DOI: https://doi.org/10.4038/java.v3i1.117

Journal of Agriculture and Value Addition, 2020, Vol. 3 (1): 26-42

RESEARCH ARTICLE

Population dynamics of vermiculated sailfin catfish, *Pterygoplichthys disjunctivus*, Weber 1991 (Family Loricariidae) in Victoria (Central province) and Kalawewa (North-Central province) reservoirs, Sri Lanka

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Submitted: June 23, 2019; Revised: June 17, 2020; Accepted: June 23, 2020
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ABSTRACT

Introduction of alien invasive species has created adverse impacts on biodiversity in many places in the world. Scientific studies on such populations are important to formulate control measures of invasive species. In this study, population dynamics of invasive P. disjunctivus were studied in Victoria reservoir and Kalawewa reservoir in Sri Lanka. Present study was based on the fish landing sites harvested with 80 mm meshed gill nets in two reservoirs. Fish samples: 2454 from Victoria and 1515 from Kalawewa were studied once a month in two years of duration from January 2015 to December 2017 and standard length (SL) frequency data (LFD) were recorded. LFD were analyzed for fitting von Bertalanffy growth model for growth. An initial estimate of asymptotic standard lengths (L_∞) was obtained using Powell-Wetherall method as implemented in the FiSAT II (version 1.2.2) software package. Asymptotic standard length and growth constant (K, yearly basis) were then determined by ELEFAN routine which were consistent with L_∞ estimated using Powell-Wetherall method. Total mortality (Z) was calculated using original LFD by the length-converted catch curve method. Natural mortality (M) was estimated. Initial estimate of asymptotic standard lengths (L_∞) were Victoria: 33.15 cm and Kalawewa: 35.28 cm. Asymptotic standard length and growth constant (K, yearly basis) estimated by ELEFAN were: 34.13 cm and 34.87 cm in Victoria and Kalawewa reservoirs, respectively. Total mortality (Z) values were reported as 1.22/y in Victoria and 1.32/y in Kalawewa. Estimated natural mortality (M) values were 0.87/y in Vicoria and 0.80/y in Kalawewa. Relative yield-per-recruit analysis and probability of capture with FISAT II software indicated that relative yield-per-recruit was 0.075 and 0.065 in the current exploitation rate in Victoria and Kalawewa reservoirs, respectively. Probabilities of capture of fish for Victoria and Kalawewa were 50% at 16 cm and 50% of 20 cm, respectively. It also revealed that there will be a great potential to optimize the fishery by increasing exploitation ratio from the present levels by increasing length at first capture from the present levels of 16.2 cm to 20.0 cm and 20.1 cm to 21.0 cm for Victoria and Kalawewa reservoirs, respectively. Gill nets can be used to increase harvest potential by increasing fishing effort to control and to produce value added products this species.

Keywords: *Pterygoplichthys disjunctivus, population dynamics, management*

INTRODUCTION

Invasive species create several negative impacts on natural ecosystems (IUCN 2011). Some members in Family Loricariidae have been reported as invasive species in different parts of the world and their physiological and adaptive characteristics led them to become a plague in the introduced environment (Krishnakumar *et al.,* 2009). The Loricariid catfishes were reported as alien invasive species (AIS) in Sri Lanka (Sumanasinghe and Amarasinghe, 2014). Armored catfishes are also known as 'tank cleaner' or 'janitor fish', locally (Krishnakumar *et al.*, 2009). When an exotic species is introduced into a habitual aquatic system, sometimes it affects the ecosystem adversely and also threatens native species that reside within. Native species cannot cope with unfair competition created by the exotic invasive species, which possess various ecological changes, and local fish species fail to win the competition. There are many records on ecological impacts of invasion of exotic species all over the world (Crivelli, 1995; Simberloff, 1996; Pimentel *et al.,* 2000; Saşı and Balık, 2003; İnnal and Erk'akan, 2006; Cook-Hildreth *et al.,* 2016). *Pterygoplichthys disjunctivus* is endemic to neo-tropical South America (Armbruster, 2004). This widespread invasive species is common in the tropical fish trade and has been introduced to different regions of the world such as North America, Asia and Europe (Nico, 2009; Simonovic, 2010; Wei, 2017) by aquarium release or by escaping from aquaculture farms (Page and Robins, 2006). Accidental introduction of South American sailfin catfish through ornamental fish industry is one of the main environmental concerns in Sri Lankan reservoirs (Marambe *et al.,* 2011).

