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Fish Assemblage Structure of Two Contrasting Stream Catchments of the Mahaweli River Basin in Sri Lanka: Hallmarks of Human Exploitation and Implications for Conservation

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Abstract: Patterns of fish community composition in the Mahaweli ichthyological region of Sri Lanka were examined in agricultural tributaries of the Uma-oya catchment of the upper Mahaweli River in comparison to more pristine streams in a nature reserve in the Amban-ganga catchment. The Uma-oya catchment shows characteristics commonly observed in extensive agricultural exploitation such as impaired water quality and altered riparian vegetation. The most abundant fish species in the two regions were *Garra ceylonensis*, *Devario malabaricus*, and *Rasbora daniconius*, although their relative abundance differed between sites. *G. ceylonensis* and *Neomacheilus notostigma* were the only endemic fish species in common but the latter has been extremely depauperate. Endemism is higher in the reference sites (62.5%) than agricultural sites (ca. 25%); some of the reference streams showed greater diversity with unique fish species and a few species that have not been recorded previously in the catchment. The ichthyofaunal similarity between two catchments was 39% and fish species diversity was negatively correlated with stream gradients (Pearson correlation (-0.630); r^2 = 39.6% p = 0.028). Species density and biomass of *G. ceylonensis* and *D. malabaricus* were positively associated with some water quality parameters. The presence of exotic fish species were amongst the primary discriminants between human exploited and least-exploited (reference) streams. The possible negative impact of exotic *Oreochromis niloticus* (Nile tilapia) on indigenous *G. ceylonensis* is highlighted. This paper provides impetus for making several hypotheses for sustainability of stream fish assemblages in highly exploited agricultural catchments in Sri Lanka.

Keywords: Agricultural catchment, *Devario malabaricus*, Exotic fish, *Garra ceylonensis*, Knuckles streams, Mahaweli River basin, Nitrate, Phosphate, *Rasbora daniconius*, Sri Lanka.

INTRODUCTION

Sri Lanka is a small island (65,662 km^2) off the southern tip of the Indian peninsula between latitudes 5" 55' and 9" 55' N and longitudes 79" 41' and 80" 53' E. The central cross section of the island is characterized by a three-peneplane altitudinal model [1], which divides prominent slope breaks into coastal lowlands (up to 270 m and 0 - 15 degrees slope), uplands (270 m - 1,060 m altitude and 10 - 35 degrees slope), and highlands with well-defined high plains and plateau (910 m - 2,424 m). This geomorphology gives rise to 103 radially draining perennial river systems, which can be grouped based on fish faunal distribution into six major river basins: Mahaweli, Kelani, Kalu, Gin, Nilwala [2] and Walawe [3].

Sri Lankan streams and rivers house a diverse fish assemblage comprising 34 families from freshwater and saltwater ecosystems. The fish assemblage is not as diverse as other tropical countries [4], but it shares ancestral fish assemblages common to Asia. All of the 19 freshwater fish families recorded [5, 6] also occur in the southern regional part of Western Ghats [7] (i.e., the closest landmass of India). Differences in composition compared with the higher diversity in Western Ghats (25 families) may have appeared during the geological separation in Pleistocene ages [8]. This supports the scenario that these two areas remained in contact before their earlier separation and remained isolated for a long time in support of a distinct fish assemblage (i.e., endemic) in this continental Island.

Pethiyagoda [2] described Sri Lanka's 109 freshwater and brackish species, and found cyprinids the most abundant (41, including 24 introduced fish species; [5]. Of the 85 native freshwater species, 38 are endemic to Sri Lanka [9], and 49% of these are cyprinids, while the rest belong to 25 other families. The taxonomic identification of freshwater fish species is not complete and several indigenous cyprinids known to occur in Western Ghats (India) [7] have been identified as new species in Sri Lanka [10-12]. A most recent update of freshwater and brackish water fish species in Sri Lanka is presented in the Appendix **1**.

There have been few fish surveys along gradients in Sri Lankan streams, and the dominant fish distribution pattern in

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the highland plateaus is unknown. Studies on freshwater fishes in Sri Lanka have been limited to commercial fisheries, and even these have been largely restricted to some of the man-made reservoirs such as Parakrama Samudra [13], and Tissawewa [14]. In a study of the longitudinal gradient in the upper Walawe River basin from an elevation of 200 m up to 2,000 m above mean sea level (MSL), the diversity and abundance of fishes diminished with ascending altitude, where maximum elevation for occurrence of indigenous fishes was 1,400 m above MSL [3]. A recent comparative study [15] on riverine fish assemblages in dry and wet zones in Sri Lanka revealed varied assemblage composition along the longitudinal gradient, with abundance and assemblage structure varying along the two streams due to habitat characteristics. This implies that there are few potential environmental fish sentinels in streams at higher elevations; more importantly, the endemic species are limited in these areas to less than six [16].

In small islands like Sri Lanka where freshwater fish species are limited, threats can be overwhelmingly detrimental to the overall conservation agenda. Of the 85 freshwater species listed by Pethiyagoda [5], 29 freshwater fish species are listed as threatened and 10 as highly threatened in the context of the national fish conservation agenda. Streams and rivers (i.e. lotic environments) hold two-thirds of the endemic species and they account for more than 90% of threatened or vulnerable fish species [17]. The indigenous fish base is threatened by multiple disturbances including water pollution, sedimentation, deforestation, water diversion and impoundments, exotic fish introductions and over-exploitation [17-19]. Collares-Pereira & Cowx [20] reviewed various threats to freshwater fishes and ranked species introductions as the leading threat. Of the other potential threats, there is an increasing focus on pesticides in Sri Lanka, although the majority of studies have been conducted in the laboratory [21-23] and few are based on real exposure environments [24-26].

Fish population strength and dynamics in streams and rivers are essential components in study designs for fish conservation and management. In this study, we describe the community structure of fish species in streams in two river catchments in Sri Lanka: one with a history of intensive agricultural exploitation, as well as the least exploited catchment in the Mahaweli River basin in a nature reserve. We present results of seasonal sampling using two methods of fishing techniques conducted during February (2009) through January (2010). This preliminary study was designed to ascertain spatial and temporal distribution of abundant fish species in potential river catchments for designing agricultural impact studies on riverine fish species and for collecting baseline reference data.

MATERIALS AND METHODS

Study Area

The Mahaweli River is the longest river (335 km) with the highest discharge in Sri Lanka, and a catchment area of approximately 20% (10,327 km^2) of the total area of the country [18, 27]. The upper catchment covers approximately 25% of the central highland in Sri Lanka with more than five distinct basins; the Uma-oya basin is the largest [28]. The mean annual discharge is > 14.5 (± 2.8 SD) million m^3 (as measured at the Welimada gauging station during 1993 - 2004; Mahaweli Authority, Sri Lanka). The catchment receives annually 1,570 - 2,180 mm of rainfall (as measured in 6 stations within the catchment during 2008 - 2010; Department of Meteorology, Sri Lanka). The temperature maximum 28.7 ^{o}C and minimum 16.2 ^{o}C were recorded during 2008 - 2009 in the catchment. In addition to agriculture, the catchment is compounded with chanalization for irrigation, and stresses associated with a fishery, tourism, hydro-electricity and water supply for domestic, public and urban necessities. Twelve sites were selected for the collection of baseline information. The sites were represented by 8 locations (i.e., agriculturally impacted sites) of the Uma-oya catchment (stem stream) and its tributary streams, and potential reference locations from the Amban-ganga upper catchment. The Amban-ganga headwater streams are located in the Knuckles region draining to the Mahaweli River; Kalu-ganga (river) and Kambarawa-ganga are separate drainage systems in the Mahaweli River basin (Fig. **1**, Table **1**). The Knuckles is covered with montane forests and an associated buffer zone of approximately 260 km^2 area which spans from 200 to 1,900 m above MSL [29]. The Knuckles streams represent a part of Amban-ganga catchment which receives annually 1,435 - 2,111 mm of rainfall (as measured in 6 stations within the catchment during 2008 - 2010). The maximum temperature of 31.5 ^{o}C and minimum of 20.2 ^{o}C was recorded during 2008 - 2009 (Department of Meteorology, Sri Lanka). Intensive human activities in most of the areas have been arrested after the declaration of the area as Conservation Forest in May 2000 by the Government of Sri Lanka. A superficial estimation using a topographical map (1: 63,360; Survey Department, Sri Lanka, 1995) revealed that sampling locations in both catchments were falling into 3rd and 4th river order.

The upper reaches in both catchments are distinctly different from downstream locations, with cascading and down-pouring rapids with steep slopes. The stream sections of other sites in the Uma-oya were gently sloping tributaries with slow to moderate rapids, runs and water stagnant pools. All sampling sections were composed of riffles, runs, cruises and some pools made blocked by boulders. The surrounding topographies of all sections in the Uma-oya were extensively utilized and riparian areas were primarily cleared for vegetable cultivation. When riparian vegetation did exist, it consisted primarily of giant cane (*Arundo donax*) which grows to 5 - 6 m height, interspersed in rare instances with bushes and taller trees. This plant is often used for fences and trellis and during harvesting the stream is blocked by giant cane clearings and floating remnants can often be seen. The surrounding vegetation in reference streams was a dense rain forest with tall canopy devoid of immediate human impact (Table **1**).

