Sri Lanka J. Aquat. Sci. **13** (2008): 23-38

Population dynamics of *Hyporhamphus limbatus* (Beloniformes, Hemiramphidae) in two lowland reservoirs of Sri Lanka

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Abstract

Although *Hyporhamphus limbatus* is found in several lowland reservoirs of Sri Lanka, due to gear restrictions imposed through fisheries regulations, this species remains unexploited or under-exploited in spite of having a good consumer preference. Population dynamics of *H. limbatus* in two Sri Lankan reservoirs, namely Minneriya and Udawalawe were investigated in the present study. Length frequency data of *H. limbatus* caught in shore seine nets of mesh sizes 1 mm, 5 mm and 7 mm were analysed using FiSAT software package and the von Bertalanffy growth parameters were estimated for non-seasonalised growth. Asymptotic total length was 155.4 mm for Minneriya and 156.4 mm for Udawalawe. Growth constants of *H. limbatus* for Minneriya and Udawalawe were 1.37 and 1.09 year^{-1} respectively. High total mortality rates (4.90 in Minneriya and 3.01 in Udawalawe), which are equivalent to production/biomass ratio indicate that both stocks can withstand heavy fishing. Relative yield-per-recruit (Y'/R) analyses indicate that at present these stocks are under-exploited and that by increasing size at first capture to about 70 mm, Y'/R can be optimized at the exploitation rate of 0.6. The shore seine nets of 5 mm mesh sizes can be used to exploit *H. limbatus* in both reservoirs. However, juveniles of exotic cichlids and other non-target species caught in the nets are needed to be released back to reservoirs.

Introduction

Hyporhamphus limbatus (Valencinnes) (Synonyms: *Hemiramphus limbatus*, *Hyporhamphus gaimardi*) is originally a marine species (Munro 1955) but there are established population of this species in several lowland freshwater reservoirs of Sri Lanka (Schiemer and Hofer 1983; De Silva 1988; Silva and Davies 1988; Pethiyagoda 1991; Chandrasoma and Wijeyaratne 1990; Piet et al. 1999; Weliange and Amarasinghe 2003). In some Sri Lankan reservoirs such as Mahawilachchiya, Kaudulla, Minneriya and Udawalwe, this species is exploited at subsistence level using small-mesh (5 mm stretched mesh) drag nets (Silva and Davies 1988; Chandrasoma and Wijeyaratne 1990). Although this species has a good consumer preference, only sporadic exploitation of *H. limbatus* is evident possibly due to gear restrictions in Sri Lankan reservoirs imposed through fisheries regulations. In the Sri Lankan reservoir fisheries, use of any kind of drag nets or seine nets is not allowed and the minimum permissible mesh size (stretched) in the gillnet fishery is 8.5 cm.

Although information about some biological aspects of *H. limbatus* is available (Silva and Davies 1988; Chandrasoma and Wijeyaratne 1990; Weliange and Amarasinghe 2003; Ariyaratne et al. 2008), no studies have been reported on the population dynamics of this species in Sri Lankan reservoirs. Such knowledge will be useful for defining optimal fishing strategies for these fish stocks. This is of particular importance because utilization of biological fish production in Sri Lankan reservoirs is known to be incomplete (Pet et al. 1996). In the present paper, an attempt is made to investigate population dynamics of *H. limbatus* in two Sri Lankan reservoirs using length-based stock assessment methods.

Materials and Methods

Studies were conducted in Minneriya (8º02’ N; 80º53’ E) and Udawalawe (6º27’ N; 80º50’ E), two lowland reservoirs of Sri Lanka. Some physico-chemical and biological characteristics of the two reservoirs are given in Table 1. The most dominant species in the fisheries of the two reservoirs are *Oreochromis mossambicus* and *O. niloticus*. In Udawalawe, *Labeo dussumieri*, *L. rohita* and *Catla catla* also form significant proportions of landings especially during the rainy season (Sricharoendham et al. 2008). Although some fishers in these two reservoirs catch *H. limbatus* using drag nets, which are illegal, collection of length frequency data (LFD) from the landings of fishers was impracticable. This was mainly due to the reason that being an illegal fishing method, fishers do not land their *H. limbatus* catches at the regular landing sites.

Table 1. Some morphometric, hydrological, physico-chemical and biological parameters of the two reservoirs studies*.