Species of genus *Pterygoplichthys*; *P. disjunctivus* and *P. pardalis,* have been reported from seven provinces of Sri Lanka (Epa, 2014). *Pterygoplichthys* spp. have significant impacts on fish fauna and fisheries activities in Sri Lankan reservoirs creating competition for food and entangling in gillnets (Sumanasinghe and Amarasinghe, 2014; Wijethunga and Epa, 2008). *Pterygoplichthys disjunctivus* has created significant negative effects on the fisheries in Victoria and Kalawewa reservoirs. According to the information of fishers entangled sailfin catfish struggle to escape the net for longtime and due to disturbances target species were scraping from the fishing gear. Also, damages created by this fish to the gill nets will reduce the lifetime of the fishing gear. Sumanasinghe and Amarasinghe (2014) have mentioned that it is difficult to eradicate Loricariid catfishes from the inland water bodies where they have already established but it might be possible to control increment of the population. They have also stated that investigation of population dynamics of Loricariid catfish in different localities is important to find out the likelihood to support commercial scale exploitation.

Studies on the species identification and biology are available (Wijethunga and Epa, 2008; Bijukumar *et al.,* 2015; Hue Wei, 2017) but there are no studies on population dynamics of this genus except the records of Sumanasinghe and Amarasinghe (2014). In order to control and/or to eradicate this invasive species, one of the feasible alternatives is to increase their market value through introduction of postharvest value addition methods such as fish paste for human consumption and fish meals to feed fish (Mendoza-Alfaro *et al.,* 2009;

Sumanasinghe and Amarasinghe, 2014). Population information such as growth and mortality rates, recruitment patterns and current exploitation levels of this species help to form the basis for management strategies and eradication of *P. disjunctivus*. In the present study, an attempt is made to investigate population dynamics of *P. disjunctivus* in Victoria and Kalawewa reservoirs using length-based stock assessment methodologies to fill the research gap. The findings of present study will be useful to support whether *P. disjunctivus* populations in Victoria and Kalawewa reservoirs can be effectively exploited and identify the possibility for further increase of exploitation as a mean of a control measure. Effective harvesting of *P. disjunctivus* by increasing the current fishing effort is useful in enhancing fish production. Surplus production is useful to produce value added products such as dry or smoked fish, fish paste and fish meals by creating a market for the value-added products.

MATERIALS AND METHODS

Victoria and Kalawewa reservoirs were selected for this study. Kalawewa reservoir is located in the North-Central province and the Victoria reservoir is located in the Central province of the country. Kalawewa is a shallow reservoir when compared with Victoria reservoir. Irrespective to the morphometric and hydrological differences *Pterygoplichthys* spp. have established naturally recruiting populations in both the reservoirs and were with existing fisheries. Samples were collected from fish landings at Haragama landing site of Victoria reservoir and from the main landing site of the Kalawewa reservoir.

Growth parameters

Fish samples were collected which were caught using 84 mm meshed gill nets. Standard Length (SL) of fish samples of *P. disjunctivus* caught from Victoria (2454) and Kalawewa (1515) reservoirs were measured once a month, during 2015 – 2017. Standard Length Frequency Data (LFQ) were recorded, separately. The separate LFQ data for Victoria and Kalawewa reservoirs were loaded to the FiSAT II (version 1.2.2) software package (Gayanilo *et al.,* 2005). The estimations of growth parameters were performed according to the details of step wise procedure following Athukorala and Amarasinghe (2010), as follows.

The length frequencies were analysed for fitting von Bertalanffy growth model for growth according to the following equation with FiSAT II (version 1.2.2) software package.

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

L_t = Length of fish at time t
L_∞ = Asymptotic standard length (mean length of oldest fish cohort)
K = Growth constant per year (curvature parameter)
T = Time

t_o = Initial condition parameter (age at length zero)

For this purpose, an initial estimate of asymptotic standard length (L_∞) was obtained using the Powell-Wetherall method as implemented in the FiSAT II (version 1.2.2) software package as follows.

$$[\bar{L} - L'] = a + b L' \tag{2}$$

L' = Smallest length for each length class
$\bar{L}$ = Mean length of fish longer than L'
a and b = Constants

In the above equation 2, the constant $a = -b^* L_\infty$ and, constant $b = -K / (Z+K)$ where, Z = total mortality rate per year. The intercept of the Powell-Wetherall method was used to estimate asymptotic length L_∞. The estimates of L_∞ and K, yearly basis were then determined by electronic length frequency analysis (ELEFAN I) routine of FISAT II software. In ELEFAN I, von Bertalanffy growth model was 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. The growth constant or the curvature parameter (K) for the optimum growth curve and the asymptotic standard length or the mean length of oldest fish cohort (L_∞) was computed. Then, von Bertalanffy growth curve and the Powell-Wetherall plot of *P. disjunctivus* were illustrated for the two reservoirs.