Fish Community Assessment

Quantitative sampling was conducted along pre-determined sections from the Uma-oya (stream) and Amban-ganga catchments in February, July and September (2009) and January (2010). Sampling was always started from the lower (downstream) end of the stream section and proceeded upstream encompassing every geomorphic channel units i.e., pools, runs and riffles. The reach length in any of the location in the Uma-oya and Knuckles streams were not less

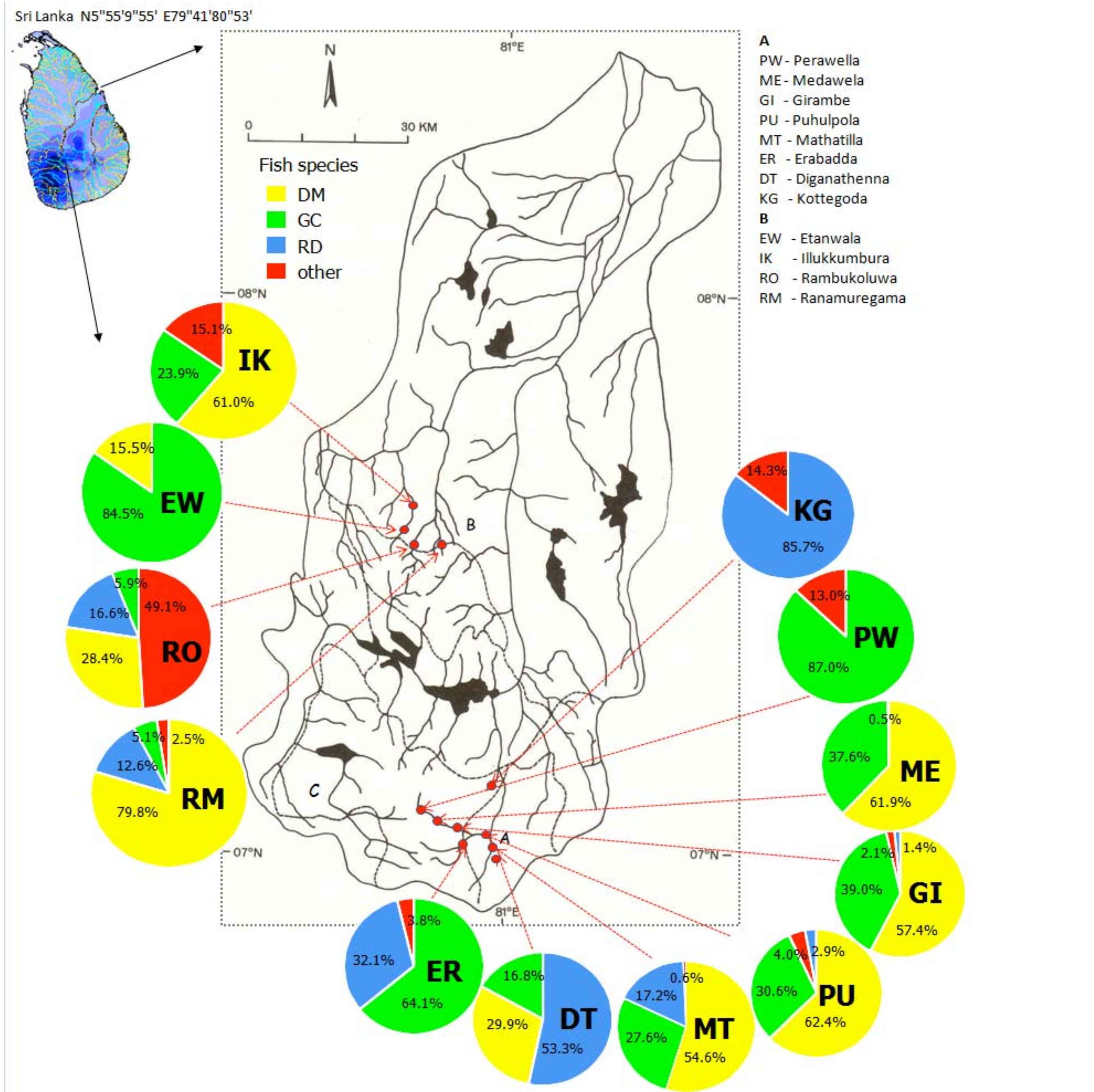

Fig. (1). Map of major stream distribution and sampling locations in the Mahaweli River basin of Sri Lanka: (**A**) Location of the Uma-oya catchment and sampling sites; and (**B**) Location of the Amban-ganga catchment and sampling sites (Modified from Silva [18]). Sampling sites are shown by (●). Pie-charts show fish species composition (% by density) of most abundant species of *Garra ceylonensis* (GC), *Devario malabaricus* (DM) and *Rasbora daniconius* (RD) estimated in a single sampling event using composite nets in January, 2010. The composition of other species is as per Table **2**.

than 38 m and the stream wetted width: length ratio was at the minimum of 1: 6 and extended up to 1: 400 in fish depauperate situations. In an effort to understand the spatial and temporal scale fish assemblage compositions in study sites, duplicate surveys were conducted representing low-flow months of southwestern and northeastern monsoons.

February and July (2009) samplings were conducted by electrofishing using back-pack EFKO equipment with Honda aggregate; blocking nets were not used. Three fishing runs were conducted at an interval of 35 - 45 min, with a minimum of 30 min of standing time between runs. Bateman *et al*.,[30] proposed single-pass electrofishing as providing accurate estimate of population measures such as length-frequency distribution of fish. Initial fish surveys were conducted across multiple habitats, using a minimum of two pools and riffle sections to be included in a predetermined stream section (reach) (Table **1**). Some of the past studies of Sri Lankan freshwater stream fish community composition and their persistence have been described as pool- and riffle-dwelling species [16, 31] with different species composition.

September (2009) and January (2010) samplings were conducted by three methods of netting (i.e., one cast nets, two dip nets and one drag net) employing 4 - 5 investigators and collecting all trapped fish. In order to harmonize fishing efforts between sites, three upstream passes were conducted for three types of netting, for example; (1) cast net was

Table 1. Water Quality (mean ± SD) and Some Habitat Properties in Sampling Sites in the Uma-Oya and Knuckles Streams

Site†	Coordinates	Elev. (m) above MSL	Water quality						Habitat property			
			Condu. (µS/cm)	DO (mg/L)	NO^{3-} (mg/L)	PO_4^{2-} (mg/L)	Chlor. *a* (mg/L)	SO_4^{2-} (mg/L)	Mesohabitat♣	Substrate♠	Aerial cover (%)♥	Riparian vegetation♦
Uma-oya (stream)												
PW	N06°55'25.9" E080°51'49.4"	1,187	155	7.5 ±0.5	0.079 ±0.015	0.062 ±0.008	1.01 ±0.10	4.4 ±0.7	riffle>>pool>run	Boulders, rubbles, bedrock	50-80	90% giant cane, 10% bushes and tall trees
ME	N06°56'33.9" E080°50'25.3"	1,110	154	6.9 ±0.5	1.222 ±0.160	0.504 ±0.023	5.13 ±0.34	8.8 ±0.8	riffle>>pool>run	Boulders, rubbles, silt	5-10	70% giant cane, 30% bushes
ER	N06°53'00.3" E080°52'38.1"	1,106	173	6.6 ±0.3	0.553 ±0.103	0.259 ±0.029	1.42 ±0.13	5.4 ±0.5	pool>>riffle>run	Rubble, sand, silt	0-20	10% giant cane, 60% bushes and tall trees, 30% open space
DT	N06°51'24.7" E080°57'55.3"	1,058	114	7.2 ±0.5	0.317 ±0.021	0.123 ±0.014	4.29 ±0.30	2.6 ±0.2	pool>run>riffle	Boulders, silt, sand	30-60	100% bushes and tall trees
GI	N06°54'49.5" E080°53'12.5"	1,054	249	8.5 ±1.2	1.103 ±0.044	0.278 ±0.036	7.04 ±0.41	11.7 ±1.4	run>riffle>pool	Rubbles, sand, silt	40-60	100% giant cane
MT	N06°51'58.5" E080°57'11.8"	1,030	91	6.7 ±0.5	0.237 ±0.015	0.108 ±0.014	2.11 ±0.11	1.6 ±0.2	riffle>>pool>run	Boulders, rubbles, silt	5-10	40% giant cane, 10% bushes, 50% open space
PU	N06°54'45.9" E080°55'48.1"	981	236	7.1 ±0.5	0.886 ±0.147	0.094 ±0.019	1.02 ±0.13	9.5 ±1.3	run>pool>riffle	Boulders, sand, silt	10-20	90% giant cane, 10% tall trees
KG	N06°57'41.7" E080°56'09.7"	963	122	7.0 ±0.5	0.400 ±0.01	0.215 ±0.021	4.12 ±0.40	4.7 ±0.1	pool>>riffle>run	Boulders, silt, clay	30-50	40% giant cane, 60% bushes and tall trees
Knuckles streams												
EW	N07°29'49.8" E080°44'57.8"	807	21	6.6 ±0.4	0.092 ±0.045	0.080 ±0.010	1.92 ±0.31	0.8 ±0.1	pool>>>riffle	Boulders, bedrock, sand, silt	20-40	100% bushes and tall trees (forest cover)
IK	N07°32'08.5" E080°46'19.0"	482	28	6.7 ±0.5	0.165 ±0.12	0.059 ±0.040	1.04 ±0.24	2.2 ±0.1	run>riffle>pool	Boulders, bedrock, rubbles	30-40	100% bushes and tall trees (forest cover)
RM	N07°30'11.8" E080°49'51.3"	339	31	6.8 ±0.5	0.061 ±0.08	0.091 ±0.041	1.17 ±0.22	1.4 ±0.2	pool>riffle>run	Boulders, bedrock, rubbles, silt	80-90	75% bushes and tall trees (forest cover), 25% grass
RO	N07°31'20.2" E080°47'57.0"	217	41	6.7 ±0.4	0.129 ±0.08	0.106 ±0.08	7.16 ±0.56	3.4 ±0.3	run>>riffle>pool	Rubbles, sand, silt	30-50	100% tall trees (forest cover)

† Descriptive site codes see on Fig. (**1**).
♣ Mesohabitat classification was based on Didier & Kestemont [93]; the strength of coverage of each mesohabitat is denoted by (>)
♠ Substrate types were approximated to classification by silt (mud or clay, organic muck), sand, gravel (2 - 50 mm), rubble (50 - 200 mm**),** boulder (> 200 mm), or bedrock.
♥ Based on best personal judgment
♦ % contribution within 5 m from the stream margin

employed in consecutive and non overlapping stream sections, approximately 4 m in length (= diameter of the cast net); (2) 2 dip nets were employed for stream sections in edges in a similar way approximately 50 cm in diameter; and (3) drag net (1 m in width and 6 m in length) was employed for the middle stream sections. The stretched mesh size was 10 mm in all nets. The two sampling methods were standardized as far as possible between sites by means of number of runs, time between consecutive runs, and unit area. During net sampling, all sampling reaches were isolated at the top and bottom of each reach by stop nets (10 mm stretched mesh size) to prevent fish movement in or out of the area during sampling. In a few occasions, natural boulder barriers provided adequate blockage. All samplings were conducted during the day time between 9:00 to 15:00 hrs.

