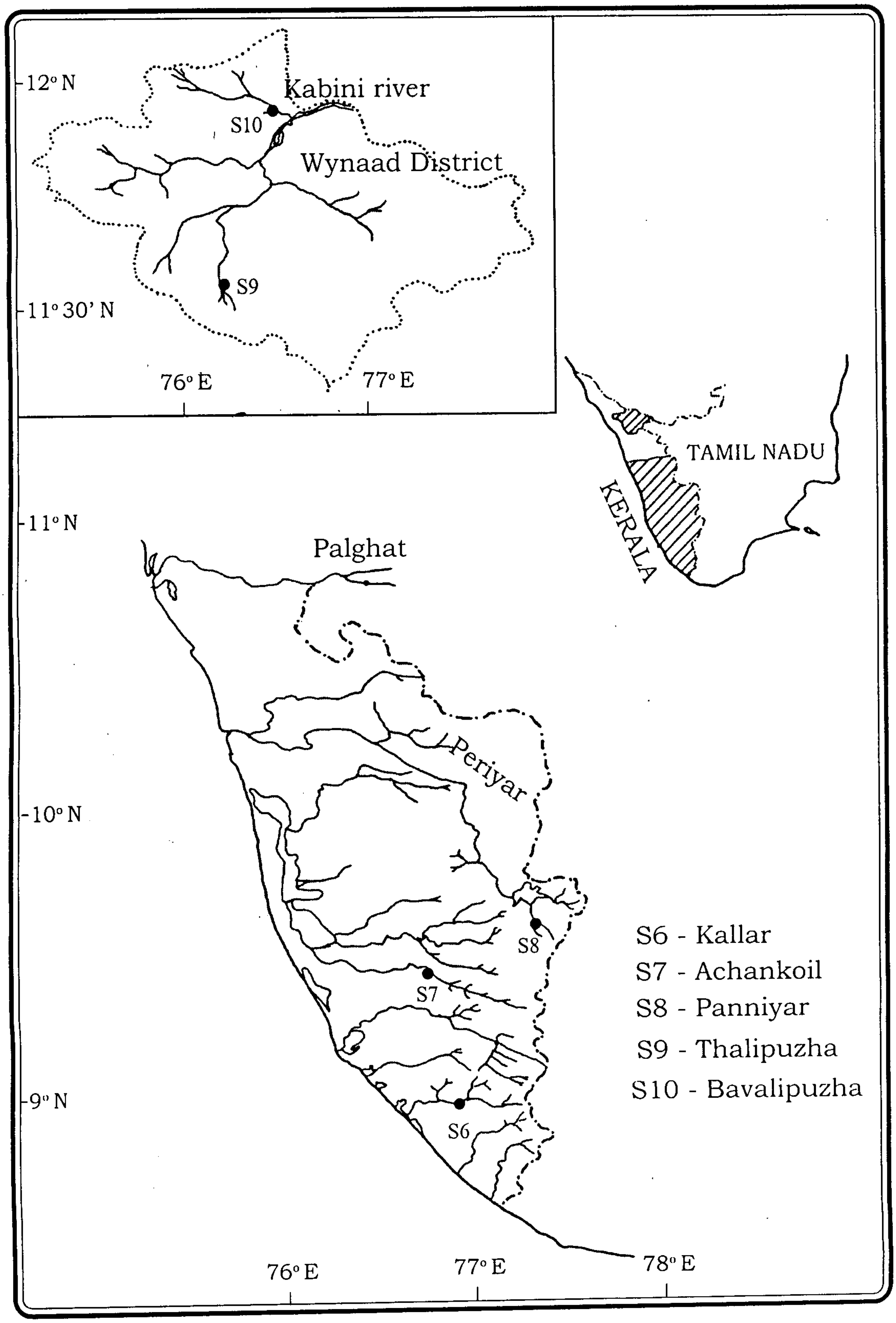

Figure 3. Map showing the study streams in Kerala part of Western Ghats.

overstory and understory of old growth forests which provide 60 - 70 % cover. Both sides of the stream bank beyond the riparian zone are inhabited by human.

Site 11. Ekachi (S11)

Ekachi is one of the tributaries of a east flowing river called Heamavathi (a sub basin of Cauvery river). It originates from Mudigere hills of Western Ghats, Chickmagalur district of Karnataka. Sampling site (Fig. 4) is located 15 km from Mudigere town at an altitude of 700 m MSL. (lat. 12° 45' N and long. 75° 45' E). It is a third order stream with a maximum width of 8 m, the stream bed mainly comprises of bedrocks, boulders and cobbles. Water temperature is 24 ± 2°C. Riparian vegetation is completely altered on both sides of the bank for paddy cultivation. Scattered midstory trees provide stream cover 40 %. Check dam for bathing purposes are common and the downstream is much more disturbed. Stream bank stability is poor, unstable and secondary confinements are found along the course.

Site 12. Kigga (S12)

Kigga is one of the tributaries of a west flowing river called Thunga. It originates from the Kudremukh Wildlife Sanctuary of Chickmagalur district, Karnataka. Sampling site (Fig. 4) is located 10 km from the Sringeri town. There is a famous waterfall called Kigga falls in the upstream of the sampling site with a height of 50 m at an altitude of 900 m MSL. (lat. 13°

20' N and long. 76° 15' E). It is a third order stream with a maximum width of 6 m and the stream bed mainly consists of bedrocks and boulders. Water temperature is 18 ± 2°C. Below the falls a narrow channel is formed with full canopy cover mostly overstory old growth forest which provides stream cover of 82 %. Both the banks are stable and the stream is less disturbed by human activity.

Site 13. Thunga (S13)

Thunga is one of the major sub basins of the largest east flowing river called Krishna. Several streams like Nagatheertha, Nanthini, Nalini, Kangamula, Kigga and Suthan abbi originate from Kudremukh and Sringeri hills, Chickmangalur district, Karnataka. Sampling site (Fig. 4) is located in the Sringeri town (1 km down from Sringeri Mutt) at an altitude of 400 m MSL. (lat. 13° 45' N and long. 76° 20' E). It is a fifth order stream with a maximum width of 20 m, the stream bed comprises mostly of cobbles, gravels and sand. In the upstream near the Mutt, more than 650 number of adult *Tor* spp. aggregation is maintained under Mutt control. A high density of viable population of the critically endangered genera of *Tor* is found only in this temple sanctuary. Water temperature is 21 ± 2°C. Riparian vegetation is completely altered, with narrow strips of herbs, shrubs and bamboos which provide stream cover of a range of 10 - 15 %. In the upstream region, undisturbed riparian canopy still exists.

Site 14. Sirkuli (S14)

Sirkuli is the upstream of Aghanashini river and it is one of the major perennial west flowing rivers in Uttar Kannada district of Karnataka. It originates from Manjaguni hills at an altitude ranging from 600 - 900 m MSL near Sirsi town. Hamagar holi (stream) a tributary of Aghanashini joining at Sirkuli village. Sampling site (Fig. 4) is located in Sirkuli village (10 km from Sirsi town, near confluence point of Hamagar holi) at 14° 30' N lat. and 74° 45' E long. It is a third order stream with a maximum width of 15 m and the stream bed comprises mostly of bedrocks and boulders. The water temperature is 32 ± 2°C. Stream banks are unstable and riparian vegetation is formed of old growth overstory and midstory trees, which provide stream cover of a range of 60 - 70 %. Aghanashini, the only undammed, preserve some excellent riverine habitats including the Unchalli falls (100 m) and its spray zone.

Site 15. Ganeshpal (S15)

Ganeshpal is one of the tributary of Bedti river another major east flowing river in Uttar Kannada district of Karnataka. It originates from south of Dhaward town. Sampling site (Fig. 4) is located at Manjikera village at an altitude of 700 m MSL. (lat. 14° 15' N and long.74° 45' E). It is a fourth order stream and the stream bed comprises mainly of bedrocks and boulders. Water temperature is 28 ± 2°C. Riparian vegetation is formed of thick canopy cover of overstory, understory and shrubs, which provide stream cover of 30 %. Stream bank is unstable.

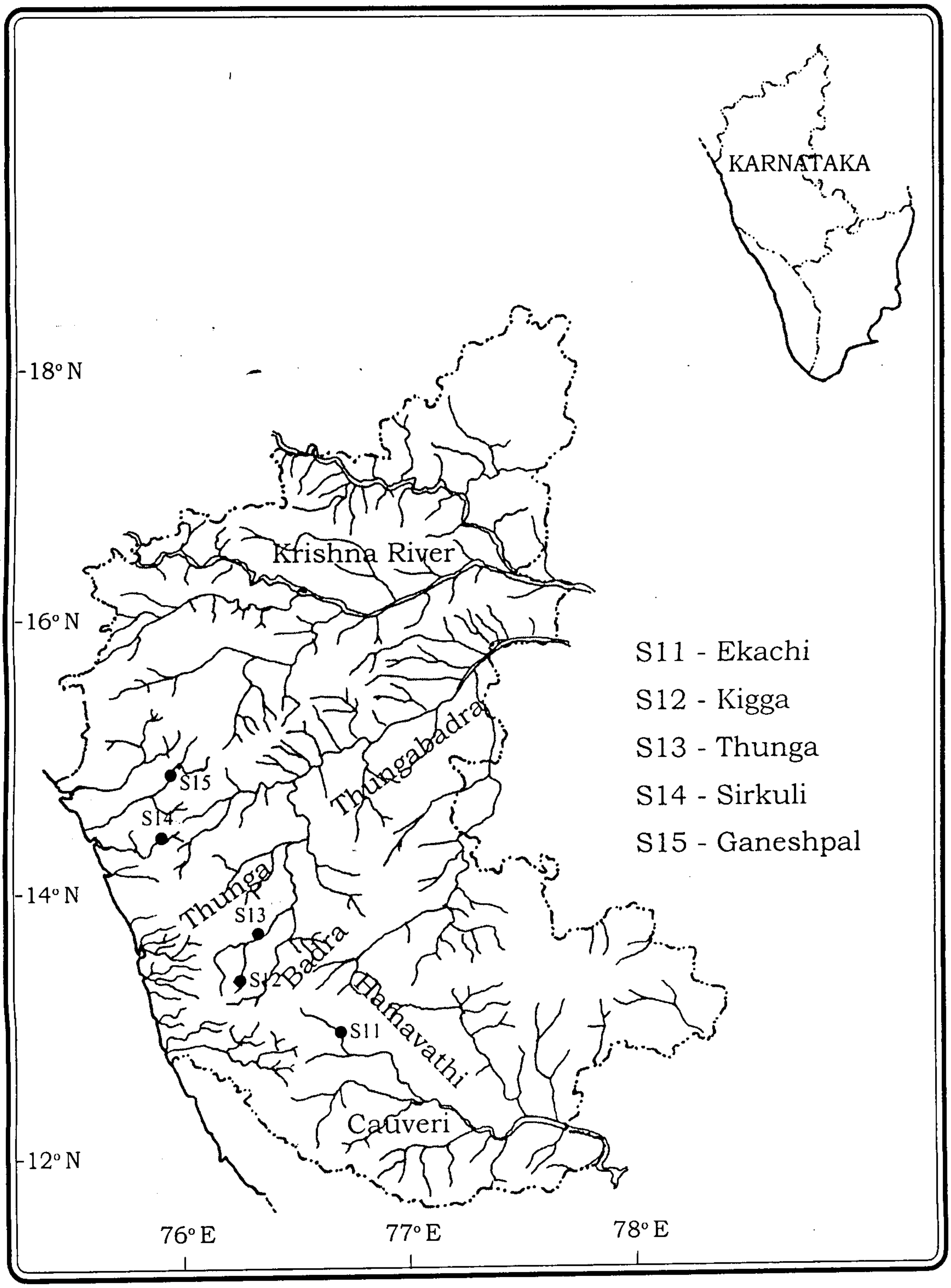

Figure 4. Map showing the study streams in Karnataka part of Western Ghats.

Table 1. Summary of study sites characters in the Western Ghats.

Sites	River basin East/West flowing	Latitude/ longitude	Altitude (m)	Stream order	Stream gradient (%)	Air temp (°C)	Mean width (m)	Riparian vegetation
Samikuchi	Chittar - II West flowing	8° 25' N 77° 25' E	500	3	7	28	45.6	50 % overstorey, midstorey old growth trees and rubber plantation
Thalayanai	Manimuthar East flowing	8° 35' N 77° 25' E	300	3	7	32	25.6	60 – 70 % overstorey and midstorey old growth forest trees.
Karaiyar	Tamiraparani East flowing	8° 40' N 77° 20' E	300	3	7	30	13.8	70 – 80 % old growth forest trees
Hanumannadhi	Chittar East flowing	9° 05' N 77° 20' E	200	3	2	30	37.4	20 % planted areca and coconut forms
Gugalthurai	Cauveri East flowing	11° 40' N 76° 45' E	600	3	6	30	11.5	60 % midstorey forest trees
Kallar	Vamanapuram West flowing	8° 45' N 77° 15' E	800	3	7	28	22	70 % old growth forest trees
Achankoil	Achankoil West flowing	9° 10' N 76° 50' E	600	4	4	27	20	70 – 80 % midstorey and overstorey (old growth forest trees)
Panniyar	Periyar West flowing	9° 45' N 77° 15' E	912	3	6	28	14	60 – 70 % plantations, clove and cardomam
Thalipuzha	Cauvery East flowing	11° 30' N 76° 15' E	750	3	3	31	9.1	50 %, Areca and orcharel plantation
Bavalipuzha	Cauvery East flowing	11° 55' N 76° 45' E	1350	3	4	31	20	60 – 70 % old growth forest tree
Ekachi	Cauvery East flowing	12° 45' N 75° 45' E	700	3	4	26	21	40 % scatted midstorey tree
Kigga	Thunga East flowing	13° 20' N 75° 15' E	900	3	8	20	9.5	82 % midstorey old growth forest trees
Thunga	Thungabadhra basin, East flowing	13° 45' N 76° 20' E		5	1	26	80	10 – 15 %, herbs, shrubs and bamboos
Sirkuli	Aghanasini West flowing	14° 30' N 74° 45' E	900	3	4	34	55	60 – 70 % midstorey and overstorey (old growth forest trees)
Ganeshpal	Bedti river West flowing	14° 15' N 74° 45' E	700	4	3	29	75	30 % overstorey, understorey and shrubs

Materials and Methods

Antony Johnson, J. 1999: Diversity and ecological structure of fishes in selected streams/rivers in Western Ghats. Ph.D Thesis, Manonmaniam Sundaranar University, Tirunelveli, India.

3. MATERIALS AND METHODS

3. 1. Quantification of habitats

Quantification of habitat and habitat inventory were carried out using the methods described in Armantrout (1990a) and Arunchalam (1995). Inventory was carried out at a fixed point which is designated as 0. This reference point can be readily recognizable by others with permanent features like confluence of tributaries, bridge, culert or any other man-made structures. The inventory was done in one habitat at a time moving upstream. Different habitat types such as pools, riffles, runs, cascades, falls etc., were recorded within 100 m stretch. Pools are areas of slow, tranquil flow without small-scale hydraulic jumps or free surface in stabilities and with few boulders exposed at low flow (Grant *et al.*, 1990). Riffles are areas of subcritical flow modified by local free-surface instabilities and small hydraulic jumps over bed roughness elements. Water surface typically has a rippled appearance; depths are shallower and velocities greater than in pools at low flow (Grant *et al.*, 1990). Runs are channel unit distinguished from riffle by greater percentage of stream area, substratum more or less homogeneous with cobbles or gravels and at low flow (Armantrout, 1990a). Cascades are steep channel units where water flows over large boulders in a series of short, well-defined steps about one particle diameter (~ 0.2 to 1.0 m) high that are separated by areas of more tranquil flow less than one channel width in length create a staircase appearance. Cascades have more than 50 % of stream area in supercritical flow (Grant, *et al.,* 1990).

Fish populations were estimated in each habitat type based on fish catch and underwater observation. The habitat specific utilization coefficient was calculated for individual fish species using the electivity index of Ivelev (1961) based on Schlosser (1991).

$$\text{Utilization coefficient} = \frac{\text{Habitat specific density} - \text{Average total density}}{\text{Average total density}}$$

Habitat utilization theoretically commences from minus one, indicating total non-use of the habitat type to positive infinity as a greater proportion of the population resides in the habitat type of interest. Fewer species of fishes were excluded, because of less frequency of occurrence.

Habitat-use guilds were proposed on the basis of information of fish sample, underwater observation and habitat utilization coefficient.

3. 1. 1. Measurement of macrohabitat characters

Each stream reach in the study site was quantified for depth, flow and substrate characteristics. Number of transects usually 5-10 were taken across the stream channel depth and water velocity and dominant substrates were measured or estimated at 0.5 or 1 m intervals across the transects. Interval width depends on channel width. Water velocity was recorded with a digital electronic pigmy water current meter (Model : Propeller type no. Lynx pp.001).

Habitat structure was evaluated in each site on the basis of depth, current velocity and substrate types following the Schlosser (1982) and Pusey *et al.* (1993). Substrate was classified into six categories; Bedrock, boulder, cobble, gravel, sand and leaf litters (Table 2) and were estimated visually. Depth and current measurements were subsequently divided into six (D_1-D_6) and four (F_1-F_4) categories, respectively (Table 2) to facilitate computation of habitat complexity index.

Depth, current and substrate categories used were constant for all streams. The data from each measurement point represents a particular habitat configuration expressed in three dimensions (depth, current, substrate). The number of unique configuration of each category and their frequencies of occurrence were used to compute Shannon index of habitat complexity at each sampling site. Percentage of pool and riffle habitats was estimated for each site. Area of each site was estimated from length and mean width of the channel. Volume of each site was estimated from area and mean depth (Angermeier and Schlosser, 1989). Riparian cover

Table 2 : Categories of depth, velocity, substrate types and fish cover used to compute the index of habitat diversity and microhabitat measurement in study streams.

Variables	Categories
Depth (cm)	D_1 (0 - 10), D_2 (11 - 30), D_3 (31 - 60), D_4 (61 - 100), D_5 (101 - 150), D_6 (> 150)
Velocity (m/sec)	Stagnant (0 - 0.15), Low (0.16 - 0.30), Moderate (0.31 - 0.60), Fast (> 0.60)
Substrate (mm)	Bedrock (> 512 mm), Boulder (128 - 512 mm), Cobble (64- 128 mm), Gravel (16 - 64 mm), Sand (1 - 16 mm), Leaf litter (on sand or silt)
Fish cover (coded)	1 - No cover; 2 - Small boulder undercut; 3 - Boulder undercut; 4 - Submerged log; 5 - Overhanging vegetation; 6 - Bedrock undercut; 7 - Root undercut.

in the site was estimated using spherical densiometer (model : C) stream gradient was measured using a clinometre (model : suunto PM5/360 PC).

Relationship among number of individuals, number of species, habitat areas, habitat volume, percentage of pool and riffle, percentage of riparian cover and habitat complexity were examined using linear regression (Angermeier and Schlosser, 1989). Habitat area, habitat volume and number of individual fishes, riparian cover and percentage of pool - riffle were $\log_{10}$ - transformed in the analysis in order to minimize effects of non-normality.

3. 1. 2. Measurement of microhabitat availability

Microhabitat observations were made during daylight hours by use of face mask and snorkel as majority of fishes were active during daylight hours (Grossman and Freeman, 1987). In the microhabitat analysis cyprinid species alone were taken into account, because in all study streams the dominant assemblage members were cyprinids. Members of this family typically are quiescent during nocturnal hours (Helfman, 1983). Observations were made only on fish that were feeding, holding in current or otherwise behaving in a natural manner. The presence of slow-moving observer did not appear to affect fish behaviour and fishes frequently fed directly underneath or within 20 cm of observers.

Quantification of the availability of microhabitats was carried out using Instream Flow Incremental Methodology (IFIM), outlined by Bovee

(1982). It has been widely used in United States and Canada for predicting fish population density (Reiser *et al.*, 1989; Armour and Taylor, 1991). Each site (100 m reach) was divided into 10 m segments and 5 to 10 transects were placed across each segment regularly. In each transect water column depth, velocity, substrate types and cover complex were recorded. Habitat types classification in the present study was based on the system of Bovee (1982) and Armantrout (1990a) with some modifications. The microhabitat availability (velocity, depth, cover and substrate type) were assessed by random sampling approach with each sample having a frequency of one. All samples having the same habitat measurements were combined to determine the total frequency of samples with that unique combination of characteristics. The probability of such combination was then computed by dividing the frequency of its occurrence by the total number of samples in the database. A frequency histogram was constructed for each category in each study site. The spatial differences in microhabitat availability data were tested by using Principal Component Analysis (PCA). PCA with varimax rotation was accomplished (SPSS 7.5).

3. 1. 3. Microhabitat use

For each observation the following microhabitat parameters were measured based on method described in Bovee (1982) and Moyle and Vondracek (1985) . Depth of water column, distance of fish from bottom, water velocity near the fish, substrate composition over fish and fish cover complex were measured. The amount of cover was visually scored on a scale of 1 to 7 (Table 2) based on Bovee (1982). Such visual estimations had the advantage of being readily readable in the field and were consistent among all samples.

Based on the number of individuals observed, the frequency distribution for the microhabitat variables were calculated. The microhabitat use in assemblage members was quantified using the Principal Component Analysis (PCA). The mean value of each attribute for each species was used as input.

3. 2. Fish assemblage structure

Fishes were sampled in all study streams in one occasion from July 1996 to January 1999 in different habitats such as pools, riffles, runs, etc. Fish catch was performed using monofilamentous gill nets of different mesh sizes (10 to 34 mm), multifilamentous gill nets, drag nets, scoop net and cast net. Fishes were examined, counted and were released back in to the system after taking few specimens (5 - 10) which were preserved in buffered formalin (10 %) and transported to the laboratory for further analysis. Species identification was carried out using standard fish taxonomy textbooks (Talwar and Jhingran, 1991; Jayaram, 1999). Conservation status of species was based on conservation and Assessment and Management programme, 1997 (CAMP workshop).

Fish abundance data were subjected to diversity measures by counting the number of species in the habitat or community *i.e.*, species richness (S) which is the most widely adapted diversity index (Gaston, 1996). However, it does not account for the extent of representation of each of the species in the community. Since in the resent investigation along with the number, the frequencies of the species was also considered, it would be appropriate to adapt Shannon index (Magurran, 1988).

$$H' = - \Sigma \, pi \ln pi$$

where, H' = Shannon index

pi = is the proportion of individual found in the i^{th} species.

The similarity of fish community was calculated by using Jaccard's measures (Cj)

$$Cj = j \,/\, (a + b - j)$$

where, Cj = is the Jaccard's similarity index.

j = the number of species common to both sites

a = the number of species in site a, and

b = the number of species in site b.

If Cj is 1, it denotes complete similarity (*i.e.*, where two sets of species are identical) and if it is 0, it denotes the two sets are dissimilar and have no species in common occurrence (Magurran, 1988).

Further species abundance and their relative frequencies were subjected to cluster analysis. The most similar sites in this matrix are combined to form a single linkage cluster. The analysis was proceeded by successively clustering similar sites until all were combined in a single dendrogram (Magurran, loc. cit).

3. 3. Water quality

Water samples were collected (in 2 liter PVC container) from each site and brought to the laboratory for further analysis and / or stored for future analysis. All water quality parameters were estimated by using standard methods (APHA, 1995). Conductivity and temperature were measured in the field. Dissolved oxygen was estimated by modified Winkler's method. Total alkalinity was measured by bromocresol green-methyl red as endpoint indicators. Hardness was measured by EDTA titrimetric method. Total dissolved solids was measured by comparing conductance against evaporation method. The relationship between the water quality parameters and the fish abundance was determined by Canonical Correlation Analysis (CCA) (SPSS, 7.5).

3. 4. Fish gut content analysis

Fish gut content analysis of 5 to 45 individuals of each cyprinid taxon were used. First one third part of the gut was used for analysis. The stomach or intestine upto the first bend was removed and contents were examined under low power microscope or stereoscopic microscope. Diets of fishes were classified into animal matter, higher plant matter, algae and detritus and relative biovolumes of each diet categories were determined. The classification of diet categories and estimations were followed using the methods described in Arunachalam *et al.*, (1988).

The estimated individual guts were then pooled into size classes and the data were classified using cluster analysis. Similarly between pairs of species were calculated using Eucledcan distance, which were then, grouped using single linkage cluster.

For each species, diet breadth (B) was determined using the formula of Levins (1968). Diet breadth is measure the degree to which the population are specilised in diet categories. The dietary overlap (S) for each pair of species were determined using Schoener's (1970) index.

Diet breath (B) = $1 / S\ Pij^2$

where, Pij is the proportion of the *food items* in each category.

Diet overlap (S) = $1 - {}^{1}/_{2}\ S\ (Pxi - Pyi)$.

where, Pxi is the proportion of item 'i' in the diet of species 'x'

Pyi is the proportion of item 'i' in the diet of species 'y'.

The values for diet similarity index ranges from 0 (indicating no overlap) to 1 (indicating complete overlap). The major purpose of resource partioning study is to analyse the number of sepcies that can stably co-exist (Schoener, 1974a).

Antony Johnson, J. 1999: Diversity and ecological structure of fishes in selected streams/rivers in Western Ghats. Ph.D Thesis, Manonmaniam Sundaranar University, Tirunelveli, India.