Mortality parameters

Total mortality rate per year (Z) was calculated using original LFD by the length-converted catch curve method (Gayanilo and Pauly, 1997). In this method, the slope of the 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 total mortality (Z) according to the following equation.

$$\ln (C_i / \Delta t) = C - Zt \tag{3}$$

Δt = Constant time interval
C_i = Number of fish caught for i^{th} age class
T = Time (age)
C = Constant

In the above equation (1), the FiSAT II (version 1.2.2) software package automatically converts length data into age data when the growth parameters L_∞, K and t_o values were available using the inverse version of above mentioned von Bertalanffy growth equation (1). Gradient value of the equation 1 is equal to total mortality rate per year (Z). The length converted catch curve was illustrated to obtain the estimation of Z, for *P. disjunctivus* in the two reservoirs. Natural mortality rate per year (M) was estimated for *P. disjunctivus* in the two reservoirs using the following empirical equation derived by Pauly (1980) with FISAT II software when the growth parameters values L_{∞}, K were available.

$$Log_{10}(M) = -0.0152 - 0.279\ Log_{10}(L_{\infty}) + 0.6543\ Log_{10}(K) + 0.4634\ Log_{10}(T) \quad (4)$$

T = Mean habitat annual temperature (°C)
The estimated M and Z were used to estimate the fishing mortality rate per year (F) as follows.

$$F = Z - M \quad (5)$$

The recruitment pattern for *P. disjunctivus* in the two reservoirs was also estimated with FISAT II software when the growth parameters values L_{∞}, K were available.

Probabilities of capture

Extrapolating the data points of the length-converted catch curve method, a probability of capture file was created using FISAT II software. Then, the plot of probability of capture against length plot was created for *P. disjunctivus* in the two reservoirs. Lengths at which 25, 50 and 75% fishes get retained were illustrated for Victoria and Kalawewa reservoirs. Afterwards, the length which represented 50% probability of catch amount i.e. the length which 50% of the catch retained ($L_{50\%}$) was estimated. This length was taken as the length at first capture ($L_{50\%}$) of *P. disjunctivus* in the two reservoirs.

Virtual population analysis

Length structured virtual population analysis were proceeded using estimated values of L_{∞}, K and fishing mortality (F). Using the given F value, length structured virtual population analysis presented series of F values for each length class for the reconstructed fish population in fish numbers.

Relative yield per recruit (Y'/R)

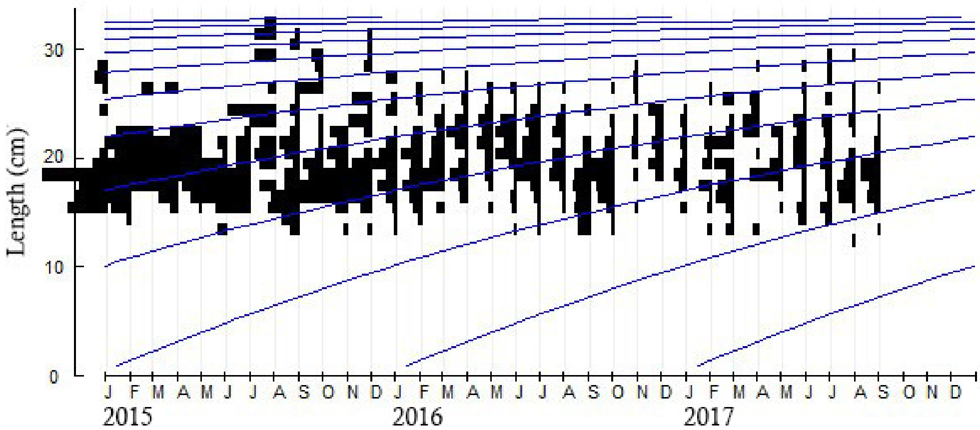
Relative yield-per-recruit (Y'/R) where Y' = relative yield; R = number of recruits was also determined using FISAT II software according to Beverton and Holt (1966) as a function of exploitation ratio (E). Y'/R was estimated for the present levels of age at first capture ($L_{50\%}$) as in section 2.3 with the parameters L_{∞} and K as in section 2.1. Relative yield-per-recruit against exploitation ratio was graphically illustrated (both 3D and 2D forms) for *P. disjunctivus* in the two reservoirs.

Then the growth parameters (L_{∞} and K), mortality parameters (Z, M and F), exploitation ratio (E) and age at first capture ($L_{50\%}$) values of *P. disjunctivus* in the two reservoirs, were tabulated for the comparison.