Parameter	Minneriya	Udawalawe
Type	Irrigation	Irrigation
River basin	Mahaweli	Walawe
Year of construction	276 AD (Renovated in1903)	1969
Altitude (m above mean sea level)	96.0	88.4
Area (km^2)	25.5	34.1
Mean depth (m)	5.8	7.9
Maximum depth (m)	13.0	20
Volume (x 10^6 m^3)	170.2	268
Catchment area (km^2)	249	1,164
Dead storage (x 10^6 m^3)	3.2	26.26
Shoreline (km)	60.4	53.0
Shoreline development	2.78	4.38
Temperature °C	26.5 – 31.5	26.5 – 29.2
Conductivity (μS cm^{-1})	97 – 203	102 – 160
Secchi depth (cm)	45 – 280	50 – 250
Chl-a (μg l^{-1})	6.0 – 40.0	5.0 – 14.0

*Source: Weliange and Amarasinghe (2007) and Silva et al. (2008).

For collection of LFD, experimental fishing was therefore carried out using shore seine nets of three mesh sizes (1 mm, 5 mm and 7 mm). The length of the seine net of 1 mm mesh size was 8.5 m and the height was 1 m. The length and height of the seine net of 5 mm mesh size were 25 m and 1.9 m respectively. The 7 mm mesh seine net was of 50 m in length and 2.3 m in height. The floats fixed to the head rope and the lead sinkers of the bottom rope facilitated the operation of the nets which was performed by four persons. Experimental fishing for collection of LFD of *H. limbatus* was carried out approximately bimonthly. In Minneriya reservoir, there were 13 fishing trials from August 1998 to January 2001 whereas 12 fishing trials were carried out in Udawalawe reservoir from September 1998 to May 2000. On each field visit, there were 3-4 sampling dates during when 2 to 6 fishing trials were carried out from seine nets of each mesh size in different locations of inshore area of each reservoir, depending on the bottom characteristics and absence of impediments to shore seining. Total length (TL) of each *H. limbatus* caught was measured *in situ* using a measuring board to the nearest mm. As *H. limbatus* has an elongated lower jaw and an opposite heterocercal caudal fin, TL was measured from the tip of the lower jaw to the edge of the lower lobe of the caudal fin. TL measurements of *H. limbatus* during each field visit in each reservoir were pooled and were grouped into 5 mm class intervals.

LFD were analyzed using FiSAT II (version 1.2.2) software package (Gayanilo et al. 2006) for fitting the von Bertalanffy growth model for non-seasonalized growth described by the following equation.

$$L_t = L_\infty [1 - e^{-K(t-t_o)}] \qquad (1)$$

where L_t is the length of fish at age t, L_∞ is the asymptotic length, K is the growth constant and t_0 is the theoretical age at length zero. As ELEFAN and similar methods of analyzing LFD are known to be effective when one of the two von Bertalanffy parameters, L_∞ or K, is approximated (Basson et al. 1988), $L_\infty \approx L_{max}$ where L_{max} = maximum length in the catch samples, was assumed as the root value (Gayanilo and Pauly 1997). Using this root value, preliminary estimates of L_∞ and K were then determined by means of ELEFAN I routine of FiSAT II software. In ELEFAN I, von Bertalanffy growth model is fitted by a non-parametric method where the optimum growth curve that passes through the highest number of peaks in the length frequency samples which are sequentially arranged with time as determined from the goodness of fit value, Rn (Gayanilo and Pauly 1997). Here, restructuring of length frequencies i.e., dividing frequencies of each length class by moving average over five length-classes, followed by their transformation using average adjusted frequency value minus 1 as the denominator, allows the identification of peaks independent of their height.

As the sampling devices were seine nets of 1 mm, 5 mm and 7 mm mesh sizes, small fish which can escape from the meshes do not represent the population. However, for fitting von Bertalanffy growth model, small size classes of fish in the catch sample are important because they determine the curvature of growth curve. Hence, the following procedure was adopted to correct the LFD for selectivity effects of the sampling gear as proposed by Pauly (1986).

First, using the preliminary estimates of L_∞ and K, total mortality (Z) was calculated from the LFD by the length-converted catch curve method (Pauly 1983a). In this method, the slope of the following linear regression line fitted to the right hand descending part of the catch curve, starting from the second highest data point, gives an estimate of Z.

$$\mathrm{Ln}(C_i/\Delta t) = c - Zt_i \qquad (2)$$

where, $\Delta t = (1/K)\ln[(L_\infty - L_i)/(L_\infty - L_{i+1})]$ and, L_i and L_{i+1} are lower and upper limits of the i^{th} length class respectively.

Secondly, through the detailed analysis of the ascending part of the length-converted catch curve, probabilities of capture of smaller size classes were determined. Finally, LFD were corrected using these probabilities of capture. These corrected LFD were then used to determine final estimates of the von Bertalanffy growth parameters (L_∞ and K) by means of ELEFAN I routine of FiSAT II software.