Penczak & Glowacki [32] studied electrofisher efficiency in stream habitats and have shown a high level of efficiency with less than 5% escapes. It was also reported that there has

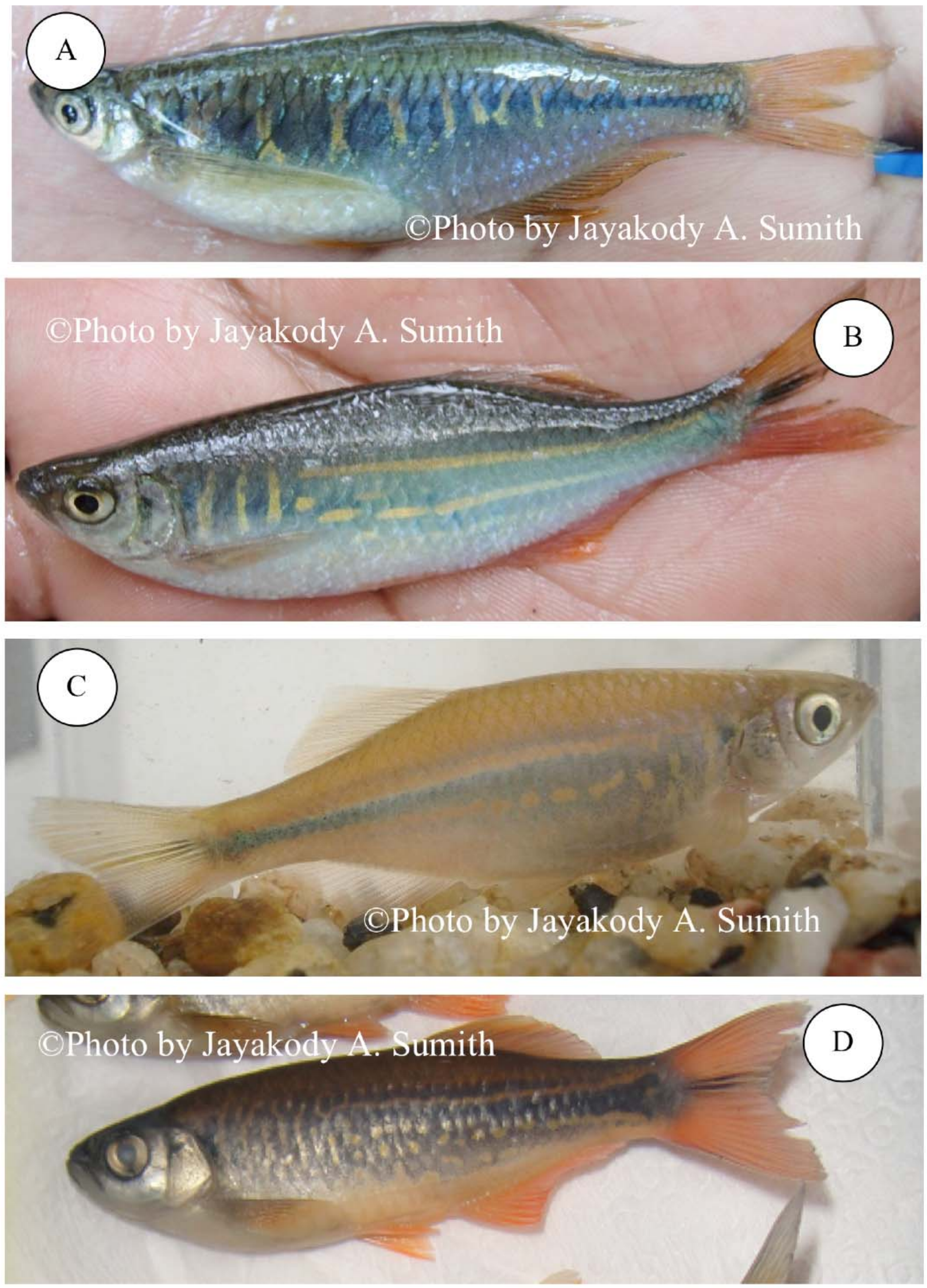

Fig. (2). The genus *Devario* in Sri Lankan study streams; (**A**) *Devario pathirana* (Note characteristic "Y" shape vertical elements on the body); (**B**), (**C**) and (**D**) represent *D. malabaricus* from Kalu-ganga (Rambukoluwa, N06°57'41.7" E80°56'09.7"), Uma-oya (Medawela, N06°56'33.9" E80°50'25.3") and Hatton-oya (Hatton, N06°54'10.8" E80°34'59.8") in the Mahaweli River basin, respectively (Note different vertical element patterns on body across locations. Phenotypically, the presence of "vertical elements" in the pigment pattern in deeper-bodied *D. malabaricus* is linked with adulthood [44].

been no significant difference between pooled benthic and non-benthic fish species in the final catch. The cast net was more efficient in catching benthic *G. ceylonensis* in a long reach, which increased sampling efficiency considerably. All fish specimens were identified using morphological and meristic characteristics [2, 12, 33, 34], counted, and measured for total length (L) (± 0.1 cm) and weight (W) (± 0.01 g) on the site. Fish collected by multiple passes were pooled to represent the total assemblage for the given site and given time.

Taxonomic Discrepancies

D. malabaricus is a widely distributed species in Sri Lanka [2] while its closest relative *D. aequipinnatus* (McClelland, 1839) has been recorded in the Knuckles drainages [5]. The *Danio* spp. has been interchangeably identified as *D. malabaricus* [2, 35-37] and *D. aequipinnatus* [38-40], as distinct species [41], and declared to be synonymous [42]. Moyle & Senanayake [16] and Wickramanayake & Moyle [32] specified *D. malabaricus* as deep-bodied species that inhabiting fast-flowing hill streams. Arunachalam [43] reported homologous populations from the Western Ghats (India) streams as *D. aequipinnatus*. Detailed taxonomic studies on these “two forms” could not be found within the country. However, during the current fish survey some subtle morphological characters such as varied pattern of vertical elements [44] and partly analogous dorsal body curveture to another closest relative *D. pathirana* were observed in the Knuckles populations over Uma-oya (Fig. (**2**). For the purpose of this paper, the nomenclature of *D. malabaricus* (Jerdon, 1849) will be used in order to be consistent with the IUCN [45] and the FishBase database (www.fishbase.org).

Despite broad geographic distribution of *G. ceylonensis* [46], Pethiyagoda [2] reported a sympatric occurrence of *G. phillipsi* (Deraniyagala, 1933; Phillip’s Garra) in hilly drainages of the Knuckles region [46]. *G. phillipsi* has shown almost no variation in taxonomical significant characters and was once defined as a sub species of *G. ceylonensis* [2]. We have initiated a genomic assessment of species differences for morphologically cryptic *Garra* specimens from prospective localities for possible sympatric occurrence. For the purpose of this paper, all specimens of the genus *Garra* will be identified as *G. ceylonensis* (Bleeker, 1863).

Sample Analysis

All fish were maintained in well aerated water after capture. After measurements, all immature *G. ceylonensis*, *R. daniconius* and *D. malabaricus* and all other species were released just below the sampling stretch. To calculate fish species per unit area, total numbers were divided by the surface area (m^2) of each study reach, calculated as the length of the reach multiplied by the mean wetted-width based on measurements taken at 5-m intervals. Water samples were taken (January 2010) in pre-cleaned plastic containers and transported on ice and analyzed in the Ecology and Environmental Biology laboratory of the Institute of Fundamental Studies, Kandy, Sri Lanka for major water quality parameters using standard methods [47]. Electrical conductivity, temperature and pH of surface water were measured *in situ*. The hourly temperature profiles in study streams were measured in selected locations by placing HOBO® water temp proV2 data loggers.

Data Assessment and Statistical Analysis

Fish species diversity was measured in terms of evenness and richness using diversity analysis using Shannon-Weaver measure of diversity [48]. Shannon-Weaver index is expressed as:

$$H' = - \sum p_j \ln p_j$$

Where in an assemblage of species, the ∑ represents the proportion of $_j$th individual species (p_j) summed to the total number of species (*S*).

The evenness is E = H’/lnS where E is the evenness, and S is the number of species. Since, the present study focused two streams in different geographies, the coefficient of biogeographic resemblance (CBR) was calculated; Adite & Thielen [49] used the following formula;

This coefficient was defined as follows:

$$CBR = 2C/(N_1 + N_2)$$

Where C is the number of species common to two streams (localities), N_1 and N_2 the respective number of species in the stream in question. CBR ranges from 0 (no species in common) to 1 (both the same number and kinds of species shared).

Data were presented as either mean ± standard deviation (SD) or quantitative descriptors (%). Basic descriptive statistics on primary data were obtained using Minitab® version 16. Means of differences were tested using 1-way ANOVA and consistencies in differences were identified by Kruskal-Wallis test. The existence of correlations between fish density and stream gradient was tested by Pearson correlation procedure. Qualitative assessments were made where appropriate. A canonical correspondence analysis (CCA) correlation plot (by XLSTAT® version 2010.3.05 for Widows XP) was performed on water quality variables to facilitate detection of any relationship with fish density and diversity parameters in selected sites. Statistical analyses were performed using Minitab® version 16 for Windows (Minitab, Inc.) and alpha levels were set at 0.05.