RESULTS

The growth curves of *Pterygoplichthys disjunctivus* which were determined by means of ELEFAN I, superimposed on LFD for Victoria (a) and Kalawewa (b) reservoirs are shown in Figure 1. Here, growth curves were superimposed over the length frequency histograms. Several growth curves of *P. disjunctivus* illustrate the presence of several fish age groups (cohorts) of *P. disjunctivus* in both reservoirs.

a)



b)

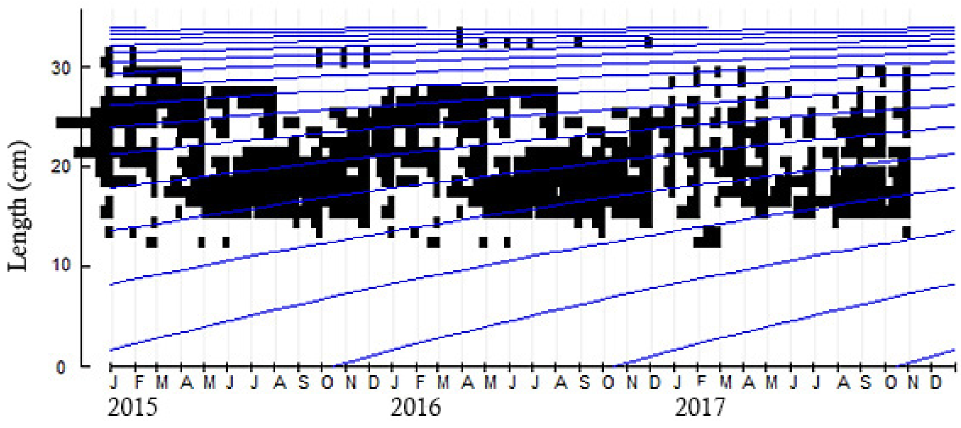


Figure 1: a) Growth curves of *P. disjunctivus* which were determined by means of ELEFAN I, superimposed on LFD for Victoria reservoir. b) Growth curves of *P. disjunctivus* which were determined by means of ELEFAN I, superimposed on LFD for Kalawewa reservoir.

Figure 2 shows the Powell-Wetherall plots of *P. disjunctivus* of Victoria (a) and Kalawewa (b) reservoirs. The values of asymptotic lengths estimated by

ELEFAN I are in consistent with the values estimated by Powell-Wetherall method (Figure 2) and estimated as 33.15 cm for Victoria and 35.28 cm for Kalawewa reservoirs. This indicates the high accuracy of asymptotic lengths. Asymptotic lengths (L_∞) and growth constants (K^{yr-1}) estimated for Victoria reservoir by ELEFAN I were 34.13 cm and 0.34 yr^{-1}, respectively. Those values for Kalawewa reservoir were 34.87 cm and 0.30 yr^{-1}, respectively (Table 1).

Length converted catch curves of *P. disjunctivus* of Victoria and Kalawewa reservoirs are shown in Figure 3. Gradient value of length converted catch curve (Figure 3) estimated the total mortality values (Z) as 1.22 and 1.32 y^{-1} for Victoria and Kalawewa reservoirs, respectively. The data points of open circles were excluded from analysis (when the relative age was low) because those fish were not under full exploitation. The data points at higher ages in Figure 3 (a) were also excluded from analysis because fish numbers at higher ages were lower.

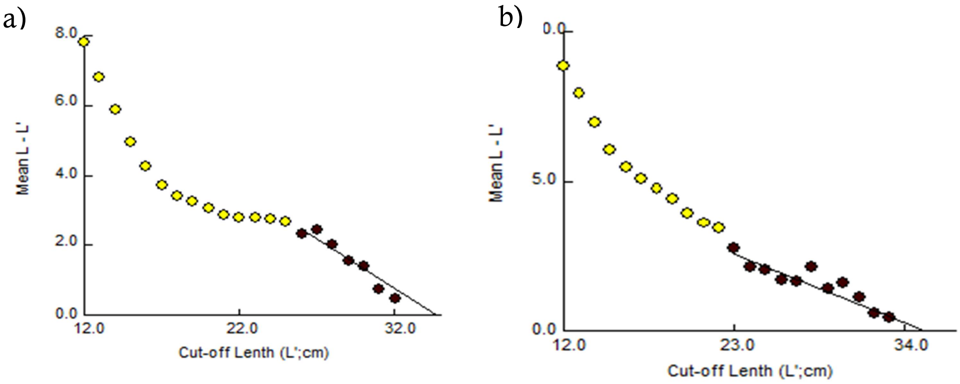


Figure 2: Powell-Wetherall plots of *P. disjunctivus* of (a) Victoria and (b) Kalawewa reservoirs. The data points of open circles were excluded from analysis because those fishes were not under full exploitation.