As L_∞ and K are not species-specific but are inversely proportional, the following growth performance index (φ'), which falls within a narrow range for taxonomically close species (Moreau et al. 1986), was used to compare growth parameters of hemiramphid species in different localities.

$$\varphi' = \text{Log}(K) + 2\,\text{Log}(L_\infty) \qquad (3)$$

As φ' is sensitive to the units of measurement of L_∞ and K and the expression of L_∞ (i.e., TL, SL or any other measurement), comparable units and expressions of growth parameters were used in calculating φ'. The growth data of hemiramphids, as reported in www.fishbase.org, were compared with those of *H. limbatus* in Minneriya and Udawalawe reservoirs using an auximetric plot, i.e., plot of Ln K against Ln L_∞ (Pauly 1998).

The third parameter of the von Bertalanffy growth model, the theoretical age at length zero (t_0) was estimated using the following empirical relationship (Pauly 1983b).

$$\text{Log}_{10}(-t_o) = -0.3922 - 0.2752\,\text{Log}_{10}\,L_\infty - 1.038\,\text{Log}_{10}\,K \qquad (4)$$

Using the final estimates of L_∞ and K, Z values were again estimated from the length-converted catch curve method based on the original, uncorrected LFD. Similarly, from the detailed analysis of ascending part of the length-converted catch curve, probabilities of capture in different size classes were determined. From a plot of probabilities of capture against length, length at 50% retention was estimated which was considered as the length at first capture (L_c).

Natural mortality (M) was estimated using the following empirical equation derived by Pauly (1980).

$$\text{Ln}(M) = -0.0152 - 0.279\,\text{Ln}(L_\infty) + 0.6543\,\text{Ln}(K) + 0.463\,\text{Ln}(T) \qquad (5)$$

In this method, L_∞ was expressed in TL in cm, K was on annual basis and T was in degrees Celsius. Fishing mortality (F) was estimated by subtracting M from Z and the exploitation rate (E) was estimated as F/Z (Pauly 1983b).

Recruitment patterns of *H. limbatus* in the two reservoirs were determined from the routine implemented in FiSAT II software, which involved backward projection of length frequencies onto time axis based on growth parameters. Relative yield-per-recruit (Y'/R) analysis was carried out incorporating probabilities of capture (Pauly and Soriano 1986; Gayanilo and Pauly 1997) as determined for the sampling gear. Assuming that *H. limbatus* is exploited from the drag nets, which have similar selection characteristics, optimal fishing strategies were determined by the Y'/R analysis. In order to allow fishers to increase the efficiency of fishing effort, the E value which corresponds to 10% of the maximum rate of Y'/R increase with increasing E, defined as $E_{0.1}$ was determined as an index of assessing status of the fishery (Gayanilo and Pauly 1997).

Results

The LFD of *H. limbatus* caught in 1 mm, 5 mm and 7 mm mesh shore seine nets are shown in Figure 1. A wide range of lengths was recorded when LFD of catches of seine nets of all three mesh sizes were considered. The growth curves of *H. limbatus* in Minneriya and Udawalawe reservoirs superimposed on LFD are shown in Figures 2a and 3a respectively. The corresponding Rn values (Gayanilo and Pauly 1997) in Minneriya and Udawalawe were 0.199 and 0.135 respectively indicating that all the available peaks in the LFD are not explained by the growth curves possibly due to the continuous recruitment. The von Bertalanffy growth parameters of *H. limbatus* in the two reservoirs are given in Table 2. Length-converted catch curves of *H. limbatus* in Minneriya (Figure 2b) and Udawalawe (Figure 3b) showed erratic patterns in the descending arms of the curves, possibly due to non-proportional representation of abundance in the exploited phase by catch samples. The sigmoid selection curves of *H. limbatus* in beach seines in the two reservoirs (Figures 2c and 3c respectively for Minneriya and Udawalawe) permitted estimation of L_c for both populations and Y'/R analysis incorporating probabilities of capture (Pauly and Soriano 1986).

In both reservoirs, *H. limbatus* showed two peak recruitment pulses (Figures 2d and 3d in Minneriya and Udawalawe respectively). In Minneriya, recruitment pulses in February and August occurred during the dry months whereas in Udawalawe, peak recruitment coincided with rainy seasons in May and November.

The estimated growth performance indices (ϕ') of *H. limbatus* in the two reservoirs fall within the range of hemiramphids in different localities (Table 3). Also, from the plot of Ln K against Ln L_∞ in different stocks of hemiramphids as reported in www.fishbase.org (Figure 4) that can be considered as the 'growth space' of the members of this family (Pauly 1998), it is evident that the estimates of L_∞ and K of *H. limbatus* in the two reservoirs are biologically reasonable.

