Asian Fisheries Science **28** (2015): 130-142
©Asian Fisheries Society
ISSN 0116-6514

Age, Growth and Population Dynamics of an Endangered Fish *Sahyadria denisonii* (Day 1865) from the Western Ghats Hotspot of India

S. SAJAN[1,2*], T.V. ANNA MERCY[1] and V. MALIKA[3]

[1]School of Fisheries Resource Management and Harvest Technology, Kerala University of Fisheries and Ocean Studies (KUFOS), Kochi, Kerala, 682 506, India
[2]School of Bioscience, Mahatma Gandhi University, Priyadarshini Hills, Kottayam, Kerala, 686 560, India
[3]School of Management Studies and Entrepreneurship, Kerala University of Fisheries and Ocean Studies (KUFOS), Kochi, Kerala, 682 506, India

Abstract

The population structure, age, growth, mortality and harvest intensity of redline torpedo barb *Sahyadria denisonii* (Day 1865) in the River Valapattanam was studied using length-frequency based analysis. The von Bertalanffy growth functions estimated were L_t=158 [1-e$^{-0.8(t+0.0203)}$] and growth parameters of von Bertlanffy equation were L_∞= 158 mm, K= 0.8 year^{-1} and t_0= -0.0203. The present level of exploitation (E=0.60) is higher than the Gulland equation (E=0.5) which is an indication of over exploitation. The recruitment pattern was continuous, and displaying a single major peak event per year. Management practices recommend the establishment of a closed season from November to February to protect the spawning stock and stock wise river ranching of captive bred young ones.

Introduction

Age and growth determination in fish are important aspects of population dynamics, which forms the basis of calculations of growth, mortality and recruitment (Sparre and Venema 1992; Coban et al. 2013). These parameters provide tools for scientific interpretation of population dynamics as well as formulation of conservation policies. Though comprehensive information on the population regulation and exploitation patterns of a large number of marine fish species are currently available (Maccord et al. 2007), similar database on freshwater fishes of India is yet to be generated. A few available reports are those of Qasim and Bhatt (l964), Khan and Siddiqui (l973), Desai and Shrivastava (l990), Kurup (l997), Bhatt et al. (2000), Euphrasia (2004), Kurup et al. (2008), Manojkumar (2007) and Prasad et al. (2012).

Exploitation of freshwater fishes from rivers of Kerala (India) gained great momentum during the last decade, which has led to the depletion of many species of freshwater indigenous fish resources. Raghavan et al. (2013) reported that more than 1.5 million freshwater fishes of 30 threatened species were traded from India during 2005-2012, to which *Sahyadria denisonii* (Day 1865) contributed a major share.

*Corresponding author. E-mail address: sajanpolayil@gmail.com

Over the last few decades wild population of *S. denisonii* has declined due to indiscriminate aquarium trade (Mercy et al. 2013a; Raghavan et al. 2013; Liya and Ramachandran 2013). According to the latest IUCN assessment, *S. denisonii* is listed under the endangered category. In this context, this species is considered a suitable candidate for the study of population characteristics to ascertain the present status of the stock. In the present study an attempt is made to investigate the age, growth, mortality, and exploitation parameters of this species, which may help in designing suitable management policies for its conservation.

Materials and Methods

The Western Ghats, extending along the west coast of India (180,000 km), is one of 34 global biodiversity hotspots (Raghavan et al. 2011). Monthly samples of the fish were collected from the catch for aquarium trade at collection sites in River Valapattanam, Kerala during September 2011-August 2013 (n=1,037). Valapattanam River lies in the Western Ghats region of South India (Latitude 11°93'N; Longitude 73°73'E) and has an overall passage length of 110 km. The sampling sites were selected based on the high occurrence of *S. denisonii* in the catches of local fishermen. Samples were collected using the encircling/drag net (40-60 m length, 1.0-2.0 m depth and 6 mm mesh size), which is capable of retaining small and larger fishes. The randomly sampled live fishes were anaesthetised at a dose of 300 $mg \cdot L^{-1}$ of MS-222 (Mercy et al. 2013b) and then preserved in 10% formalin. Length was measured with Vernier callipers to the nearest 0.1 cm, by following the standard procedures described by Dwivedi and Menezes (1974).

Length frequency data were processed by the methodology of Gayanilo et al. (2005) using the length based approaches described in the FAO-ICLARM stock assessment tool (FiSAT-II) package. Length frequency data were grouped into 10 mm class interval and analysed using FiSAT-II software. The inverse von Bertalanffy growth equation was used to determine *S. denisonii* lengths at different ages (Sparre and Venema 1992). Growth parameters like asymptotic length (L_∞), growth coefficient (K) and t_0 were obtained using the ELEFAN programme from the fitted curve with maximum goodness-of-fit (R_n). The growth equation can be written as: $L_t = L_\infty[1\text{-}exp^{-K(t-t_0)}]$; where, L_t = length at age *t*, L_∞ = asymptotic length or the maximum length that the fish can theoretically attain, *exp* = base of the natural log, *K* = growth coefficient (the rate at which the fish approaches asymptotic length), *t* = age of fish, t_0 = the hypothetical age which the fish would have had at zero length. 't_0' was estimated using Bertalanffy (1938) plot in which the results of the regression of $\ln(1-L_t/L_\infty)$ against 't' was used.