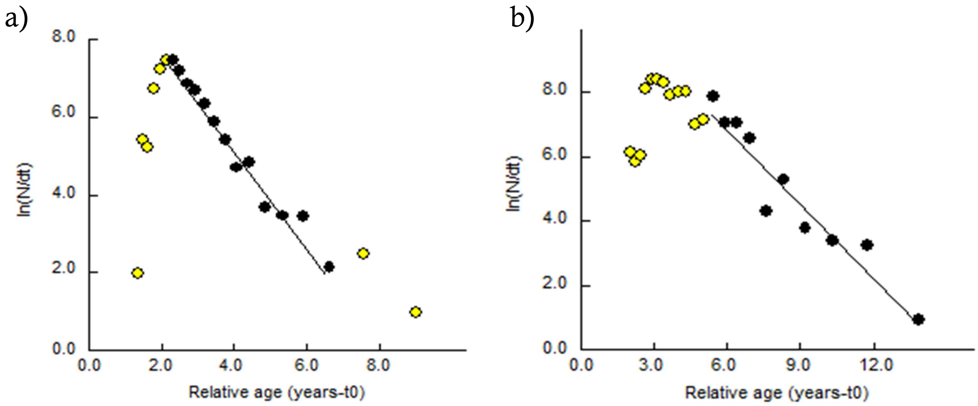
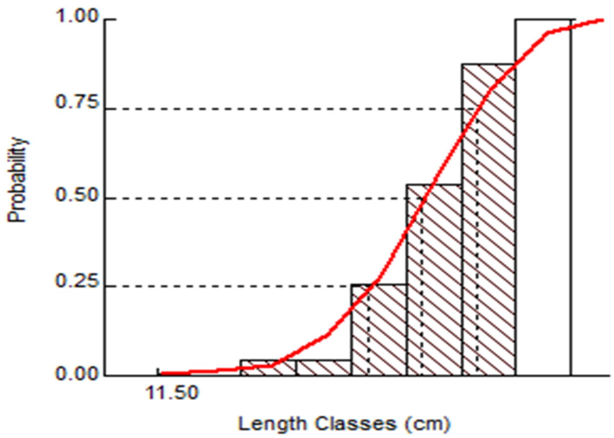


Figure 3: Length converted catch curves of *P. disjunctivus* of (a) Victoria and (b) Kalawewa reservoirs.

Length which 50% of fish retention, L_{50}, (probability = 0.50) was taken as the length at first capture. L_{50} value for Victoria reservoir was 16.2 cm and L_{50} value for Kalawewa reservoir was 20.1 cm. L_{50} of Victoria is comparatively lower than that of Kalawewa.

a)



b)

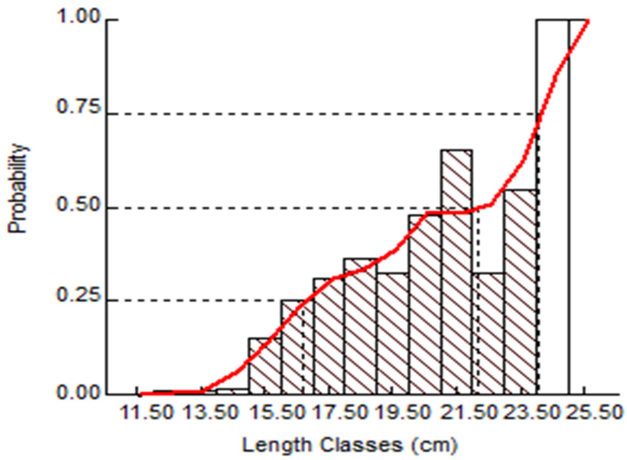
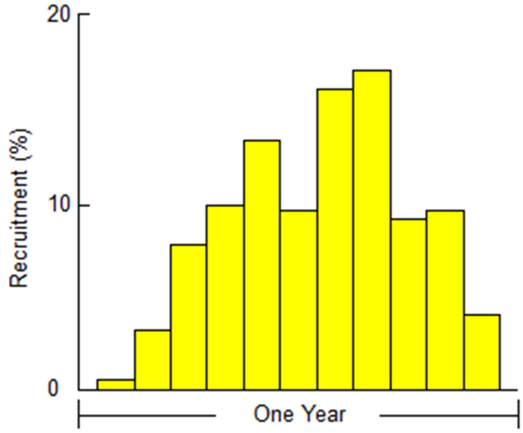


Figure 4: Probabilities of capture of *P. disjunctivus* of Victoria (a) and Kalawewa (b) reservoirs.

Annual recruitment pattern of *P. disjunctivus* is shown in Figure 5. Approximately two prominent recruitment cycles can be identified with the two peaks of the below figures. First cycle was from March to May and the second cycle was from July to September in Figure 5 (a) and (b), respectively.

a)