Y'/R curves of *H. limbatus* as a function of exploitation rate at the present size at first capture for the two reservoirs are shown in Figure 5. Also shown in Figure 5 are the Y'/R isopleths of *H. limbatus* in the two reservoirs. The estimated mortality rates, mean length at 50% retention, optimal exploitation rate (E_{opt}) and $E_{0.1}$ are given in Table 4. The exploitation rates of *H. limbatus* in Minneriya and Udawalawe reservoirs were 0.46 and 0.25 respectively, indicating that the both stocks are underexploited. In Minneriya, $E_{0.1}$ (0.45) is more or less similar to the present level of E indicating a safe exploitation of *H. limbatus* stock in this reservoir. In Udawalawe reservoir on the other hand $E_{0.1}$ (0.40) is much higher than the present E so that there is a provision for further intensification of exploitation. As evident from the Y'/R isopleths (Figure 5), optimal L_c of *H. limbatus* in both reservoirs is greater than 70 mm. As such, it is possible to increase the exploitation rate to the level of about 0.6 if the L_c is increased to about 70 mm.

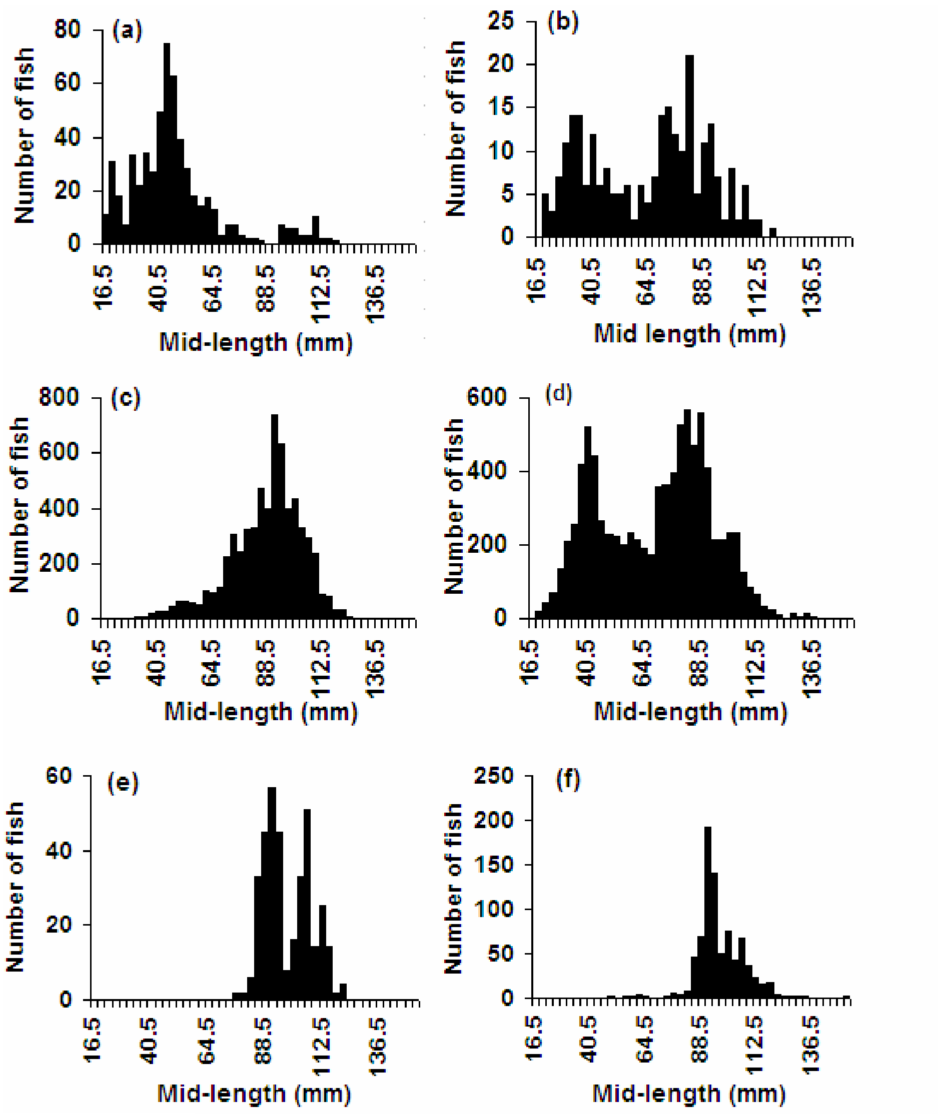

Figure 1. The length frequency data of*H. limbatus* caught in 1 mm, 5 mm and 7 mm mesh shore seine nets in two reservoirs of Sri Lanka. (a) 1 mm mesh net in Minneriya; (b) 1 mm mesh net in Udawalawe; (c); 5 mm mesh net in Minneriya; (d) 5 mm mesh net in Udawalawe; (e) 7 mm mesh net in Minneriya; (f) 7 mm mesh net in Udawalawe.