RESULTS

Fish Speciation in the Uma-oya

In total, 6,767 of fish specimens were captured and measured. The total catch (%) of *D. malabaricus* was significantly ($p < 0.05$) improved by net sampling compared to electrofishing, but both methods achieved similar measures of relative abundance for *G. ceylonensis* (Fig. (**3**)); there were insufficient data to compare with other species. Fourteen species were identified from the Uma-oya and tributary streams, and cyprinids represented over 46% of the catch; they had previously been shown to be the most abundant fish species [3, 18, 50]. Initial surveys in the uppermost streams in the higher ranges in the Uma-oya catchment in Nuwara Eliya (1,865 m above MSL) found no fishes and further studies were restricted to downstream locations. The highest elevation site at Perawella (1,187 m above MSL) contained only two fish species: *G. ceylonensis* (72.4%) and *Lepidocephalichthys thermalis* (Cobitidae; 27.6%).

Table 2. Fish Species Present in Preliminary Sampling Sites in the Knuckles and Uma-Oya Tributaries†

Family/Species	English name (Sinhala name)	Relative abundance (% by number)											
		Knuckles streams				Uma-oya streams							
		IK	EW	RO	RM	PW	ME	GI	ER	PU	DT	MT	KG
Cyprinidae													
*Garra ceylonensis**	Ceylon stone sucker (Gal pandiya)	23.9	84.5	5.9	9.7	72.4	66.8	37.5	75.6	36.0	50.4	21.7	-
*G. phillipsi**††	Phillip's garra	?	?	?	?	?	?	?	?	?	?	?	-
Rasbora daniconius	Striped rasbora (Dandiya)	-	-	16.6	21.0	-	-	-	11.6	1.7	17.8	4.1	42.8
Devario malabaricus	Giant danio (Rath kailaya)	61.0	15.5	28.4	56.4	-	26.9	43.4	-	54.2	30.6	70.1	-
D. aequipinnatus††	Giant danio	?	?	?	?	-	?	?	-	?	?	?	-
*D. pathirana**	Barred danio	-	-	3.6	-	-	-	-	-	-	-	-	-
Tor khudree	Deccan mahseer (Leylla)	0.5	-	10.7	-	-	-	-	-	2.4	-	-	2.3
Puntius bimaculatus	Redside barb (Ipilli kadaya)	1.1	-	17.2	3.9	-	1.6	4.5	3.2	0.8	1.2	1.0	34.5
P. dorsalis	Long snouted barb (Katu kureya)	-	-	0.6	-	-	-	-	-	0.1	-	-	0.1
P. sarana	Olive barb (Mas pethiya)	-	-	-	-	-	-	-	-	-	-	0.1	-
*P. martenstyni**	Martenstyn's barb	13.5	-	10.1	-	-	-	-	-	-	-	-	-
*P. singhala**	Singhala barb	-	-	3.0	-	-	-	-	-	-	-	-	-
*P. kamalika**	Kami's barb	-	-	2.4	-	-	-	-	-	-	-	-	-
*P. srilankensis**	Blotched filamented barb (Dankudu pethiya)	0.3	-	1.2	-	-	-	-	-	-	-	-	-
Channidae													
Channa gachua	Snakehead (Paradal kanaya)	-	-	-	-	-	0.1	7.2	1.7	1.1	-	-	-
Channa orientalis	Walking snakehead (Kola kanaya)	-	-	-	2.6	-	-	-	-	-	-	-	-
Clariidae													
*Clarias brachysoma**	Walking catfish (Magura)	-	-	-	0.4	-	-	-	-	-	-	-	-
Cobitiidae													
*Lepidocephalichthys jonklaasi**	Jonklaas's loach (Pulli ehirava)	-	-	-	0.8	-	-	-	-	-	-	-	-
Lepidocephalichthys thermalis	Common spiny loach (Ehirava)	-	-	-	-	27.6	3.7	4.7	0.2	2.6	-	-	-

(Table 2). Contd…..

Family/Species	English name (Sinhala name)	Relative abundance (% by number)											
		Knuckles streams				Uma-oya streams							
		IK	EW	RO	RM	PW	ME	GI	ER	PU	DT	MT	KG
Balitoridae													
*Neomacheilus notostigma**	Banded mountain loach (Puwakbadilla)	-	-	-	5.2	-	-	-	-	-	-	-	0.8
Osphronemidae													
*Belontia signata**	Ceylonese combtail (Thalkossa)	-	-	1.2	-	-	-	-	-	-	-	-	-
Cichlidae													
Oreochromis niloticus†	Nile tilapia (Theppeli)	-	-	-	-	-	-	-	-	-	-	-	19.5
Anguillidae													
Anguilla sp.	Eel (Anda)	-	-	-	-	-	-	-	-	-	-	0.3	-
Poeciliidae													
Poecillia reticulata†	Guppy (Saree guppy)	-	-	-	-	-	0.9	1.7	7.7	1.1	-	0.9	-
Xiphophorus hellerii†	Green swordtail	-	-	-	-	-	-	1.0	-	-	-	1.9	-

Descriptive site codes see on Fig. (**1**).
‡Values are pooled average percent abundance of 4 sampling efforts except PU where 3, RM where 2 and IK, EW, RO, PW, DT, MT and KG only one sampling estimates are given.
*Endemic fish species.
†Exotic fish species.
††Reserved for possible sympatric existence in the Knuckles streams [2].
? = Unknown or data deficient.

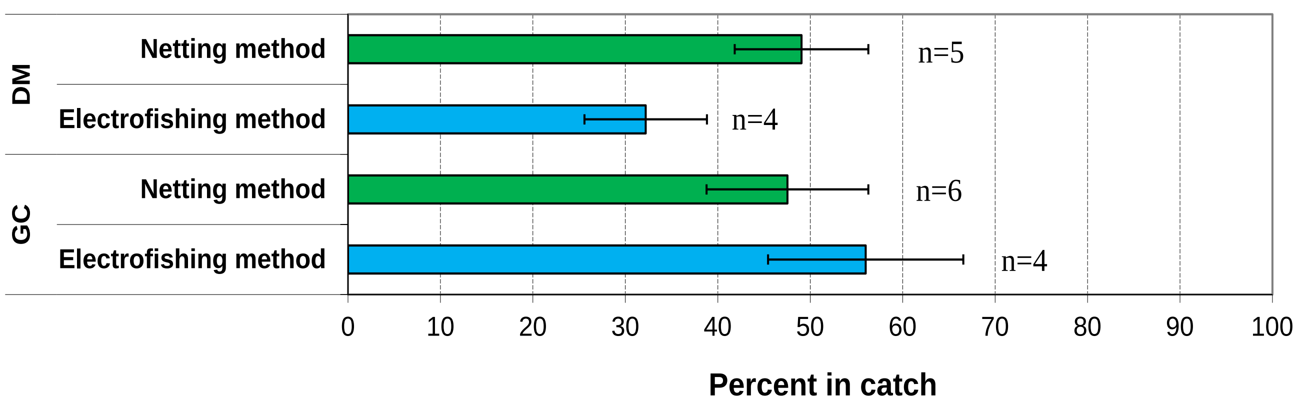

Fig. (3). Population estimates (mean ± SE) by two sampling techniques, expressed as percentage of total catch (catchability) in stream sections in the Uma-oya. The number (n) of sampling trials in different stream sections are shown on the top of the bar. GC = *G. ceylonensis* (represents benthic species); DM = *D. malabaricus* (represents pelagic species).

Between 4 and 7 species were collected at all other sites (Table **2**), with the exception of Puhulpola, which contained 9 species. All species represented < 10% of the catch, except for a few dominant species at each site and the dominant species varied between sites. In the middle catchments, regardless of capture method, more than 80% of individuals were either a combination of *G. ceylonensis* and *D. malabaricus* or *G. ceylonensis* and *R. daniconius* in 9 out of 11 surveys. Irrespective of the stream topography (i.e., riffle, pool, run or mix), season of sampling and fishing method, all of the sites in the Uma-oya were dominated by *G. ceylonensis* except Girambe (July, January), Puhulpola (September, January), and Mathatilla (January) and *G. ceylonensis* was completely absent in the Kottegoda site. Alternatively, *G. ceylonensis* had second dominance to *D. malabaricus* in five occasions of their co-occurrence. *G.*