Mortality coefficients, viz., total mortality (Z), instantaneous natural mortality (M), fishing mortality (F) and exploitation rate (E) were estimated using the FiSAT-II programme (Pauly 1980; Gayanilo and Pauly 1997). Natural mortality was calculated using the empirical formula: $\log(M) = 0.0152-0.279\log(L_\infty)+0.6543\log(K)+0.463\log(T)$ of Pauly (1980). The optimum length of exploitation (L_{opt}) was estimated empirically from the equation of Froese and Binohlan (2000) as $L_{opt} = 3*L_\infty/(3+M/K)$, where L_∞ = the asymptotic length, M = the natural mortality and K = the growth coefficient.

By plotting the cumulative probability of capture against mid-length, from this resultant curve, the length at first capture (L_c) was taken as corresponding to the cumulative probability at 50%. Length structured virtual population analysis was estimated using FiSAT-II programme. The longevity (t_{max}) of the species was then calculated from $t_{max} = 3/K$ by Pauly and Munro (1984).

The total stock was estimated by the relation between yield and exploitation ratio: total stock = Y/U, where Y = yield and U = exploitation ratio. The relative yield-per-recruit (Y/R) model of Beverton and Holt (1966) incorporated in the FiSAT programme was used to estimate the Y/R and relative biomass-per-recruit (B/R). The computed exploitation rate (E) was compared with the expected values of E_{max} (the value of exploitation rate giving maximum Y/R), E_{10} (the value of 'E' at which marginal increase in Y/R is 10% of its value at E = 0) and E_{50} (the value of 'E' at 50% of the unexploited B/R) (Sparre and Venema 1992; Gayanilo and Pauly 1997).

Results

Population structure and recruitment

The sampled population of *S. denisonii* from the River Valapattanam during September 2011 to August 2013 ranged in size from 33 to 140 mm total length. Maximum length was recorded in the length class of 130-140 mm and 50-60 mm length group were the dominant classes. The smallest individual was sampled during April-June (33 mm), while the largest individual (140 mm) was sampled during October. Maximum number of samples was collected during 2011-2012 in the length class of 50-60 mm and during 2012-2013 in 80-90 mm length class. This study suggests that there are specific trends in the catches of *S. denisonii* in different months.

Age and growth parameters

The original length frequency distribution was restructured (10 mm class interval) and the best fitting growth curve was obtained by the method of joining peaks using the ELEFAN-I routines incorporated in the FiSAT-II package. The best value of the ratio of the number of peaks through which the curve passes relative to the total number of peaks (Rn) obtained was 0.499. The growth parameters were estimated as L_∞ = 158 mm, K = 0.8 year^{-1} and t_0 = -0.0203 for River Valapattanam. Growth curve showed that the whole population of *S. denisonii* comprised of a single cohort which originated during December-February (Fig. 1). These results suggested that the fish have a relatively short life cycle with a fast growth rate. The longevity (t_{max}) of the species was calculated from the relationship described by Pauly and Munro (1984) and t_{max}= 3/K, using the 'K' which was calculated as 3.75 years for the River Valapattanam. Estimated length at age by empirical method is shown in Fig. 2. Based on the values arrived at through ELEFAN-I, the von Berttalanfy growth function equation (VBGF) of *S. denisonii* (Fig. 2) can be expressed as: $L_t = 158\ [1\text{-}e\text{-}^{0.8(t+0.0203)}]$.

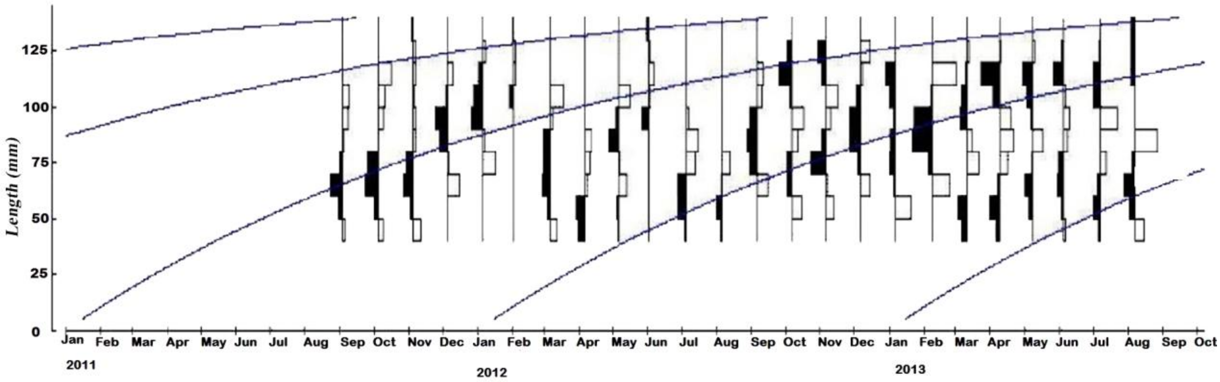

Fig. 1. Monthly restructured length frequency distribution of *Sahyadria denisonii* with the estimated growth curves.

On applying the VBGF equation, *S. denisonii* attained a length of 88.15 mm at the end of the first year, 126.61 mm at the end of the second year, 143.9 mm at the end of the third year and 151.66 mm at the end of the fourth year of life (Table. 1). *Sahyadria denisonii* was found to exhibit fastest increment in length during the first year of its life (38.46 mm). Age of captured fishes ranged between '0' to 'III', and the first and second year classes were dominant. The length at first maturity (L_m) was estimated as 81 mm (80-90 mm) and 92 mm (90-100 mm) for males and females respectively (Sajan 2015) implying that fish caught at 0+ year class are highly vulnerable to fishing before reaching their first spawning (Fig. 2).