4. Results

4. 1. Fish assemblage structure

Seventy three species of primary freshwater fishes were recorded in the 15 study streams of Western Ghats. Among which 29 species belonging to 16 genera, 6 families and 3 orders were obtained in the study streams in Tamil Nadu (Table 3). Among the twenty nine species, cyprinids were the most dominant group in the assemblage (66.6 to 83.3%) and among the cyprinids *Danio aequipinnatus, Garra mullya, Rasbora daniconius* and the Balitoridae *Noemacheilus triangularis* were represented in all the study streams (Plate 1). The small barbs *Puntius bimaculatus* was also commonly represented in the fish assemblages in all the study sites, except at Karaiyar stream. Thalayanai stream had the high species richness with 18 species including big sized barbs *Hypselobarbus curmuca, H. kolus, H. dubius, H. dobsoni, Tor khudree malabaricus* and *Barbodes sarana*. The specialised forms such as *Bhavania australis, Glyptothorax madraspatanum* and *Silurus wynaadensis* were also present (Plate 2). A new species *Puntius kannikattiensis* described from Karaiyar stream (Arunachalam and

Plate 1. **Common hill stream fishes of Western Ghats**

a) *Barilius bakeri*

b) *Danio aequipinnatus*

c) *Garra mullya*

d) *Puntius amphibius*

e) *Puntius filamentosus*

f) *Puntius ticto*

g) *Rasbora daniconius*

h) *Salmostoma clupeoides*

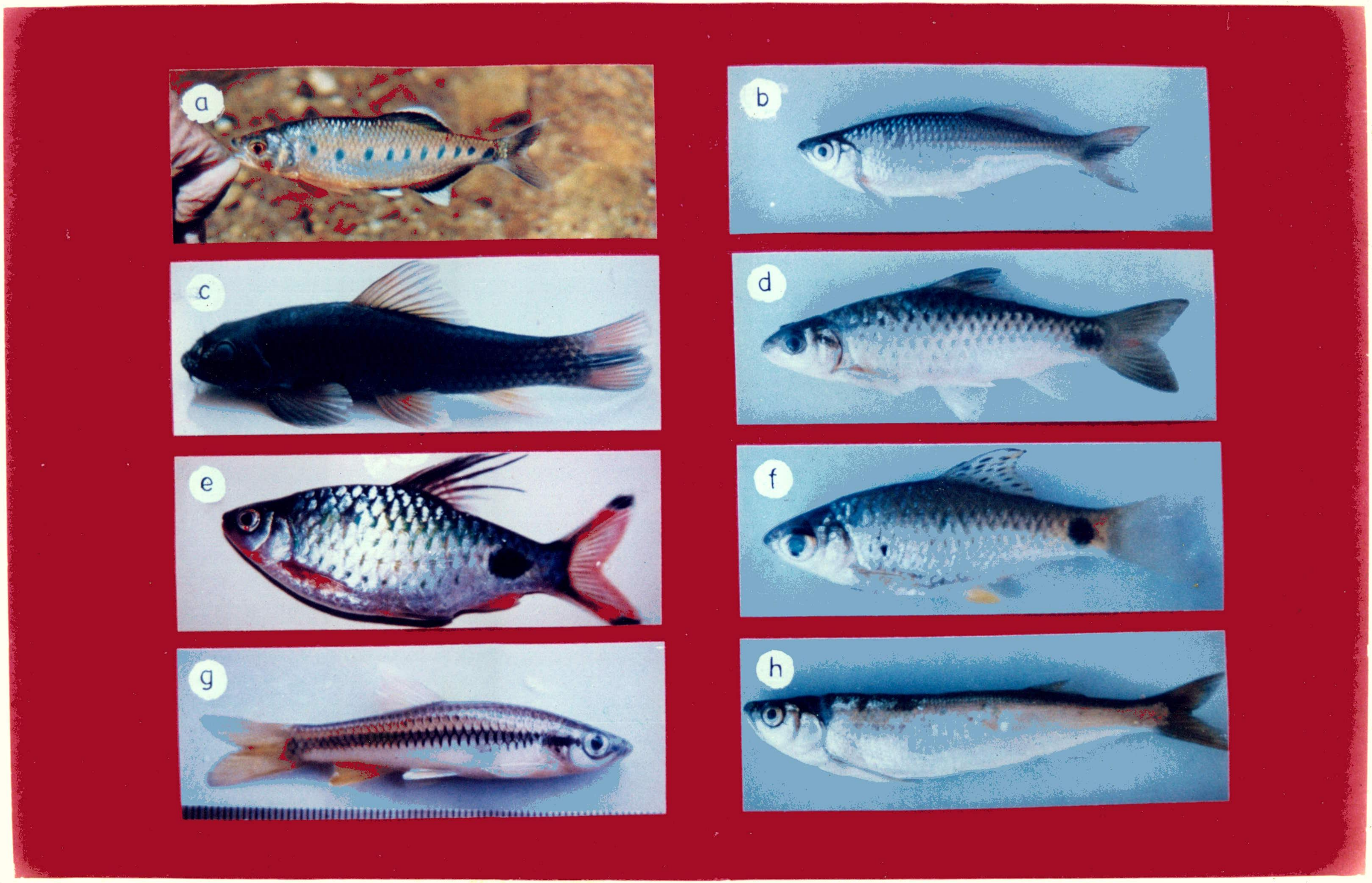
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Table 3. List of fish species recorded from study streams in Tamil Nadu part of Western Ghats.

Fish species	Samikuchi	Thalayanai	Karaiyar	Hanuman nadhi	Gugal thurai
Cyriniformes					
Cyprinidae					
Genus : Barbodes					
Barbodes carnaticus	-	-	-	-	48
Barbodes sarana	-	8	-	-	12
Genus : Barilius					
Barilius bakeri	42	-	-	-	-
Barilius gatensis	-	-	-	-	24
Genus : Danio					
Danio aequipinnatus	42	85	68	88	44
Genus : Garra					
Garra mullya	32	48	18	36	24
Genus : Horalabiosa					
Horalabiosa joshuai	-	-	28	-	-
Genus : Hypselobarbus					
Hypselobarbus curmuca	-	16	-	-	-
Hypselobarbus dobsoni	-	68	-	-	-
Hypselobarbus dubius	-	18	-	-	-
Hypselobarbus micropogon	-	-	-		32
Genus : Puntius					
Puntius amphibius	-	68	-	-	-
Puntius arulius tambraparniei	-	88	22	-	-
Puntius bimaculatus	64	45	-	34	28
Puntius dorsalis	32	22	-	-	38
Puntius filamentosus	22	38	24	-	14
*Puntius kannikattiensis**	-	-	22	-	-
Puntius melanampyx	32	-	-	-	-
Puntius ticto	18	-	-	-	26
Genus : Rasbora					
Rasbora daniconius	22	32	32	43	38
Genus : Salmostoma					
Salmostoma clupeoides	-	-	-	-	20

* New description

Genus : Tor					
Tor khudree	24	-	37	-	23
Tor khudree malabaricus	-	12	-	-	-
Balitoridae Genus : Bhavania					
Bhavania australis	12	18	17	-	-
Genus : Noemacheilus					
Noemacheilus triangularis	12	15	10	24	18
Cobitidae Genus : Lepidocephalus					
Lepidocephalus thermalis	-	-	-	14	18
Siluriformes **Siluridae** Genus : Silurus					
Silurus wynaadensis	-	8	-	-	-
Sisoridae Genus : Glyptothorax					
Glyptothorax madraspatanum	-	2	-	-	-
Perciformes **Mastacembelidae** Genus : Mastaecembelus					
Mastacembelus armatus	-	4	-	-	-

Johnson, 1999) was also included in the study (Plate 3a). Next to that Gugalthurai stream was found to have maximum species richness (S = 15). It also harboured big sized barbs like *Barbodes carnaticus, B. sarana, Hypselobarbus micropogon* and the deccan mahseer *Tor khudree.* Low species richness was recorded in Hanumannadhi stream, where only 6 species were present and all of them were common species. Specialised hill stream fishes were absent in this stream.

Streams in Kerala part of Western Ghats was represented by 48 species belonging to 26 genera 13 families and 4 orders (Table 4). The dominant cyprinid population constituted 50 to 77.7 % in the assemblage (Table 6). Also recently described species such as *Homaloptera santhamparaiensis* and *Horalabiosa arunachalami* from Panniyar stream of Periyar river basin (Arunachalam *et al.*, 1999; Johnson and Soranam, 1999) were also included in the assemblage structure (Plate 3). Low cyprinid population (50 %) was observed in Panniyar stream and it harboured some specilised forms like *Glyptothorax madraspatanum, Noemacheilus guentheri, N. keralensis* and *N. triangularis* (Plate 2). Species like *Danio aequipinnatus* and *Garra mullya* were present predominantly in all the study streams, except Panniyar stream where *Barilius bakeri* and *Garra mcclellandi* were represented. Kallar stream and Achankoil river had the high species richness, with 17 species. The big sized barbs such as *Hypselobarbus kurali, Tor khudree* and the murrel *Channa orientalis* and the specialised catfish *Silurus wynaadensis* were present.

Plate 2. **Specialised hill stream fishes of Western Ghats**

a) *Balitora mysorensis*

b) *Bhavania australis*

c) *Glyptothorax madraspatanum*

d) *Glyptothorax trewavasae*

e) *Garra bicornuta*

f) *Garra gotyla stenorhynchus*

g) *Noemalheilus denisoni*

h) *Noemacheilus keralensis*

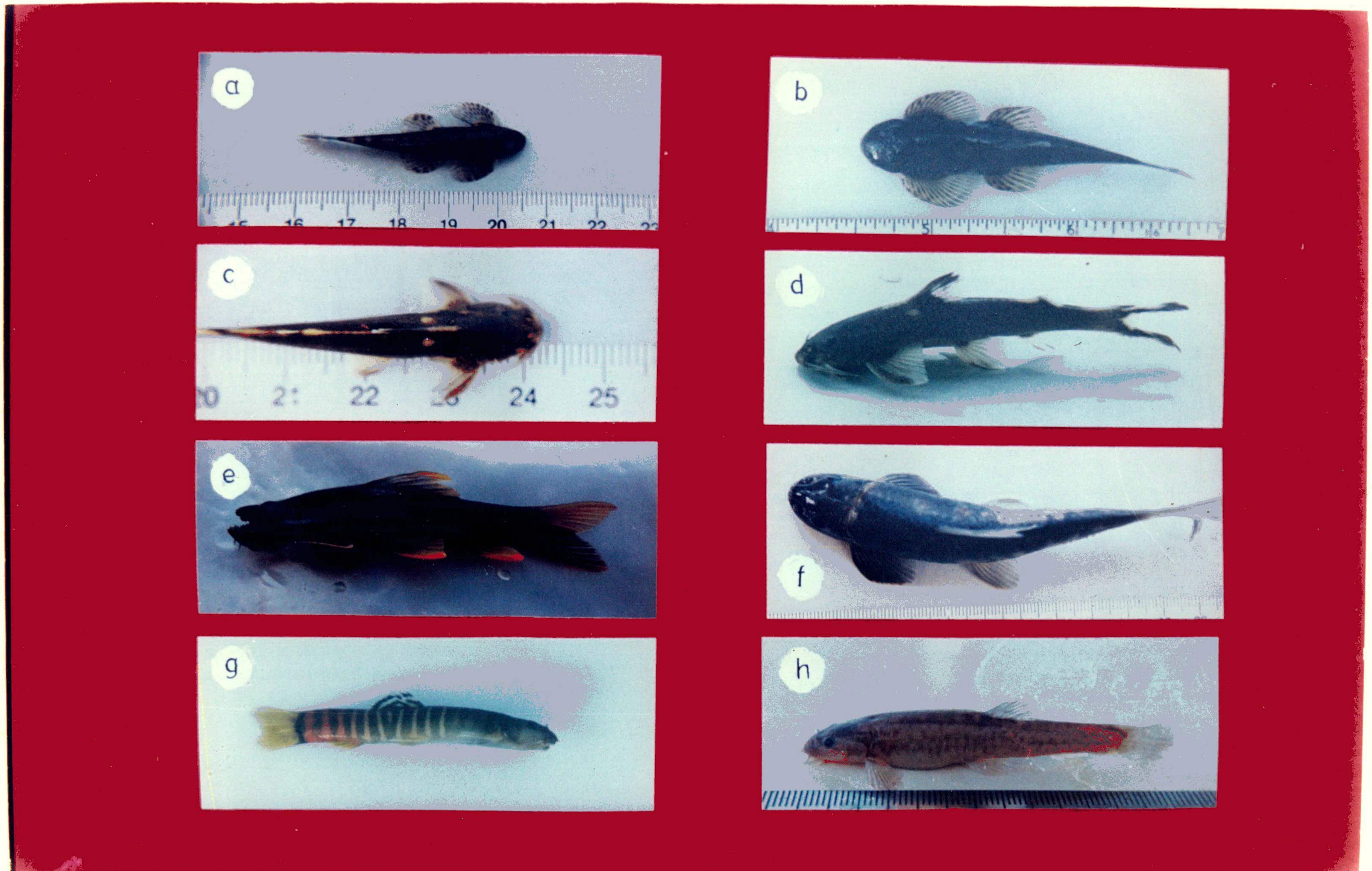
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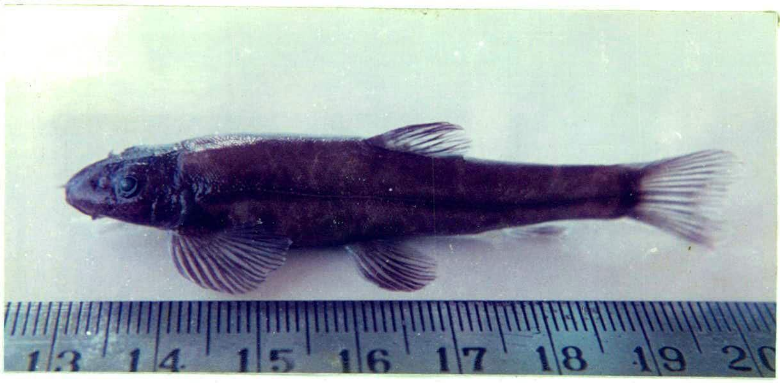
Plate 3. Newly described fishes from Western Ghats

a) *Homalaptera santhamparaiensis*



b) *Horalabiosa arunachalami*

c) *Puntius kannikattiensis*

Table 4. List of fish species recorded from study streams in Kerala part of Western Ghats.

Fish species	Kallar	Achan koil	Panniyar	Thali puzha	Bavali puzha
Cyprinodontiformes **Aplocheilidae** Genus : Aplocheilus					
Aplocheilus lineatus	-	18	-	11	-
Aplocheilus panchax	-	8	-	-	-
Cypriniformes **Cyrinidae** Genus : Barilius					
Barilius bakeri	72	76	44	-	-
Barilius gatensis	-	-	-	54	-
Genus : Danio					
Danio aequipinnatus	38	34	-	42	28
Danio (Brachydanio) rerio	-	-	-	-	25
Genus : Garra					
Garra gotyla stenorhynchus	-	-	-	-	15
Garra hughi	15	-	-	-	-
Garra mcclellandi	-	-	33	-	-
Garra mullya	45	46	-	36	42
Genus : Horalabiosa					
*Horalabiosa arunachalami**	-	-	11	-	-
Genus : Hypselobarbus					
Hypselobarbus kurali	26	-	-	-	-
Hypselobarbus micropogon	-	-	-	8	-
Genus : Osteochilichthys					
Osteochilichthys nashii	-	-	-	15	-
Genus : Puntius					
Puntius amphibius	-	55	-	-	-
Puntius arenatus	-	32	-	-	-
Puntius conchonius	-	-	-	16	22
Puntius denisonii	-	24	-		-
Puntius dorsalis	-	38	-		-
Puntius fasciatus	35	-	-	-	-
Puntius filamentosus	56	52	-	-	-
Puntius melanampyx	65	46	45	32	-

* New description

Puntius parrah	-	-	-	-	34
Puntius sophore	-	-	-	-	24
Genus : Rasbora					
Rasbora caverii	-	-	-	-	14
Rasbora daniconius	34	54	45	-	-
Genus : Salmostoma					
Salmostoma boopis	-	15	-	-	-
Salmostoma clupeoides	-	-	-	-	15
Genus : Tor					
Tor khudree	30	-	-	-	-
Balitoridae Genus : Bhavania					
Bhavania australis	24	22	-	-	-
Genus : Noemacheilus					
Noemacheilus denisoni	15	-	-	-	-
Noemacheilus guentheri	-	-	6	-	-
Noemacheilus keralensis	-	-	28	-	-
Noemacheilus triangularis	28	-	25	-	-
Genus : Homaloptera					
*Homaloptera santhamparaiensis**	-	-	7	-	-
Cobitidae Genus : Botia					
Botia striata	5	-	-	-	-
Genus : Lepidocephalus					
Lepidocephalus thermalis	15	-	-	-	-
Siluriformes **Bagridae** Genus : Mystus					
Mystus armatus	-	-	-	25	-
Genus : Batasio					
Batasio travancoria	-	10	-	-	-
Clariidae Genus : Clarias					
Clarias dussumieri	-	-	-	-	15

* New description

Siluridae Genus : Silurus					
Silurus wynaadensis	8	-	-	-	-
Sisoridae Genus : Glyptothorax					
Glyptothorax madraspatanum	-	-	5	-	-
Schilbeidae Genus : Proeutrotiichthys					
Proeutropiichthys taakree taakree	-	4	-	-	-
Perciformes **Ambassidae** Genus : Pseudambassis					
Pseudambassis baculis	-	-	-	-	28
Pseudambassis ranga	-	-	-	-	24
Channidae Genus : Channa					
Channa orientalis	10	-	-	-	-
Cichlidae Genus : Etroplus					
Etroplus maculatus	-	34	-	-	-
Mastacembelidae Genus : Mastacembelus					
Mastacembelus armatus	-	-	-	-	10

In Karnataka streams, 33 species belonging to 18 genera, 6 families and 4 orders were recorded (Table 5). Cyprinids dominated the assemblages with a range of 45.5 to 87.5% (Table 6) and among them *Danio aequipinnatus* was recorded in all the study streams. Low cyprinid assemblage was represented in the high gradient stream Kigga, where the highly specialised forms such as *Balitora mysorensis, Bhavania australis, Glyptothorax trewavasae, Noemocheilis denisoni* and *N. semiarmatus* were recorded (Plate 2). High species richness was found in Thunga river (S = 16) and the species *Hypselobarbus kolus, Puntius pulchellus, Barilius gatensis, Garra bicornuta, Osteochilichthys nashii* and *O. thomassi* were recorded only from that site. The deccan mahseer *Tor khudree* was represented in Kigga falls and in Thunga river. *Puntius bimaculatus* was recorded only in Ekachi stream and the big sized barb *Hypselobarbus jerdoni* was found in streams of Sirkuli and Ganeshpal (Plate 4). Ekachi, Kigga and Sirkuli sites had similar species richness (S = 11) and the low species richness (S = 9) was recorded in Ganeshpal.

4. 1. 1. Species diversity and similarity

In Tamil Nadu, Thalayanai (H' = 1.11) and Gugalthurai (H' = 1.08) streams recorded high species diversity. In Hanumannadhi stream low value (H' = 0.71) was rcorded. All sites other than Thalayanai clustered together when the dendrogram was drawn based on the Pearson correlation between sites (Fig. 5). Jaccard similarity coefficient showed that Samikuchi and Gugalthurai streams shared the common fish species assemblage

Table 5. List of fish species recorded from study streams in Karnataka part of Western Ghats.

Fish species	Ekachi	Kigga	Thunga	Sirkuli	Ganeshpal
Cyprinodontiformes					
Aplocheilidae					
Genus : Aplocheilus					
Aplocheilus lineatus	-	-	15	5	-
Aplocheilus panchax	-	16	-	-	-
Cyriniformes					
Cyprinidae					
Genus : Amblypharyngodon					
Amblypharyngodon microlepis	-	-	-	-	36
Genus : Barilius					
Barilius bendelisis	-	-	28	-	-
Barilius canarensis	22	42	24	-	-
Barilius gatensis	45	-	55	-	-
Genus : Danio					
Danio aequipinnatus	20	36	64	44	48
Genus : Esomus					
Esomus barbatus	-	-	-	-	15
Genus : Garra					
Garra bicornuta	-	-	18	-	-
Garra gotyla stenorhynchus	22	-	10	-	-
Garra mullya	32	44	15	-	-
Genus : Hypselobarbus					
Hypselobarbus jerdoni	-	-	-	64	58
Hypselobrabus kolus	-	-	20	-	-
Genus : Osteochilichthys					
Osteochilichthys nashii	-	-	15	-	-
Osteochilichthys thomassi	-	-	12	-	-
Genus : Puntius					
Puntius amphibius	-	-	-	20	-
Puntius bimaculatus	48	-	-	-	-
Puntius conchonius	15	-	-	-	-
Puntius fasciatus	24	-	-	-	-
Puntius narayani	-	-	25	52	44
Puntius pulchellus	-	-	42	-	-
Puntius ticto	-	-	-	32	28

Genus : Rasbora					
Rasbora caverii	32	-	-	15	20
Rasbora daniconius	-	28	18	-	-
Genus : Salmostoma					
Salmostoma boopis	-	-	-	35	-
Genus : Tor					
Tor khudree	-	10	25	-	-
Balitoridae Genus : Balitora					
Balitora mysorensis	-	10	-	-	-
Genus : Bhavania					
Bhavania australis	-	12	-	-	-
Genus : Noemacheilus					
Noemacheilus denisoni	-	20	-	18	-
Noemacheilus semiarmatus	34	22	12	-	-
Gobitidae Genus : Lepidocephalus					
Lepidocephalus thermalis	12	-	-	10	14
Gobiidae Genus : Glassogobius					
Glossogobius giuris	-	-	-	12	18
Siluriformes **Sisoridae** Genus : Glyptothorax					
Glyptothorax trewavasae	-	6	-	-	-

Table 6. Species richness, species diversity and percentage of cyprinids in study streams of Western Ghats.

Sites	Species richness (S)	Species diversity (H')	Percentage of Cyprinids
Samikuchi	12	1.03	83.3
Thalayanai	18	1.11	77.7
Karaiyar	10	0.94	80.0
Hanumannadhi	6	0.71	66.6
Gugalthurai	15	1.08	80.0
Kallar	17	1.14	58.8
Achankoil	17	1.15	64.7
Panniyar	10	0.90	50.0
Thalipuzha	9	0.88	77.7
Bavalipuzha	15	1.08	53.3
Ekachi	11	1.01	81.8
Kigga	11	0.97	45.5
Thunga	16	1.16	87.5
Sirkuli	11	0.95	63.6
Ganeshpal	9	0.91	77.7

(Table 7). Thalayanai stream represented the most distinct species assemblage and did not cluster with any other sites in Tamil Nadu (Fig. 5a). In Kerala part higher species diversity were found in Kallar stream (H' = 1.14) and Achankoil river (H' = 1.15). These two sites were also clustered distinctly in dendrogram (Fig. 5b). Jaccard similarity showed similarity in faunal assemblages (Table 7a, b, c). Bavalipuzha river had a distinct faunal assemblage and did not cluster with other sites (Fig. 5b). In Karnataka state Thunga river showed maximum diversity value of 1.16 and low value was found in Ganeshpal (H' = 0.91). The dendrogram showed that all sites were similar except Sirkuli and Ganeshpal which were clustered together (Fig. 5c).

4. 1. 2. Endemism and current conservation status

Out of 73 species, 44 species (including newly described species) are endemic to Western Ghats of Peninsular India (Table 8). Among the endemic species 8 are strictly endemic to Kerala (*Batasio travancoria, Clarias dussumieri, Horalabiosa arunachalami, Homaloptera santhamparaiensis, Hypselobarbus kurali, Puntius denisonii, Noemacheilus guentheri* and *N. keralensis*), 3 are endemic to Tamil Nadu (*Horalabiosa joshuai, Puntius arulius tambraparniei* and *Puntius kannikattiensis*) and one (*Garra bicornuta*) is endemic to Karnataka. Among the Western Ghats endemic forms 23 species (52.2%) are in threatened categories (Table 8), of which four species, *Puntius arulius tambraparniei, Puntius narayani, Tor khudree malabaricus* and *Silurus wynaadensis* are critically endangered

Table 7a. Jaccard similarity coefficient of fish density among the five study streams in Tamil Nadu part of Western Ghats.

	1	2	3	4	5
Samikuchi	0				
Thalayanai	0.38	0			
Karaiyar	0.46	0.35	0		
Hanumannadhi	0.38	0.27	0.33	0	
Gugalthurai	0.47	0.37	0.30	0.37	0

Table 7b. Jaccard similarity coefficient of fish density among the five study streams in Kerala part of Western Ghats.

	1	2	3	4	5
Kallar	0				
Achankoil	0.26	0			
Panniyar	0.13	0.13	0		
Thalipuzha	0.14	0.18	0.06	0	
Bavalipuzha	0.10	0.10	0.04	0.14	0

Table 7c. Jaccard similarity coefficient of fish density among the five study streams in Karnataka part of Western Ghats.

	1	2	3	4	5
Ekachi	0				
Kigga	0.22	0			
Thunga	0.26	0.26	0		
Sirkuli	0.16	0.10	0.12	0	
Ganeshpal	0.18	0.05	0.08	0.54	0

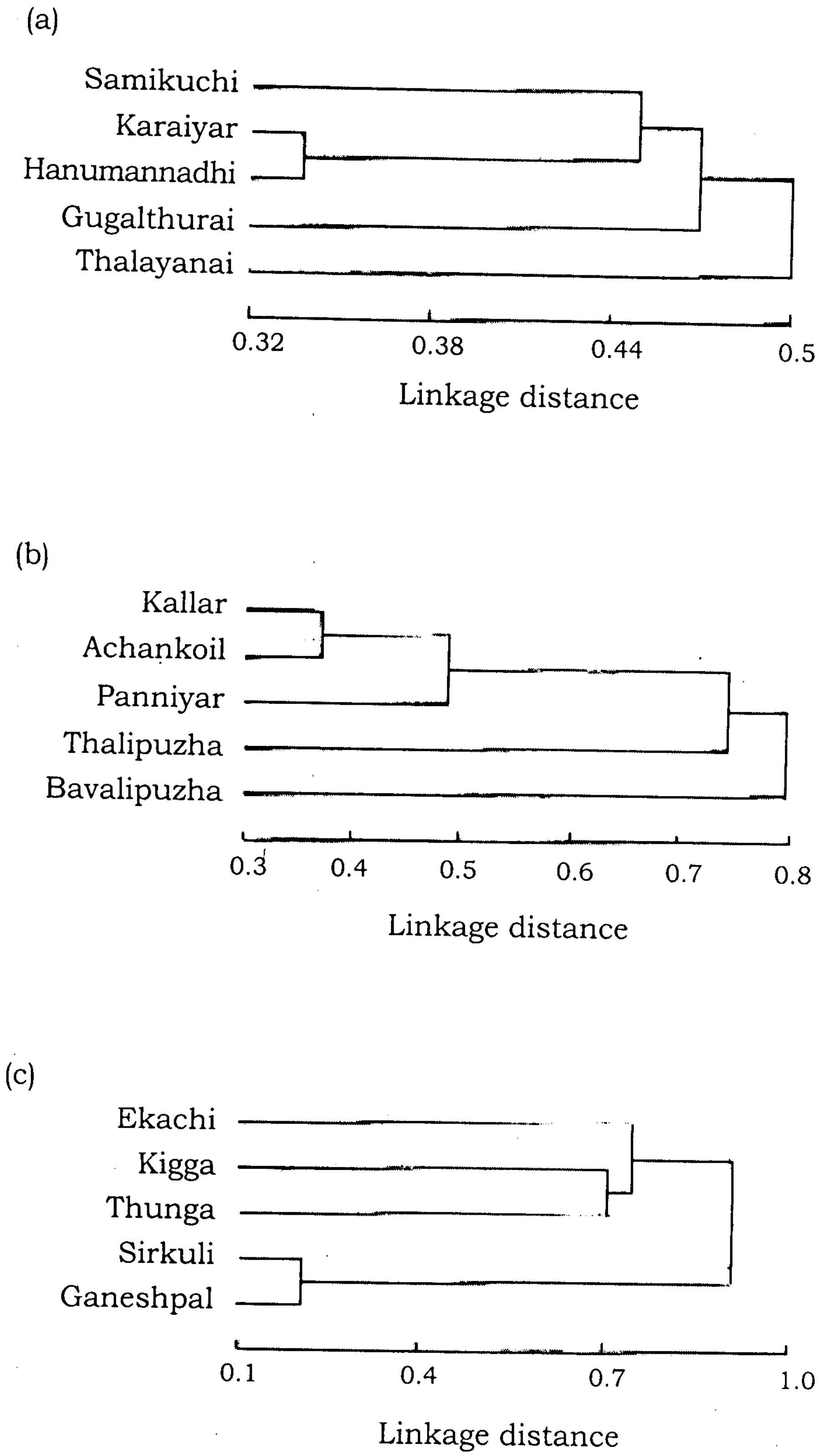


Figure 5. Dendrogram showing similarity among different sites in terms of frequency of fish species. Similarity between pairs of sites were calculated using Pearson - 'r' which were then grouped using single linkage. (a) similarity in Tamil Nadu streams, (b) similarity in Kerala streams and (c) similarity in Karnataka streams.