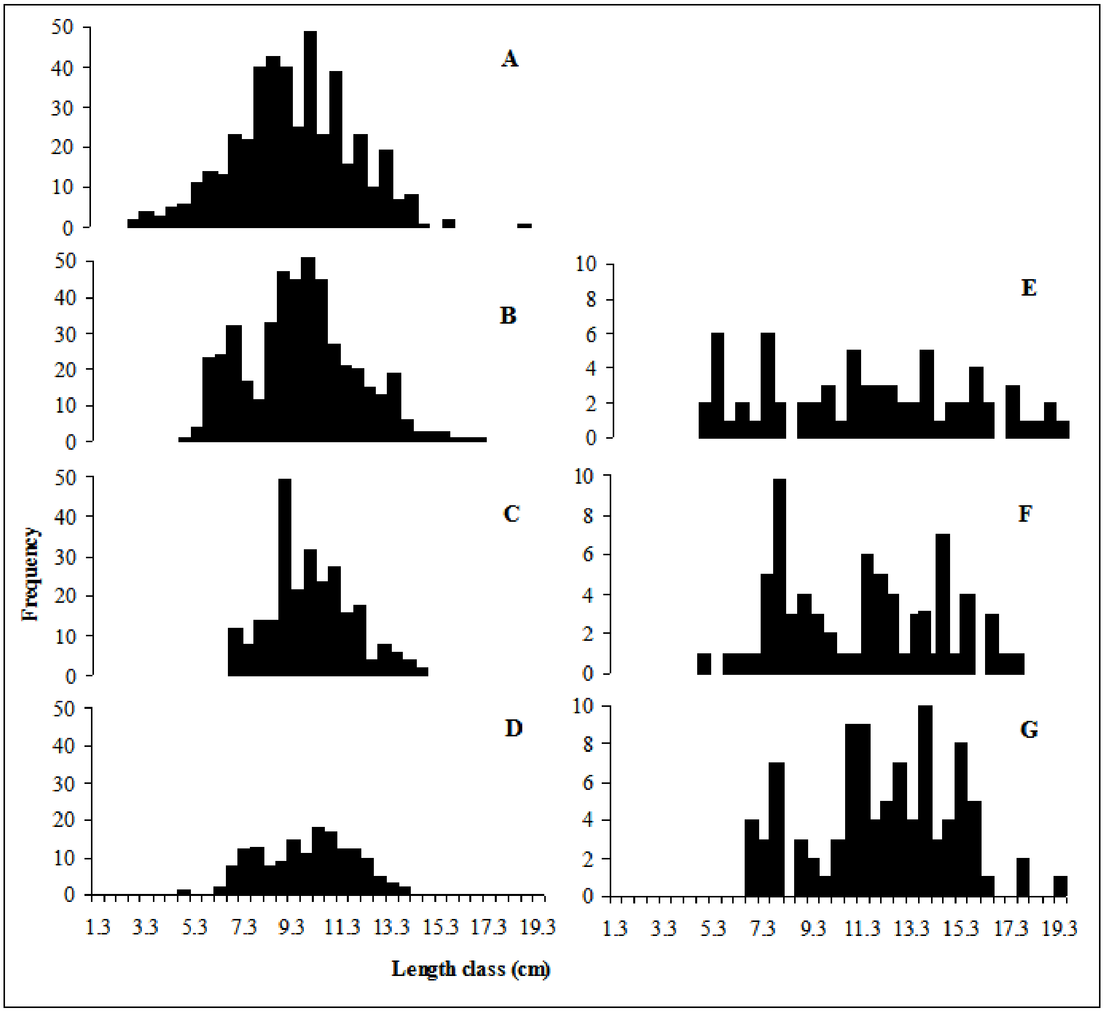

Fig. (4). The length-frequency distributions of Ceylon stone sucker (*G. ceylonensis*) sampled by electrofisher in February 2009 (**A**) and July 2009 (**B**) in Medawela and July 2009 (**E**) in Puhulpola. (**C**) and (**D**) sampled by using 10 mm mesh nets in September 2009 and January 2010 in Medawela, respectively. (**F**) and (**G**) are by 10 mm mesh nets in September 2009 and January 2010 in Puhulpola in the Uma-oya, upper Mahaweli River catchment, Sri Lanka [Population size, Mean ± SD (**A**) N = 449, 9.5 ± 2.2; (**B**) N = 470, 9.1 ± 2.3; (**C**) N = 269, 9.8 ± 1.6; (**D**) N = 158, 9.8 ± 1.9; (**E**) N = 70, 11.4 ± 4.1; (**F**) N = 71, 10.9 ± 3.1; (**G**) N = 100, 12.2 ± 2.8. The skewness in probability plots of (**A**), (**B**), (**C**) and (**D**) were unimodal and normally distributed ($p < 0.05$) while (**E**), (**F**) and (**G**) were bimodal. Means of (**C**) and (**D**) are not significantly different by Kruskal-Wallis test ($p > 0.05$).

ceylonensis and *D. malabaricus* combination (co-occurrence) accounted over 65.6 through 96.7% of catches in any of the site. Only *G. ceylonensis* in Erabadda had ~76% of abundance that meets the abundance scale (76 - 100%) by a single species as proposed by Jadhav *et al.*,[51].

The upper Mahaweli streams were also dominated by either *R. daniconius* (17.8 and 42.9% of the catch at Erabadda and Kottegoda locations) or *G. ceylonensis* (50.4 and 75.6% of the catch at Diganatenna and Erabadda). The Erabadda site was dominated by *G. ceylonensis* and *R. daniconius* at all times (February, July, September and January), representing between 56 and 100% of the catch. *D. malabaricus* dominated at higher elevation sites at Girambe, Mathatilla and Puhulpola, but sites high in *D. malabaricus* were never high in abundance of *R. daniconius*; at Erabadda and Kottegoda where *R. daniconius* was found, not a single specimen of *D. malabaricus* was found. However, in sites where co-occurrences were observed (Puhulpola, Mathatilla and Diganathenna), *R. daniconius* was always at a lower abundance (Table **2**).

Though the *Puntius* genus accounts for more than 20 Sri Lankan cyprinid species [52], there was limited representation in the Uma-oya (Table **2**). Out of five *Puntius* spp. reported for most dominance in highland streams [53], *Puntius bimaculatus* was recorded widely in the Uma-oya in excess of 5% and only one specimen each of *P. dorsalis* and *P. sarana* was encountered even though it has been reported as a broadly distributed species across different elevations [50].

Other abundant species (> 5%) included *Lepidocephalichthys thermalis*, *Channa gachua*, *Poecillia reticulata* (Peters, 1859) and *Oreochromis niloticus*, and a few individuals were collected of *Xiphophorus hellerii*, *Tor khudree* and one specimen each of *Anguilla* sp. and *Neomacheilus notostigma*. Nile tilapia (*O. niloticus*) were collected in one of the tributary drainages in Uma-oya

(Kottegoda - N06°57'41.7" E80°56'09.7" 963 m above MSL) (5/100 m^2), along with *P. bimaculatus* (13 /100 m^2) and striped rasbora (*R. daniconius*) (16 /100 m^2) in January 2010; this was the only site where *G. ceylonensis* were completely absent. Twenty six individuals of *O. niloticus* in a total length (range) 8.5 - 28.3 cm and weight of 11.25 - > 200 g were caught in one collection. This is the first record of the existence of *O. niloticus* in the Uma-oya.

Other than species composition, the population structure of fish exhibited some striking differences among sampling sites. In general, length-frequency data of *G. ceylonensis* in sites where they were present showed clear population structure; left-ward shifting recruitment clusters and right-ward shifting aged-clusters. The skewness in length-frequency probability plots of *G. ceylonensis* in Medawela (Uma-oya) were unimodal and normally distributed ($p < 0.05$) while in Puhulpola, the population structure was staggering with prominant loss of individuals in some size-classes (Fig. **4**).

Fish Speciation in the Amban-ganga Catchment (Knuckles Streams)

Cyprinid species made up 68.6% (11 of 16) of species found in the Knuckles streams out of 1,063 fish specimens collected (Table **2**), with 6 families represented. *G. ceylonensis* was the dominant species (84.5%) in Etanwala (Theligam-oya upstream). In the rest of the 3 sites, *D. malabaricus* was dominant and *R. daniconius* the second most dominant when all 3 species were present. More than 80% of individuals were from three species, with *G. ceylonensis*, *D. malabaricus* and *R. daniconius* representing 880 individuals out of total 1,063 (82.8%); the remaining 12 species were rare. In Rambukoluwa (Kalu-ganga stream), *R. daniconius* and *P. bimaculatus* occurred with similar abundance (16.6 and 17.2%, respectively). Cyprinids like *P. martenstyni* and *Tor khudree* represented over 10% of individuals in two locations in the Knuckles streams. Similar to the Uma-oya, *R. daniconius* was completely absent from Etanwala and Illukkumbura sites (Theligam-oya upstream and downstream locations, respectively) while slight to strong inhibition by *D. malabaricus* was observed in Rambukoluwa (Kalu-ganga) and Ranamure-oya sites (Table **2**).

N. notostigma (Balitoridae) and *Lepidocephalichthys jonklaasi* (Cobitiidae) collectively represented 6% in the Ranamure-oya site. Only 2 specimens of *L. jonklaasi* were collected along the stretch which had the second lowest relative abundance at 0.8%. Several other fish species who had less than 5% abundance were *Puntius singhala*, *P. kamalika*, *P. dorsalis* and *P. srilankensis*, *D. pathirana* (family: Cyprinidae), *Belontia signata* (Osphronemidae), *Channa orientalis* (Channidae) and *Clarias brachysoma* (Clariidae). There were 9 endemic freshwater fish species found in the Knuckles streams out of 12 endemics recorded from the Mahaweli River basin by Silva [18].

Fish Faunal Similarity and Endemism

The highest Shannon-Weaver fish diversity (2.01) was present in Rambukoluwa (Kalu-ganga) and the lowest (0.43) in Etanwala (Theligam-oya upstream) in the Amban-ganga catchment. The ichthyofaunal similarity between two catchments was 39% (Table **3**) and fish species diversity was negatively correlated with stream gradients (Pearson correlation (-0.630); $r^2 = 39.6\%$ $p = 0.028$).

All sites in the Knuckles streams were allied with diversity rather than density indices (Fig. **4**). Fish density estimates did not show linear relationships with environmental variables (e.g., nitrate, phosphate, sulphate, chlorophyll-*a* content) ($p = 0.189$) (Fig. **4**). However, there were significant associations of phosphate (Pearson's correlation 0.851, $p < 0.001$) and nitrate (Pearson's correlation 0.662, $p = 0.019$) with *G. ceylonensis* density and overall density with phosphates (Pearson's correlation 0.883, $p = < 0.001$) and nitrates (Pearson's correlation 0.783, $p = 0.003$). Also, there was a positive association of nitrate content and *D. malabaricus* density (Pearson's correlation 0.617, $p = 0.033$).

Endemism is highest in the Amban-ganga (reference) catchment in the Knuckles area compared to the agricultural (Uma-oya) catchment (Table **3**). Kalu-ganga in the Knuckles showed highest endemism (61.5%) where, 7 out of 11 species were endemic to the country. In the Uma-oya, only

Table 3. Fish Diversity Indices in Sampling Sites (Descriptive Site Codes See on Fig. (1).