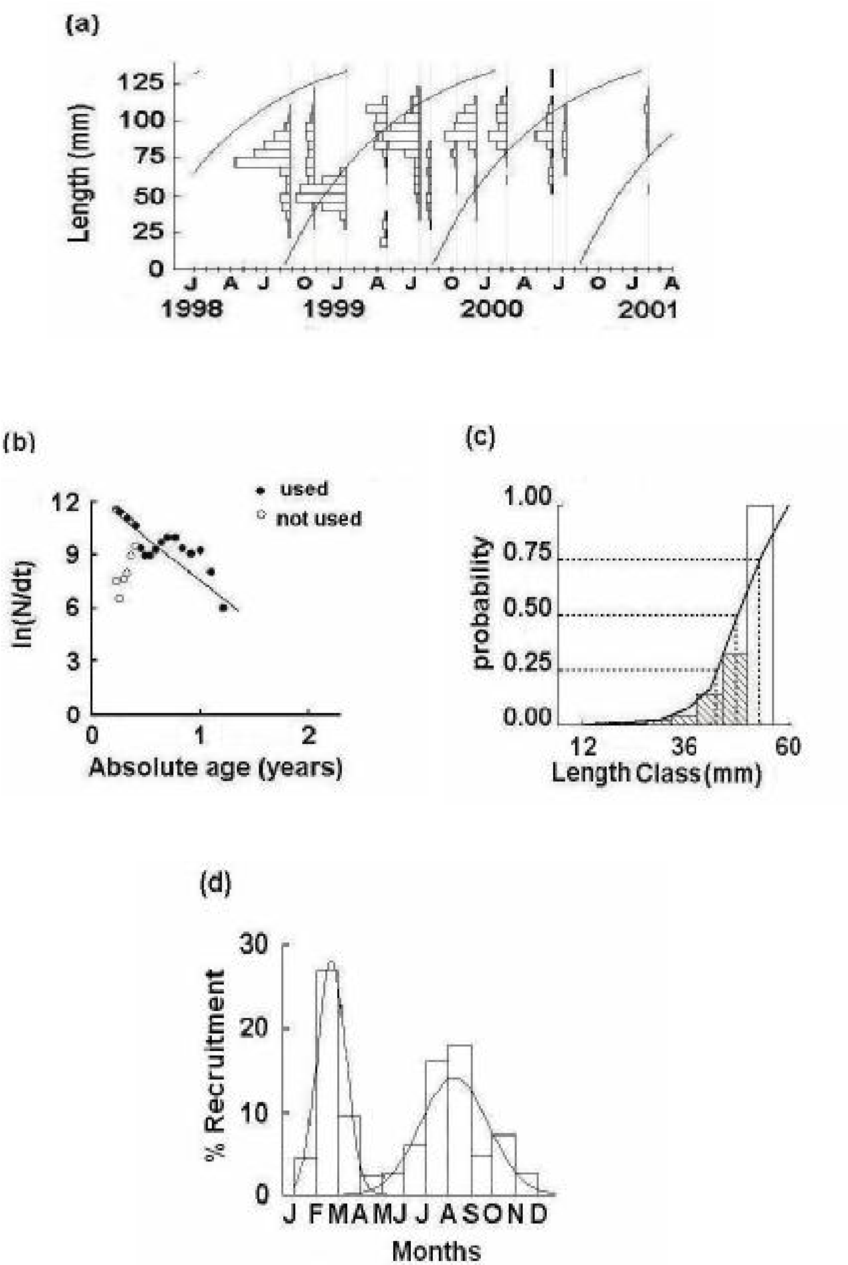

Figure 2. (a) The growth curves superimposed on length frequency data, (b) length-converted catch curve, (c) selection curve and (d) recruitment pattern of *H. limbatus* in Minneriya reservoir.