Table 8. List of Western Ghats endemic species recorded from the study streams and their current conservation status.

	Species	Endemic to			Status*
		TN	KL	KN	
1.	*Balitora mysorensis*				NA
2.	*Barbodes carnaticus*				VU
3.	*Barilius bakeri*				VU
4.	*Barilius canarensis*				NA
5.	*Batasio travancoria*		+		EN
6.	*Bhavania australis*				EN
7.	*Botia striata*				EN
8.	*Clarias dussumieri*		+		NA
9.	*Garra bicornuta*			+	NA
10.	*Garra gotyla stenorhynchus*				EN
11.	*Garra hughi*				EN
12.	*Garra mcclellendi*				NA
13.	*Glyptothorax madraspatanum*				VU
14.	*Glyptothorax trewavasae*				NA
15.	*Homaloptera santhamparaiensis*		+		NA
16.	*Horalabiosa arunachalami*		+		NA
17.	*Horalabiosa joshuai*	+			NA
18.	*Hypselobarbus curmuca*				EN
19.	*Hypselobarbus dubius*				EN
20.	*Hypselobarbus dobsoni*				NA
21.	*Hypselobarbus jerdoni*				EN
22.	*Hypselobarbus kolus*				EN
23.	*Hypselobarbus kurali*		+		EN
24.	*Hypselobarbus micropogon*				EN
25.	*Noemacheilus denisoni*				NA
26.	*Noemacheilus guentheri*		+		LR-lc
27.	*Noemacheilus keralensis*		+		EN
28.	*Noemacheilus semiarmatus*				LR-lc
29.	*Noemacheilus triangularis*				LR-lc
30.	*Osteochilichthys nashii*				NA
31.	*Osteochilichthys thomassi*				NA
32.	*Puntius arenatus*				NA
33.	*Puntius arulius tambraparniei*	+			CR
34.	*Puntius denisonii*		+		EN
35.	*Puntius fasciatus*				EN
36.	*Puntius kannikattiensis*	+			NA
37.	*Puntius melanampyx*				LR-lc
38.	*Puntius narayani*				CR
39.	*Puntius parrah*				EN
40.	*Puntius pulchellus*				NA
41.	*Rasbora caverii*				NA
42.	*Silurus wynaadensis*				CR
43.	*Tor khudree*				VU
44.	*Tor khudree malabaricus*				CR

* CR - Critically endangered; EN - Endangered; VU - Vulnerable; LR-lc - Lower risk-least concern; NA - Not assessed; TN - Tamil Nadu; KL - Kerala; KN - Karnataka.

Plate 4. Big sized threatened barbs of Western Ghats

a) *Barbodes carnaticus*

b) *Hypselobarbus curmuca*

c) *Hypselobarbus dubius*

d) *Hypselobarbus dobsoni*

e) *Hypselobarbus kolus*

f) *Hypselobarbus kurali*

g) *Hypselobarbus jerdoni*

h) *Tor khudree*


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Plate 5. Critically endangered fishes of Western Ghats

a) *Puntius arulius tambraparniei*

b) *Puntius narayani*

c) *Silurus wynaadensis*

d) *Tor khudree malabaricus*

(Plate 5); fourteen species (*Garra gotyla stenorhynchus, Bhavania australis, Garra hughi, Puntius deniisonii, P. fasciatus, P. parrah, Hypselobarbus curmuca, H. kolus, H. kurali, H. dubius, H. micropogon, H. jerdoni, Noemacheilus keralensis* and *Botia striata*) are endagered (Plate 4); five species (*Barbodes carnaticus, Batasio travancoria, Glyptothorax madraspatanum, Tor khudree* and *Noemacheilus semiarmatus*) are in vulnerable categories.

4. 2. Water Chemistry

Water quality parameters measured at each study site were broadly similar (Table 9a, b, c). Water was generally poor in dissolved ions, leading to low conductivities except at Thunga river (0.62 μ/mhos), Ganeshpal (0.67μ/mhos) and Kigga falls (0.22 μ/mhos). Water temperature was slightly lower in Kigga falls (18° C) when compared to other streams. Higher value of total hardness and alkalinity were recorded in Hanumannadhi, Kigga falls and Thunga river. The concentration of dissolved oxygen was not much varied between streams.

Results of Canonical Correlations of water quality variables and the fish abundance showed that the fish dencities were not much influenced by dissolved oxygen, total hardness and alkalinity, whereas it had strong association with temperature and conductivity (Fig. 6).

Table 9. Water-quality parameters in the study streams of Western Ghats. (a) Streams from Tamil Nadu region (b) Kerala region and (c) Karnataka region.

Variables	Samikuchi	Talayanai	Karaiyar	Hanuman nadhi	Gugal thurai
Water temperature (°C)	26	29	23	20	27
Dissolved oxygen (mg/l)	8.0	8.0	7.5	7.5	7.0
Total hardness (mg/l)	20	30	32	116	64
Alkalinity (mg/l)	24	38	34	98	62
Conductivity (μ/mhos)	0.09	0.09	0.09	0.041	0.025
Total dissolved solids (mg/l)	58.5	58.5	58.5	26.65	16.25

(b)

Variables	Kallar	Achankoil	Panniyar	Thalipuzha	Bavali puzha
Water temperature (°C)	26	26	26	23	31
Dissolved oxygen (mg/l)	7.2	8.0	9.0	8.0	7.5
Total hardness (mg/l)	21	30	32	28	24
Alkalinity (mg/l)	30	18	30	32	28
Conductivity (μ/mhos)	0.04	0.09	0.045	0.034	0.072
Total dissolved solids (mg/l)	26	58.5	29.25	22.1	46.8

(c)

Variables	Ekachi	Kigga	Thunga	Sirkuli	Ganeshpal
Water temperature (°C)	24	18	21	32	28
Dissolved oxygen (mg/l)	7.5	9.6	8.5	8.0	7.0
Total hadness (mg/l)	38	62	64	36	38
Alkalinity (mg/l)	42	70	72	32	32
Conductivity (μ/mhos)	0.18	0.22	0.62	0.079	0.67
Total dissolved solids (mg/l)	117.0	143	403	51.35	435.5

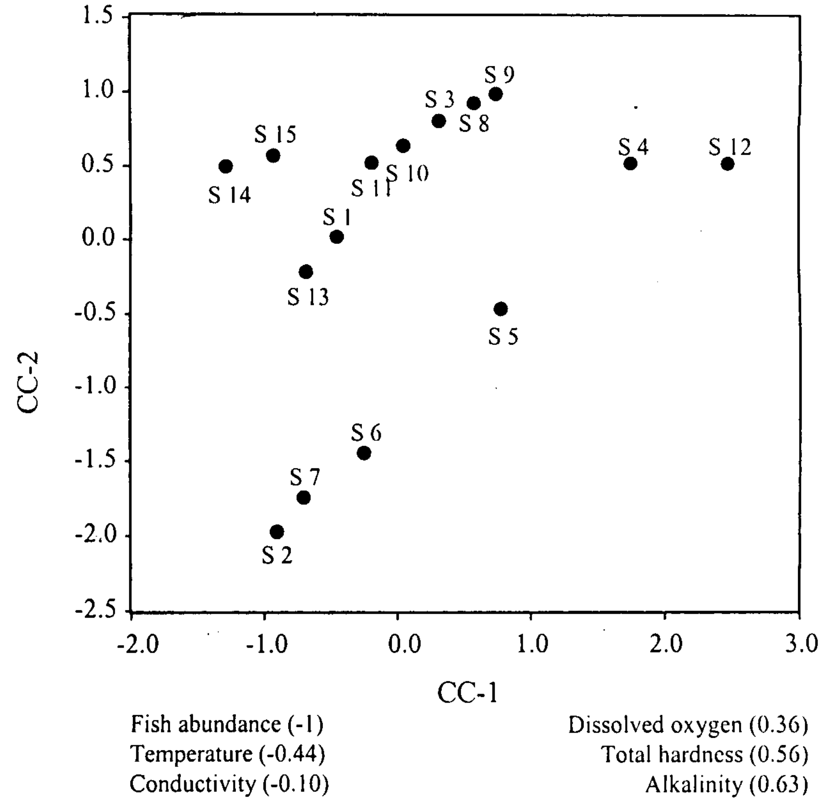


Figure 6. Canonical correlation plot of fish abundance and water quality parameters in Western Ghats streams. (S1 - Samikuchi, S2 - Thalayanai, S3 - Karaiyar, S4 - Hanumannadhi, S5 - Gugalthurai, S6 - Kallar, S7 - Achankoil, S8 - Panniyar, S9 - Thalipuzha, S10 - Bavalipuzha, S11 - Ekachi, S12 - Kigga, S13 - Thunga, S14 - Sirkuli, S15 - Ganeshpal).

4. 3. Macrohabitat variables and fish assemblage structure

4. 3. 1. Habitat utilization

In the streams of Western Ghats, the major habitat types such as pools, riffles, runs, cascades and falls were identified (Plate 6) and among them the pools and riffles were frequently accounted in 100 m stretch (Table 10). Low gradient and high gradient riffles were also observed. Cascades and falls were tended to be small and less frequent, whereas big falls habitats were excluded from the study streams. Among the study sites, Samikuchi, Thalayanai, Karaiyar and Gugalthurai streams in Tamil Nadu part were represented highly diverse habitats (Table 11a). Also large and deeper pool habitats with occurence (24 %) were found in Thunga river.

In small spatial scale, within stream reaches or within specific types of habitat the habitat utilization by various species were distinct. In total 11392.9 m^2 of wetted surface area and 4932. 98 m^3 volume were surveyed and 5284 number of fishes were counted in 252 individual habitats. Pools and riffle transects had more fishes than run and cascade transects. Specific habitat utilization coefficients for individual fish species were presented in Figures 7- 9. The dominant cyprinids utilized pool, riffle and run habitats. The big sized barbs *Hypselobarbus curmuca, H. dubius, H. kurali, H. micropogon, Barbodes carnaticus* and the small barbs such as *P. arulius tambraparniei, P. arenatus, P. fasciatus P. conchonius, P. melanampyx, P. narayani, P. kannikattiensis* and *P. parrah,*

Plate 6. Major habitat types in Western Ghats streams

a) Pool

b) Cascade

c) Riffle

d) Run

Table 10. Relative proportion (percentage) of pool and riffle habitats in the study streams of Western Ghats.

Sites	Pools (%)	Riffles (%)
Samikuchi	38	33
Thalayanai	37	26
Karaiyar	45	35
Hanumannadhi	26	33
Gugalthurai	35	30
Kallar	37	25
Achankoil	25	44
Panniyar	33	20
Thalipuzha	40	25
Bavalipuzha	26	37
Ekachi	43	36
Kigga	24	41
Thunga	24	41
Sirkuli	43	29
Ganeshpal	42	25

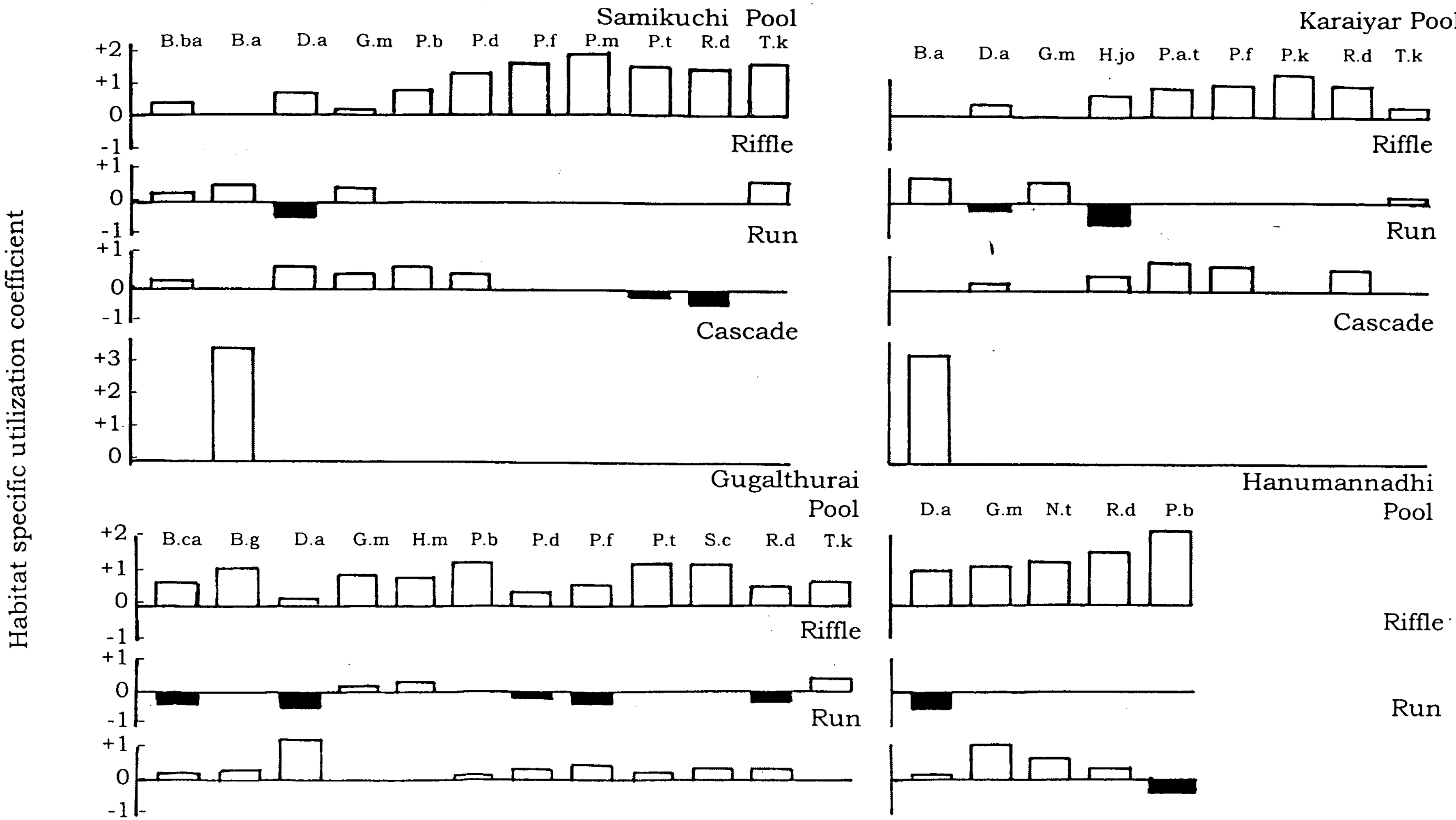


Figure 7a. Habitat specific utilization coefficient of fishes in streams of Tamil Nadu part of Western Ghats. Species abbreviations are given in Appendix I.

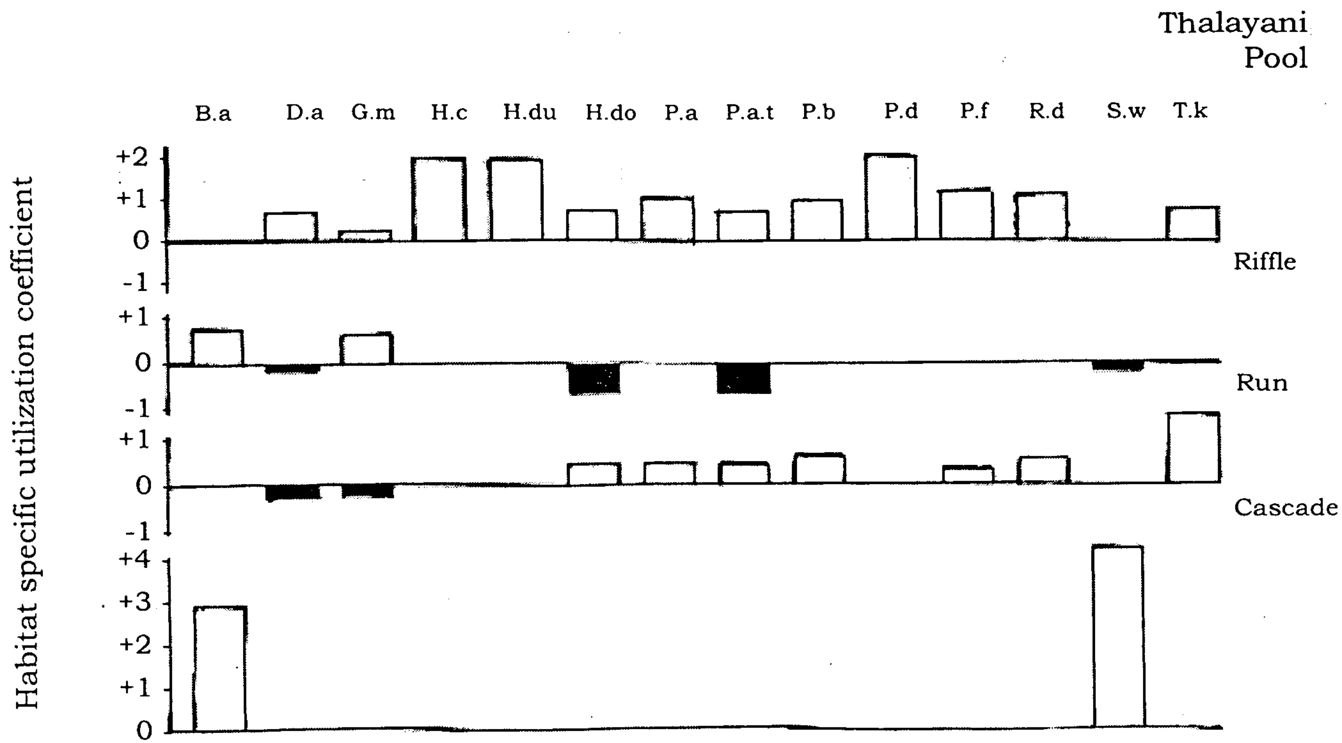


Figure 7b. Habitat specific utilization coefficient of fishes in Thalayanai stream of Tamil Nadu part of Western Ghats. Species abbreviations are given in Appendix I.

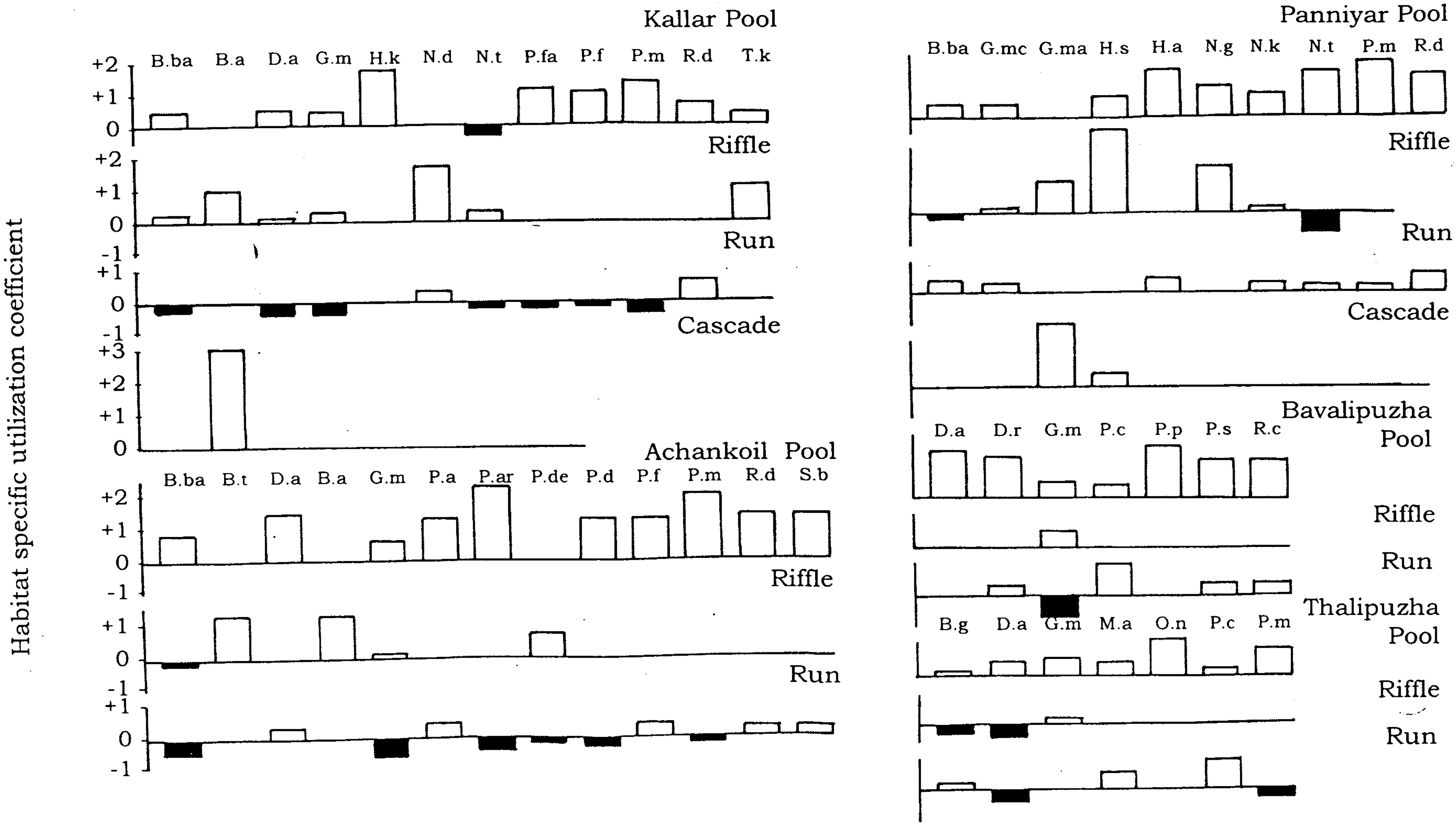


Figure 8. Habitat specific utilization coefficient of fishes in streams of Kerala part of Western Ghats. Species abbreviations are given in Appendix I.

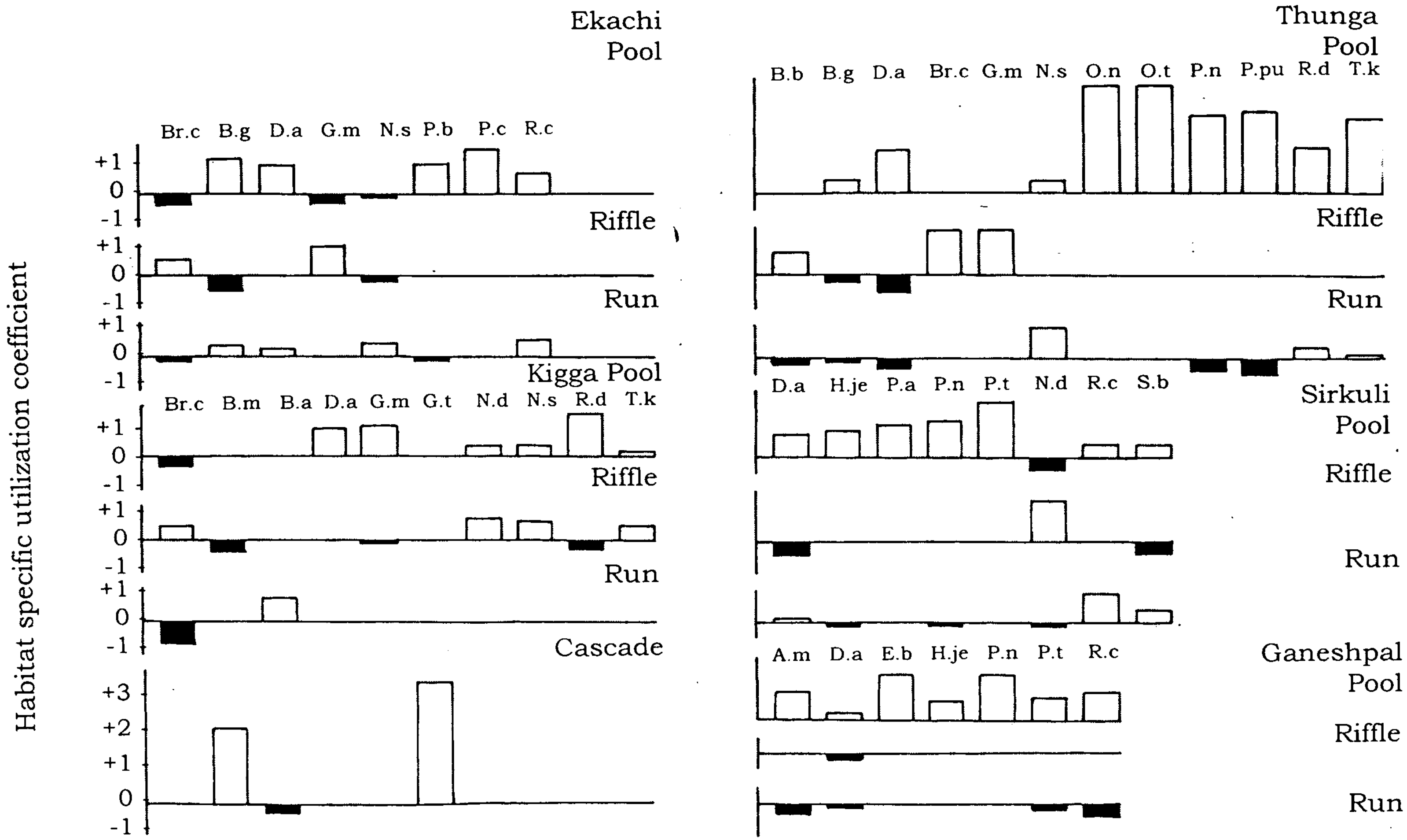


Figure 9. Habitat specific utilization coefficient of fishes in streams of Karnataka part of Western Ghats. Species abbreviations are given in Appendix I.

Osteochilichthys nashii, and *O. thomassi* exclusively used the pool habitats. *Danio aequipinnatus, Rasbora doniconius, R. caverii, Garra mullya, G. mcclellandi, Tor khudree, T. khudree malabaricus, Hypselobarbus dobsoni, H. jerdoni, Barilius bakeri, B. gatensis, Amblypharyngodon microlepis, Horalabiosa arunachalami, H. joshuai, Salmostoma boopis, Noemacheilus keralensis, Puntius amphibius, P. bimaculatus, P. dorsalis, P. filamentosus* and *P. ticto* predominantly utilized pool habitats and were also found to use the edges of riffle and run habitats.

The high gradient riffles were the mostly preffered habitats for the species such as *Barilius canarensis, B. bendelisis, Puntius denisonii, Noemacheilus denisoni, N. guentheri, N. semiarmatus* and *N. triangularis.* The hill stream loaches like *Bhavana australis, Balitoria mysorensis, Homaloptera santhamparaiensis* and the hill stream catfishes, *Glyptothorax madraspatanum, G. trewavasae, Batasio travancoria* and *Silurus wynaadenis* utilized cascades and high gradient riffles.