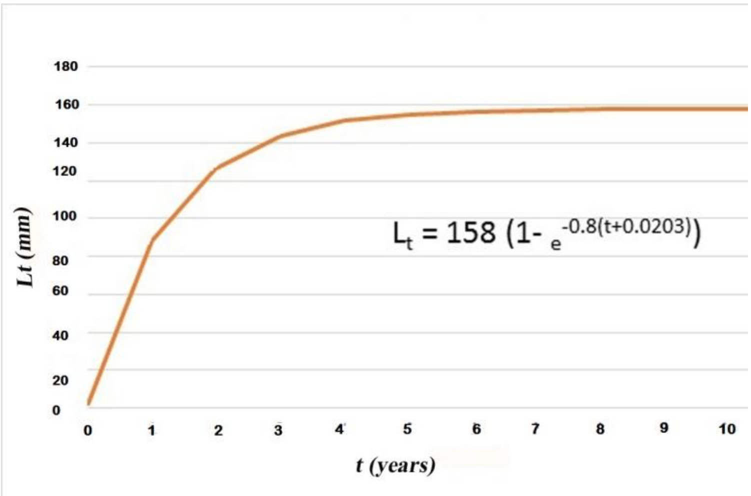

Fig. 2. Length at age of pooled population of *Sahyadria denisonii*.

Estimation of mortality and exploitation

The length converted catch curve from mortality estimates of pooled population of *S. denisonii* of the River Valapattanam is depicted in Fig. 3. The instantaneous total mortality coefficient (Z) of *S. denisonii* was estimated as 2.09 year^{-1}. Natural mortality-coefficient (M) of *S. denisonii* was estimated as 0.83 year^{-1}. The fishing mortality (F= Z-M) computed for *S. denisonii* was 1.26 year^{-1}. The exploitation rate (E= F/Z) was estimated as 0.60. The optimum length (L_{opt}) estimated empirically by Froese and Binohlan (2000) was 111.39 mm and the estimated L_{opt}/L_∞ value was 0.74.

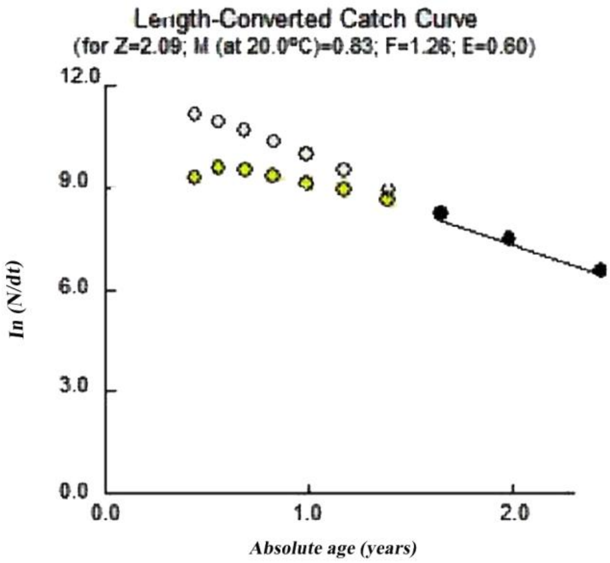

Fig. 3. Total mortality (Z) using by linearised catch curve method.

Probability of capture

The estimates of probabilities of capture and length at first capture (L_c) values were calculated using the length converted catch curve method which was plotted in Fig. 4. The values obtained by probabilities of capture were L_{25} = 55 mm, L_{50} = 90 mm and L_{75} = 105 mm. The minimum length at first maturity (L_m) for female of *S. denisonii* was observed to be 92 mm in the length class of 90-100mm. L_c/L_{50} calculated from the study is lower than L_m, implying that individual fish of this stock are vulnerable to fishing before reaching first sexual maturity.

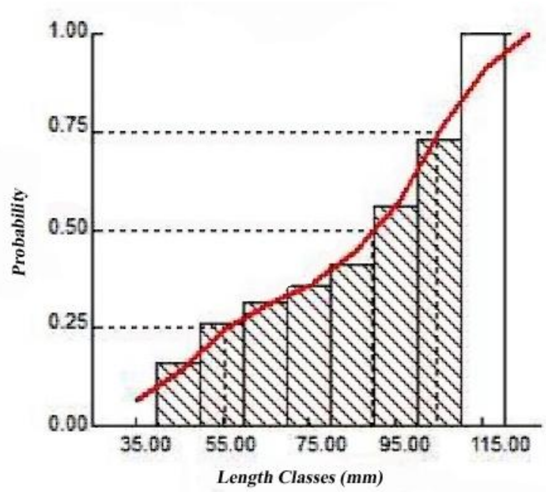

Fig. 4. Probabilities of capture pattern of pooled population of *Sahyadria denisonii*.

Yield-per-recruit and biomass-per-recruit

The estimates of probabilities of capture and length at first capture values were used as inputs for relative yield-per-recruit of Beverton and Holt (Y/R). The L_C/L_∞ and M/K values used for Y/R analysis were 0.567 and 1.0375 respectively. The relative yield per recruit and biomass per recruit in *S. denisonii* is depicted in Fig. 5. The relative yield per recruit reached the maximum at an exploitation rate of 0.737(E_{max}).