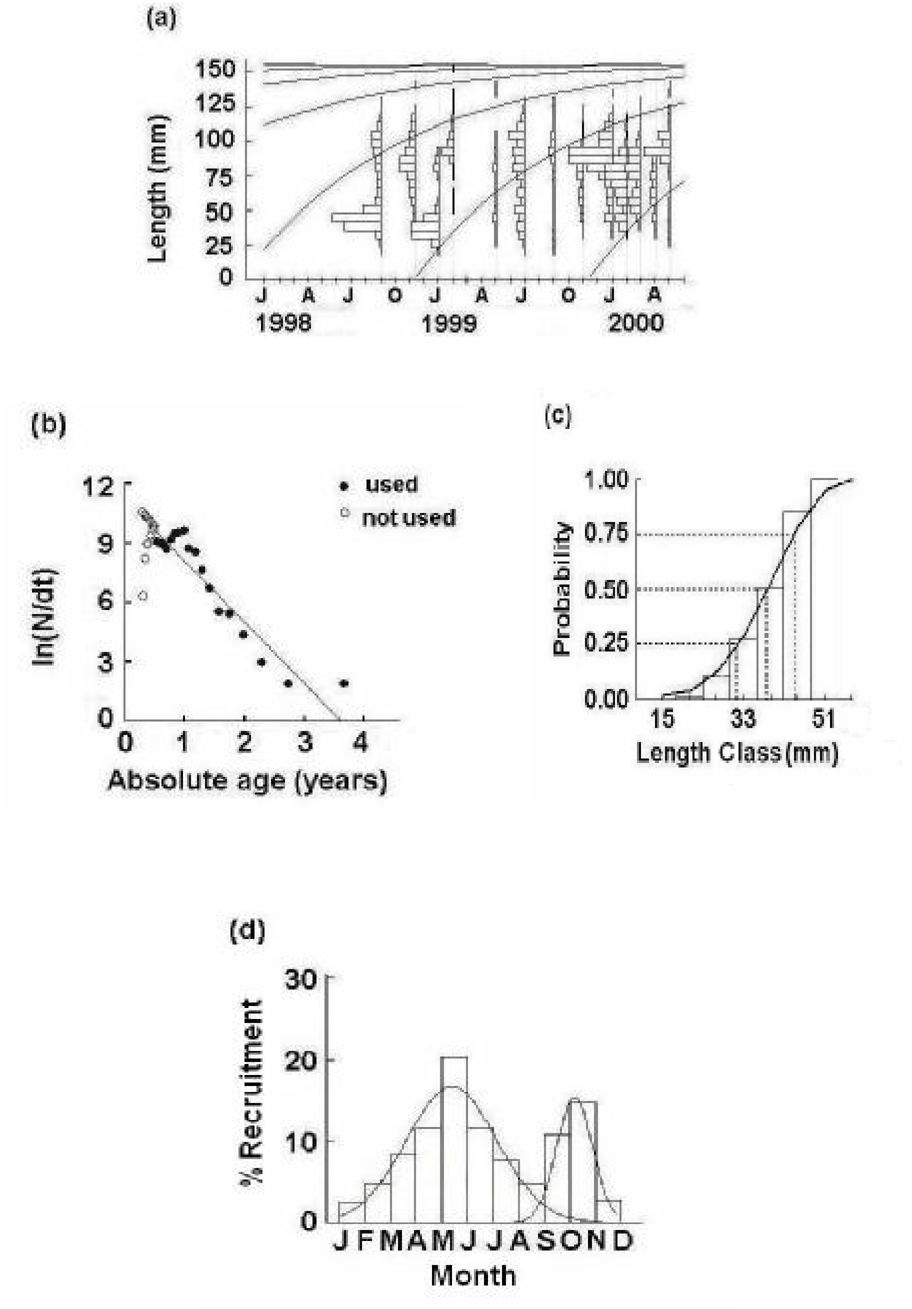

Figure 3. (a) The growth curves superimposed on length frequency data, (b) length-converted catch curve, (c) selection curve and (d) recruitment pattern of *H. limbatus* in Udawalawe reservoir.

Table 3. The growth performance indices (φ') of *H. limbatus* in Minneriya and Udawalawe reservoirs. For comparison, mean and range of φ' values of 13 populations of the family Hemiramphidae are also given. Here, φ' was estimated using asymptotic total length in mm and growth constant on annual basis.

Species/Locality	φ'	Authority
H. limbatus		
Minneriya	4.52	Present study
Udawalawe	4.43	Present study
Hemiramphidae(13 genera)		
Various localities	4.70 (3.86-5.40 range)	www.fishbase.org

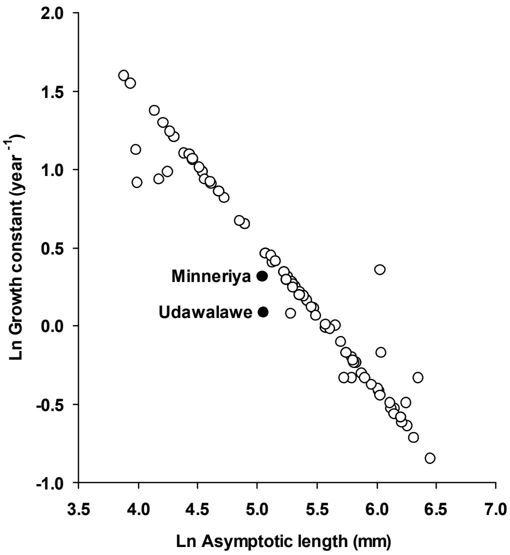

Figure 4. The plot of Ln L_∞ against Ln K in 95 populations of hemiramphids, as reported in www.fishbase.org and the two populations of *H. limbatus* in the present study. The black dots represent *H. limbatus* in Minneriya and Udawalawe reservoirs.