4. 3. 2. Habitat guilds

Based on the information from gill net sampling, underwater observation and habitat specific utilization coefficient, fishes were classified into five habitat use guilds, (edge pool, mid pool, riffle, cascade and generalised). *Barilius bakeri, B. gatensis, Rasbora doniconius, R. caverii, Puntius amphibius, P. arenatus, P. dorsalis, P. parrah. P. sophore, P. bimaculatus, P. narayani* and *Hypselobabus jerdoni* were on transitional habitats between pools and riffles (edge pool guild), especially in shallower region. The largest fishes, *Hypselobarbus dobsoni, H. micropogon, H. curmuca, H. dubius, H. kurali, Tor khudree, T. khudree malabaricus, Osteochilichthys nashii, O.thomassi* and *Barbodes carnaticus* preferred deeper pool habitats than other members of this guild (Fig 7 - 9). They were the dominant members in the mid pool guild. The juvenils of the largest fishes and *Puntius denisonii, Noemacheilus denisoni, N. guentheri, N. triangularis, N. semiarmatus, Garra mullya, Barilius bendelisis, B. canarensis, Batasio travancoria* and *Homaloptera santhamparaiensis* were the most common species in shallower habitats with moderate to fast flow. These members comprised as pool/or riffle guild.

Hill stream loaches *Bhavania australis, Balitora mysorensis* and the catfishes *Glyptothorax madraspatanum, G. trewavasae* and *Silurus wynaadensis* were abundant in turbulent flow habitats (cascade guild). Members of this guild were also present in the riffle guild. The fifth group of guild (generalist) consisted of *Puntius filamentosus, Danio aequipinnatus* and *Horalabiosa joshuai* which used all habitats.

4. 3. 3. Relationship between habitat characteristics and species abundance

Structural characteristics such as mean channel width, mean depth and mean flow were varied among the study streams (Table 11a, b, c). Stream width was lowest in Gugalthurai stream (Tamil Nadu). Highest

Table 11a. Structural characteristics of study streams in Tamil Nadu part of Western Ghats.

Sites	Samikuchi	Thalayanai	Karaiyar	Hanuman nadhi	Gugul thurai
Habitat types					
(100 m reach)					
Pools	8	7	9	4	7
Riffles	7	5	7	5	6
Runs	3	4	2	4	4
Cascades	3	3	2	2	3
Mean width (m)	45.6	25.6	13.8	37.4	11.5
Mean depth (cm)	53.25	84.3	51.8	23.3	53.5
Depth (%)					
D1 0 - 10	13.0	4.7	6.9	4.3	0
D2 11 - 30	30.4	9.5	37.9	56.6	31.8
D3 31 - 60	19.6	26.5	20.7	34.8	27.3
D4 61 - 100	29.6	31.0	20.7	4.3	31.8
D5 101 - 150	7.4	14.3	10.3	0	9.0
D6 > 150	0	14.3	3.5	0	0
Mean flow (V = m/sec)	0.226	0.399	0.269	0.167	0.187
Flow (%)					
Stagnant 0 - 0.15	37.5	25	0	55.5	46.0
Slow 0.16 - 0.30	25.0	0	80	44.5	23.3
Moderate 0.31 - 0.60	37.5	50	20	0	30.7
Turbulent > 0.60	0	25	0	0	0
Substrates (%)					
Bedrock	57.5	30.8	11.2	26.5	14
Boulder	18.2	40.0	33.7	18.6	24
Cobble	12.3	12.4	15.0	26.5	30
Gravel	3.0	10.0	3.8	0	8
Sand	7.5	4.8	32.5	28.4	17
Leaf litter	1.5	2.0	3.8	0	7
Fish covers (%)					
No cover	0	0	10	10	0
Small boulder undercut	31	18	22	22	13
Boulder undercut	28	24	17	17	30
Submerged log	7	6	6	6	0
Overhanging vegetation	3	13	17	17	18
Bedrock undercut	31	24	24	0	30
Root undercut	0	15	15	17	9

Table 11b. Structural characteristics of study streams in Kerala part of Western Ghats.

Sites	Kallar	Achankoil	Panniyar	Thali puzha	Bavali puzha
Habitat types					
(100 m reach)					
Pools	6	4	5	8	5
Riffles	4	7	3	5	7
Runs	4	5	4	4	6
Cascades	2	-	3	3	1
Mean width (m)	22	20	14	9.1	20
Mean depth (cm)	98.6	34.8	10	38.9	69.0
Depth (%)					
D1 0 - 10	6	2	10	3	0
D2 11 - 30	15	23	33	39.4	11.1
D3 31 - 60	30	42.7	37	36.4	28.9
D4 61 - 100	24.5	26.	20	21.2	51.1
D5 101 - 150	20.5	0	0	0	8.9
D6 > 150	4	6.3	0	0	0
Mean flow (V = m/sec)	0.28	0.32	0.3	0.203	0.144
Flow (%)					
Stagnant 0 - 0.15	15	33	70	50	60
Slow 0.16 - 0.30	42.2	15.5	20	33.3	10
Moderate 0.31 - 0.6	25	36.5	0	16.7	30
Turbulent > 0.6	17.5	15	0	0	0
Substrates (%)					
Bedrock	9.5	9	23	8	47
Boulder	12.5	12	20	42	29.42.0
Cobble	22.0	22	14	6	1.9
Gravel	21.5	21	12	3	14.7
Sand	26.5	28	20	31	5.0
Leaf litter	8.0	8	11	10	
Fish covers (%)					
No cover	0	15	0	18	10
Small boulder undercut	37	0	40	27	20
Boulder undercut	30	0	12	27	40
Submerged log	0	15	0	0	0
Overhanging vegetation	15	46	20	14	10
Bedrock undercut	12	0	16	9	10
Root undercut	6	24	12	5	10

Table 11c. Structural characteristics of study streams in Karnataka part of Western Ghats.

Sites	Ekachi	Kigga	Thunga	Sirkuli	Ganeshpal
Habitat types					
(100 m reach)					
Pools	6	4	4	6	5
Riffles	5	7	7	4	3
Runs	3	6	6	4	4
Cascades	-	-	-	2	-
Mean width (m)	21	9.5	80	55	75
Mean depth (cm)	36.3	54.3	84.7	52.9	62.5
Depth (%)					
D1 0 - 10	0	0	0	17.2	0
D2 11 - 30	35	21.4	21.1	38.0	18.2
D3 31 - 60	65	46.4	26.3	13.8	27.2
D4 61 - 100	0	28.6	26.3	17.2	36.4
D5 101 - 150	0	3.6	7.9	3.5	18.2
D6 > 150	0	0	18.4	10.3	0
Mean flow (V = m/sec)	0.199	0.286	0.267	0.268	0.061
Flow (%)					
Stagnant 0 - 0.15	46.2	50.0	11.1	38.5	90
Slow 0.16 - 0.30	23.0	16.7	44.4	23.0	10
Moderate 0.31 - 0.60	30.8	33.3	44.4	30.8	0
Turbulent > 0.61	0	0	0	7.7	0
Substrates (%)					
Bedrock	35	70.8	10	19.5	60
Boulder	13.3	10.8	-	9.7	20
Cobble	21	6.6	-	25.3	-
Gravel	9	1.4	10	13.4	10
Sand	16.8	6.6	80	17.9	10
Leaf litter	4.9	3.8	-	14.2	-
Fish covers (%)					
No cover	30	0	67	13	25
Small boulder undercut	26	23	0	17	10
Boulder undercut	17	12	22	13	25
Submerged log	0	0	0	0	0
Overhanging vegetation	9	32	0	13	0
Bedrock undercut	9	12	11	22	35
Root undercut	17	5	0	22	5

mean velocity (0.399 m/sec.) was recorded in Thalayanai stream of Tamil Nadu region. More deeper habitat was recorded in Thalayanai stream and Thunga river (Table 11a, c). Habitat characters such as habitat diversity (depth, current and substrate), habitat area, habitat volume, instream cover and percentage of pool and riffle habitat were considered to be important in determining fish abundance. Among the fifteen streams, the greater species richness were found in streams such as Thalayanai, Gugalthurai, Kallar and Achankoil with highest habitat diversity, habitat area, habitat volume, instream cover and fish abundance (Table 12), whereas less species richness streams had low habitat heterogeneity.

Relationship between habitat characteristics and species diversity were examined using simple linear regression (Table 13). There was a positive correlation between habitat characteristics and fish abundance in all the sites and the results were highly significant ($p > 0.01$) (site volume $r = 0.53$; site area $r = 0.66$; habitat diversity $r = 0.67$). Regression analysis also showed that habitat diversity, habitat volume, habitat area, instream cover and percentage of pools - riffles had some capability of predicting fish abundance.

4. 4. Microhabitat analysis

4. 4. 1. Microhabitat availability

The frequency histogram analysis habitats of the Western Ghats streams displayed great amount of variation among streams (Figs. 10 –

Table 12. Total fish density (100 m reach), index of habitat diversity, habitat area, volume, instream cover and percentage of pool and riffle habitat in the study streams of Western Ghats.

Streams	Habitat area (m^2)	Habitat volume (m^3)	Instream cover (%)	Pool, riffles (%)	Habitat diversity	Fish density (Nos.)
Samikuchi	953	306.73	50	71	1.654	354
Thalayanai	1103	628	80	63	1.7912	595
Karaiyar	884	326.62	75	80	1.55	278
Hanumannadhi	589	206.4	20	60	1.31	239
Gugalthurai	912	428.23	60	65	1.75	407
Kallar	924	265.5	75	63	1.8579	521
Achankoil	964	288.54	80	69	1.8655	568
Panniyar	597.8	225.34	70	53	1.5685	249
Thalipuzha	764.1	367.63	25	65	1.4788	239
Bavalipuzha	842	267.69	65	63	1.4608	296
Ekachi	659	233.5	65	79	1.4471	306
Kigga	399	147.11	85	65	1.3998	246
Thunga	896	525.8	40	65	1.3676	398
Sirkuli	1115	388.47	65	71	1.9049	307
Ganeshpal	755	327.42	30	66	1.1963	281

Table 13. Regression of fish abundance vs. habitat area, habitat volume, instream cover, percentage of pool – riffle and habitat diversity.

Variables	**Intercept B**	**Slope A**	**r**
Habitat area	0.58	1.45	0.66*
Habitat volume	0.62	0.91	0.53*
Instream cover	0.66	0.08	0.45
% of pools - riffles	0.21	1.31	0.56*
Habitat diversity	1.11	-1.23	0.67*

* P > 0.01

12). Thalayanai stream (Tamil Nadu) showed a wide range of microhabitat variables, such as substrates (bedrock to leaf litter), depth (shallow to deeper area). The major substrate type was bedrock and boulders and the bedrock-boulder undercuttings were the dominant fish cover (Fig. 10b). Comparatively poor habitat characteristics were recorded in Hanumannadhi stream, the important fish covers like submerged logs, overhanging vegetation and root undercut were absent (no cover area was 42%) (Fig. 10b). High variation in flow patterns was noted in Thalayanai and Gugalthurai streams (Fig. 10a). In Kerala part, microhabitat heterogeneity was found to be high in Kallar and Achankoil streams (Figs. 11a, b), and the substrate types were mainly boulders, cobbles, gravels and sand. In Kallar stream the dominant cover types were bedrock and boulder undercut and overhanging vegetation while in Achankoil, overhanging vegetation and root undercut were the major fish cover types (Fig. 11b). In Panniyar stream, bedrock, boulders and sand were the major substrate types and the cover was relatively less; boulder undercut and overhanging vegetation were the dominant fish cover (Fig. 11b). Low stream velocity was recorded in Panniyar stream and Bavalipuzha where most of the areas were stagnant (Fig. 11a).

In Karnataka part, Thunga river had more deeper areas with moderate flow. The dominant substrate type was gravel (80%) and the fish cover complex was very poor (no cover area was 66%), whereas in Kigga stream, dominant substrate type was bedrock and bedrock and

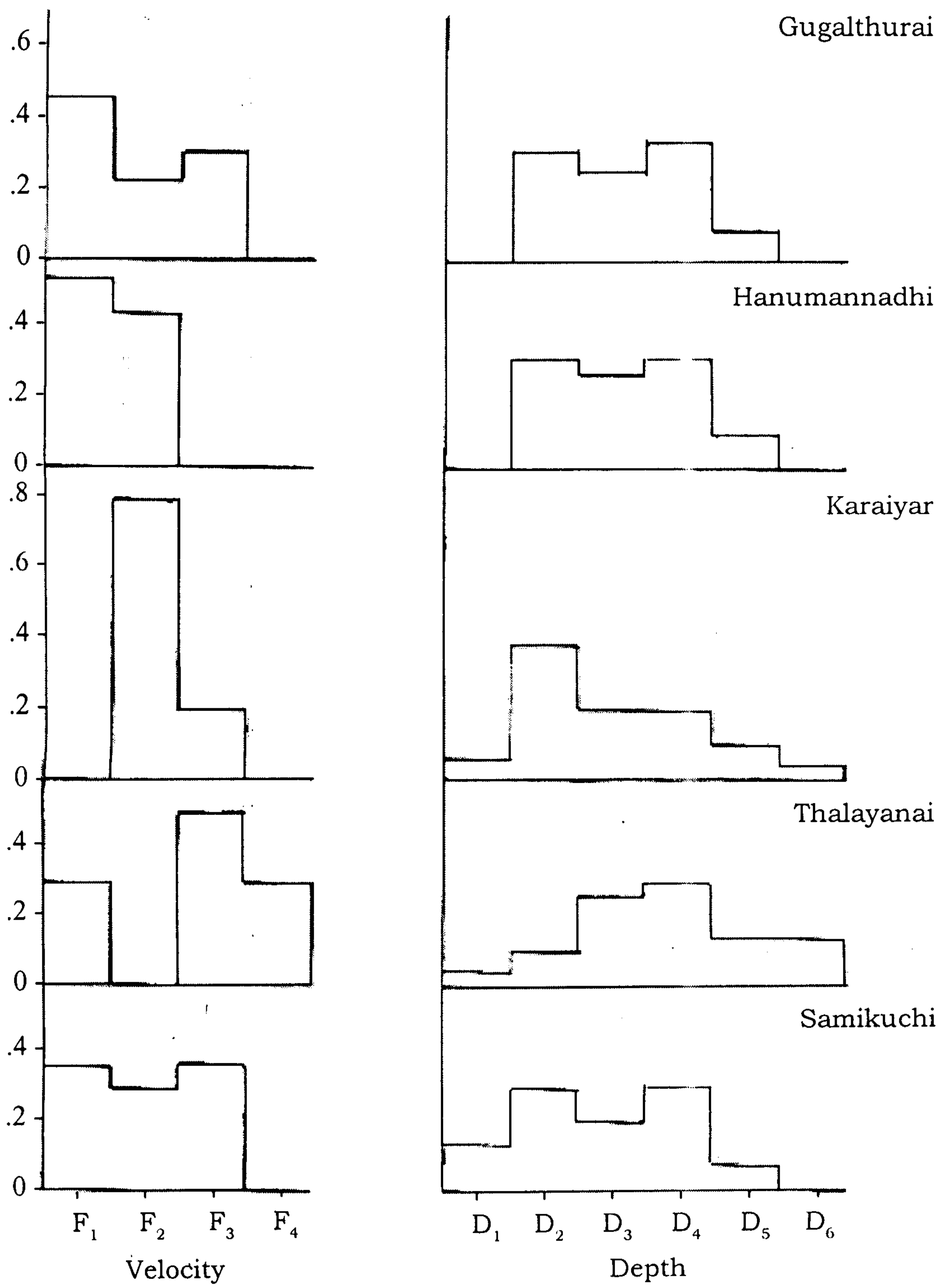


Figure 10a. Frequency distribution of velocity and depth categories in streams in Tamil Nadu part of Western Ghats (Velocity (m/sec) : F_1 = 0 - 0.15; F_2 = 0.16 - 0.30; F_3 = 0.31 - 0.60; F_4 = > 0.60. Depth (cm) : D_1= 0 - 10; D_2 = 11 - 30; D_3 = 31 - 60; D_4 = 61 - 100; D_5 = 101 - 150; D_6 = > 150).

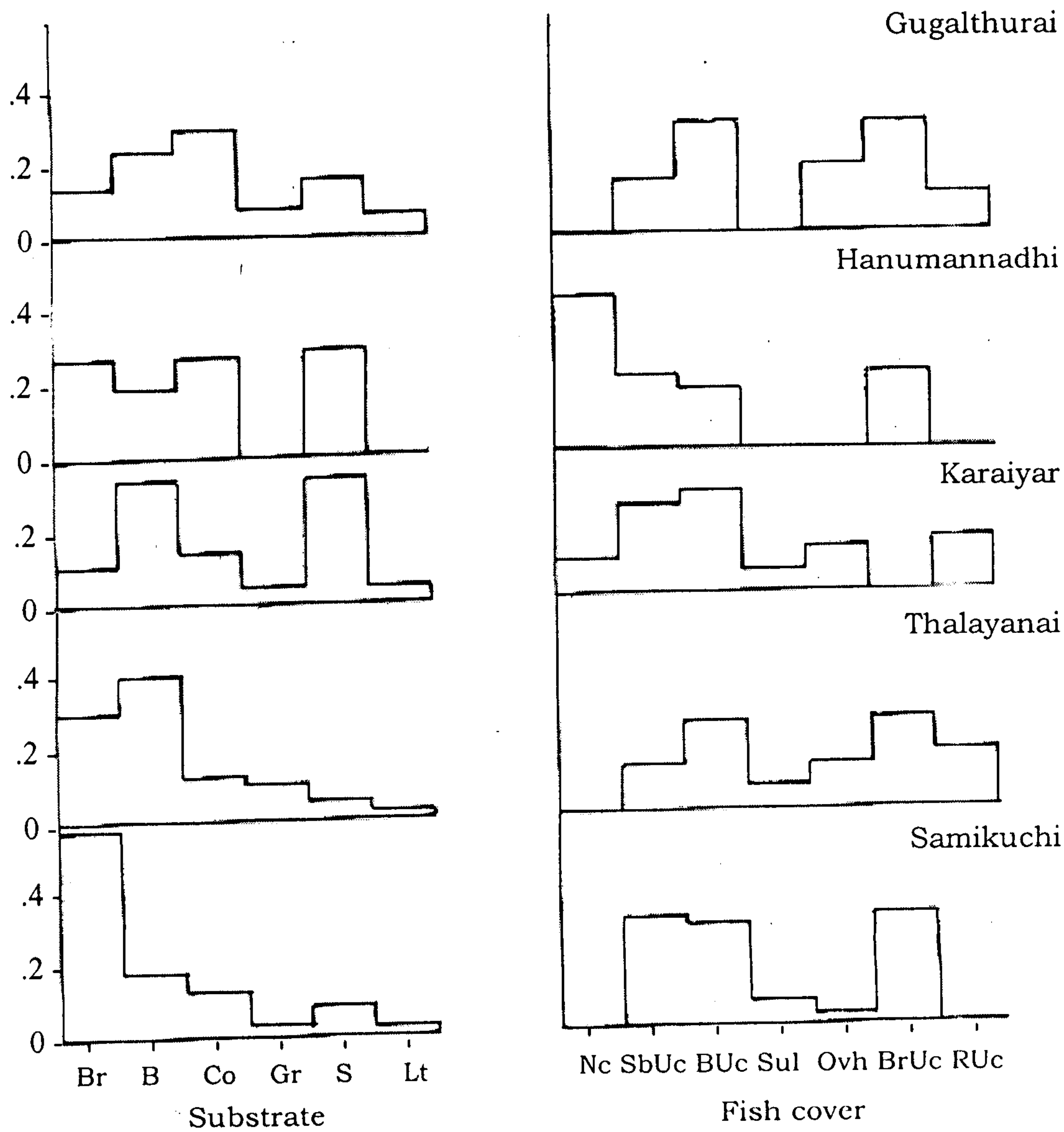


Figure 10b. Frequency distribution of substrates and fish cover categories in streams in Tamil Nadu part of Western Ghats (Substrates: Br = Bedrock; B = Boulder; Co = Cobble; Gr = Gravel; S = Sand; Lt = Leaf litter. Fish cover : Nc = No cover; SbUc = Small boulder undercut; BUc = Boulder undercut; Sul = Submerged logs; Ovh = Overhanging vegetation; BrUc = Bedrock undercut; RUc = Root undercut).

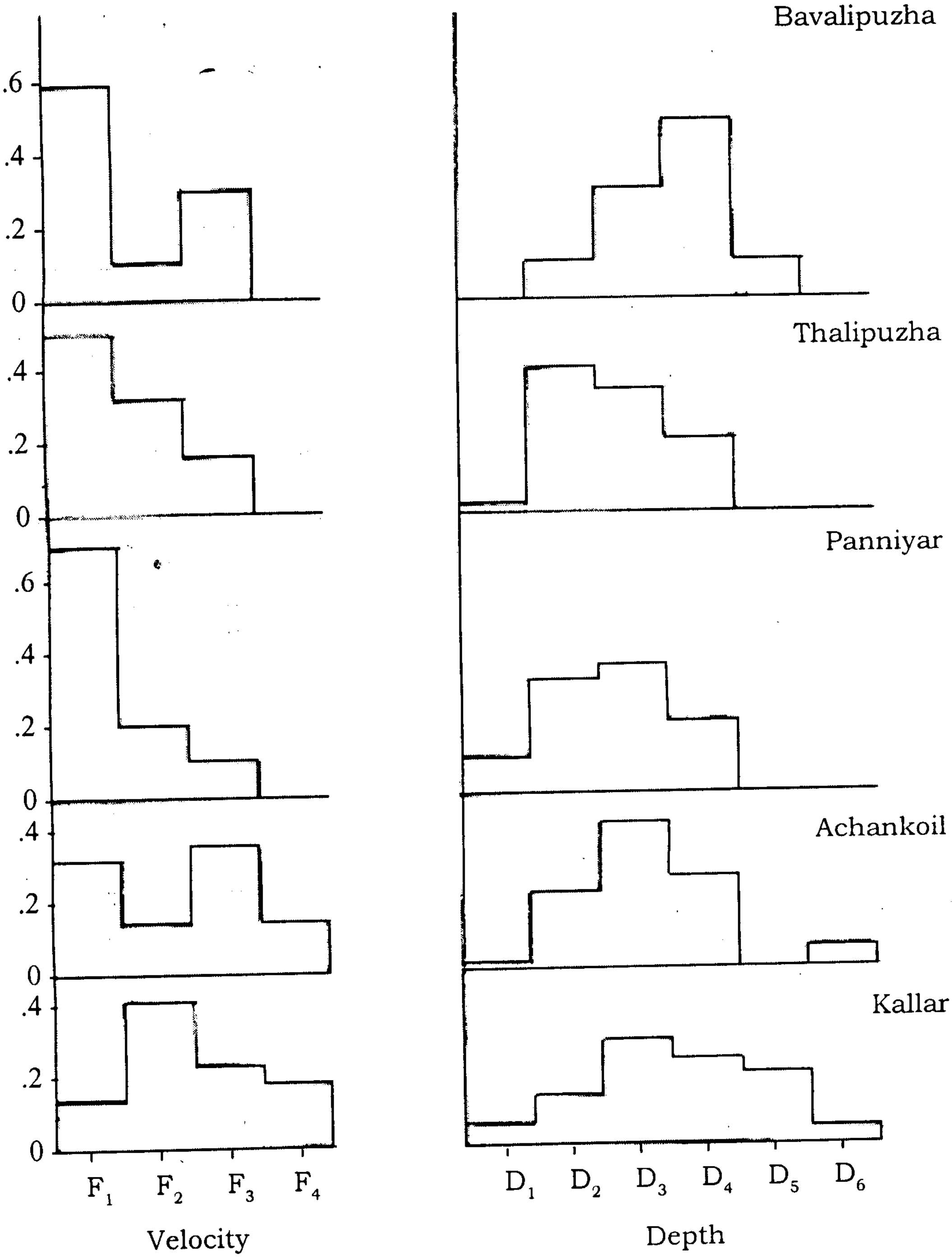


Figure 11a. Frequency distribution of velocity and depth categories in streams in Kerala part of Western Ghats (Velocity (m/sec) : F_1 = 0 - 0.15; F_2 = 0.16 - 0.30; F_3 = 0.31 - 0.60; F_4 = > 0.60. Depth (cm) : D_1= 0 - 10; D_2 = 11 - 30; D_3 = 31 - 60; D_4 = 61 - 100; D_5 = 101 - 150; D_6 = > 150).

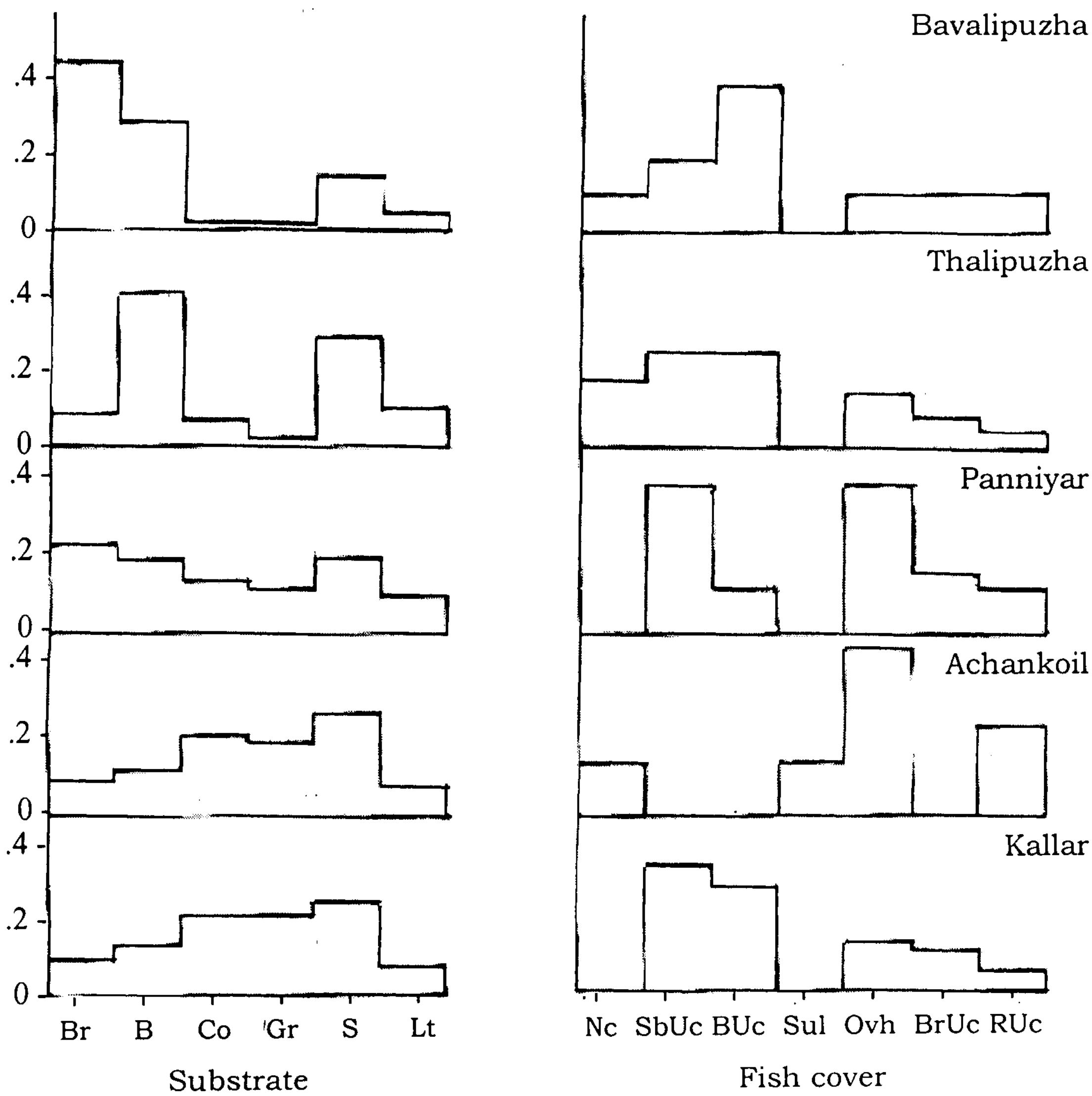


Figure 11b. Frequency distribution of substrates and fish cover categories in streams in Kerala part of Western Ghats (Substrates : Br = Bedrock; B = Boulder; Co = Cobble; Gr = Gravel; S = Sand; Lt = Leaf litter. Fish cover : Nc = No cover; SbUc = Small boulder undercut; BUc = Boulder undercut; Sul = Submerged logs; Ovh = Overhanging vegetation; BrUc = Bedrock undercut; RUc = Root undercut).