Index	Uma-oya stream								Knuckles streams			
	PW	ME	ER	DT	GI	MT	PU	KG	EW	IK	RM	RO
No. of species (S)	2	6	6	4	7	8	9	6	2	6	8	11
No. of individuals/100 m^2 (mean)†	1.6	232.3	138.7	58.8	76.3	66.5	85.4	37.2	28.7	16.8	46.0	15.4
Shannon-Weaver diversity (H’)	0.59	0.93	0.73	1.07	1.17	0.90	1.07	1.13	0.43	1.01	1.20	2.01
Evenness (H’/lnS)	0.85	0.52	0.41	0.77	0.60	0.46	0.49	0.70	0.62	0.56	0.58	0.84
Dominance♣	-	0.93	-	0.81	0.81	0.93	0.91	-	1.0	0.85	0.70	0.34
Coefficient of Geographic Resemblance (CBR)								0.39				
Endemism (%)	50	16.6	16.6	25	14.3	14.3	11.1	20	50	25	50	61.5

†Data averaged to a single fishing effort where multiple sampling events performed.
♣ Calculated for the most abundant pair of *G. ceylonensis* and *D. malabaricus*.

G. ceylonensis and *N. notostigma* were found to be endemic; the latter was a single specimen (Kottegoda site). *P. bimaculatus* (Bleeker, 1863) was one of the common species found in both geographies; relative abundance varied from 0.8 - 34.6% in the Uma-oya stream and 1.1 - 17.2% in the Knuckles streams (Table **2**).

One of the most intriguing observations of this study was that there seemed to be small-scale inhibition between the two fish species, striped rasbora (*R. daniconius*) and giant danio (*D. malabaricus*). Of the 8 sites in the Uma-oya stream, *R. daniconius* was found only in 5 sites and except Puhulpola, other 4 locations can be categorically identified as tributary streams from various altitudes (Fig. **1**); attempts to find *R. daniconius* in extended stream sections outside the pre-determined sampling stretches were unsuccessful. There were comparable abundance of *R. daniconius* in Erabadda site (1,106 m above MSL) in February (2009), July (2009), September (2009) through January (2010) ranging from 7 - 24 individuals /100 m^2.

In the Uma-oya catchment, it is increasingly common to observe thick stands of giant cane (*Arundo donax*) either planted or invaded in stream banks. The relative contribution of this vegetation type in stream banks of 8 study sites was in a range from none (i.e., zero percent, where dominant vegetation type other than *A. donax*) to 100% of *A. donax* (Table **1**). There was a negative relationship [54] between percent *A. donax* stand in the riparian area and the abundance of *R. daniconius* (Table **2**) although the correlation (-0.541) was statistically non significant ($p = 0.165$). However, quantitative observations showed that at sites ($n = 4$) where *A. donax* stand was 70 - 100% had a lesser abundance (0 - 1.7%) of *R. daniconius*. Alternatively, in sites ($n = 3$) where *A. donax* stand was 0 - 40% had a higher relative abundance of *R. daniconius* in a range from 11.6 - 42.7%; the only exception was at Mathatilla where lesser abundance of *R. daniconius* (4.1%) was observed under lesser riparian stand of *A. donax* (40%).

DISCUSSION

In total, 23 fish species were categorically identified in the Uma-oya and Knuckles streams. Sampling may have underestimated carnivorous predatory species that are more active at night [55, 56]. Although *Clarias teysmanni*, *Ompok bimaculatus*, *Channa striata*, *C. punctata*, *C. marulius*, and *Anabas testudineus* have been reported to be present in the Mahaweli River basin, only *Clarias brachysoma*, *Channa gachua* and *C. orientalis* were encountered (Appendix **1**). *C. gachua* is one of the secondary consumers in Sri Lankan freshwater fishes [57], and they may have contributed to the fish structure in some of the locations in the Uma-oya. Mirandu *et al.*,[58] reported the presence of *C. orientalis* in the Knuckles streams which has been restricted to the southwestern ichthyological province.

No native species were found at the highest elevation, which agrees with with Costa [59] that highland plateau streams at an elevation of approximately 2,200 m are sparsely colonized by rainbow trout (*Oncorhynchus mykiss*) that were introduced to Sri Lanka in 1889. The highest site with fish (1,187 m) contained only *G. ceylonensis* and *Lepidocephalichthys thermalis* which are both benthic dwellers adapted for periodic torrential conditions [60] with dorsoventrally compressed bodies with flattened heads, broad pectoral fins, and reduced or absent gas bladders [8]. Previous studies have concluded that the highland plateau in Sri Lanka is dominated by either *G. ceylonensis* and *L. thermalis* [3] or *R. daniconius* and *N. notostigma* [16]. Silva [18] reported the occurrence of *Lepidocephalichthys jonklaasi* on the southern slopes of the Knuckles range although Pethiyagoda [2] and Ott & Ende [61] have reported its type locality in southwestern parts of Sri Lanka.

According to the ichthyofaunal compilation by Silva [18], 44 species have been recorded in the Mahaweli River basin out of 58 indigenous and endemic fish species in Sri Lanka, with *G. ceylonensis*, *R. daniconius* and *D. aequipinnatus* most common. Both stream catchments showed these species to be dominant, consistent with Starmühlner [62], who reported that upper-course fish community between 500 - 1,500 m were dominated by populations of *D. malabaricus*, *R. daniconius*, *P. bimaculatus*, *L. thermalis* and *N. notostigma* under low flow velocity regimes of 0 - 75 cm sec^{-1}. Starmühlner [62] also found that *G. ceylonensis* dominated at current velocities from 30 and above 100 cm sec^{-1}, implying that *G. ceylonensis* prefers high flow area. *G. ceylonensis* is widely distributed in Sri Lanka across streams below 100 to 1,500 m above MSL elevations [3, 15, 62], and *N. notostigma* is a common dispersant in mid to high elevations (500 - 1,500 m above MSL) under low flow velocity regime of 0 - 75 cm sec^{-1} [62]. Although several authors [3, 18] identified *P. bimaculatus* as endemic to Sri Lanka, recent records [52] suggest this may be a common dispersant from the Indian mainland.

The abundance of *D. malabaricus* in either the first or second rank in highland streams has not been reported in other catchments [3]. Similarly, Arunachalam [43] recorded *D. aequipinnatus* (= *D. malabaricus*; [2]), *R. daniconius* and *G. mullya* were most abundant in all streams within 600 - 800 m elevations in the Western Ghats in India. The similarities of fish communities in Sri Lanka and Western Ghats has also been reported by Kortmulder *et al.*,[63]. If there really is spatial competition between these species, as previously suggested by Moyle & Senanayake [16], this could partly explain the absence or near-absence of *R. daniconius* from some of the locations in the Uma-oya and the Knuckles streams with high densities of *D. malabaricus*. It has been suggested that *R. daniconius* and *D. malabaricus* are mutually incompatible for niche utilization for food resources [16, 39], although there were several sites in this study where they were mutually abundant: Rambukoluwa (217 m above MSL); February, 2009 in Ranamure-oya (339 m above MSL) and Diganatenna in the Uma-oya (1,058 m above MSL).

The limited fish faunal assemblages in the Uma-oya are ecologically significant as only single species of *Garra*, *Devario* and *Rasbora* are represented, and 14, 6 and 14 species are reported in these genera in India, respectively [8]. Of 17 member species of the genus *Garra* reported on the African continent, 11 species have been reported in Ethiopia alone [64]. The significant abundance of *D. malabaricus* in the Mahaweli River basin (15.5 - 61% in the Knuckles streams and 26.9 - 70.1% in the Uma-oya stream) in contrast to 0.06% in the Walawa River basin [3] suggests that they may also be useful as an environmental sentinel. According to De Silva *et al.*,[65], *R. daniconius* and *Devario* spp. (i.e. *D. aequipinnatus*) were recorded to be amongst the co-habiting species in Sri Lankan streams. However, Moyle & Senanayake [16] speculated limited co-occurrence of *R. daniconius* with *D. malabaricus* due to competition for niche dimensions. The lesser abundance of *G. ceylonensis* in the Knuckles streams may be site-specific where abundance of food resources such as algal biomass is limited due to aerial forest cover [66].

One of the interesting observations of this survey was the occurrence of *Devario pathirana* and *P. kamalika* in the Kalu-ganga (Rambukoluwa), which has reported to be found from the southwestern ichthyological province before [2]. These species has not been recorded in the ichthyofaunal compilation of the Mahaweli River basin by Silva [18]. In fact, Silva's [18] freshwater fish compilation in the Mahaweli ichthyological province did not record the presence of *Puntius* (= *Barbus*) *amphibius*, which was subsequently named as *P. kamalika* [12] (Appendix **1**).

Stream types in Sri Lanka can be differentiated into rocky hill (Perawella - Uma-oya stream; Etanwala and Ranamuregama - Knuckles streams) versus winding hill (all others), into wet zone and dry zone streams, and into high elevation and low elevation. Schut *et al.*,[39] found that *R. daniconius* distribution was restricted to winding hill streams while *D. malabaricus* to rocky hill streams. Weliange [15] reported that *R. daniconius* is one of the species commonly found in the wet zone and the dry zone in Sri Lanka (below 200 m above MSL). Along a longitudinal gradient in the upper Walawe River basin from an elevation of 200 m up to 2,000 m above MSL, Jinadasa *et al.*,[3] recorded that the rank abundance at lower elevations was in the order of *R. daniconius*>*P. bimaculatus*>*G. ceylonensis* whereas the abundance was in the order of *G. ceylonensis*>*Schistura notostigma*>*Lepidocephalichthys thermalis* above 600 m MSL. Therefore, *R. daniconius* in principle may be a low elevation species, but Jinadasa *et al.*,[3] did not observe a dominant distribution of *D. malabaricus* in higher elevations in Sri Lanka, as observed in our study. The co-occurrence and positive association of fish species in assemblages is a subject of extensive debate in tropical streams [67].