Discussion

Fishes of the family Hemiramphidae are widely distributed throughout the world and are exploited by commercial and recreational fisheries in many countries (Collete 1974; Sokolovsky and Sokolovskaya 1999; McBride and Thurman 2003; www.fishbase.org). In several lowland reservoirs of Sri Lanka, *H. limbatus* is found in abundance (Schiemer and Hofer 1983; De Silva 1988; Silva and Davies 1988; Pethiyagoda 1991; Piet et al. 1999).

Although this species is exploited in small-scale in some reservoirs, as a whole this species remains unexploited or under-exploited due to mesh regulations and gear restrictions in Sri Lankan reservoirs. The importance of the study of population dynamics of *H. limbatus* is two-fold. First, the reservoir fishery of the country is almost entirely dependent on the exotic cichlid species (*O. mossambicus* and *O. niloticus*) so that diversification of the fishery is necessary for more complete utilization of biological fish production, as suggested by Pet et al. (1996). Secondly, to understand the trophic interactions in reservoir fish communities where size-selective zooplanktivorous fish species such as *H. limbatus* are present, investigation of population dynamics of zooplanktivorous fish species is imperative. *H. limbatus* is predominantly a zooplankton feeder (Weliange and Amarasinghe 2003) and is reported to be mainly selecting the medium and larger-sized cladocerans, which are slow swimmers, and the large adult insects (Ariyaratne et al. 2008). According to the trophic cascade hypothesis (i.e., the control of zooplankton by size-selective zooplanktivorous fish) zooplanktivorous fish affect the structure of the zooplankton community and in turn, influence the phytoplankton assemblage, primary production and nutrient turnover rates (McQueen et al., 1986; Carpenter et al., 1987; Carpenter and Kitchell, 1993).

Table 4. Total mortality (Z), natural mortality (M), fishing mortality (F), exploitation rates and mean sizes at first capture (L_c) of *H. limbatus* in Minneriya and Udawalawe reservoirs. Optimal exploitation rates (E_{opt}) and $E_{0.1}$ (see text for definition) at the present levels of L_c are also given here. E_{max} – Exploitation rate corresponding to maximum Y'/R; $L_{c\ (max)}$ - L_c corresponding to maximum Y'/R.; For other abbreviations, see text.

Parameter	Minneriya	Udawalawe
Z (year^{-1})	4.90	3.01
M (year^{-1})	2.63	2.26
F (year^{-1})	2.27	0.75
E	0.46	0.25
L_c (mm)	48.2	37.9
E_{opt} (at the present L_c)	0.54	0.48
$E_{0.1}$ (at the present L_c)	0.45	0.40
E_{max}	0.62	0.60
$L_{c\ (max)}$ (mm)	69.9	68.8

The present analysis has shown that *H. limbatus* in Minneriya and Udawalawe reservoirs can be exploited using shore seine nets of 1 mm, 5 mm and 7 mm mesh sizes. However, it must be noted that as there is a danger of catching juveniles of exotic cichlids (i.e., *O. mossambicus* and *O. niloticus*) in these shore seine nets, exploitation of *H. limbatus* using shore seines should be carefully monitored to minimize mortality of cichlid juveniles. As *H.*

limbatus caught in seine nets can be easily sorted while keeping the net in water, juvenile cichlids and other non-target species that are caught can be released back to the reservoir. As L_∞ and K are not species-specific parameters, comparison of growth must be taken as a multivariate problem in which both L_∞ and K can be simultaneously considered. In this context, the growth performance index (φ'; Moreau et al. 1986) is suitable for comparison of overall growth performance of different stocks. The φ' value is shown to be more or less constant for a family for a similar taxon (Moreau et al. 1986). With the present estimates of L_∞ and K for *H. limbatus*, φ' was 4.52 in Minneriya and 4.43 in Udawalawe. These estimates are in agreement with the estimates of φ' of hemiramphids as reported in www.fishbase.org. Here, it must be noted that for the purpose of comparison, all φ' values were estimated using L_∞ as total length in mm and K on annual basis.