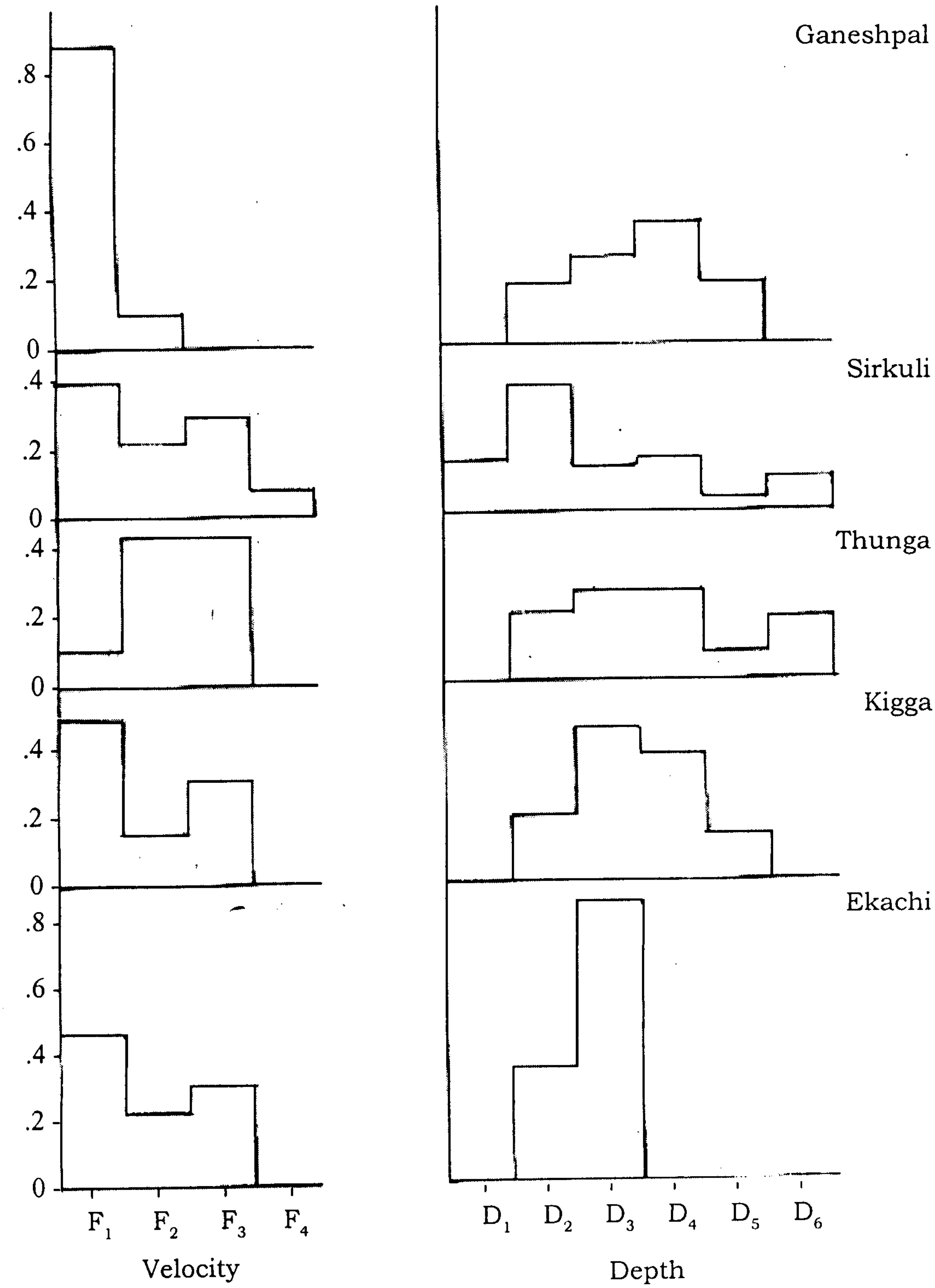


Figure 12a. Frequency distribution of velocity and depth categories in streams in Karnataka part of Western Ghats (Velocity (m/sec) : F_1 = 0 - 0.15; F_2 = 0.16 - 0.30; F_3 = 0.31 - 0.60; F_4 = > 0.60. Depth (cm) : D_1= 0 - 10; D_2 = 11 - 30; D_3 = 31 - 60; D_4 = 61 - 100; D_5 = 101 - 150; D_6 = > 150).

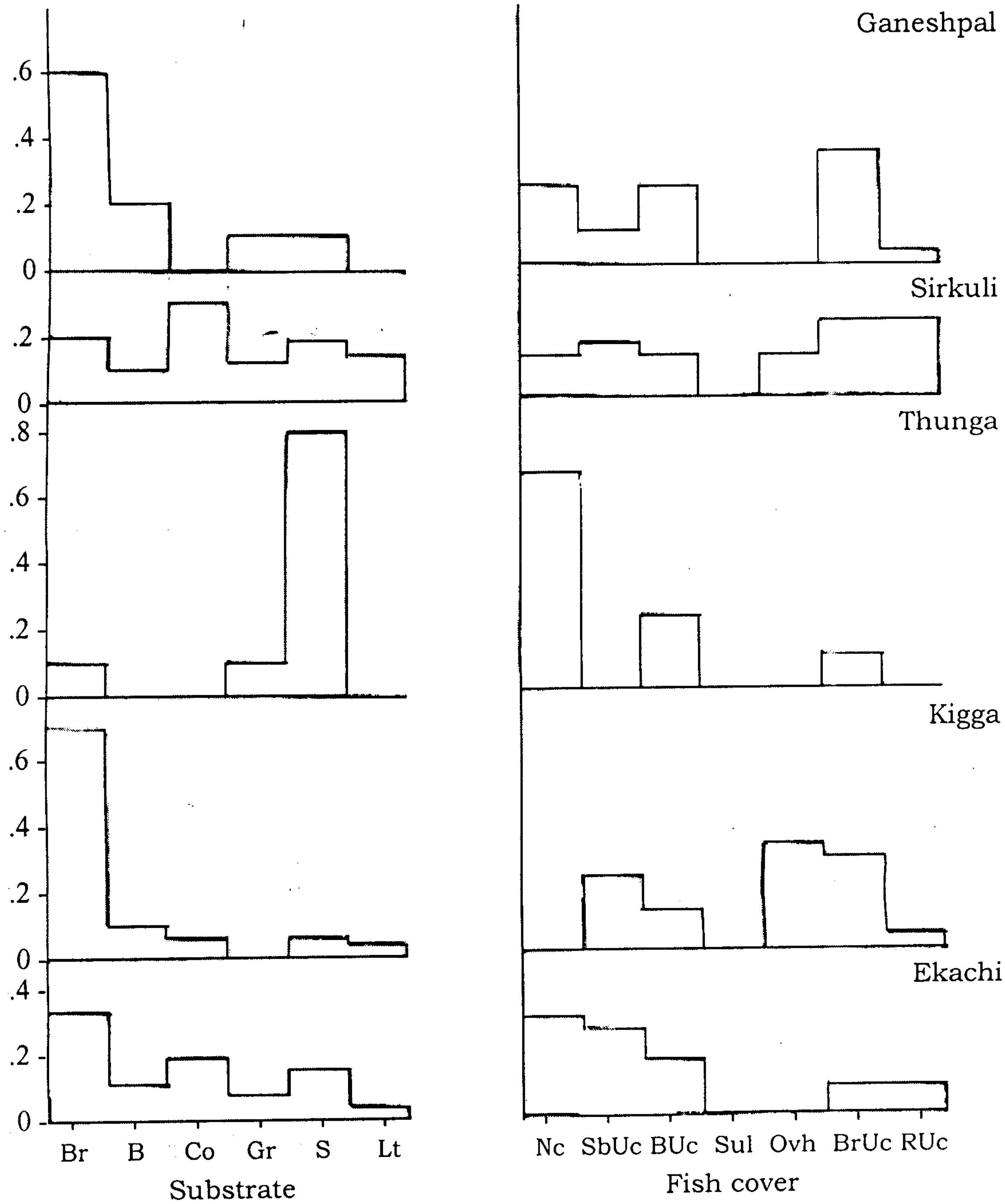


Figure 12b. Frequency distribution of substrates and fish cover categories in streams in Karnataka part of Western Ghats (Substrates : Br = Bedrock; B = Boulder; Co = Cobble; Gr = Gravel; S = Sand; Lt = Leaf litter. Fish cover : Nc = No cover; SbUc = Small boulder undercut; BUc = Boulder undercut; Sul = Submerged logs; Ovh = Overhanging vegetation; BrUc = Bedrock undercut; RUc = Root undercut).

boulder undercut and overhanging vegetation were the dominant fish cover (Fig. 12b). Comparatively very poor microhabitat structures were recorded in Ganeshpal stream (Figs. 12a, b).

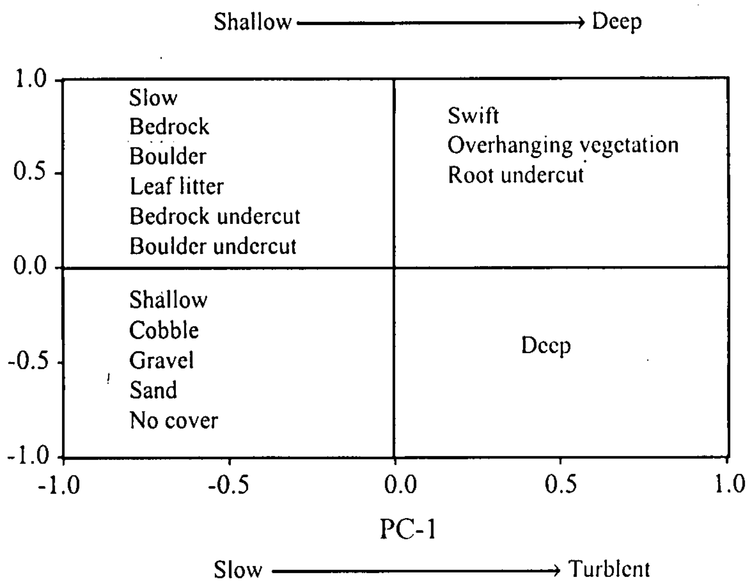
First two components were extracted by Principal Component Analysis with 62% of variance in microhabitat variables. Component one (23% variance explained) showed that large positive values were weighted heavily for deeper areas, highest velocity, great amount of gravel and cover (submerged logs, overhanging vegetation and root undercut). Therefore a strong negative value in PC-I indicated a habitat with low velocity, shallow, rocky substrates and bedrock – boulder undercut and no cover area for cover data (Table 14). Component two indicated that habitat with bedrock and boulders as dominant substrate types and good amount of cover. Large positive value of PC-II was corresponded to the rocky substrate (bedrock and boulders).

The result of microhabitat availability data indicated that the stream Thalayanai, Kallar and Sirkuli had the high velocity, more deeper habitats, greater amount of substrate heterogeneity with cover complex. Conversely, the Achankoil stream had turbulent flow, deeper habitats, great amount of erosional substrates (mostly gravel and sand) and poor cover complex (Fig. 13), whereas the Thunga site had poor habitat characteristics with shallow area, low flow and gravel and sand substrates with no cover. Despite the substantial level of microhabitat variability recorded among the Western Ghats streams (Fig 13).

Table 14. Principal Component loadings for microhabitat availability in Western Ghats streams on two factors produced by principal component analysis.

Variables	PC I	PC II
Flow		
Stagnant	-0.42	0.41
Slow	-0.22	-0.58
Moderate	0.47	-0.01
Turbulent	0.78	0.21
Depth		
D1	0.22	0.21
D2	-0.21	-0.51
D3	0.00	-0.13
D4	0.25	0.11
D5	0.17	0.31
D6	0.78	-0.42
Substrates		
Bedrock	-0.42	0.60
Boulder	-0.14	0.38
Cobble	0.39	-0.05
Gravel	0.79	-0.08
Sand	-0.03	-0.90
Leaf litter	0.48	0.09
Fish Cover		
No cover	-0.31	-0.82
Small boulder undercut	-0.22	0.46
Boulder undercut	-0.47	0.28
Submerged log	0.64	-0.02
Overhanging vegetation	0.69	0.06
Bedrock undercut	-0.43	0.55
Root undercut	0.80	0.17
Variants explained	5.22	3.83
Percentage of variance	23.10	39.42

(a)



(b)

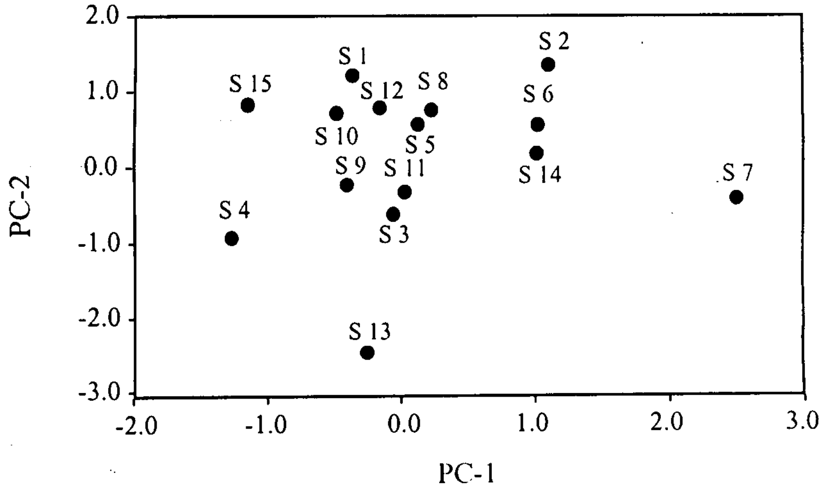


Figure 13. Principal component plot of microhabitat availability in streams of Western Ghats. (a) Characteristics of the quadrants of the graph of first two principal component and (b) Principal components scores for fifteen streams. (S1 - Samikuchi, S2 - Thalayanai, S3 - Karaiyar, S4 - Hanumannadhi, S5 - Gugalthurai, S6 - Kallar, S7 - Achankoil, S8 - Panniyar, S9 - Thalipuzha, S10 - Bavalipuzha, S11 - Ekachi, S12 - Kigga, S13 - Thunga, S14 - Sirkuli, S15 - Ganeshpal).

4. 4. 2. Microhabitat use

The microhabitat use in Western Ghats fish assemblages produced 25 to 95% of the variance in the data extracted by Principal Component Analysis. Two components were extracted for the fifteen streams and the individual microhabitat variable loadings, total variance and percentage of variance in individual streams were presented in Tables 15 - 17.

In Samikuchi stream (Fig 14a), *Barilius bakeri* and *Danio aequipinnatus* occupied deeper areas with and higher velocities and preferred bedrock, cobble and gravel substratum. They used boulder undercut and overhanging vegetation as major cover. *Rasbora daniconius* and *Puntius filamentosus* occurred in deeper areas with medium flow and bedrock, cobble and gravel were the preferred substrate types. They were found closer to boulder undercut. *Garra mullya* and *Tor khudree* also used same category of depth, substratum and cover like *Rasbora daniconius* and *Puntius filamentosus*, but velocity preference was medium flow region. The small barbs *Puntius bimaculatus, P. dorsalis, P. melanampyx* were found in shallow area with low flow and they used sand and leaf litter substrata with small boulder undercut as cover. In Thalayanai stream, the usage of depth, flow, substratum and cover by *Danio aequipinnatus, Rasbora daniconius, Puntius bimaculatus, P. dorsalis* and *P. filamentosus*, were found to be in low flow region with the substrates such as cobble, boulder and sand (Fig. 14 b). They preferred boulder and bedrock undercut as cover whereas the big sized barbs *Barbodes sarana, Hypselobarbus curmuca, H.*

Table 15. Principal component loadings for microhabitat use of cyprinids on two factors produced by principal components analysis in streams of Tamil Nadu part of Western Ghats.

Variables	Samikuchi		Thalayanai		Karaiyar		Hanumannadhi		Gugalthurai	
	PC - I	PC - II	PC - I	PC - II	PC - I	PC - II	PC - I	PC - II	PC - I	PC - II
Depth	0.79	-0.05	0.79	-0.05	0.26	0.02	0.32	0.10	0.27	-0.02
Flow	0.46	0.12	0.46	0.12	0.14	-0.05	0.21	0.48	0.16	0.17
Bedrock (S_1)	0.10	-0.80	0.66	-0.03	-	-	-	-	0.003	0.18
Boulder (S_2)	-	-	-0.36	-0.03	-0.07	-0.12	-	-	0.04	0.21
Cobble (S_3)	0.22	-0.01	-0.20	0.67	-0.02	0.40	-	-	-0.21	-0.009
Gravel (S_4)	0.00	0.37	0.30	0.41	-0.20	-0.11	-0.03	0.35	0.16	-0.07
Sand (S_5)	-0.02	0.39	-0.12	-0.75	0.24	-0.06	0.03	-0.35	0.11	-0.27
Leaf litter (S_6)	-0.60	0.001	-	-	-	-	-	-	-	-
No cover (C_1)	-	-	-	-	-	-	0.30	0.06	-	-
Small boulder undercut (C_2)	-0.83	0.30	-0.36	0.87	-0.20	-0.11	-0.30	-0.06	-0.23	-0.09
Boulder undercut (C_3)	0.09	-0.94	-0.44	-0.66	-0.03	-0.20	-	-	-0.03	0.18
Submerged log (C_4)	-	-	-	-	-	-	-	-	-	-
Overhanging vegetation (C_5)	0.64	0.61	0.93	-0.01	0.21	0.01	-	-	0.23	-0.27
Bedrock undercut (C_6)	-	-	-0.03	-0.27	-	-	-	-	0.07	0.20
Root undercut (C_7)	-	-	-	-	-0.02	0.40	-	-	-	-
Variance explained	2.97	-	2.79	25.44	3.55	2.32	3.40	2.30	3.29	2.87
Percent of variance (Cumulative)	29.75	-	25.44	48.19	35.51	58.71	56.76	95.21	29.93	59.10

Table 16. Principal component loading for microhabitat use of cyprinids on two factors produced by principal components analysis in streams of Kerala part of Western Ghats.

Variables	Kallar		Achankoil		Panniyar		Thalipuzha		Bavalipuzha	
	PC - I	PC - II	PC - I	PC - II	PC - I	PC - II	PC - I	PC - II	PC - I	PC - II
Depth	0.08	0.20	-0.02	-0.003	0.19	0.15	0.18	0.11	0.27	-0.001
Flow	0.27	0.05	0.077	0.23	0.24	-0.04	0.15	0.14	0.14	0.26
Bedrock (S_1)	0.26	0.04	0.06	0.20	0.23	-0.077	-0.002	0.18	0.24	-0.002
Boulder (S_2)	-0.03	-0.11	0.12	-0.25	-0.10	-0.07	0.23	-0.26	-0.13	0.26
Cobble (S_3)	-0.000	-0.24	-0.28	0.05	-0.05	-0.16	-0.09	0.006	-0.15	0.04
Gravel (S_4)	-	-	0.20	-0.15	-	-	0.01	0.22	0.01	-0.23
Sand (S_5)	-0.03	0.14	-0.10	0.10	-0.05	0.35	-0.10	-0.02	0.01	-0.16
Leaf litter (S_6)	-0.26	0.17	-	-	-	-	-0.11	-0.04	-	-
No cover (C_1)	-	-	-	-	-	-	-	-	-	-
Small boulder undercut (C_2)	-0.22	0.08	-0.31	0.11	-0.17	-0.13	-0.22	-0.04	-0.22	0.06
Boulder undercut (C_3)	0.03	-0.32	0.13	-0.32	-	-	0.23	-0.26	-0.14	0.14
Submerged log (C_4)	-	-	-	-	-	-	-	-	-	-
Overhanging vegetation (C_5)	-0.07	0.25	0.08	0.23	-0.05	0.35	0.01	0.22	0.10	0.12
Bedrock undercut (C_6)	0.21	0.03	-	-	0.22	-0.15	-0.002	0.18	0.24	-0.00
Root undercut (C_7)	-	-	-0.02	-0.003	-	-	-	-	0.05	-0.32
Variance explained	3.31	2.60	3.82	2.02	4.05	2.76	4.32	2.64	3.24	2.41
Percent of variance (Cumulative)	30.16	53.80	34.80	53.24	45.09	75.80	36.06	58.07	27.03	47.11

Table 17. Principal component loading for microhabitat use of cyprinids on two factors produced by principal components analysis in streams of Karnataka part of Western Ghats.

Variables	Ekachi		Kigga		Thunga		Sirkuli		Ganeshpal	
	PC - I	PC - II	PC - I	PC - II	PC - I	PC - II	PC - I	PC - II	PC - I	PC - II
Depth	0.23	-0.10	0.11	0.23	0.24	0.006	0.22	-0.05	0.17	0.03
Flow	0.22	0.08	-0.12	0.13	-0.05	0.27	0.16	0.19	0.21	-0.001
Bedrock (S_1)	-	-	-0.28	0.07	0.08	0.36	-	-	0.15	-0.04
Boulder (S_2)	-0.006	0.16	0.08	-0.29	-0.30	-0.04	-	-	0.13	-0.07
Cobble (S_3)	-0.18	0.01	-	-	-	-	-0.01	0.33	-	-
Gravel (S_4)	0.13	0.18	0.16	0.02	0.13	-0.08	0.21	-0.16	-0.10	-0.34
Sand (S_5)	0.09	-0.32	0.09	0.17	0.12	-0.16	-0.18	-0.09	-0.10	0.39
Leaf litter (S_6)	-0.07	0.05	-	-	-	-	-	-	-	-
No cover (C_1)	-	-	-	-	0.20	-0.16	-	-	-	-
Small boulder undercut (C_2)	-0.20	-0.04	-	-	-0.13	-0.03	-0.15	-0.18	-0.19	-0.19
Boulder undercut (C_3)	-	-	0.08	-0.29	-0.26	-0.02	-0.02	0.39	0.22	-0.08
Submerged log (C_4)	-	-	-	-	-	-	-	-	-	-
Overhanging vegetation (C_5)	0.16	-0.30	0.21	0.16	-	-	0.21	-0.06	-	-
Bedrock undercut (C_6)	0.11	0.27	-0.28	0.07	0.13	0.33	-	-	-0.01	0.38
Root undercut (C_7)	-0.07	0.05	-	-	0.01	-0.11	-0.04	-0.06	-	-
Variance explained	3.90	2.69	3.64	2.95	2.95	2.44	4.47	2.42	4.39	2.06
Percent of variance (Cumulative)	35.48	59.98	40.46	73.32	26.84	49.06	49.70	76.60	48.87	71.78

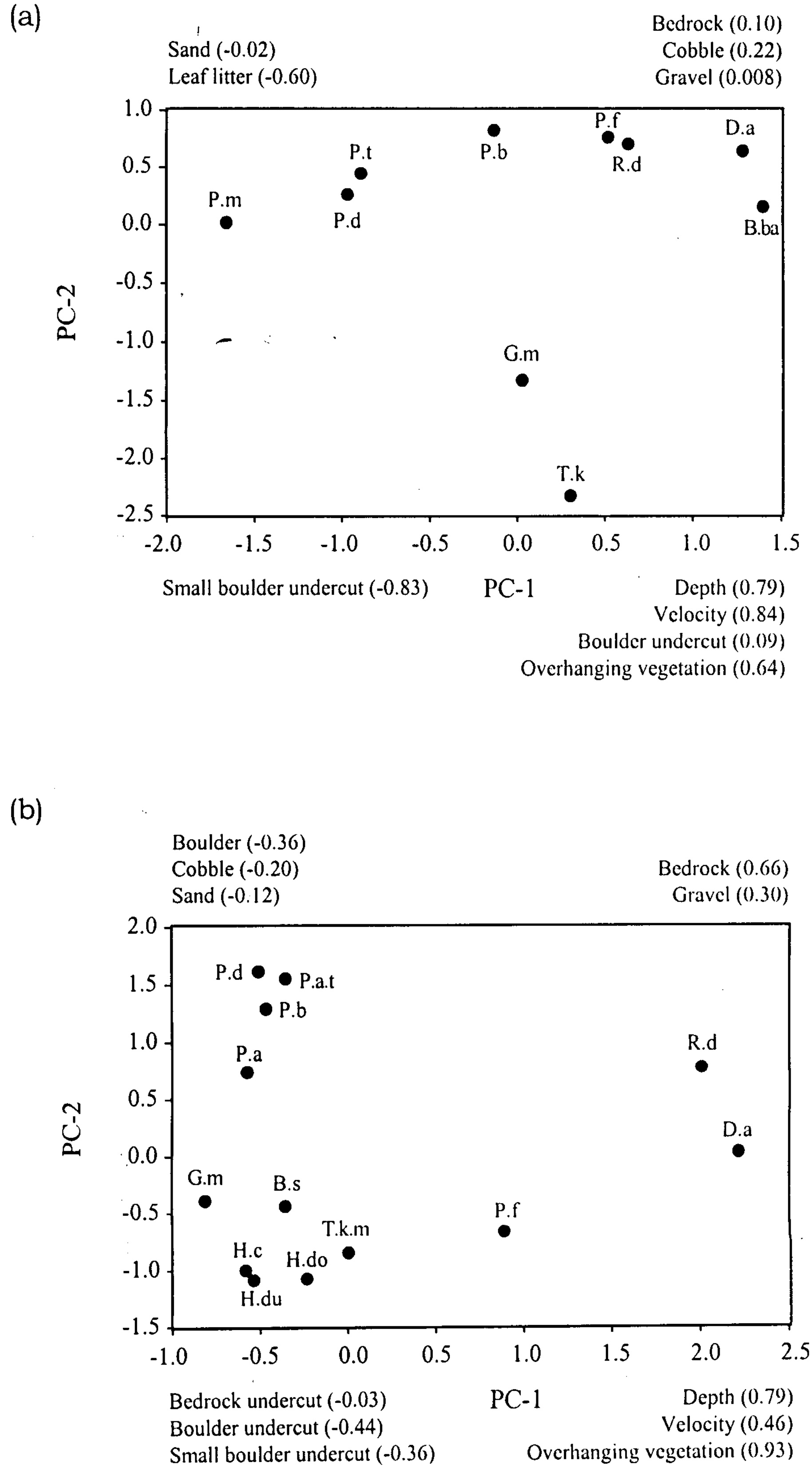
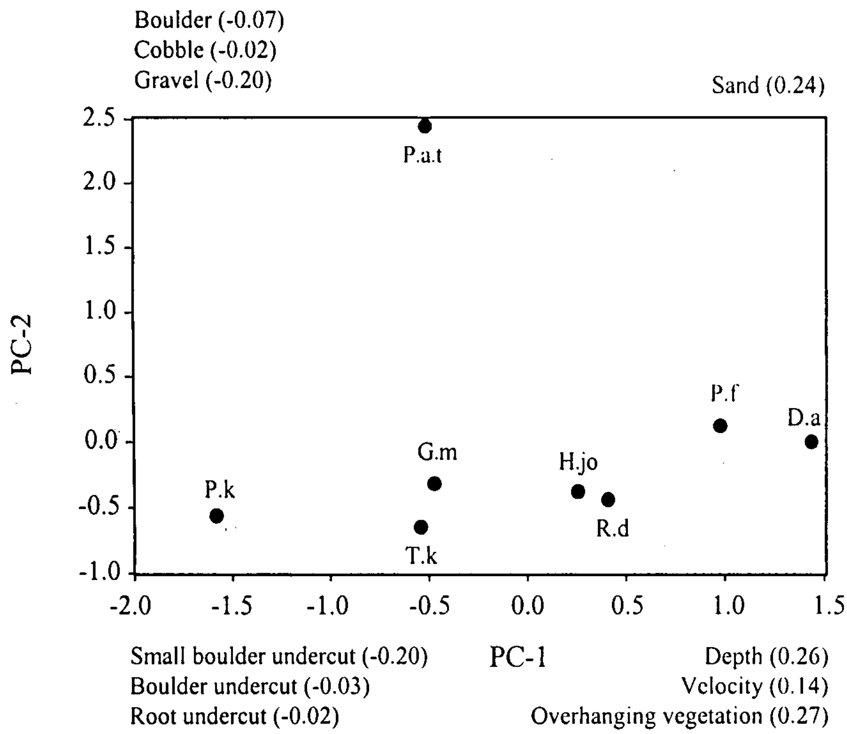


Figure 14. Principal components plot of mean habitat use by cyprinid fishes in Samikuchi (a) and Thalayanai (b) streams (Tamil Nadu) in Western Ghats. Species abbrevations are given in appendix I.

dobsoni and *Tor khudree malabaricus* and also *Garra mullya* were found in low flow habitats with cobble, boulder and sand (Fig. 14 b). They preferred boulder and bedrock undercut as cover whereas *P. amphibius* and *P. arulius tambraparniei* also preferred shallow and low flow with boulder and cobble substrata. In Karaiyar (Fig. 15a), *Danio aequipinnatus* and *Puntius filamentosus* were observed in deeper area with high velocity and they occurred in sandy substratum with vegetation cover. *Rasbora daniconius* and *Horalabiosa joshuai* utilized medium depth with medium flow in gravel and sand substrates with overhanging vegetation. The usage of microhabitat by *Garra mullya* and *Tor khudree* were similar as in Samikuchi stream (Figs. 14a, 15a). The endemic species *Puntius arulius tambraparniei* and the newly described species *P. kannikattiensis* exhibited distinct patterns of microhabitat use (Fig 15a). *P. arulius tambraparniei* was found in shallow area, medium flow with boulder and cobble substrata and it used root undercut as cover, whereas *P. kannikattiensis* was also found in shallow region with low flow with boulder and gravel substrates.