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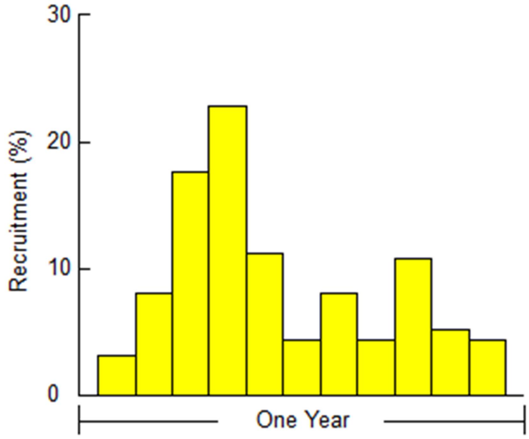
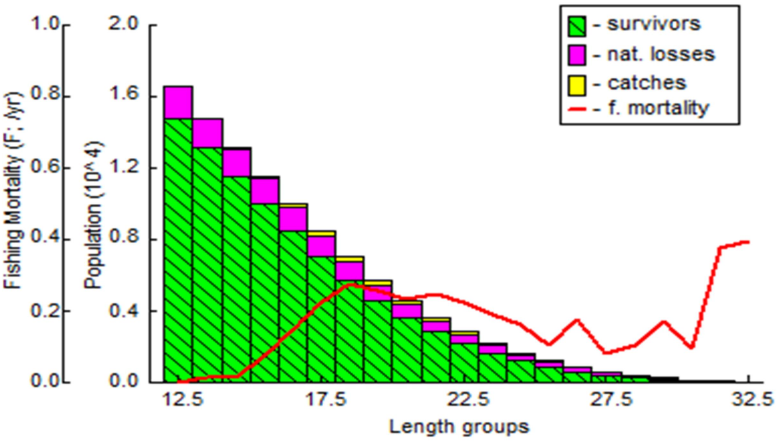


Figure 5: Recruitment patterns of *P. disjunctivus* in (a) Victoria and (b) Kalawewa reservoirs.

Figure 6 shows the length structured virtual population analysis of *P. disjunctivus* which is a reconstruction of the population backward. The legend shows number of survivors, natural mortality, fish catch by green, violet and yellow colours. Fishing mortality is indicated by red line. Natural mortality (M) values estimated were 0.87 and 0.80 y^{-1} in Victoria reservoir and in Kalawewa reservoir, respectively. Hence, the fishing mortality (F) was calculated as 0.35 and 0.52 yr^{-1} for Victoria reservoir and Kalawewa reservoirs, respectively. For the length structured virtual population analysis (Figure 6) population was reconstructed according to given M and F values. Figure 6 illustrates number of survivors and number of losses due to M and F in each length group of fish.

a)



b)

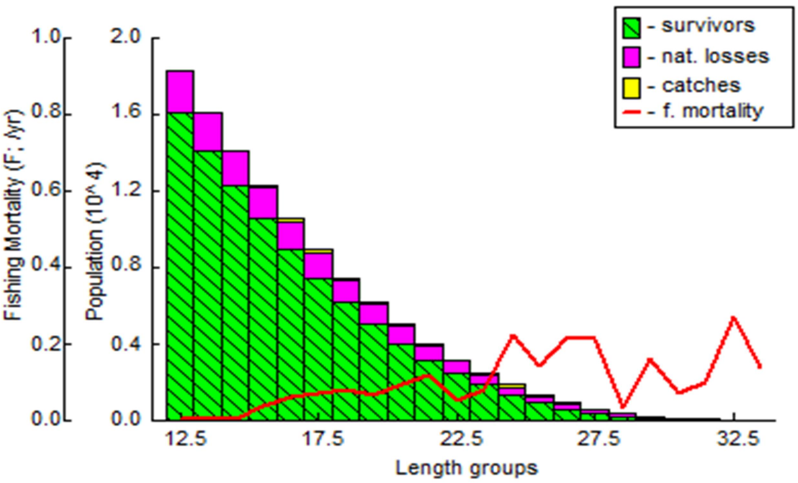
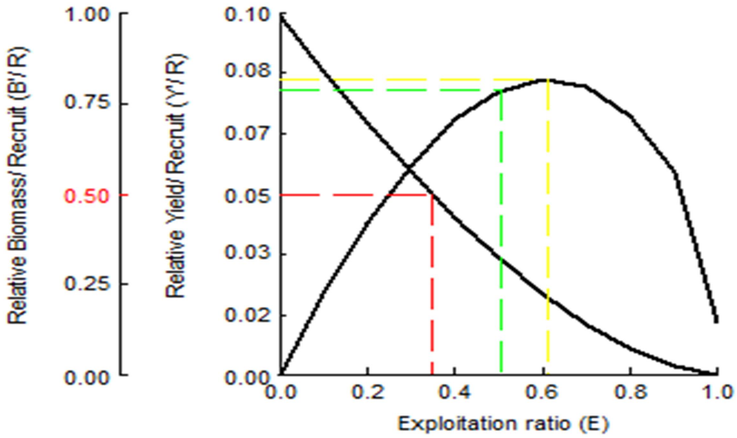


Figure 6: Length structured virtual population analysis of *P. disjunctivus* of Victoria (a) and Kalawewa (b) reservoirs.