It may be noted that the present exploitation rate (E=0.60) does not exceed the maximum exploitation rate (E_{max}=0.737). The values of $E_{O.1}$ and $E_{O.5}$ were estimated as 0.656 and 0.383 respectively. The results of length based virtual population analysis showed that fishing mortality (F) increased to a maximum of 2.40 at 120-130 mm size (Fig. 6). This indicated that catches increases substantially from 50-60 mm and attained maximum at 110-130 mm size groups (Fig. 6).

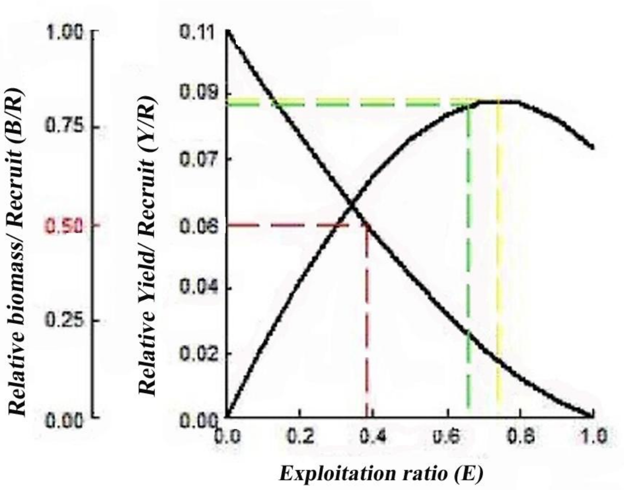

Fig. 5. Relative yield per recruit and biomass per recruit of pooled population of *Sahyadria denisonii* ($E_{0.5}$, $E_{0.1}$, E_{max})

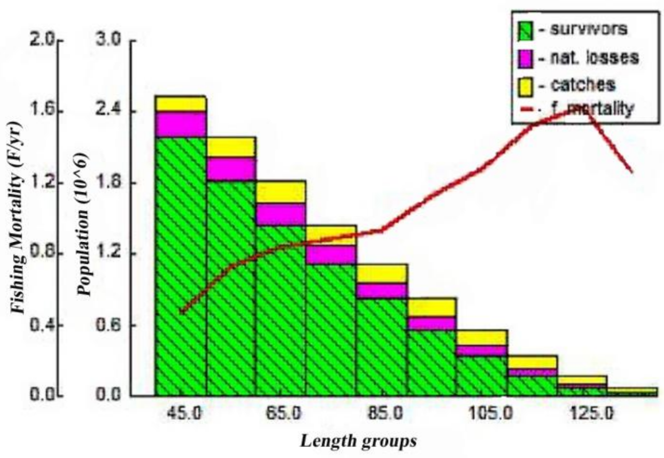

Fig. 6. Length based virtual population analysis of pooled population of *Sahyadria denisonii*.

Discussion

Sahyadria denisonii, an endemic species from southern India is categorised as endangered (EN) in the IUCN Red List. The results on the population characteristics of the species may help in the formulation of suitable conservation management programmes for the protection of this threatened fish. The maximum length recorded during the present study was 140 mm, which is greater than the earlier record (136 mm) from the River Valapattanam (Mercy et al. 2013b), 110 mm from the River Chaliyar (Solomon et al. 2011) and 107 mm from River Kariangode (Mercy et al. 2013c), but lower than the 156 mm from River Kanjirampuzha (Kurup et al. 2008) and 162 mm from River Chandragiri (Solomon et al. 2011). This is an indication of clear stock-specific population structuring of *S. denisonii* between rivers in the Western Ghats.

These results are in agreement with John (2009) in S. *denisonii* and Raghavan et al. (2011) in *Tor khudree* (Sykes 1839) from the Western Ghats of Kerala. These growth differences can be attributed to differences in environmental factors, particularly water temperature and food availability in rivers (De Silva et al. 1985; Froese 2006; Ahamed et al. 2012).

According to Froese (2006), growth in fishes is not constant throughout their life; young fish grow rapidly and then growth decreases as the animal advances in age until there is no further growth. In the present study, growth curves showed that the population comprised of a single cohort originated during December-February (Fig. 2). However, it has been reported that *S. denisonii* spawn mainly during November- February (Solomon et al. 2011; Mercy et al. 2013a; Sajan 2015). It is expected that the major recruitment peak (March-June) detected in this study should correspond to the major spawning season. The estimated L_∞ (158 mm) and K (0.8 year^{-1}) were similar to many other cyprinid species. In the present study, *S. denisonii* showed rapid growth rate (0.8 year^{-1}) similar to 0.8 year^{-1} in *Osteobrama bakeri* (Day 1873) reported by Euphrasia (2004), but lower than 0.81 year^{-1} in *Labeo dussumierii* (Valenciennes) by Kurup (1997), 1.19 year^{-1} in *Dawkinsia filamentosus* (Valenciennes 1844), 1.06 year^{-1} in *Rasbora daniocnius* (Hamilton 1822), 0.93 year^{-1} in *Amblypharyngodon melettinus* (Valenciennes 1844), 0.96 year^{-1} in *Esomus thermoicos* (Valenciennes 1842) by Wijeyaratne and Perera (2001) and 0.97 year^{-1} in *Puntius carnaticus* (Jerdon 1849) by Manojkumar (2007). The high growth co-efficient (K) value indicated that, *S. denisonii* attained asymptotic length (L_∞) rapidly which is in agreement with Pauly and Munro (1984) and Tsikliras et al. (2013), that species having shorter life have higher 'K' value and reach their L_∞ within one or two years.