In Hanumannadhi (Fig. 15 b), *Danio aequipinnatus* and *Rasbora daniconius* occurred in deeper area with high to medium flow and were found in gravel and sand substrates with bedrock undercut as cover. *Garra mullya* and *Puntius bimaculatus* were confined to low flow with gravel and sand. They used small boulderedges undercut as cover. In Gugalthurai (Fig. 16), *Danio aequipinnatus, Barilius gatensis* and *Barbodes carnaticus* occurred in deep areas with high velocity, but the usage of substrates and

(a)



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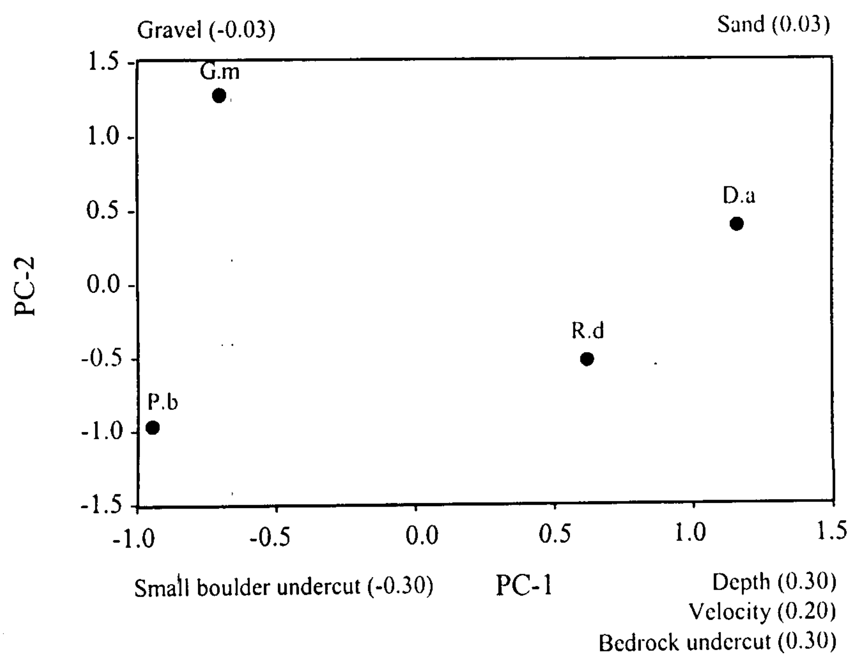


Figure 15. Principal components plot of mean habitat use by cyprinid fishes in Karaiyar (a) and Hanumannadhi (b) streams (Tamil Nadu) in Western Ghats. Species abbrevations are given in appendix I.

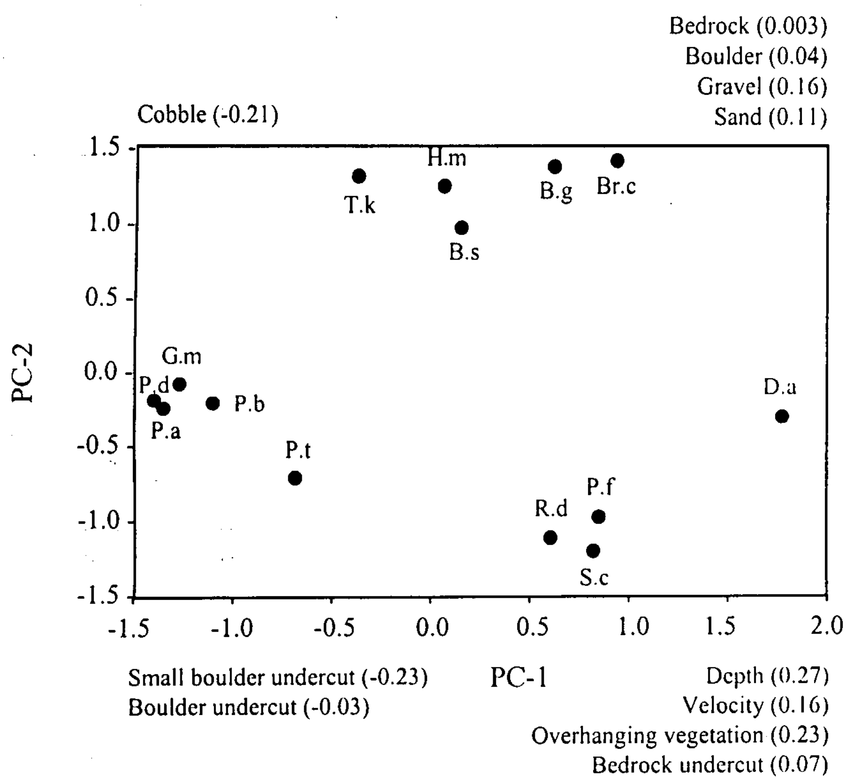
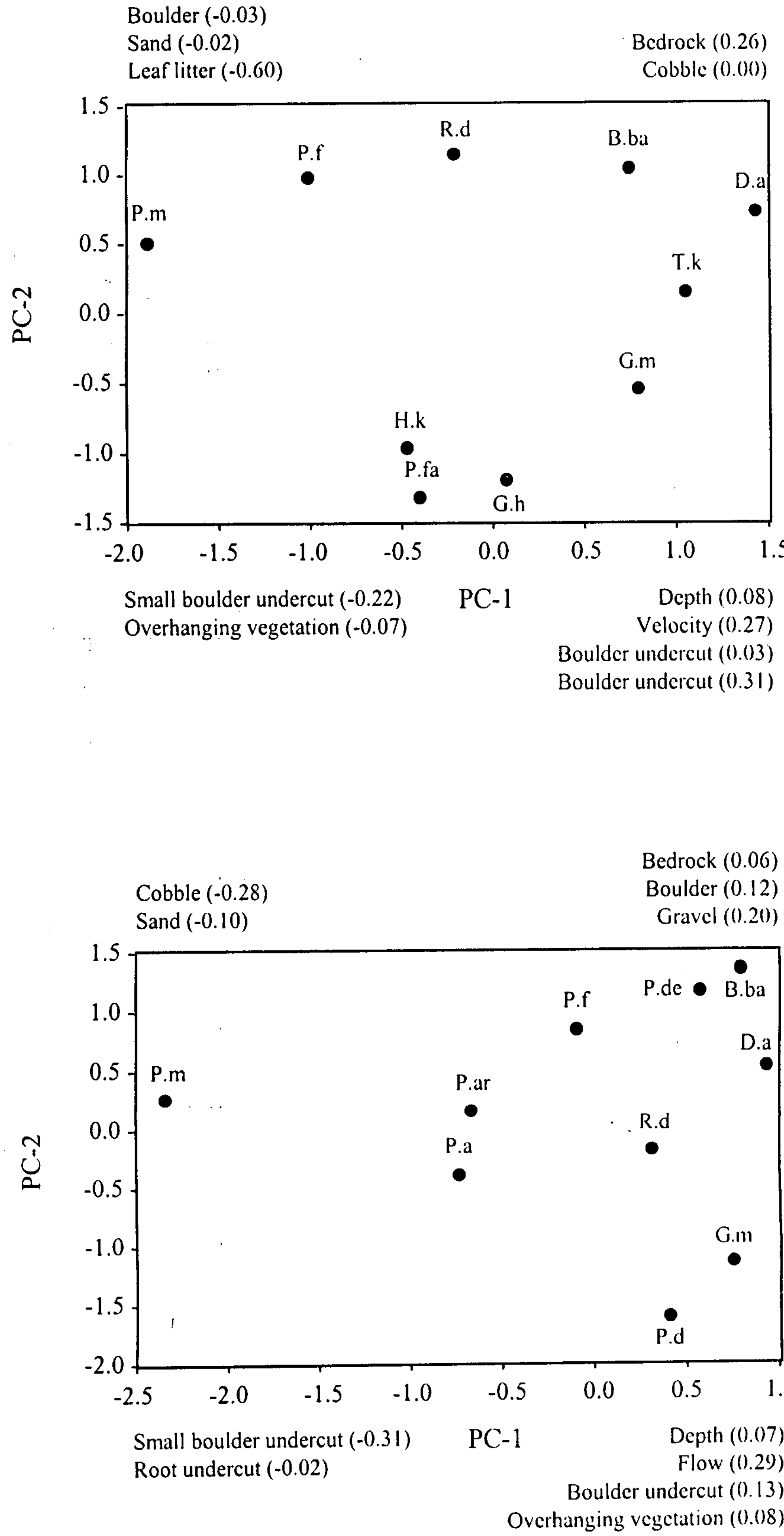


Figure 16. Principal components plot of mean habitat use by cyprinid fishes in Gugalthurai stream (Tamil Nadu) in Western Ghats. Species abbrevations are given in appendix I.

cover varied. *D. aequipinnatus* used gravel and sand substrates with overhanging vegetation whereas *B. gatensis* and *Barbodes carnaticus* preferred boulder and bedrock and the big sized barbs *Hypselobarbus micropogon*, *Tor khudree* and *Barbodes sarana* preferred shallow to deeper area, moderate flow habitat with rocky substratum (bedrock and boulders). *Rasbora daniconius, Puntius filamentosus* and *Salmostoma clupeoides* also used same category of depth and flow, like *Barilius gatensis and Barbodes carnaticus*, but they were found in gravel and sand substrates with overhanging vegetation. *Garra mullya, Puntius amphibius, P. bimaculatus, P. dorsalis* and *P. ticto* were found in low velocity with gravel and cobble (Fig 16).

In Kallar, (Fig. 17a), *Danio aequipinnatus, Barilius bakeri, Rasbora daniconius, Tor khudree* and *Garra mullya* used similar ranges of depth, flow, substrates and cover parameters as in Samikuchi stream of Tamil Nadu (Figs. 14a, 17a). *D. aequipinnatus* and *B. bakeri* preferred deeper and higher velocity and used bedrock, cobble and gravel substratum. They used boulder undercut and overhanging vegetation as major cover types. *Rasbora daniconius* occurred in deeper area with medium flow and bedrock, cobble and gravel were the preferred substrate types and they were found closer to boulder undercut. *Garra mullya* and *Tor khudree* also used same category of depth, substratum and cover as *Rasbora daniconius* but the velocity preference was in medium flow region. *Hypselobarbus kurali,*

(a)



(b)

Figure 17. Principal components plot of mean habitat use by cyprinid fishes in Kallar (a) and Achankoil (b) streams (Kerala) in Western Ghats. Species abbrevations are given in appendix I.

Puntius fasciatus and *Garra hughi* utilized shallow to deep area, low velocity with bedrock and boulder. *Puntius melanampyx* and *P. filamentosus* were in shallow depth with low flow habitat with sand and leaf litter and the overhanging vegetation was the major cover.

In Achankoil river (Fig 17b), *Danio aequipinnatus, Barilius bakeri* and *Puntius denisonii* formed one group and they made use of higher depth and velocity. They preferred gravel substratum with overhanging vegetation as cover. *Puntius amphibius, P. arenatus, P filamentosus* and *Rasbora daniconius* preferred area with low velocity and shallow habitat. *Garra mullya* and *Puntius dorsalis* also used similar type of depth and flow but they were found in bedrock and boulder substrates with boulder undercut as cover. *Puntius melanampyx* distinctly used shallower areas with low flow habitat with cobble and sand substratum. They preferred root undercut as cover (Fig. 17b). In Panniyar stream (Fig. 18), the usage of habitat by *Barilius bakeri* was similar to the usage in Samikuchi and Kallar streams (Figs. 14a, 17a). *Rasbora daniconius* were in shallow area with low velocity and they were towards sandy substratum. Likewise *Horalabiosa arunachalami* used similar range of depth and flow as by *R. daniconius* but were in boulder and cobble substrates. *Garra mcclellandi* and *Puntius melanampyx* co-existed with similar type of microhabitat use (Fig. 18).

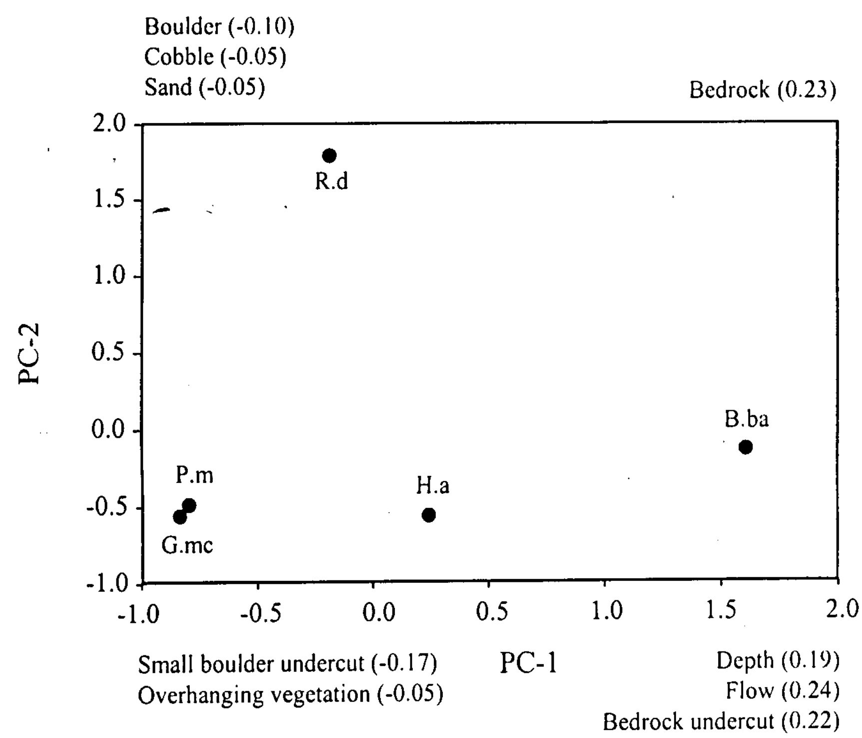


Figure 18. Principal components plot of mean habitat use by cyprinid fishes in Panniyar stream (Kerala) in Western Ghats. Species abbrevations are given in appendix I.

In Thalipuzha stream (Fig. 19a), *Barilius gatensis, Danio aequipinnatus, Osteochilichthys nashii* and *Hypselobarbus micropogon* used deeper areas with high velocity with boulder and gravels but they differed in cover utilization. While *D. aequipinnatus* and *B. gatensis* preferred mostly overhanging vegetation and *O. nashii* and *H. micropogon* were towards boulder undercut (Fig. 19a). *Garra mullya, Puntius conchonius* and *P. melanampyx* were found in shallow area with low flow region and were found in cobble, sand and leaf litter. In Bavalipuzha stream, *Danio aequipinnatus, Barilius gatensis, Salmostoma clupeoides* and *Rasbora caverii* were found in medium to high depth with swift flow region and they utilized bedrock, gravel and sand substratum with overhanging vegetation and root undercut as cover types (Fig. 19b). *Danio (Brachydanio) rerio* and *Puntius conchonius* were in shallow region with low flow and they were towards boulders. *Garra gotyla stenorhynchus, G. mullya, Puntius parrah* and *P. sophore* preferred shallow region with low flow and were in boulder and cobble substrates (Fig. 19b).

In Ekachi stream (Fig. 20a), *Barilius gatensis, B. canarensis, Danio aequipinnatus* and *Rasbora daniconius* were found in deeper habitats with high velocity and they used gravel and sand, but they were differing in the cover usage. *B. gatensis* and *B. canarensis* preferred bedrock undercut whereas *D. aequipinnatus* and *R. daniconius* were towards overhanging vegetation. *Garra gotyla stenorhynchus* used distinct pattern of microhabitats. They occurred in medium depth moderate velocity and

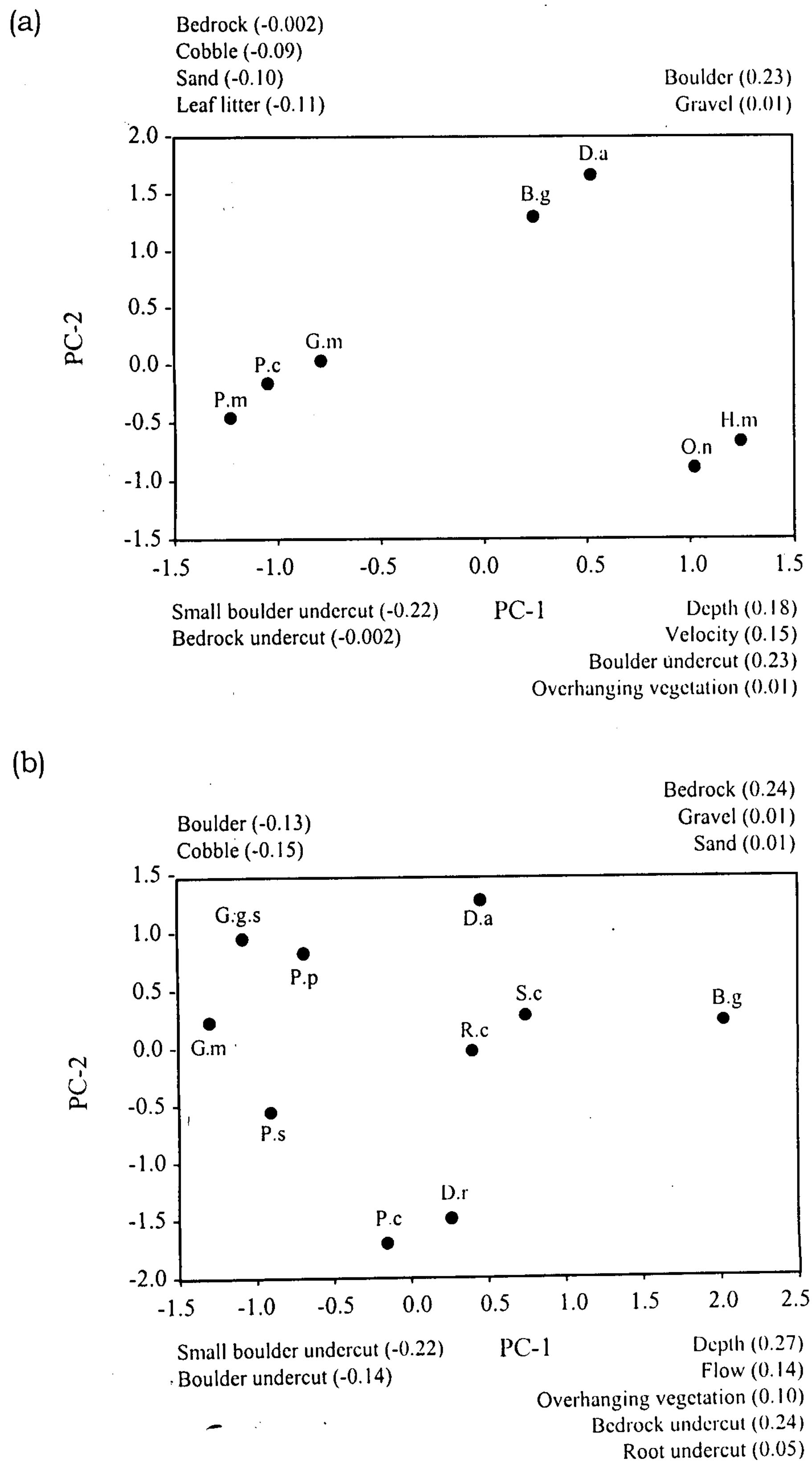
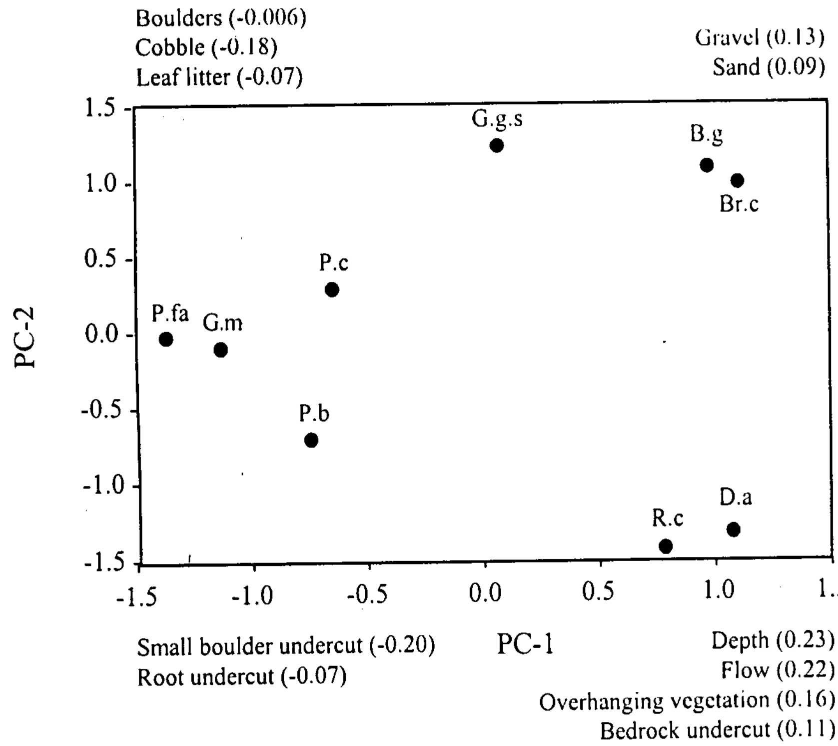


Figure 19. Principal components plot of mean habitat use by cyprinid fishes in Thalipuzha (a) and Bavalipuzha (b) streams (Kelara) in Western Ghats. Species abbrevations are given in appendix I.

(a)



(b)

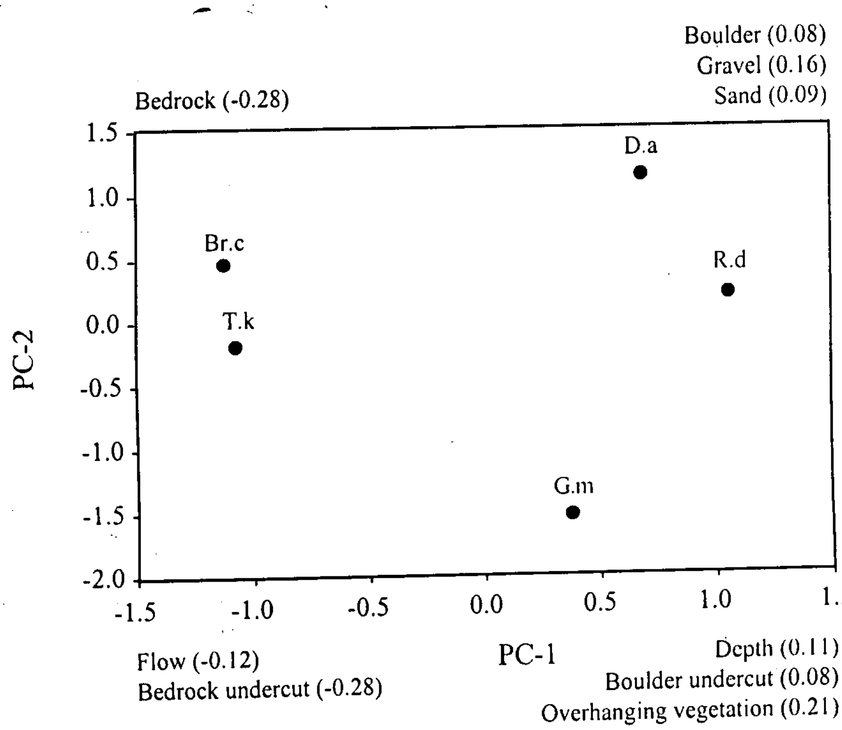


Figure 20. Principal components plot of mean habitat use by cyprinid fishes in Ekachi (a) and Kigga (b) streams (Karnataka) in Western Ghats. Species abbrevations are given in appendix I.

they were towards boulders. *Garra mullya, Puntius conchonius* and *P. bimaculatus* preferred shallow habitats with low flow and they used cobble, sand and leaf litter as substrates with boulder and root undercut as cover (Fig. 20a).

In Kigga stream, *Barilius canarensis* and *Tor khudree* were found in swift flowing areas with rocky substratum (bedrock and boulders), whereas *Danio aequipinnatus, Garra mullya* and *Rasbora daniconius* were in deeper areas with low to medium flow. But they used distinct pattern of substrates and cover; while *D. aequipinnatus* was in sand *R. daniconicus* was in gravel substratum but both were utilized overhanging vegetation as cover (Fig. 20b). *G. mullya* was towards boulders.