Figure 7 shows relative biomass-per-recruit (B'/R) values and relative yield per recruit Y'/R as a function of exploitation ratio (E) corresponding to estimated length at first capture (L_{50}) of (a) Victoria and (b) Kalawewa reservoirs. The input parameters were asymptotic length (L_{∞}), natural mortality (M) and growth constant (K) (Table 1). In Figure 7 (a) for Victoria reservoir the outputs; E_{max} (exploitation rate which produces maximum Y'/R) was ~0.6 which is the maximum exploitation ratio for Victoria reservoir. Current exploitation ratio (~0.5) and its corresponding Y'/R is also indicated for Victoria reservoir. In Figure 7 (a) for Victoria reservoir E' (Exploitation ratio which B'/R = 0.05) was 0.35. Similarly, in Figure 7 (b) for Kalawewa reservoir, the outputs; E_{max} (exploitation rate which produces maximum yield) was ~0.6 which is the maximum exploitation ratio for Kalawewa reservoir. Current exploitation ratio

(~0.55) and its corresponding Y'/R is also indicated for Kalawewa reservoir. In Figure 7 (b) for Kalawewa reservoir E' (Exploitation ratio which B'/R = 0.05) was 0.275.

a)



b)

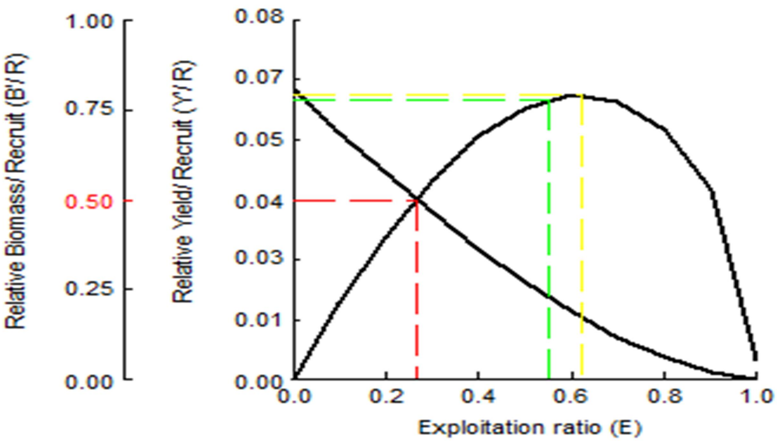
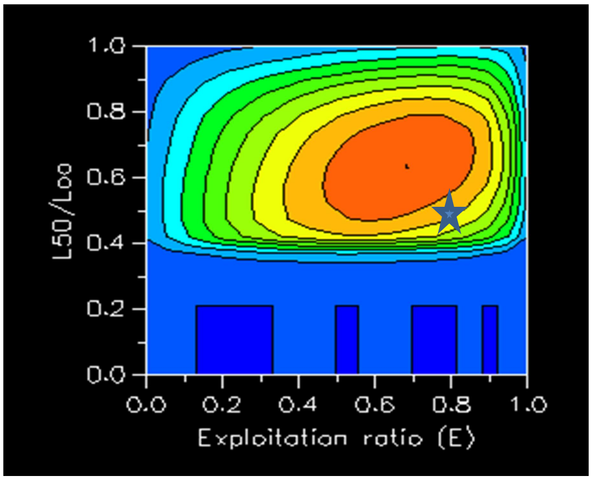


Figure 7: Relative yield per recruit Y'/R and relative biomass-per-recruit (B'/R) and values of *P. disjunctivus* for (a) Victoria and (b) Kalawewa reservoirs.

The input parameters for relative yield isopleths were $L_{50}/L\infty$ and M/K for the two reservoirs (Table 1). The star mark in Figure 8 (a) and (b) indicate the highest Y'/R and exploitation ratio (E) and length at first capture (L_{50}) values for both reservoirs (a and b). So, in Figure 8 (a) Y'/R can be increased by mounting exploitation ratio (E) up to 0.7 from the current maximum exploitation ratio, 0.6. For this purpose, the current length at first capture, L_{50} (16.2 cm: Table 1) of *P. disjunctivus* in Victoria reservoir should be increased up to 20 cm (E = 0.6 = L_c/L_∞, L_∞ = 34.13 cm, so, L_c = ~20 cm).

Similarly, in Figure 8 (b) Y'/R can be increased by increasing exploitation ratio (E) up to 0.7 from the current maximum exploitation ratio, 0.6 for Kalawewa reservoir. For this purpose the current length at first capture, L_{50} (20.1 cm: Table 1) of *P. disjunctivus* in Kalawewa reservoir should be increased up to 21 cm (E = 0.6 = L_c/L_∞, L_∞ = 34.87 cm, so, L_c = ~21 cm).