On applying the average growth co-efficient (K) estimated by ELEFAN-I, *S. denisonii* attained an average length of 88.15, 126.61, 143.9, and 151.66 mm at the end of 1, 2, 3, 4 years respectively. *Sahyadria denisonii* was found to exhibit fastest length increment during the first year of its life similar to many other cyprinid species. In the present study, the age group of captured fish ranged between one to three years, but the dominant group belonged to the first and second year class. Based on the present results, majority of *S. denisonii* recruited to harvestable fishery for ornamental fish trade fall in the length class ≤ 80 mm, and it is apparent that the exploited stock invariably belonged to the first year age group. Thus *S. denisonii* experienced harvest pressure in the River Valapattanam. In the present study life span of *S. denisonii* was found to be 3.75 years, while Kurup et al. (2008) estimated longevity as 6.65 years in River Kanjirampuzha and 5-6 years by Anon (2014) in different rivers. According to Cha et al. (2004), differences in longevity of one species between different rivers are attributed to environmental factors primarily water temperature. In the present study, total mortality (Z), natural mortality (M), and fishing mortality (F) were estimated as 2.09 year^{-1}, 0.83 year^{1} and 1.26 year^{-1} respectively. This high fishing mortality (1.26 year^{1}) over natural mortality (0.83 year^{-1}) of *S. denisonii* indicated that this species is undergoing fishing pressure. Natural mortality is dependent on several biological and environmental factors, so precise estimation of it is often difficult (Pauly 1980; Cushing 1981). The estimated natural mortality rate of *S. denisonii* (M=0.83 year^{-1}) is higher than that of *P. carnaticus* (M=0.54 year^{-1}) as reported by Manojkumar (2007), and *Garra surendranathanii* (Shaji, Arun and Easa 1996) (M=0.63 year^{-1}) by Sunesh Thamby (2009).

It is, however, lower than that of *P. ticto* (M=2.08 year^{-1}) as reported by Mitra et al. (2011), and *O. bakerii* (M=1.2 year^{-1}) by Euphrasia (2004). The reliability of natural mortality can be determined by the estimation of M/K ratio, which normally lies within the range of 1 and 2.5 for most fish (Beverton and Holt 1959). In the present study, M/K ratio was 1.0375, which is within the normal range and hence can be suggested that the natural mortality estimated for *S. denisonii* is reliable. The estimated fishing mortality rate of *S. denisonii* (F = 1.26 year^{-1}) is higher than that of *P. ticto* (F = 0.49 year^{-1}) as reported by Mitra et al. (2011), while lower than that of *O. bakerii* (F=4.18 year^{-1}) reported by Euphrasia (2004), *G. surendranathanii* (F=2.22 year^{-1}) by Sunesh Thamby (2009) and *P. carnaticus* (F=1.81 year^{-1}) by Manojkumar (2007).

According to the present study, the exploited population of *S. denisonii* from the River Valapattanam during 2011-2013 was mainly comprised of individuals ranging from 40-90 mm which come under the age class of 0^+ and 1^+ year. Issac and Ruffino (1996) and Prasad et al. (2012) reported that the capture of juvenile fishes before they reach their maturity or first spawning may affect the sustainability of stock. The value of mean length at which 50% of the population of female *S. denisonii* reaches first maturity (L_m) is about 95-97 mm. Similar observations were found by Kurup et al. (2008), Solomon et al. (2011), Mercy et al. (2013a) and Sajan (2015). Thus, it is apparent that L_{50} calculated from the present study is lower than L_m, implying that individual fish of this stock are vulnerable to fishing before reaching sexual maturity. In the present study, the optimum length (L_{opt}) for sustainable harvesting of *S. denisonii* was calculated as 117 mm TL.

In the present study, the relative yield per recruit (Y/R) reached a maximum at an exploitation rate (E_{max}) of 0.737 and with an increase in the exploitation rate, Y/R decreased. Over exploitation is considered to be a causative factor for the decline of freshwater biodiversity (Allan et al. 2005; Ahmed et al. 2005). According to Gulland (1971), a stock is optimally exploited when fishing mortality (F) equals natural mortality (M), or E = F/Z = 0.5. The results also showed that, the current exploitation rate (E = 0.60) is higher than the optimum exploitation rate ($E_{0.5}$ = 0.383). Gulland (1971) suggested that a fish stock is optimally exploited at a level of fishing mortality that generates E = 0.50, which means that by using Gulland's rule, *S. denisonii* are being over exploited. The exploitation status of a stock can also be worked out by examining the Z/K ratio which as a rule of thumb should be '1' for growth-dominated fish and more than '2'for mortality-dominated (Balli et al. 2011). In the present study, the Z/K ratio is 2.61, which also indicates over exploitation of the stocks.