In Thunga river (Fig. 21), *Rasbora daniconicus, Barilius bendelisis, B. gatensis* and *Puntius pulchellus* formed a group which preferred deeper habitats with high velocity and were found in gravel and sand with no cover area. *Garra bicornuta* and *Barilius canarensis* also preferred the same category of depth and flow but they were towards bedrock and boulders with bedrock and boulder undercut as cover. Another group, *Garra gotyla stenorhynchus, G. mullya, Tor khudree* and *Hypselobarbus kolus* was found in shallow and low flow area with boulders and they used bedrock and boulder undercut as cover. *Osteochilichthys nashii, O. thomassi* and *Puntius narayani* preferred medium deep areas with moderate flow and they were towards gravel and sand.

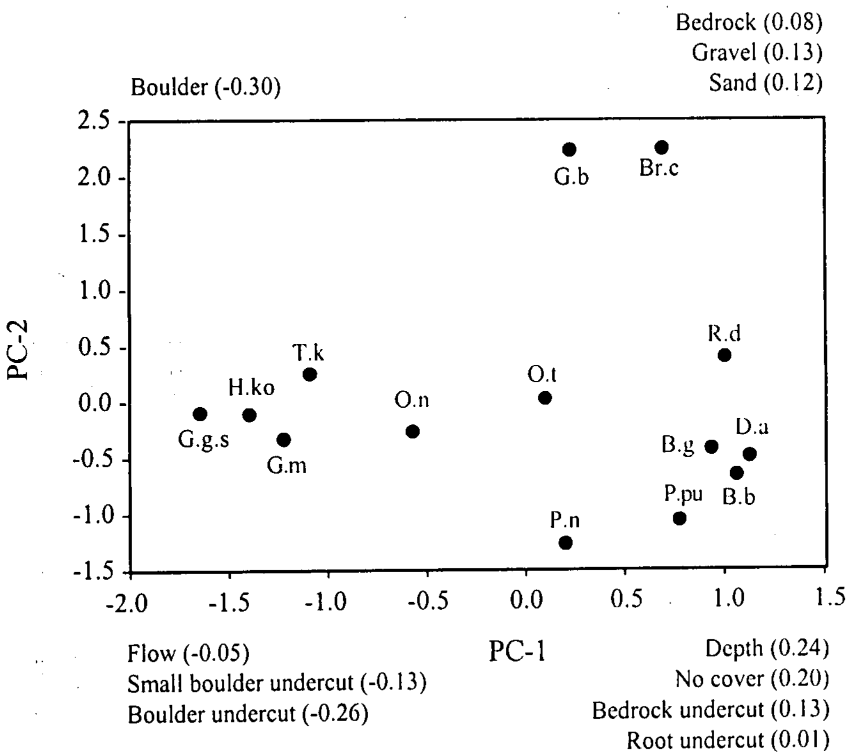


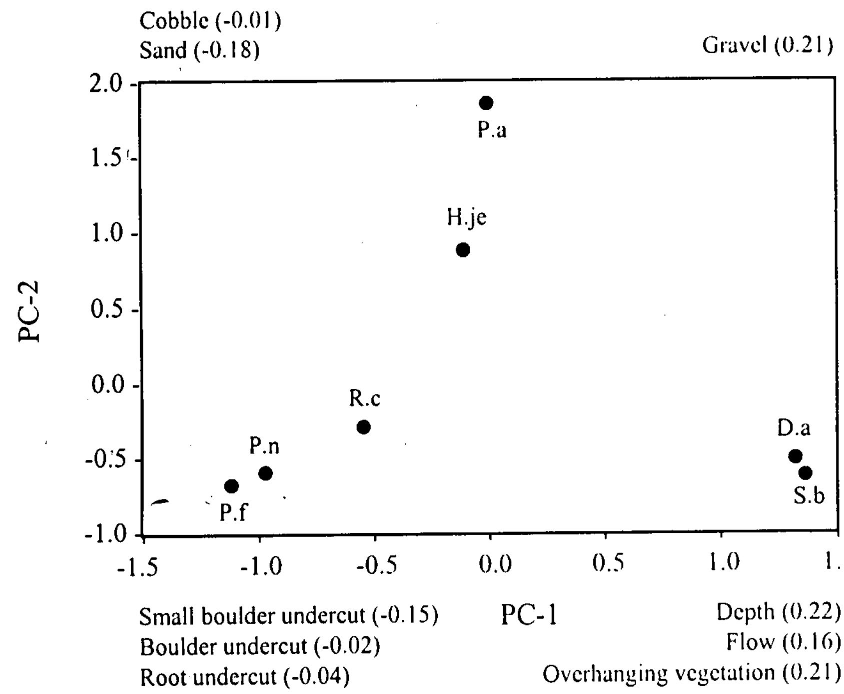
Figure 21. Principal components plot of mean habitat use by cyprinid fishes in Thunga stream (Karnataka) in Western Ghats. Species abbrevations are given in appendix I.

In Sirkuli region, *Danio aequipinnatus* and *Salmostoma boopis* co-existed with similar type of microhabitat and were found in deeper habitats with high velocity and they were in gravel substratum with vegetational cover (Fig. 22a). *Puntius amphibius* and *Hypselobarbus jerdoni* were found in medium depth with moderate flow and they were towards rocky substrates (bedrock and boulders) with bedrock and boulder undercut as cover. *Puntius narayani, P. filamentosus* and *Rasbora caverii* were found in shallow low flow region with sand and gravel (Fig. 22a). In Ganeshpal stream (Fig. 22b), *Danio aequipinnatus* and *Hypselobarbus jerdoni* occurred in deeper habitats with high velocity and they were confined to rocky substrate with bedrock and boulder undercut as cover. *Puntius narayani, P. ticto, Amblypharyngodon microlepis* and *Esomus barbatus* utilized shallow region with fast flowing habitats and they were towards boulder and cobbles. *Rasbora caverii* used a distinct pattern of microhabitat which used medium depth with moderate velocity habitats and was towards sandy substrate (Fig. 22b).

4. 5. Feeding habits

The gut contents of 396 cyprinid fishes belonging to 25 species were investigated. The diets of the individual fish species were shown in Fig. 9. The animal matter consisting of fallen terrestrial insects and benthic invertebrate larvae were the predominant food items in fourteen species (56 to 83 %). The great majority of fishes (fourteen species) primarily consumed animal matter, next to that they fed on allochthonous plant

(a)



(b)

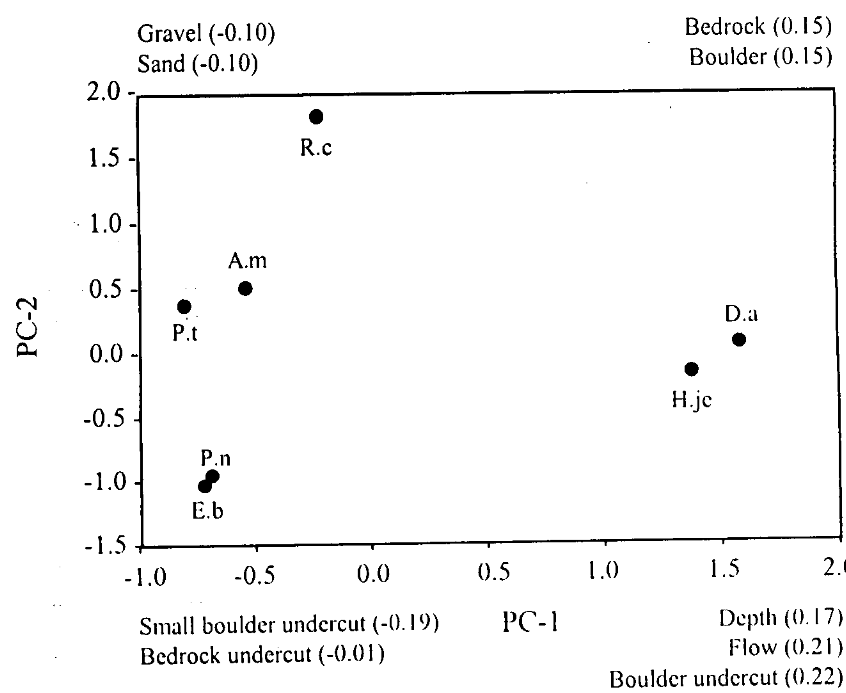


Figure 22. Principal components plot of mean habitat use by cyprinid fishes in Sirkuli (a) and Ganeshpal (b) streams (Karnataka) in Western Ghats. Species abbrevations are given in appendix I.

matter rather than algae or diatoms (group A in Fig. 23). Among them five species, *Danio aequipinnatus, Rasbora danicorius, Salmostoma boopis, Barilius bendelisis* and *B. canarensis* were mainly confined to animal matter. They consumed largely on red ants, spiders, flies and drifted benthic invertebrates. The rest and other groups in the gut contents consisted mainly of higher plant material and chitinous materials and wings of flies (Fig. 23 and Table 18). Dietary composition of *Barilius bakeri, B. gatensis, Salmostoma clupeoides, Puntius bimaculatus, P. dorsalis, P. arulius tambraparniei, Hypselobarbus dobsoni, H. dubius* and *H. jerdoni* were largely animal and plant matter (Fig. 23). Diets of *Barilius bakeri, B. gatensis* and *Salmostoma clupeoides* was similar with that of *S. boopis, Barilius bendelisis, B. canarensis, Danio aequipinnatus* and *Rasbora daniconius*. Benthic invertebrates were the main components of the gut contents of *Puntius bimaculatus, P. dorsalis* and *P. arulius tambraparniei*. The rest and other groups mainly consisted of higher plant matter, detritus and sand (Table 18). The big sized barbs *Hypselobarbus dobsoni H. dubius* and *H. jerdoni* fed on high proportion of animal matter (both terrestrial and benthic invertebrates). The rest and other groups consisted of higher plant matter, molluscan shells, chitinous materials and crustaceans (Table 18).

The next largest group consisted of six species (*Barbodes carnaticus, Horalabiosa jushuai, Puntius filamentosus, P. amphibius, P. conchonius* and *Tor khudree*), which fed on variety of sources such as fallen terrestrial insects, benthic invertebrates, higher plant matter, detritus and

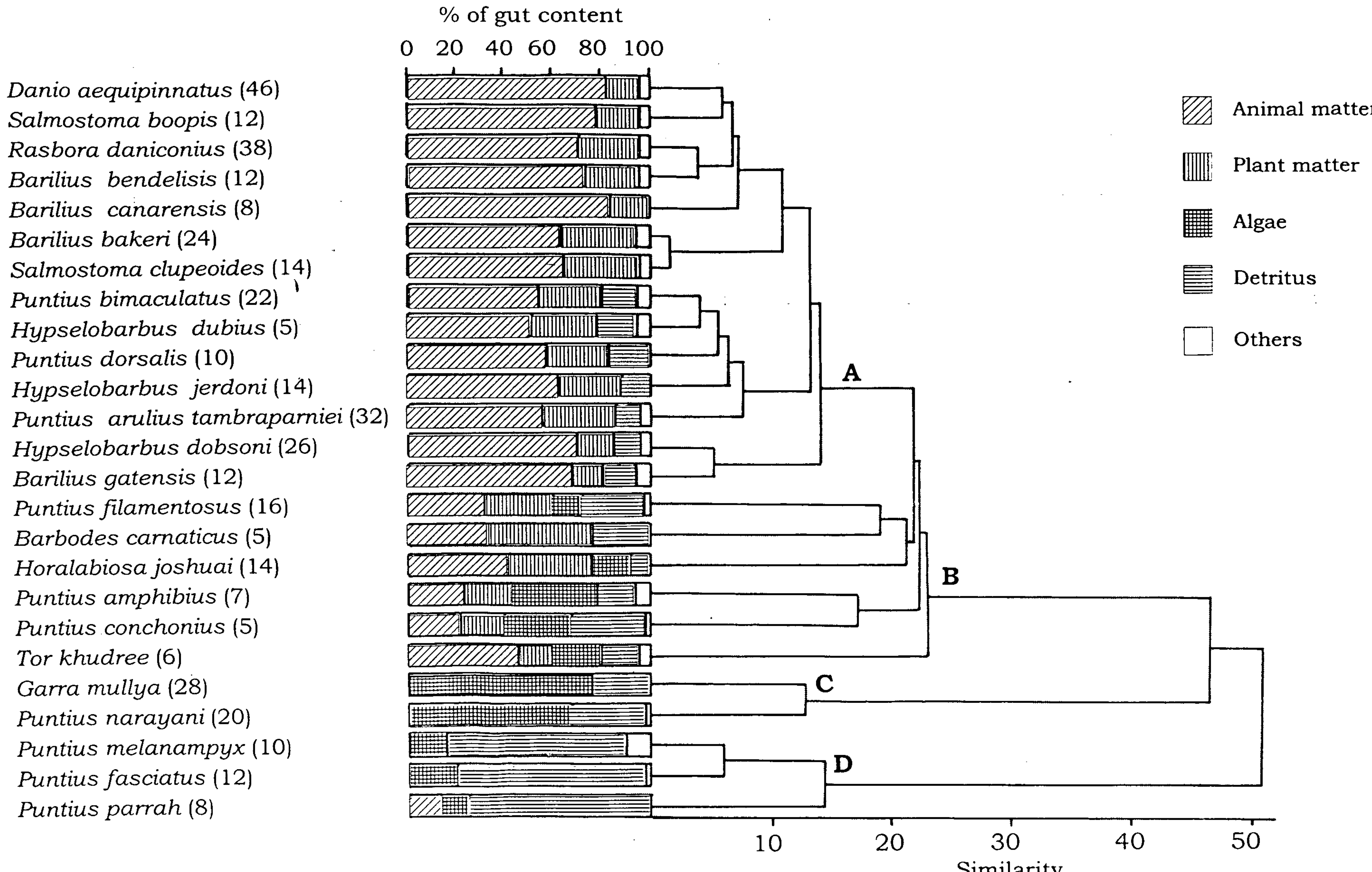


Figure 23. Proportional abundance of major dietary catagories in fish diets. Similarity between pairs of species were calculated using Euclidean distance. Number of guts analysed are shown in parentheses after species.

Table 18. Classification of rest and other groups (X) in the diets of cyprinid fishes. Species abbreviations are given in Appendix - I.

Items	Fish Species				
	B.b, Br.C, B.ba, B.g, D.a, R.d, S.b. S.c	**P.b, P.d, P.a.t**	**H.je, H.do, H.du**	**P.f, P.a, P.c, T.k**	**P.m, P. fa, P.p**
Plant seeds	X	X	X		X
Chitinous material	X		X	X	
Crustaceans			X	X	
Molluscan shells			X	X	
Wings of flies	X				
Parts of benthic invertebrates		X			
Sand		X		X	X

filamentous algae (group B in Fig. 23). Considerably higher proportion of animal matter was noted in the gut contents of *Tor khudree* and *Horalabiosa joshuai* though the proportion of the plant matter and algae was much less (Fig. 23). Algae was the main component of the gut contents of *P. amphibius* and *P. conchonius* compared to other diet categories. The gut contents of *P. filamentosus* exhibited equal proportion of animal matter, plant matter and detritus. The rest and other categories of in gut contents of *P. filamentosus, P. amphibius, P. conchonius* and *Tor khudree* consisted of chitinous materials, crustaceans, molluscan shells and sand (Table 18). Dietary composition of *Puntius melanampyx, P. fasciatus* and *P. parrah* were largely of detritus. They consumed predominantly (75 to 80 %) on dead and decayed organic matter (group D in Fig. 23) and the rest and other groups in the gut consisted of algae, higher plant matter and sand (Table. 18). Algae was the main dietary component of the gut contents of *Garra mullya* and *Puntius narayani.* They consumed largely (60 to 70 %) on periphytic filamentous algae (group C in Fig. 23).

In the food overlap analysis, fishes used broad food categories in the assemblages. Of 300 species pairs 128 showed high overlap values (> 0.67); 93 had values between 0.33 and 0.67; 64 had overlap values < 0.33 and 15 had no overlap. The species *Garra mullya, Puntius amphibius, P. fasciatus, P. narayani, P. melanampyx* and *P. parrah* had low overlap value compared with other species pairs (Table 19). The diet breadths of each species varied widely (1.04 to 4.06). The diet breadth of *Danio*

Table 19 : Maxtrix of diet overlap and diet breadth (B) of cyprinid fishes in Western Ghats streams. Species abbreviations are given in appendix I.

Spp.	B	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
D. a	1.4	.89	.00	.72	.72	.85	.74	.47	.05	.00	.41	.47	.67	.14	.74	.81	.85	.92	.95	.96	.82	.49	.62	.82	.00
R. d	1.7		.00	.82	.83	.88	.67	.57	.05	.00	.49	.81	.42	.14	.85	.92	.85	.98	.88	.93	.92	.56	.65	.64	.00
G. m	1.99			.16	.10	.13	.13	.34	.39	.44	.50	.17	.52	.36	.12	.00	.14	.00	.00	.00	.00	.24	.35	.44	.90
P. b	1.7				.94	.85	.97	.76	.2	.18	.64	.96	.58	.30	.92	.85	.85	.80	.71	.75	.85	.75	.80	.45	.18
P. ar	1.8					.84	.93	.73	.14	.12	.58	.91	.52	.14	.92	.00	.82	.80	.72	.75	.90	.74	.74	.46	.32
H. do	1.7						.82	.62	.15	.15	.54	.86	.52	.27	.89	.82	.95	.88	.85	.88	.85	.62	.77	.45	.15
H. du	2.7							.78	.23	.20	.64	.94	.60	.44	.89	.82	.83	.77	.68	.72	.82	.77	.80	.75	.20
P. f	3.86								.40	.39	.74	.74	.79	.51	.70	.63	.61	.56	.48	.35	.63	.84	.77	.80	.39
P. m	1.7									.92	.34	.17	.47	.86	.12	.06	.20	.05	.00	.07	.05	.24	.35	.23	.47
P. fa	1.45										.37	.17	.52	.86	.12	.02	.16	.02	.00	.02	.02	.24	.37	.23	.52
P. a	4.06											.59	.85	.41	.56	.50	.56	.49	.40	.46	.49	.59	.79	.67	.52
P. d	2.3												.57	.31	.95	.83	.84	.78	.74	.73	.83	.76	.75	.75	.17
P. c	4.0													.56	.52	.42	.50	.42	.39	.40	.42	.64	.75	.63	.60
P. p	1.7														.26	.14	.28	.14	.14	.14	.14	.38	.41	.35	.42
H. je	2.14															.88	.86	.82	.78	.77	.89	.72	.72	.76	.25
B. ba	1.98																.82	.89	.80	.85	.99	.64	.65	.72	.02
B. g	2.03																	.85	.80	.86	.82	.60	.76	.62	.16
B. b	1.65																		.91	.95	.90	.54	.65	.62	.02
Br. c	1.4																			.94	.81	.50	.60	.58	.00
S. b	0.94																				.85	.49	.65	.57	.01
S. c	1.94																					.64	.65	.72	.02
B. c	2.9																						.64	.77	.24
T. k	3.4																							.80	.37
H. jo	1.04																								.23
P. n	1.8																								

aequipinnatus, Rasbora daniconius, Garra mullya, Puntius amphibius, P. arenatus, P. bimaculatus, P. fasciatus, P. melanampyx, P. parrah, Hypselobarbus dobsoni, Barilius bakeri, B. bendelisis, B. canarensis, Salmostoma boopis, S. clupeoides and *Horalabiosa joshuai* were relatively narrow (Table 19). They had strong dietary segregation between species. While the other species *Puntius filamentosus, P. amphibius, P. conchonius* and *Tor khudree* had broad (high) diet breadth (Table 19). They consumed a wide rage of food categories available in the environment (generalists).

4. 6. Guild structure

From the results of the microhabitat utilization and feeding habits fish assemblages in Western Ghats streams exhibited four general pattern of resource (food and space) use : benthic, mid-water column, surface and generalist which can be classified into a guild structure. Species comprising the benthic guild were *Garra mullya, G. mcclellandi, G. bicornuta, Puntius amphibius, P. conchonius, P. dorsalis, P. fasciatus, P. melanampyx, P. bimaculatus, P. kannikattiensis, P. narayani, P. sophore, P. ticto, P. parrah, Hypselobarbus curmuca, H. dubius, H. micropogon, H. kurali, Tor khudree* and *T. khudree malabaricus* as were found nearer to the substrates, at lower velocities and generally in shallower water than members of the other guilds. They fed almost completely on bottom substrates and benthic invertebrates. In contrast member of the surface water guild, *Danio aequipinnatus, Danio (Brachydanio) rerio, Barilius bakeri, B. bendelisis, B. gatensis, B. canarensis, Salmostoma boopis, S. clupeoides* and *Puntius* *denisonii* were characteristically occupied microhabitat far from the substratum, higher velocities and higher position (surface) in the water column and the diet preference was more towards higher plant and animal matter. *Rasbora daniconius, R. caverii, Hypselobarbus jerdoni, Osteochilichthys nashii, O. thomassi, Barbodes carnaticus, B. sarana, Puntius arenatus* and *P. pulchellus* occupied middle position of water column (mid-water guild) and the food utilization was towards animal and higher plant matter. The fourth group of guild consisted of *Puntius arulius tambraparniei, P. filamentosus, Horalabiosa joshuai* and *Hypselobarbus dobsoni* which utilized deeper area to shallow water and they also occupied almost all substrate types. They also had broad diet breadth and high dietary overlap with members of other guilds.

4. 7. Man made alterations in Western Ghats streams

Western Ghats streams are the most affected ecosystems from human interference than other regions. Most of the streams in Western Ghats have easy access to human activities such as extraction of water for drinking and agricultural practices, removal of riparian corridor for conversion of cash crop plantations, sand and gravel extraction and construction of dams for hydroelectric power projects. The major man - made activities were identified in the study streams (Table 20). Among the 15 streams, Bavalipuzha, Thalipuzha in Kerala, Ekachi, Thunga, Sirkuli, Ganeshpal in Karnataka and Samikuchi in Tamil Nadu are highly disturbed by local people for their day to day activities like bathing,

Table 20. Major man-made alterations in the streams of Western Ghats.

Sites	Nature of alterations	Bank stability (%)	Activities
Samikuchi	habitat alterations	40	sand and gravel extraction
Thalayanai	well protected under Forest Department	100	relatively less disturbed
Karaiyar	well protected under Forest Department	100	relatively less disturbed
Hanumannadhi	riparian forest removal	30	areca nut and orchard plantations
Gugalthurai	well protected under Forest Department	80	relatively less disturbed
Kallar	habitat alterations	80	sand extraction and bathing
Achankoil	no alterations	40	relatively less disturbed
Panniyar	riparian forest removed	30	cash crop plantations (cardamom, clove)
Thalipuzha	riparian forest removed	45	orchard plantation and bathing
Bavalipuzha	riparian vegetation altered	40	human settlement in the riparian corridor, water extraction for drinking and irrigation
Ekachi	riparian vegetation completely altered	20	converted into paddy fields agricultural run off water entry
Kigga	no alterations	90	no major disturbance
Thunga	no riparian vegetation, eroded bank	25	agriculture activities in river bank, bathing (pilgrimage)
Sirkuli	eroded bank	50	water extraction, bathing
Ganeshpal	channelising water	40	irrigation and bathing

channelizing water for irrigation etc., In Samikuchi and Kallar streams sand collection and gravel extractions are the primary factors that lead to habitat alterations. In Hanumannadhi and Panniyar streams the natural bank vegetation are replaced by orchard and cashcrop plantations respectively which lead to poor riparian cover. Thalayanai, Karaiyar and Gugalthurai stream are unaltered and are well protected areas under Kalakad Mundanthurai Tiger reserve and Nilgiri Biosphere Reserve in Tamil Nadu.

Antony Johnson, J. 1999: Diversity and ecological structure of fishes in selected streams/rivers in Western Ghats. Ph.D Thesis, Manonmaniam Sundaranar University, Tirunelveli, India.

5. Discussion

Results are discussed in four parts: i) species diversity and pattern of species distribution, ii) influence of habitat characteristics on fish abundance iii) resource utilization of cyprinid fishes and iv) conservation of fish community in Western Ghats streams.

i. Fish diversity and pattern of species distribution

The Western Ghats streams exhibit high variability in stream fish assemblages. Assemblage composition varies between 6 and 17 species and the composition is determined by specific ecological characteristics in each stream. The first significant result is that the highest diversity of species richness and endemic forms are encountered in Thalayanai, Gugalthurai, Kallar and Achankoil streams of southern Western Ghats. Ali and Ripley (1983) hypothesise that the southern most division of Western Ghats (south of Palghat Gap 8° – 9° N) seems to be a natural pass which has played a significant role in isolating a variety of organisms on either side of it for a long period of time. It is tested and supported in birds diversity (Ali and Ripley, 1983), amphibians (Daniels, 1992; Bhatta,

1997) and in florestic diversity (Nayar, 1996). Moreover, the high hill ranges (Malabar, Travancore hills of Kerala and Nilgiris, Anamalai, Palani and Tirunelveli hills of Tamil Nadu) are largely restricted to south of 11° N. Thus it is evident that environmental conditions such as widespread rainfall (both south-west and north-east monsoons) and cooler climate have played important role in diversity pattern and endemism in southern Western Ghats (Daniels, 1992). The diversity of fish species in the present study also fall in line with the earlier findings of other flora and fauna.

The species richness of river fauna may be dependent on the accessibility of streams (Horwitz, 1978). The high species richness streams of Thalayanai and Gugalthurai are well protected in Reserve Forest area (in Kalakad Mundanthurai Tiger Reserve and Niligiri Biosphere Reserve) though Achankoil and Kallar are not in protected areas or wildlife sanctuaries. However, the high species richness accounted in site Thunga river is due to the size of the river and tributary effect (Horwitz, 1978; Vannote *et al.*, 1980; Minshall *et al.*, 1985; Zalewski and Naiman, 1985) as it is a fifth order river. In general main river channel will have high species richness (Schlosser, 1991; Puscy *et. al.*, 1993) and this is true in the present study.

Streams from Kerala part of Western Ghats are encountered with more endemic forms (8 species are strictly endemic to Kerala). These endemic fishes are usually well specialised and their movements along the river may be very limited. As a result, the distribution of many species is limited to a set of rapids, a few headwaters or a single tributary (Kottelat and Whitten, 1997). For example, the species *Puntius denisonii* is endemic to Achankoil river, found only rapids of the upstream region. Moreover, in Kerala, the streams are on high elevated hills, short stretched (west flowing) and most of the streams are undammed due to a series of rapids and pools. Hence the fauna of rapids is known to have a very high rate of endemism (Easa and Shaji; 1997; Kottelat and Whitten, 1997)

Cyprinids dominate teh assemblages structure as they occupy all possible habitats in the Western Ghats streams due to their high adoptive variability. In the present study, four of the recorded species, *Danio aequipinnatus, Garra mullya, Puntius filamentosus* and *P. conchonius* have widespread distribution in Indian region (Talwar and Jhingran, 1991; Jayaram, 1999) and they are common and abundant species in the Western Ghats streams. Such extensive distribution and their common high abundance suggest that most of these species are capable of tolerating a wide range of environmental conditions (Pusey *et al.*, 1993).