Distributions are commonly referred to ichthyofaunal provinces which include endemic species which are "native to and restricted to that system" [68, 69] and Sri Lanka has 14.2% proportion of endemic freshwater finfish species [70]. The Knuckles streams were host for several of the highly endangered or vulnerable fish species such as *D. pathirana*, *L. jonklaasi*, *P. srilankensis* and *P. martenstyni*. Pethiyagoda [5] listed 29 endemic freshwater fish species as threatened and 10 as highly threatened in the context of national fish conservation agenda. Several of these species are confined to the Knuckles streams, including *P. srilankensis* [34] and *G. phillipsi* and *D. aequipinnatus* [2] which are listed as data deficient (DD) in the IUCN Red List [45] due to incomplete life history status.

Data on biodiversity in Sri Lanka is not complete; several cyprinids have recently been added to freshwater fishes [10, 11], and one species has been rapidly declining (*Macrognathus pentophthalmos* (Teleostei: Mastacembelidae) [71]. *P. singhala* (Duncker, 1912) and *P. kamalika* are endemic and have been recently identified elsewhere in Sri Lanka [12] and were probably previously misidentified as *P. filamentosus* and *P. amphibius*, respectively [34, 72]. Some of the species known to occur in the southwestern ichthyological province (type locality) were identified in the Mahaweli ichthyological province, which include *C. brachysoma*, *D. pathirana* and *P. kamalika* [2, 12]. This implies that conservation strategies should expand to a wider geographical range than earlier assumed.

The diversity and composition of fish assemblages along the gradient of a river/stream is in agreement with the "river continuum concept" [73]. Generally, there is a progressive increase in ichthyomass downstream, thus relatively a small ichthyomass could be expected in small streams [74]. The present study revealed that phosphate and nitrate levels were positively associated with the density of *G. ceylonensis* and more interestingly *D. malabaricus* with nitrate levels at the catchment level. Dejenie *et al.*,[75] similarly found that *Garra* biomass was positively related to nutrients in reservoirs. *Garra* was positively associated with *Devario* in the Uma-oya stream, suggesting that maximum resource utilization may be at the expense of other species. *P. dorsalis* was depauperate in the middle catchment (900 - 1,200 m above MSL) of the Uma-oya. De Silva *et al.*,[50] observed that *P. bimaculatus* was positively correlated and *P. dorsalis* was negatively correlated with conductivity and phosphate. The intensive year-round agricultural practices over the past several decades may have placed stress on *P. dorsalis* populations in the Uma-oya. Eutrophication presumably increases the algae and diatoms [50] that *P. bimaculatus* feeds on [2].

Martin-Smith & Laird's [76] alternate mechanism of water physico-chemical alteration to species diversity require considerable data basis for acceptable correlations. Obviously, low oxygen may have least impact on *R. daniconius* because this species can explore water-air inter-phase and gulp air while feeding [76]. Bhat & Maguran [67] stated that habitats that are altered or disturbed by human activities can result in deviations from the co-occurrence patterns found in undisturbed localities. Since, all sampling sites with none or limited *R. daniconius* are located in the stem stream of the Uma-oya, extensive pollutant impacts could be anticipated. Habitat changes may also be playing a role - giant cane (*Arundo donax*) originated in the Asia and Mediterranean countries and has become widely established in the Uma-oya catchment [77]; *Arundo* stands may impact on *R. daniconius* existence whose diets are largely composed of allochthonous insects sourced from riparian vegetation [62]. Prem Kumar & John [78] have shown that *R. daniconius* prefers terrestrial drift food, mainly feeding on hymenopterans and coleopterans.

There was a consistently higher number of *Puntius* species in a single location in Kalu-ganga stream (Knuckles) with a total species composition of 6 as compared to 3 (besides *P. bimaculatus*, only a single specimen each of *P. dorsalis* and *P. sarana* were found) across 8 locations in the middle catchment (altitude 900 - 1,200 m above MSL) of the Uma-oya. Jinadasa *et al.*,[3] recorded 8 *Puntius* species across the Walawa River basin while Fernando *et al.*,[79] recorded 11 species across four major river basins in Sri Lanka with co-associations on various aspects [39].

Potential Impact by Exotic Fish Species

It is well known that anthropogenic impact favors exotic invasions [80, 81]. No exotic species were found in the Knuckles reference area but *O. niloticus* (Linnaeus, 1758) (family Cichlidae), *P. reticulata* (Peters, 1859) and *X. helleri* were found in the agricultural areas (Uma-oya). Collares-Pereira & Cowx [20] reported species introductions as the leading threat to freshwater fishes in the world, and their presence is regarded as a serious biotic pollutant [82]. In Sri Lanka, the out-competing of indigenous stream fishes by exotics (i.e. especially tilapians fishes) has not been reported in the literature [79, 83-85], but negative concerns have mounted on exotics with limited evidence [5, 19, 86].

The introduction of *O. niloticus* was intensified in mid 80's due to its fast growth and lower trophic position [87], and its use by fisheries biologists and managers for aquaculture and fisheries development. Reservoir fishing of exotic species is one of the important food fish exploitation ventures in Sri Lanka [4], and these species disperse because of unintentional releases from aquaculture and flooding [88]. Most of the endangered and vulnerable freshwater fish species (73%) in Sri Lanka occur only in lotic habitats associated with forested streams in higher altitudes, and the lower thermal tolerance of *O. niloticus* compared to *O. mossambicus* [89] suggests it is a threat to hillside stream fish communities. Fernando *et al.*,[79] caught sixty six (66) individuals of *O. mossambicus* during 278 fish collections in the Kelani River basin; *O. niloticus* is a food fish species introduced into inland reservoirs and can be invaded or intentionally or unintentionally introduced into tributary rivers and streams subsequently [79].

P. reticulata (Peters, 1859) and *X. hellerii* are exotic fish introductions from the aquarium industry [90]. *X. hellerii* was found in two locations, whereas *P. reticulata* was found in five locations and exceeded 5% in Girambe in the Uma-oya. The presence of these exotics should be viewed with caution since Goren & Galil [91] reported examples of non-native poeciliids out-competing native species and causing the extirpation of *G. rufa* from the Qishon River basin and *G. ghoerensis* from the southern Dead Sea in Israel. Members of Poeciliidae prey upon indigenous and endemic fish larvae and post-larvae, which have been deprived of sheltering structures. Casatti *et al.*,[81] observed *P. reticulata* abundance over 50% in degraded habitats in Brazilian streams. Orrego *et al.*,[92] reported the occurrence of *Gambusia affinis* (Family: Poeciliidae) in association with pollution in Chilean rivers.

Impact of Exploitation

Local people exploit some populations as a protein source in the Uma-oya and the Knuckles tributaries for large "food-size" individuals such as *G. ceylonensis*, *Tor khudree* and *C. gachua* (Jayakody A. Sumith, pers. observ.). The Puhulpola site seems to be a fishery hotspot for local subsistence fishermen using gill nets and cast nets. Data presented in this paper (see Fig. **4**) has direct implications on the above contention. Highly crafted fish traps made of twigs called "*kemana*" are used as fixed contrivances in the form of funnel shapes at the upstream drainages to catch ascending fish during spawning times (Fig. **6**). This type of fishing method has been possible due to reported upstream migration of *Garra* spp. in small rocky hill streams for spawning with the onset of heavy rains [2, 18].

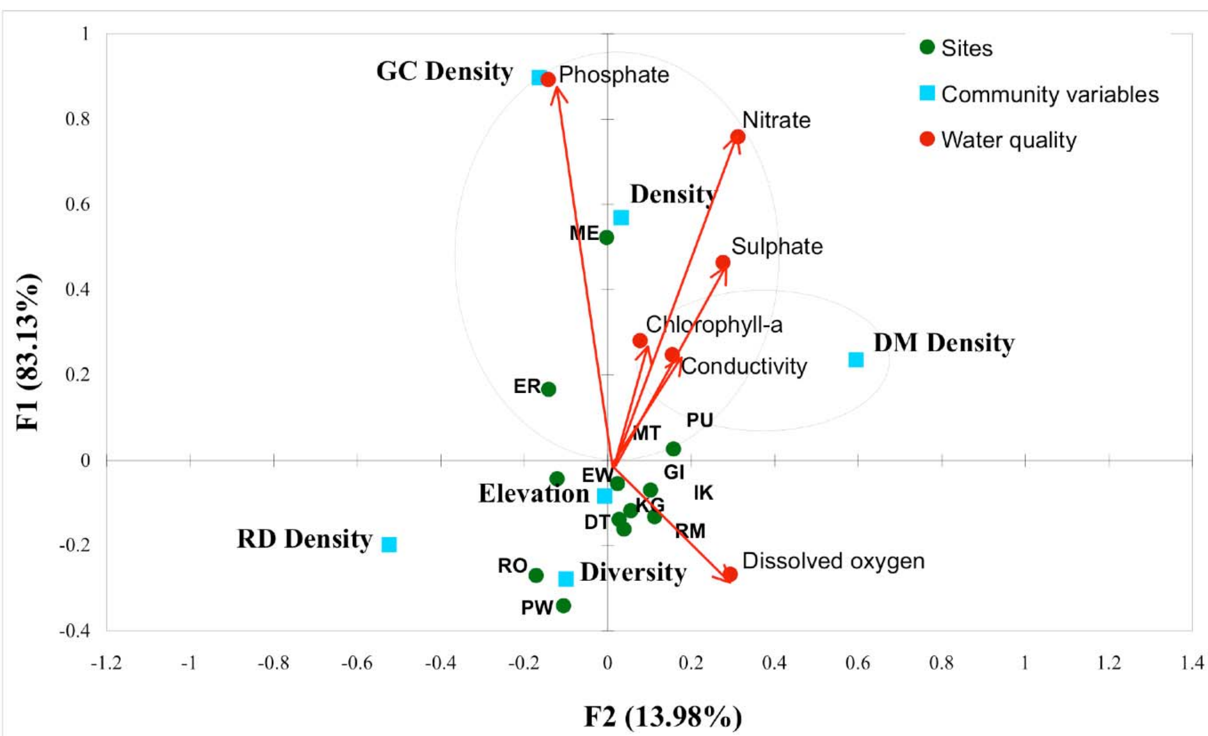

Fig. (5). Plot of Canonical Correspondence Analysis (CCA) on stream water quality variables and fish density and diversity parameters in selected sites in the Uma-oya and Knuckles streams. GC = *G. ceylonensis* (represents benthic species); DM = *D. malabaricus* (represents pelagic species); Descriptive site codes see on Fig. (**1**).