Status of conservation and management recommendations

Freshwater fish resources are viewed as open access free commodities that can be collected from nature (Raghavan 2010). *Sahyadria denisonii* stocks in the rivers of Western Ghats continue to be over exploited and there is a need to manage the stocks. The Department of Fisheries, Government of Kerala (India) issued a Government Order in 2008, restricting collection and exports and also proposed several management measures including quotas, gear restrictions, minimum catch size, and a seasonal trade ban (Mittal 2009).

However, recent studies indicated that these regulations were developed with minimum scientific input and offer little protection for this species (Solomon et al. 2011; Mercy et al. 2013a; Raghavan et al. 2013; Sajan 2015). The length at first maturity of *S. denisonii* was estimated at 81 mm for males and 92 mm for females by Solomon et al. (2011) and Mercy et al. (2013a). Based on these observations, it can be suggested that both males and females of *S. denisonii* must be allowed to grow to a size of 95 mm, so that they can spawn at least once before they are collected for trade. Collectors usually prefer to harvest smaller size groups (40-80 mm) of *S. denisonii* for aquarium trade so as to reduce mortality during wild collection, holding and transportation (personal observation). Export data from India during 2005-2012 confirm the export of juvenile *S. denisonii* of size range from 40 to 70 mm (Raghavan et al. 2013).

Thus, the protection of juveniles is probably the key factor for the sustainability of the resources, through the establishment of certain reserves or protected areas in the river to protect the spawning stock resources. It is difficult to recommend a specific gear regulation for *S. denisonii* alone since the main gear used in the Western Ghats rivers is a multispecies gear (encircling net/drag net). Therefore, implementation of specific mesh size regulation for *S. denisonii* alone is complicated. Hence, the community-based participatory management approach may be suitable for the sustainable aquarium fish trade. As a conservation measure, a seasonal closure of this species fishery was implemented based on the assumption that *S. denisonii* breed during the month of June, July and October (Kurup et al. 2008). Recent studies recorded that the breeding season of *S. denisonii* extended from October to March (Solomon et al. 2011; Mercy et al. 2010; 2013a; Sajan 2015), so the current seasonal closure as a conservation policy is therefore miscalculated (Raghavan et al. 2013).

Illegal fishing such as dynamite fishing has been banned vide the *Travancore Cochin Fisheries Act* of 1950 (Government of Kerala, India), but there is very little or no enforcement from the authorities concerned (Solomon et al. 2011) and thus the practice continues to exist even inside the protected areas in the Western Ghats region (Abraham and Kelkar 2012). Recently, the Government of Kerala has passed the *Kerala Inland Fisheries and Aquaculture Act* (2010) without any focus on the conservation and sustainable use of indigenous freshwater fishes for aquarium trade. It is also recommended that, stock wise river ranching of captive bred young ones of *S. denisonii*, similar to that described in Ogale (2002) and Basavaraja (2011) may be established in the Central and Northern Western Ghats. The establishment of certain areas in each riverine habitat as sanctuaries, protected areas (PA's), or no take zones in the Western Ghats has high importance for conservation of many endemic species of freshwater fishes.

Conclusions

From the results of the present study, it can be concluded that the stock of *S. denisonii* is over exploited. The present study provides valuable baseline data on the age, growth and population of *S. denisonii* that would be useful for fishery biologists to propose adequate policies for the sustainable management of this highly important species of the Western Ghats of India.

Acknowledgements

The authors thank the Marine Products Export Development Authority (MPEDA) for funding the project (2007-2010) on stock assessment and development of captive breeding technology of *Puntius denisonii*, an endemic indigenous ornamental fish of Western Ghats of India. The first author is thankful to the Government of Kerala for the doctoral research fellowship (Mahatma Gandhi University, Kottayam, Kerala) during 2010-2013 and he is also very grateful to the fish collectors for all their help. The first author is very much indebted to Dr. M. Harikrishnan, Associate Professor, School of Industrial Fisheries, Cochin University of Science and Technology, Ernakulam for his valuable help in the processing of population data. We thank two anonymous reviewers, whose critical comments and suggestions greatly improved the manuscript.

References

Abraham, R.K. and N. Kelkar. 2012. Do terrestrial protected areas conserve freshwater fish diversity? Results from the Western Ghats of India. Oryx 46:544-553.

Ahamed, F., Z.F. Ahmed, Y. Hossain and J. Ohtomi. 2012. Growth study of the pool barb *Puntius sophore* (Cyprinidae: Barbinae) through multi-model inferences. Zoological Studies 51:1077-1085.

Ahmed, K.K.U., S.M.N. Amin, G.C. Haldar, S. Dewan and M.M. Hossain. 2005. Population dynamics and stock assessment of *Labeo rohita* (Hamilton) in the Kaptai Reservoir, Bangladesh. Asian Fisheries Science 18:1-14.

Allan, J.D., R. Abell, Z. Hogan, C. Ravenga, B.W. Taylor, R.L. Welcomme and K. Winemiller. 2005. Over fishing of inland waters. Bioscience 55:1041-1051.

Anon. 2014. http://www.badmanstropicalfish.com/articles/lifespans-of-tropical-aquarium-fish-article99.html Accessed on 8 October 2014.

Balli, J.J., S.K. Chakraborty and A.K. Jaiswar. 2011. Population dynamics of Bombay duck *Harpadontidae nehereus* (Ham. 1822) (Teleostomi/Harpontidae) from Mumbai waters, India. Indian Journal of Geo-marine sciences 40:67-70.