Ajithkumar (1997) pointed out that the distribution of hill stream loaches, *Bhavania australis, Noemacheilus denisoni, N. guentheri, N. semiarmatus and N. triangularis* are restricted to Mysore, Nilgiris and in the central part of Western Ghats. He also stressed that the present status and distribution is not well established. Moreover, *Garra hughi* is recorded from only Cardamom and Palani hills of Western Ghats. In the present study these species are recorded from various streams in the Western Ghats (Tables 3, 4, 5) which showed that they have well established distribution in the Western Ghats streams. Moreover, the monospecies *Bhavania australis* has been recorded in almost all the study streams and their distribution range is extended up to the southern part of Western Ghats (Kallar, Achankoil, Samikuchi, Thalayanai and Karaiyar streams). Also the endangered big sized barbs *Hypselobarbus curmuca* (known from Krishna, Godavari and Cauvery basin); *H. dobsoni* (known only from Krishna river basin); *H. dubius* (small numbers in Cauvery at Nilgiris); *H. kolus* (small numbers in Godavari, Krishna and Cauvery), *Tor khudree malabaricus* (rivers of Kerala) have very restricted distribution and small fragment of population exist in the Western Ghats rivers (Talwar and Jhingran, 1991; Menon, 1992; CAMP, 1998; Jayaram, 1999). A viable populations of these endangered species are found in the Thalayanai stream (Manimuthar sub basin of Tamiraparani river) and it is a new innovation from my study. These restricted and patchy distribution of species have led to small and vulnerable population. The newly described species, *Homaloptera santhamparaiensis* (Arunachalam, Johnson and Soranam, 1999), *Horalabiosa arunachalami* (Johnson and Soranam, 1999) and *Puntius kannikattiensis* (Arunachalam and Johnson, 1999) from Western Ghats streams indicate that, the streams of Western Ghats is still underexplored and therefore further studies are warranted.

ii. Influence of habitat characteristics on fish abundance

A variety of factors control the abundance and distribution of stream fishes such as water quality, habitat availability, competition for space, flow variability and nutrient supplies from riparian habitats. Such environmental variables are easy to predict than other biotic variables like predation and competition. Single water quality parameter has been used i n earlier studies to correlate with fish abundance; for example Echelle *et al.* (1972) and Matthews (1987) showed a direct relationship between salinity or oxygen and distribution of fish species in midwestern streams in North America. Hawkes *et al.* (1986) hypothesed that the combination of different water quality parameters is likely to operate "in concert with each other as a multivariate system and not as isolated unvariate variables". He has included nine physicochemical variables in a canonical analysis of fish distribution patterns in temperate streams, but has found out only two variables (chloride and water temperature) which have strong association with abundance. Lyons (1989) has found a positive correlation of a particular fish assemblage with conductivity and water temperature. In the present study also the conductivity and water temperature have strong association with fish abundance. Result of this study also has established the fact that stream water of low ionic concentration has a restricted fauna in both abundance and species richness (Allan, 1995).

Predictable spatial pattern of channel morphology (Leopold *et al.*, 1964) and flow regime (Horwitz, 1978) exist in natural stream ecosystem. Shallow cascades, riffles and pools occur in high gradient streams, with addition of deeper pools and riffles in lower reach of stream (Leopold *et al.*, 1964; Yang, 1971). Large number of individuals are commonly found in deeper (pool) habitat with fewer, smaller individuals in shallow, unstable (riffle) habitat. Water depth is a predictor of fish density in riffles. Lower water column would at some point make riffle habitat unsuitable for fishes (Braaten and Berry Jr, 1997). Such habitat – based approach has been identified as the primary basis for assessing fish community organization (Schoener, 1974b). Numerous studies have supported this generalization for fish communities (e.g., Gibbons and Gee, 1972; Werner and Hall, 1976; Werner *et al.*, 1977; Schlosser and Toth, 1984; Bain *et al.*, 1988; Lobb and Orth, 1991; Braaten and Berry Jr, 1997). In the present study the habitat utilization coefficient based fish community – habitat model reflects five habitat use guilds in Western Ghats streams. Similar studies have been described in which two to six habitat guilds of fish in warm water streams are reported (Schlosser, 1982; Bain *et al.*, 1988; Leonard and Orth, 1988; Lobb and Orth, 1991; Aadland, 1993; Braaten and Berry Jr, 1997). The proposed habitat guilds (pool, mid-pool, riffle, cascade and generalist) are in general agreement with those guilds previously proposed in small streams of other region. Results of the present study suggest, the specialised forms (non – cyprinids) such as *Glyptothorax madraspatanum*, *G. trewavasae, Homaloptera santhamparaiensis, Bhavania australis* and *Balitora mysorensis* represent a riffle and/or cascade guilds. Similar habitat – fish community model has been reported from the Himalayan fish assemblages (Edds, 1993; Johal, 1998), where the species of *Noemacheilus* are in riffles and *Glyptothorax* are in low hill riffles.

Moreover, Braaten and Berry Jr (1997) hypothesed that, large fishes are distributed evenly among the habitat and do not exhibit changes in habitat use. However, the assemblage organization in Western Ghats streams differs substantially from the concept, because in the present finding the large sizeed fishes, such as *Barbodes carnaticus, Hypselobarbus curmuca, H. dubius, H. dobsoni, H. kolus, H. kurali, H. micropogon* and *Tor khudree malabaricus* usually inhabit mid – pool. Other studies have also supported the present findings, where large fish in small streams usually inhabit pools (Schlosser, 1982; Aadland, 1993) and woody habitats (Angermeier and Karr, 1984) in temperate streams. However, the most cyprinids species did not consistently associate with a single habitat. For example, the small cyprinds (*Danio aequipinnatus, Rasbora daniconius, R. caverii, Barilius bakeri, B. bendelisis, B. gatensis, Garra mullya, G. mcclellandi, Horalabiosa joshuai, H. arunachalami* and *Puntius filamentosus* used a variety of habitats (pools, riffles and runs) in Western Ghats streams. Such substantial overlaps in habitat utilization in cyprinid communities has also been reported in warmwater streams (Gibbons and Gee, 1972; Werner and Hall, 1976; Schlosser and Toth, 1984; Leonard and Orth, 1988) and in temperate streams (Baker and Ross, 1981; Schlosser, 1982). However, the present study reflects similarity in the habitat fish community model as in temperate streams.

The physical habitat (depth, current and substratum) forms the 'structure' within which an organism makes its home. Vegetation has also been included as a related factor because of its influence on the physical nature of streams (Schlosser, 1991; Gordon *et al.*, 1992). These factors determine the abundance and diversity of organism (Hynes, 1970; Schlosser, 1982; Hubert and Rahel 1989; Pusey *et al.*, 1993; Barretto and Uieda, 1998). The basic pattern of increasing species richness and low replacement are consistent with the hypothesis based on habitat diversity (Horwitz, 1978). The relationship between habitat diversity and fish communities has been analysed by Gorman and Karr (1978) in temperate streams in which they include the diversity of current, depth and substrate which determine the riverine fish communities.

Importance of habitat structure has been identified as the primary basis on which many biological communities are organized (Schoener, 1974b) and several studies have supported this generalization for fish communities (Evans and Noble, 1979; Schlosser, 1982; Tallman and Gee, 1982; Angermeier and Karr, 1984; Schlosser and Toth, 1984; Bain *et al.*, 1988; Angermeier and Schlosser, 1989; Aadland, 1993; Pusey *et al.*, 1993; Matthews *et al.*, 1994; Lahr and Fausch, 1997). The organization of fish assemblages in the present study also follows the uniform pattern reported from other regions. Also Williams (1964) emphasized that in larger surface areas there will be many habitats and the fauna will increase when the surface area increases. In the present study significant correlation between fish species abundance and habitat area supports the hypothesis. However, in aquatic environment, where a third spatial dimension (*i. e.*, depth) can be included in habitat patch (volume) (Angermeier and Schlosser, 1989). The volume predicted fish abundance more than habitat area, thereby suggesting that the area and depth of stream habitat also influence distribution of stream fishes (Angermeier and Schlosser, 1989; Harvey and Stewart, 1991; Pusey *et al.,* 1995). The influence of depth on fish abundance in the present study also fall in line with the earlier findings.

iii. Resource utilization of cyprinid fishes

The physical factors such as stream velocity, channel shape, channel size, substrate and vegetation combine to create 'macro and microhabitats' for stream dwelling organisms. Channel structure plays an important role in determining the distribution of macro and microhabitat features. Bovee (1982) proposed a concept that in a highly structured stream community, the stream channel provides a variety of conditions; deep-shallow, deep-fast, shallow-low and shallow-fast with various combination of substrates and cover. Number of researchers also have identified streams in which habitat availability / diversity is a good predictor of (i) the number of species present, (ii) fish species diversity or (iii) assemblage composition (Gorman and Karr, 1978; Angermeier and Karr, 1984; Meffe and Sheldon, 1988; Angermeier and Schlosser, 1989 and Pusey *et al.*, 1993, 1995; Grossman *et al.*, 1998).

An important component of the microhabitat availability analysis in the present study of the Western Ghats streams is geographically diverse habitats with differential hydraulic characters that are capable of creating suitable microhabitats for cyprinid species in different ways. The patterns of spatial resource use in assemblage members are generally similar among Western Ghats streams. For example, the differential use of flow by *Garra mullya* in streams with low to medium flow or high flow in different streams is evident in the present study. However, in the present study there are several differences in microhabitat use by species. The smaller fishes generally occupied shallower habitats and are sometimes found closer to the substrates, which showed a consistent pattern in various streams such as the use of shallow to deeper areas with low flow to high area by larger species such as *Hypselobarbus dobsoni, H. dubius, H. curmuca, H. jerdoni, Tor khudree* and adults of smaller species like *Puntius arulius tambraparniei, P. dorsalis* and *P. filamentosus*. Similar results have been observed by other investigators studying European cyprinids (Ross *et al.*, 1987; Schiemer and Spindler, 1989; Copp, 1990, 1992; Rincon *et al.*, 1992; Grossman and de Sostoa. 1994a,b).

In general, non-random use of substrata (microhabitat) is attributable to covariance of these parameters with depth and velocity. This phenomenon has also been observed in fish assemblages from American (Angermeier and Karr, 1984) and European streams (Grossman and de Sostoa, 1994 a,b). This size related shifts in microhabitat usage of stream fishes in temperate latitude are due to predation pressure by predators (Harvey and Stewart, 1991; Hill and Grossman, 1993). It is unlikely that the microhabitat used by larger species and adult of small species in the present assemblages in Western Ghats is primarily attributable to difference in the microhabitat availability in a particular stream.

Results of gut content analysis showed that the Western Ghats fish assemblages exhibit a remarkable lack of feeding specializations. In general, stream ecosystems are typically poor in nutrients, the species present are often depend heavily on allochthonous food resources (insects, leaves and fruits dropping into the water) and some extent in benthic invertebrates (Kortmulder, 1987). The allochthonous and generalised feeders are common in Western Ghats streams (Fig. 23). The gut content analysis of most common species such as *Danio aequipinnatus, Rasbora daniconius, Barilius bakeri, B. bendelisis, B. gatensis* and *B. canarensis* shows that they depend largely on terrestrial insets and plant matter. A similar type of findings has been reported by Kortmulder (1987) in streams of Sri Lanka and in cyprinids of south India by Arunachalam *et al.*, (1988, 1997). Only a limited number of species have had modest dietary specialisation. For example *Garra mullya* feeds exclusively on algae and *Puntius fasciatus* on detritus.

Based on the underwater observation, microhabitat utilization and feeding habitats, fishes of Western Ghats streams could be classified as members of trophic guilds: (i) benthic, (ii) mid-water-column, (ii) surface-water and iv) generalist. Results on the resource utilization show that there is a high degree of food and microhabitat segregation between the surface dwellers and bottom dwellers. Water velocity is one of the important microhabitat variables for spatial segregation of species (Arunachalam *et al.*, 1988). In the present study the surface guild members *Danio aequipinnatus, Barilius bakeri, B. gatensis, B. canarensis, Salmostoma cluspeoides* and *S. poobis* prefer the higher velocity while the bottom guild members *Garra mullya, G. bicornuta, G. mcclellandi, Puntius amphibius, P. bimaculatus P. kannikattiensis, P. narayani, P. sophore, P. parrah* prefer low to high velocities. High degree of spatial and dietary overlap observed in the member of mid-water and generalist guild is suggestive of the interspecific competition in determining resource utilization within the assemblage. There is a regular pattern of co-existance of surface dwellers such as *Danio aequipinnatus* and *Barilius bakeri; D. aequipinnatus* and *B. bendelisis, D. aequipinnatus* and *B. gatensis; D. aequipinnatus* and *B. canarensis; D. aequipinnatus* and *Salmostoma clupeoides*) in the study streams exhibited strong similarity in their use of space and food over spatial scale. Hence it is probble that the surface dwellers are segregated from other guilds and this kind of segregation for food and space had already been documended in stream pools of a south Indian river (Arunachlam *et al.*, 1988, 1997).

iv. Conservation of fish Community

Western Ghats streams are facing severe threat by man - made activities. Streams/rivers are altered by removal of riparian vegetation, removal of substrates and extraction of water for agriculture practices. Riparian vegetation or vegetation closely associated with wetted areas are important in protecting stream channels and improve bank stability. It prevent banks from eroding during high flow. In addition it shades the water, provides food through insects and other organic matter entering the water and contribute to fish habitat (Arumantrout, 1990). The removal of substrates through sand mining in the stream may have been responsible for the change in channel flow at Samikuchi stream. The removal of sand, during periods of natural flow tend to increase the rate of natural down stream movement of substrate resulting in changes in benthic fauna that may affects increased turbidity as a result of changing of fishes have been well documented (Liao *et al.*, 1989; Natarajan, 1989; Griffiths, 1997). Uncontrolled exploitation of surface waters results in a long-term decrease of the available water volume for fish habitation. If over exploitation occurs, the entire fish community may disappear. These changes in the aquatic system can lead to a reduced flow and water quality, reduction in food supplies, loss of spawning grounds and rearing capabilities and loss of protection and refuge areas. The result of these alteration is the reduction in fish diversity, shift in tropic variability of fish abundance in stream ecosystem (Schlosser, 1991). Since habitat requirement of most stream fishes are quite narrow, with the loss of suitable habitat, population are destroyed which eventually leading to extinction of species. A recent review on estimates of extinction rates based on the relation between habitat loss and species loss, indicates that regions rich in endemic species dominate the global patterns of extinction. (Rastogi and Rastogi, 1998).

Western Ghats streams are exhibited a high degree of habitat heterogeneity and this is reflected in its highly structured fish assemblage. However, as a result of man-made activities and habitat loss, a number of fish taxa are under threatended (Table 8). Special attention is needed to conserve and improve the stream habitat and the threatened and endemic fishes such as the big sized barbs *Hypselobarbus curmuca, H. dubius, H. dobsoni, H. kolus, H. kurali, H. micropogen, Tor khudree* and *Tor khudree malabaricus*. It can be possible through restoration of stream habitat and captive breeding of threatended species.

Ecological restoration is defined as "the process of intentionally altering a site to establish a defined, indigenous, historic ecosystem. The goal of this process is to emulate the structure, function, diversity and dynamics of the specified ecosystem" (Society of Ecological Restoration, 1991). It is possible to improve stream habitat by proper management and by establishment of fish sanctuaries for the endangered fishes. Such fish sanctuaries have already been established for the endangered species of mahseers in river Thunga (Protected under Fisheries Department of Karnataka). Complete ban should be implemented on further expansion of coffee and tea plantation, direct extraction of water, water diversion and sand mining from the headwater stream. Ranching of endangered species should be established through captive breeding techniques. Captive breeding has yet to be inadequately applied for conservation of fishes with notable exception in Hydrel lake of Tata Electric Company at Lonavala, Maharastra for breeding of threatended mahseer *Tor khudree* (Kulkarni and Ogale, 1978). In view of the less ecological information and habitat requirements on economically important big sized fishes like *Tor* spp. and *Hypselobarbus*. Present study will form a basis on the habitat requirements of the endemic and threatened fish species in Western Ghats streams. However, the pattern may vary for assemblages in streams in different land settings such as streams in altered biomes of tea and coffee plantations, lowland streams with altered riparian zones, water quality damage by industrial activities and filling of riverine wetlands for human settlements and industrial establishments.

Antony Johnson, J. 1999: Diversity and ecological structure of fishes in selected streams/rivers in Western Ghats. Ph.D Thesis, Manonmaniam Sundaranar University, Tirunelveli, India.

SUMMARY

Conservation of biodiversity requires an understanding of the processes involved in the structure and function of biotic communities. Biodiversity defines the structure and function of an organism, community etc., in a particular ecosystem. The interactive process of species in relation to the environment and the biotic interactions are important for the conservation of habitats. Fishes are important group of vertebrates in determining the trophic structure of an aquatic ecosystem in lotic community, the diversity, community structure and species assemblages are influenced by biotic and abiotic factors such as water current, depth, substrate, nutrients and riparian cover.

Habitat structure and resource in Western Ghats streams vary in ecoregions of Tamil Nadu, Kerala and Karnataka states in Peninsular India. Relationship between habitats from different biomes in the resource availability to fish assemblage has not been documented in Indian streams/ rivers. Therefore, the present study is an attempt to document the fish assemblages composition, assemblage structure and function in selected

streams/rivers of Western Ghats. The present study forms of three parts 1. fish assemblage composition and structure, 2. inventory of habitat features 3. fish assemblage function by the differential uses of food and habitats.

In fish species inventory, 73 species of fishes were recorded from fifteen study streams in Western Ghats, of which 48 species were recorded from streams of Kerala, 29 species from Tamil Nadu and 33 species from Karnataka. Cyprinids were the dominant members in the assemblage structure (45.5 to 87.5 %). Maximum species richness were encountered in streams of southern part of Western Ghats such as Thalayanai (S = 18), Kallar (S = 17), Achankoil (S = 17) and Gugalthurai (S = 15). The presence of big sized barbs like *Hypselobarbus curmuca, H. dobsoni, H. dubius, H. kolus* and *Tor khudree malabaricus* in Thalayani stream and the newly described species *Puntius kannikattiensis* from Karaiyar stream and *Homaloptera santhamparaiensis* and *Horalabiosa arunachalami* from Panniyar stream were new inovations of the present study. Out of 73 recorded species, 44 species are endemic to Western Ghats streams, of which 23 species are in threatened categories. In regional endemism 8 species are strictly endemic to Kerala region.

In species distribution, five species such as *Danio aequipinnatus, Garra mullya, Noemacheilus triangularis, Puntius filamentosus* and *P. conchonius* are common and abundant in Western Ghats streams. Patchy distribution was noted in big sized barbs and in some specilised groups. From this study the range of distribution of hill stream loaches *Bhavania australis, Noemacheilus denisonii, N. guentheri, N. denisoni, N. semiarmatus, N. triangularis* and *Garra hughi* is wide in Western Ghats streams.

Water quality studies showed that the Western Ghats streams were generally poor in dissolved ions. However, high conductivity values were recorded in Thunga river (0.62 μ/mhos) and Ganeshpal (0.67 μ/mhos). The Canonical correlation analysis of water quality variables against fish density showed that the conductivity and temperature had strong association with fish density.

In each stream reach, the major habitat types (pool, riffle, run and cascade) were identified. Samikuchi, Thalayanai, Karaiyar and Gugalthurai streams had more diverse habitat types in 100 m reach. Large and deeper habitat was recorded in Thunga river. Based on the habitat utilizaion coefficient, five habitat use guilds (pool, mid-pool, riffle, cascade and generalist) are proposed in Western Ghats streams. The specialised forms such as *Glyptothrax Madraspatanum, G. trewavasae, Homaloptera santhamparaiensis, Bhavania australis* and *Balitora mysorensis* were member of riffle or/ cascade guild. The larger fishes *Hypselobarbus curmuca, H. dubius, H. dobsoni, H. jerdoni, H. kolus, H. kurali, H. micropogon* and *Tor khudree malabaricus* are in mid-pool guild. The small cyprinids, *Danio aequipinnatus, Rasbora daniconius, Barilius bakeri, B. bendelisis, B.*

canarensis, Puntius arenatus P. bimaculatus P. conchonius P. narayani, P. fasciatus, P. melanampyx and *P. pulchellus* used pool habitats. *Puntius filamentosus, H. joshuai* are members of generalist guild.

The macrohabitat features such as habitat diversity (depth, current and substrate), habitat area, habitat volume, instream cover and percentage of pool-riffle were used for the fish assemblage pattern in Western Ghats streams. The regression analysis between habitat characteristics and fish density were highly significant ($p > 0.01$) in Western Ghats Streams.

Microhabitat analysis showed that, in Tamil Nadu the Thalayanai stream had broad range of microhabitat variables compared to poor microhabitat variables in Hanumannadhi stream. In Kerala, Kallar and Achankoil also had great amount of substrate heterogeneity. Low stream velocity was recorded in Panniyar (stagenent flow 70 %) and Bavalipuzha (stagenent flow 60 %). In Karnataka, Thunga river had more deeper area (26.3 %), dominant substrate type was gravel (80 %) with poor cover complex (no cover area was 66 %). In Kigga falls the dominant substrate type was bedrock (70 %) and also had good amount of cover complex.

Based on the Principal Component Analysis, the streams Thalayani, Kallar and Samikuchi had the high velocity, more deeper habitats and greater amount of substrate heterogeneity and cover complex. The Achankoil river had turbulant flow, deeper habitat, greater amount of erosional substrates (gravel and sand) and poor cover complex. Comparatively poor habitat characteristics were recorded in Thunga river.

The PCA of microhabitat utilization of cyprinid species explained specific water velocity, depth, substratum and cover used by individual cyprinid species in Western Ghats streams. The patterns of spatial resource used in assemblage members were generally similar among Western Ghats streams. The small species *Danio aequipinnatus, Danio (Brachydanio) reiro, Barilius bakeri, B. bendelisis, B. gatensis, B. canarensis, Salmostoma clupeoides, S. poobis* and *Puntius denisonii* had occupied microhabitat far from substratum with higher velocity. *Garra mullya, G. mcclellandi, G. hughi, G. gotyla stenorhynchus, Puntius amphibius, P. conchonius, P. dorsalis, P. fasciatus, P. melanampyx, P. bimaculatus, P. kannikattiensis, P. narayani, P. sophore, P. ticto, Hypselobarbus curmuca, H. dubius, H. micropogon, H. kurali, Tor khudree* and *T. khudree malabaricus* were found closer to the substratum and shelter at low velocity and greater water depth. *Rasbora daniconius, R. caverii, Horalabiosa joshuai, H. arunachalmi, H. dobsoni, H. jerdoni, Osteochilichthys nashii, O.thomassi, Barbodes carnaticus, B. sarana, P. arenatus, P. filamentosus, P. parrah* and *P. pulchellus* occupied medium depth with moderate flow.

Gut analysis of 25 most common cyprinid species showed that the Western Ghats fish assemblages exhibited a broad range of feeding habits. The great majority of fishes (14 species) primarily consumed animal matter consisting of fallen terrestrial insects and benthic invertebrate larvae. *Garra mullya* and *Puntius narayani* showed some feeding specilisation as they had in their diets largely of periphytic filamentous algae and diatoms. *Puntius melanampyx, P. fasciatus* and *P. parrah* fed mainly on detritus.

Based on the microhabitat utilization and feeding habit four trophic guilds (surface dweller, bottom dweller, column dweller and generalist) are proposed for Western Ghats fishes. *Danio aequipinnatus, Salmostoma clupeoides, S. poobis, Barilius bakeri, B. bendelisis, B. gatensis, B. canarensis, Puntius denisonii* are member of surface guild. *Rasbora daniconius, R. caverii, H. jerdoni, Osteochilichthys nashii, O. thomassi, Barbodus cannaticus, B. sarana, P. arenatus, P. parrah* and *P. pulchellus* are members of column dweller. Bottom guild members are *Garra mullya, Garra mcclellandi, H. gotyla stenorhynchus, Puntius amphibius, P. conchonius, P. dorsalis, P. fasciatus, P. melanampyx, P. bimaculatus, P. kannikattiensis, P. narayani, P. sophore, P. ticto, Hypselobarbus curmuca, H. dubius, H. micropogon, H. kurali, Tor khudree* and *T. khudree malabaricus. Horalabiosa joshuai, Hypselobarbus dobsoni, P. arulius tambrapariniei* and *P. filamentosus* were generalist.

In the present study, the man-made alterations in the Western Ghats streams were identified. The major disturbance like sand mining, removal of riparian vegetation, channelization and pilgirimage activities were identified in the streams Bavalipuzha, Thalipuzha, Ekachi, Thunga, Sirkuli, Ganeshpal and Samikuchi.

From this study it can be concluded that the altered habitats supported less diverse fish assemblages and undisturbed streams have more diverse and more endemic forms. The species distribution and endemism in southern part of Western Ghats might be explained by altitudinal variations, forest types and land setting. The microhabitat and microhabitat approaches used in this study provided supplemental information about the habitat requirements of fish assemblages.

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Appendix I. Fish species names and the abbreviations used in text.

A.m	*Amblypharyngodon microlepis*
B.a	*Bhavania australis*
B.b	*Barilius bendelisis*
B.ba	*Barilius bakeri*
B.ca	*Babodes carnaticus*
B.g	*Barilius gatensis*
B.m	*Balitora mysorensis*
B.s	*Barbodes sarana*
B.t	*Batasio travancoria*
Br.c	*Barilius canarensis*
D.a	*Danio aequipinnatus*
D.r	*Danio (Brachydonio) rerio*
E.b	*Esomus barbatus*
G.b	*Garra bicornuta*
G.g.s	*Garra gotyla stenorhynchus*
G.h	*Garra hughi*
G.m	*Garra mullya*
G.ma	*Glyptothorax madraspatanum*
G.mc	*Garra mcclellandi*
G.t	*Glyptothorax trewavasae*
H.a	*Horalabiosa arunachalami*
H.c	*Hypselobarbus curmuca*
H.do	*Hypselobarbus dobsoni*
H.du	*Hypselobarbus dubius*
H.je	*Hypselobarbus jerdoni*
H.jo	*Horalabiosa joshuai*
H.k	*Hypselobarbus kurali*
H.m	*Hypselobarbus micropogon*
H.s	*Homalaptera santhamparaiensis*
M.a	*Mystus armatus*
N.d	*Noemacheilus denisoni*
N.g	*Noemacheilus guentheri*

N.k	*Noemacheilus keralensis*
N.s	*Noemacheilus semiarmatus*
N.t	*Noemacheilus triangularis*
O.n	*Osteochilichthys nashii*
O.t	*Osteochilichthys thomassi*
P.a	*Puntius amphibius*
P.a.t	*Puntius arulius tambraparniei*
P.ar	*Puntius arenatus*
P.b	*Puntius bimaculatus*
P.c	*Puntius conchonius*
P.d	*Puntius dorsalis*
P.de	*Puntius denisonii*
P.f	*Puntius filametosus*
P.fa	*Puntius fasciatus*
P.k	*Puntius kannikattiensis*
P.m	*Puntius melanampyx*
P.n	*Puntius narayani*
P.p	*Puntius parrah*
P.pu	*Puntius pulchellus*
P.s	*Puntius sophore*
P.t	*Puntius ticto*
R.c	*Rasbora caverii*
R.d	*Rasbora daniconius*
S.b	*Salmostoma boopis*
S.c	*Salmostoma clupeoides*
S.w	*Silurus wynaadensis*
T.k	*Tor khudree*
T.k.m	*Tor khudree malabaricus*