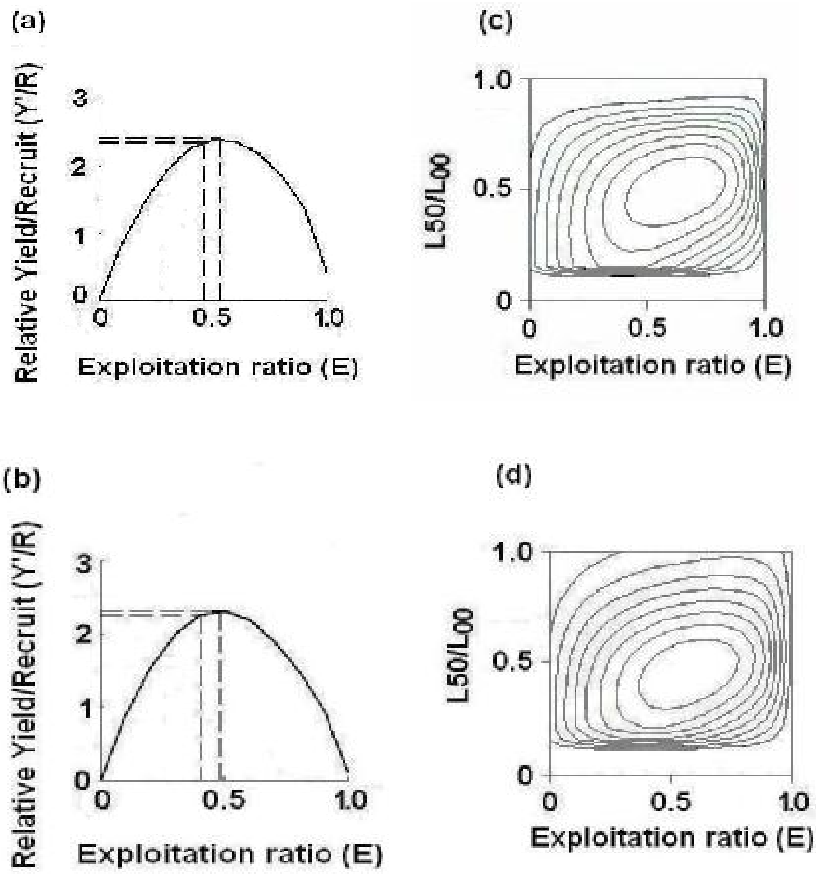

Figure 5. Y'/R curves of *H. limbatus* as a function of exploitation rate at the present size at first capture for (a) Minneriya and (b) Udawalawe and the Y'/R isopleths of *H. limbatus* for (c) Minneriya and (d) Udawalawe.

Although, erratic patterns in the descending arms of the length-converted catch curves (Figures 2b and 3b) perhaps indicate non-proportional representation of abundance in the exploited phase by catch samples, a wide range of age classes was considered in estimating Z. As such, the Z estimates in the present analysis can be considered reasonably accurate. The Z values of both stocks are considerably high (Table 4). Under steady-state assumptions, Z is known to be equivalent to production/biomass ratio (P/B) or turnover rate (Allen 1971). Therefore, it appears that both stocks can withstand heavy fishing. As there are two peak recruitment pulses in both stocks, it can also be expected that the stocks are capable of showing resilience to changing environmental conditions.

In both reservoirs, exploitation rates of *H. limbatus* were below 0.5 suggesting that the fish stocks are lightly exploited. In Minneriya reservoir however, more fishers are engaged in *H. limbatus* fishing than in Udawalawe reservoir. As there are no submerged decaying tree stumps in Minneriya reservoir in contrary to Udawalawe, drag nets and shore seine nets can be conveniently used in Minneriya reservoir. These differences in fishing intensities are also reflected by exploitation rates of *H. limbatus* in the two reservoirs. In Minneriya, exploitation rate was much higher (0.46) than in Udawalawe (E = 0.25).

The relative yield-per-recruit (Y'/R) analyses performed here were based on the overall selection patterns of the three seine nets. Based on the assumption that these three seine nets represent the small-scale fisheries of *H. limbatus* in the two reservoirs, $E_{0.1}$ in Minneriya reservoir was found to be more or less similar to the present level of exploitation. In Udawalawe reservoir, $E_{0.1}$ was much higher than the present E. The Y'/R isopleths indicate that the Y'/R can be optimized in both reservoirs at the exploitation rate of 0.6 if the L_c is increased to over 70 mm. As most of the under-sized (< 70 mm) *H. limbatus* were caught in 1 mm mesh seine net during the present study (Figure 1), use of seine nets with mesh size 5 mm and 7 mm is advocated.

Acknowledgements

This study was carried out as part of a research project funded by European Union INCO-DC Programme Project Number: IC18-CT-0190. We are thankful to Drs W.S. Weliange and C. Nissanka and Messrs M.G. Ariyaratne and R.P.P.K. Jayasinghe for their assistance in shore seining.

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