Basavaraja, N. 2011. The Deccan Mahseer-biology, breeding, culture and conservation. Seminar on Aquaculture and Mahseer biodiversity conservation. http://www.mahseertrust.org/downloads/Scientific_Publications/Basavaraja%202011.pdf Accessed on 5 September 2015.

Bertalanffy, L.V. 1938. A quantitative theory of organic growth. Human Biology 10:181-213.

Beverton, R.J.H. and S.J. Holt. 1966. Manual of methods for fish stock assessment, Part II. FAO Fisheries Technical Paper No. 38 (Rev. 1), Rome: FAO, 67 pp.

Bhatt, J.P., P. Nautiyal and H.R. Singh. 2000. Population structure of Himalayan Mahseer, a large cyprinid fish in the regulated foothill section of the river Ganga. Fisheries Research 44:267-271.

Cha, H.K., J.H. Choi and C.W. Oh. 2004. Reproduction biology and growth of the shiba shrimp, *Metapenaeus joyneri* (Decapoda: Penaeidae) on the western coast of Korea. Journal of Crustacean Biology 24:93-100.

Çoban, M.Z., F. Gunduz., F. Demirol., G.N. Ornekci., G. Karakaya and I.T.A. Alp. 2013. Population dynamics and stock assessment of *Capoeta umbla* (Heckel, 1843) in Lake Hazar, Elazig, Turkey. Turkish Journal of Fisheries and Aquatic Studies 13:221-231.

Cushing, D.H. 1981. Stock and Recruitment. In: Fisheries biology: a study in population dynamic. (ed. D.H. Cushing), pp. 142-171. University of Wisconsin Press, Madison, Wisconsin.

De Silva, S.S., J.A. Schut and K. Kortmulder. 1985. Reproductive biology of six *Barbus* species indigenous to Sri Lanka. Environmental Biology of Fishes 12:201-218.

Desai, V.R. and N.P. Shrivastava. 1990. Studies on age, growth and gear selectivity of *Cirrhinus mrigala* (Ham.) from Rihand reservoir, Uttar Pradesh. Indian Journal of Fisheries 37:305-311.

Dwivedi S.N. and M.R. Menezes. 1974. A note on morphometry and ecology *of Brachiunius orientalis* in the estuary of Goa. Geobios 1:80-83.

Euphrasia, C.J. 2004. Bionomics, resource characteristics and distribution of the threatened freshwater fishes of Kerala. Ph.D. Thesis. Cochin University of Science and Technology, 453 pp.

Froese, R. and C. Binohlan. 2000. Empirical relationships to estimate asymptotic length, length at first maturity and length at maximum yield per recruit of fishes, with a simple method to evaluate length-frequency data. Journal of Fish Biology 56:758-773.

Froese, R. 2006. Cube law, condition factor and weight-length relationships: history, meta-analysis and recommendations. Journal of Applied Ichthyology 22:241-253.

Gayanilo, Jr. F.C. and D. Pau1y. 1997. The FAO-ICLARM stock Assessment Tools (FiSAT) Reference Manual FAO Computerized information Series (Fisheries). No.8, FAO, Rome, 262 pp.

Gayanilo, Jr. F.C., P. Sparre and D. Pauly. 2005. FAO-ICLARM stock assessment tools (FiSAT-II). Revised version. User’s manual. FAO, Rome. 168 pp.

Gulland, J.A. 1971. The fish resources of ocean. West By fleet Survey, Fishing News, Ltd. FAO, 255 pp.

Isaac, V.J. and M.L. Ruffino. 1996. Population dynamics of tambaqui, *Colossoma macropomum* Cuvier, in the lower Amazon, Brazil. Fisheries Management and Ecology 3:315-333.

John, L. 2009. Population genetic structure of indigenous ornamental teleosts, *Puntius denisonii* and *Puntius chalakkudiensis* from the Western Ghats, India. Ph.D. Thesis, Cochin University of Science and Technology, 211 pp.

Khan, R.A. and A.Q. Siddiqui. 1973. Studies on the age and growth of rohu, *Labeo rohita* (Ham.) from a pond and rivers Ganga and Yamuna. Proceedings of Indian Academy Science 39:582-597.

Kurup, B.M. 1997. Age and growth of *Labeo dussumieri* (Val.) (Pisces: Cyprinidae) from the river Pamba. Indian Journal of Fisheries 44:155-163.

Kurup, B.M., K.V. Radhakrishnan and M. Harikrishnan. 2008. Population characteristics and stock assessment of *Puntius denisonii* (Day) in Kanjirapuzha River, Kerala (South India). In: Ornamental fish breeding, farming and trade. (eds. B.M. Kurup, M.R. Boopendranath, K. Ravindran, S. Banu and G.A. Nair), pp. 89-98. Kochi, Kerala.

Liya, J. and A. Ramachandran. 2013. Major sustainability issues and comparative sustainability assessment of wild caught indigenous ornamental fishes exported from Kerala, India. Fishery Technology 50:175-179.

Maccord, P.F.L., R.A.M. Silvano, M.S. Ramire and C.M. Begossi. 2007. A dynamics of artisanal fisheries in two Brazilian Amazonian reserves: Implications to co-management. Hydrobiology 583:365-376.

Manojkumar, T.G. 2007. Fish habitats and species assemblage in the selected rivers of Kerala and investigation on life history traits of *Puntius carnaticus* (Jerdon, 1849). Ph.D Thesis. Cochin University of Science and Technology, Kerala. 482 pp.