Fig. (6). Highly crafted fish trap "*kemana*" (above) and trap mouth (below) which is used to catch stream ascending *Garra* species (Photos by Jayakody A. Sumith).

In conclusion, we selected an agriculturally exploited catchment in the Uma-oya and a least-exploited catchment in the Knuckles forested area for baseline data. The Uma-oya catchment shows characteristics commonly observed in extensive agricultural exploitation such as impaired water quality and altered riparian vegetation. The most abundant fish species in the two regions were *G. ceylonensis*, *D. malabaricus*, and *R. daniconius*, although their relative abundance differed between sites. The Knuckles streams showed no exotic species and a higher level of endemism. It appears that extensive agriculture activities may induce fish species "homogenization" (favoring more abundance of certain groups of indigenous species over others) but inadequate data on "historical" status in specific ecosystems prevent making strong conclusions.

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APPENDIX 1.

List of native freshwater and brackish water fish species in Sri Lanka and the status of geographic similarity with the Western Ghats (India)

Order	Family	Species[2, 18, 52, 94]	Existence in the Mahaweli River basin (Sri Lanka) [18]	Existence in the Western Ghats (India)[7, 95-97]
Elopiformes	Megalopidae	*Megalops cyprinoids* (Broussonet)	×	√
Anguilliformes	Anguillidae	*Anguilla nebulosa* (McClelland)	√	×
		A. bicolour (McClelland)	√	√
		A. bengalensis (Gray)	×	√
Clupeiformes	Clupeidae	*Ehirava fluviatilis* (Deraniyagala)	√	×
Cypriniformes	Cyprinidae	*Amblypharyngodon melettinus* (Valenciennes)	√	×
		A. grandisquammis (Jordan & Starks 1917)	× E	×
		Chela laubuca (Hamilton-Buchanan)	√	√
		C. ceylonensis (Hamilton-Buchanan 1821)	× E	×
		Devario malabaricus (Jerdon)	√	√
		D. pathirana (Kottelat & Pethiyagoda 1990)	√ E (this study)	×
		D. aequipinnatus (McClelland 1839)	√	√
		Esomus thermoicos (Valenciennes)	× E	×
		E. danricus (Hamilton-Buchanan)	√	√
		E. lineatus (Ahl)	×	×
		Garra ceylonensis (Bleeker)	√ E	×
		G. phillipsi (Deraniyagala 1933)	√ E	×
		Labeo dussumieri (Valenciennes)	√	√
		L. fisheri (Jordan & Starks 1917)	√ E	×
		L. Lankae (Deraniyagala)	× E	×
		L. porcellus (Heckel 1838)	×	√
		L. rohita (Hamilton-Buchanan)	×	√
		Laubuca insularis (Pethiyagoda, Kottalat, Silva, Maduwage & Meegaskumbura 2008)	× E	×
		L. lankensis (Pethiyagoda, Kottalat, Silva, Maduwage & Meegaskumbura 2008)	× E	×
		L. ruhuna (Pethiyagoda, Kottalat, Silva, Maduwage & Meegaskumbura 2008)	× E	×
		L. varuna (Pethiyagoda, Kottalat, Silva, Maduwage & Meegaskumbura 2008)	× E	×
		Puntius asoka (Kottelat & Pethiyagoda 1989)	× E	×
		P. bandula (Kottelat & Pethiyagoda 1991)	× E	×
		P. amphibius (Valenciennes)	×	√
		P. bimaculatus (Bleeker)	√	√
		P. chola (Hamilton-Buchanan)	√	√
		P. cumingii (Günther)	√ E	×

		P. dorsalis (Jerdon)	√	√
		P. martenstyni (Kottelat & Pethiyagoda 1991)	× E	×
		P. nigrofasciatus (Günther)	√ E	×
		P. pleurotaenia (Bleeker)	×	√
		P. sarana (Hamilton-Buchanan)	√	√
		P. singhala (Duncker)	√ E	×
		P. srilankensis (Senanayake 1985)	√ E	×
		P. titteya (Deraniyagala)	√ E	×
		P. vittatus (Day)	×	√
		P. ticto (Hamilton-Buchanan)	√	√
		P. kamalika (Silva, Maduwage & Pethiyagoda)	√ E (this study)	×
		P. reval (Meegaskumbura, Silva, Maduwage & Pethiyagoda)	× E	×
		P. punctatus (Day)	×	×
		P. kelumi (Pethiyagoda, Silva, Maduwage & Meegaskumbura)	× E	×
		Rasbora caverii (Jerdon)	×	√
		R. daniconius (Hamilton-Buchanan)	√	√
		R. wilpita (Kottelat & Pethiyagoda 1991)	× E	×
		R. vaterifloris (Deraniyagala)	√ E	×
		R. armitagei (Gabadage & Karunaratna 1994)	× E	×
		R. naggsi (Manamendra-Arachchi & Perera 1993)	× E	×
		Tor khudree (Sykes)	√	√
		Horadandia atukorali (Deraniyagala)	×	×
	Balitoridae	*Acanthocobitis urophthalmus* (Günther)	× E	×
		Nemacheilus notostigma (Bleeker)	√ E	×
	Cobitidae	*Lepidocephalichthys jonklaasi* (Deraniyagala 1956)	√ E	×
		L. thermalis (Valenciennes)	√	√
Siluriformes	Bagridae	*Mystus gulio* (Hamilton-Buchanan)	×	√
		M. cavasius (Hamilton-Buchanan)	×	√
		M. vittatus (Bloch)	√	√
		M. keletius (Valenciennes)	√	√
		M. ankutta (Pethiyagoda, Silva & Maduwage 2008)	× E	×
	Clariidae	*Clarias brachysoma* (Günther)	√ E (this study)	×
		C. nebulosus (Deraniyagala)	× E	×
		C. teysmanni (Bleeker)	√	×
	Heteropneustidae	*Heteropneustes fossilis* (Bloch)	√	√
		H. microps (Günther 1864)	×	×
	Siluridae	*Ompok bimaculatus* (Bloch)	√	√
		Wallago attu (Bloch & Schneider)	√	√

Cyprinodontiformes	Aplocheilidae	*Aplocheilus dayi* (Steindachner)	×	×
		A. parvus (Raj)	×	×
		A. werneri (Meinken)	×	×
		A. blockii (Arnold)	×	√
		A. Panchax (Hamilton-Buchanan)	×	√
		A. lineatus (Valenciennes)	×	√
Beloniformes	Adrianichthyidae	*Oryzias melastigma* (McClelland)	×	√
	Belonidae	*Xenentodon cancila* (Hamilton-Buchanan)	×	√
	Hemirhamphidae	*Hyporhamphus limbatus* (Valenciennes)	√	√
		Zenarchopterus dispar (Valenciennes)	×	×
	Mastacembelidae	*Macrognathus aral* (Bloch & Schneider 1801)	×	×
		M. pentophthalmos (Gronow, in Gray 1854)	×	√
		Mastacembelus armatus (La Cepūde 1803)	√	×
Sygnathiformes	Syngnathidae	*Microphis brachyurus* (Bleeker)	×	×
		M. ocellatus (Duncker)	×	×
Synbranchiformes	Synbranchidae	*Ophisternon bengalense* (McClelland)	×	×
		Monopterus desilvai (McClelland)	× E	×
Perciformes	Anabantidae	*Anabas testudineus* (Bloch)	√	√
	Cichlidae	*Etroplus maculatus* (Bloch)	√	√
		E. suratensis (Bloch)	√	√
	Channidae	*Channa ara* (Deraniyagala)	× E	×
		C. gachua (Hamilton-Buchanan)	√	×
		C. orientalis (Bloch & Schneider)	√	√
		C. punctata (Bloch)	√	√
		C. striata (Bloch)	√	√
		C. marulius (Hamilton-Buchanan)	√	√
		C. asiatica (Linnaeus)	×	×
	Monodactylidae	*Monodactylus kottelati* (Pethiyagoda 1991)	×	×
	Kuhliidae	*Kuhlia marginata* (Cuvier)	×	×
	Eleotridae	*Eleotris fusca* (Forster)	×	×
		Butis butis (Hamilton-Buchanan)	×	×
	Gobiidae	*Awaous melanocephalus* (Bleeker)	×	×
		Sicyopterus griseus (Day)	×	√
		S. halei (Day 1888)	× E	×
		Sicyopus jonklaasi (Klausewitz & Henrich 1986)	× E	×
		Stenogobius macropterus (Duncker)	× E	×
		Stiphodon martenstyni (Watson)	× E	×
		Schismatogobius deraniyagalai (Kottelat & Pethiyagoda 1989)	× E	×
		Glossogobius giuris (Hamilton-Buchanan)	√	√

	Osphronemidae	*Belontia signata* (Günther)	√ E	×
		Malpulutta kretseri (Deraniyagala)	× E	×
		Pseudosphromenus cupanus (Cuvier)	×	×
		Trichogaster pectoralis (Regan)	×	×
		Osphronemus goramy (Lacepede)	×	√
	Toxotidae	*Toxotes chatareus* (Hamilton-Buchanan)	×	×
Tetraodontiformes	Tetraodontidae	*Tetraodon fluviatilis* (Hamilton-Buchanan)	×	×
		T. nigroviridis (Marion de Procé)	×	×

(√) present; (×) absent; (E) endemic to Sri Lanka

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