Mercy, T.V.A., V. Malika and S. Sajan. 2010. Breakthrough in breeding of *Puntius denisonii*. Info Fish International 3:14-17.

Mercy, T.V.A., V. Malika and S. Sajan. 2013a. Reproductive biology of *Puntius denisonii* (Day 1865)- an endemic ornamental cyprinid of the Western Ghats of India. Indian Journal of Fisheries 60:73-78.

Mercy, T.V.A., V. Malika and S. Sajan. 2013b. Use of tricaine methanesulfonate (MS 222) to induce anaesthesia in *Puntius denisonii* (Day, 1865) (Teleostei: Cypriniformes: Cyprinidae) - an endangered barb of the Western Ghats Hotspot, India. Journal of Threatened Taxa 5:4414-4419.

Mercy, T.V.A., S. Sajan and V. Malika. 2013c. Length-weight relationships of an endangered barb *Puntius denisonii* (Day 1865) from different rivers of the Western Ghats of India. International Journal of Research in Fisheries and Aquaculture 3:81-84.

Mittal, R. 2009. Business unusual: conserving Miss Kerala. Aquarama Magazine 12:7-9.

Mitra, K., V.R. Suresh, B.K. Biswas and D.K. Biswas. 2011. Biology, Fishery and population dynamics of two spotted barb, *Puntius ticto* (Hamilton, 1822) from a floodplain wetland in lower Ganga basin. Indian Journal of Fisheries 43:12-20.

Ogale, S.N. 2002. Mahseer breeding and conservation, and possibilities for commercial culture: the Indian experience. In: Coldwater fisheries in the Trans Himalayan Countries. (ed. T. Petr and S.B. Swar), pp. 193-212. FAO Fisheries Technical Paper 431.

Pauly, D. 1980. On the interrelationships between natural mortality, growth parameters, and mean environmental temperature in 175 fish stocks. Journal of de Conseil, Conseil International Pour L'Explorat de la Mer 39:175-192.

Pauly, D. 1983. Length converted catch curves. A powerful tool for fisheries research in the tropics. (Part-I). ICLARM Fish byte 1(2):9-13.

Pauly, D. 1984. Length converted catch curves. A powerful tool for fisheries research in the tropics. (Part-I). ICLARM Fish byte 8:33-38.

Prasad, G., A. Ali, M. Harikrishnan and R. Raghavan. 2012. Population dynamics of an endemic and threatened Yellow Catfish *Horabagrus brachysoma* from Periyar River, southern Western Ghats, India. Journal of Threatened Taxa 4:2333-2342.

Qasim, S.Z. and V.G. Bhatt. 1964. Occurrence of growth bones in the opercular bones of the freshwater murrel, *Ophicephalus punctatus* (Bloch). Current Science 33:19-20.

Raghavan, R., G. Prasad, A.P.H. Ali, B. Pereira, F. Baby and M. Ramprasanth. 2010. Miss Kerala added to the IUCN Red List of threatened species. Current Science 98:132.

Raghavan, R., A. Ali., N. Dahanukar and A. Rosser. 2011. Is the Deccan Mahseer, *Tor khudree* (Sykes) fishery in the Western Ghats Hotspot sustainable? A participatory approach to assessment. Fisheries Research 110:29-38.

Raghavan, R., N. Dahanukar., M.F. Tlusty., A.L. Rhyne., K. Krishna Kumar., S. Molur and A.M. Rosser. 2013. Uncovering an obscure trade: Threatened freshwater fishes and the aquarium pet markets. Biological Conservation 164:158-169.

Sajan, S. 2015. Studies on the stock dynamics and reproductive biology of *Sahyadria denisonii* (Day 1865) an endangered ornamental fish of the Western Ghats of India. Ph.D. Thesis, Mahatma Gandhi University, Kerala, India. 340 pp.

Solomon, S., M.R. Ramprasanth, F. Baby, B. Pereira, J. Tharian, A. Ali and R. Raghavan. 2011. Reproductive biology of *Puntius denisonii*, an endemic and threatened aquarium fish of the Western Ghats and its implications for conservation. Journal of Threatened Taxa 3:2071-2077.

Sparre, P. and S.C. Venama. 1992. Introduction to tropical fish stock assessment, Part-1, manual, FAO Fisheries Technical Paper No. 306/1. 376 pp.

Sunesh Thamby. 2009. Bionomics, Cryopreservation of gametes and captive breeding behaviour of threatened hill stream cyprinid, *Garra surendranathanii* (Shaji, Arun and Easa 1996). Ph.D. Thesis. Cochin University of Science and Technology, Kerala, 177 pp.

Tsikliras, A.C., K.I. Stergiou and R. Froese. 2013. Editorial note on reproductive biology of fishes. Acta Ichthyologica Et Piscatoria 43:1-5.

Wijeyaratne, M.J.S. and W.M.D.S.K. Perera. 2001. Population dynamics of potential fish species for exploitation in presently underdeveloped fisheries of some perennial reservoirs in Sri Lanka. In: Reservoir and Culture for International Agricultural Research. (ed. S.S. De Silva). pp. 188-200. Australian Centre for International Agricultural Research, Canberra, Austalia.

Received: 26/06/2015; Accepted: 29/09/2015 (MS15-53)