(a)



(b)

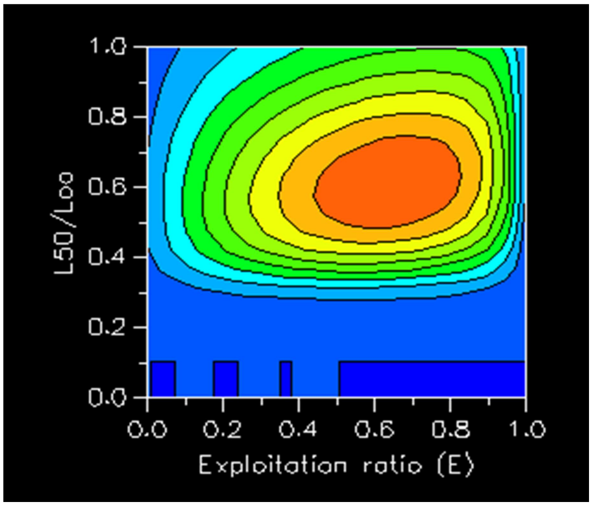


Figure 8: The relative yields per recruit (Y'/R) isopleths are shown for Victoria (a) and Kalawewa (b) reservoirs. Note that the star mark indicates the highest yields per recruit (Y'/R) and its corresponding exploitation ratio and length at fist capture.

Table 1: Summary of growth and mortality parameters and length at first capture of *P. disjunctivus* in Victoria and Kalawewa reservoirs.

Parameter	Value	
	Victoria	Kalawewa
Powell-Wetherall method Asymptotic standard length (cm)	33.15	35.28
ELEFAN I Asymptotic length (cm)	34.13	34.87
Growth constant (y^{-1})	0.34	0.30
Total mortality (y^{-1})	1.22	1.32
Natural mortality (y^{-1})	0.87	0.80
Fishing mortality ($y^{-1)}$	0.35	0.52
Exploitation ratio	0.60	0.60
Length at first capture (cm)	16.2	20.1

DISCUSSION

The growth curves of *P. disjunctivus* in both reservoirs have indicated that this species has several cohorts in these two reservoirs. The values of asymptotic standard lengths estimated by ELEFAN are in consistent with the values estimated by Powell-Wetherall method showing the high accuracy of the values (Table 1). These values are in consistent with those values of *P. pardalis* by Sumanasinghe and Amarasinghe (2014) in Polgolla reservoir in Sri Lanka. The estimated total asymptotic lengths and growth constant in present study were in accordance with the same parameters estimated (41.2 cm and 0.3^{yr-1}, respectively) by Sumanasinghe and Amarasinghe (2014).

The total mortality, natural mortality and fishing mortality values of *P. disjunctivus* are higher in both Victoria and Kalawewa reservoirs than the values of *P. pardalis* in Polgolla reservoir as reported by Sumanasinghe and Amarasinghe (2014). This may be due to the differences in fish abundance and special differences (Simpfendorfer *et al.,* 2005). The length converted catch curve method assumes a constant parameter system i.e. recruitment is constant (Sparre and Venema, 1998) which is not fulfilled in real situations and this may be another reason for the effect of estimations of mortalities. The fishing mortality rates i.e. catch per unit effort may differ from reservoir to reservoir in Sri Lanka due to reservoir morphometrics, biology of fishes and different effort levels which were used by fishermen. This may cause the differences in mortality parameters in different water bodies locally. The length at first capture values of Kalawewa is higher than that of Victoria reservoir (Length at first capture is the length where probability is 0.05 in Figure 4). Differences in catchability coefficient may directly affect the fishing efficiency (Arreguín-Sánchez, 1996). Hence differences may occur in length at first capture and other fish population parameters i.e. fishing mortality.

Year-round recruitment has been described to be a normal phenomenon for tropical fish and shrimp species (Qasim, 1973; Weber, 1976). This was observed in the present study. The annual recruitment pattern shows approximately two recruitment cycles per year of *P. disjunctivus* for the two reservoirs. This result indicates that *P. disjunctivus* cohorts recruits twice a year to the fishing grounds and become vulnerable for the gill nets in the two reservoirs. Kwarfo-Apegyah, and Ofori-Danson (2010) have also found similar recruitment patterns of major fish species in Bontanga Reservoir in Ghana.

The length structured virtual population analysis of *P. disjunctivus* show the current catch rate of *P. disjunctivus* with the current fishing mortality rate (F). It is evident that by increasing F, the catch rate can also be increased using permissible gill nets with a mesh size of 80 mm. Further, it is evident that smaller fish sizes were untouched and not exploited at current fishing mortality rates (F) using the current fishing gear i.e. gills net with 80 mm mesh.

The yield isopleths showed the exploitation rate which produces maximum yield is around 0.6 for both reservoirs. The relative yields per recruit (Y'/R) isopleths (Figure 8) illustrate that Y'/R can be increased by increasing exploitation ratio (E) up to 0.7 while increasing L_{50} up to about 20 cm, for Victoria reservoir, and increasing E up to 7.0 and L_{50} up to about 21 cm, for Kalawewa reservoir, using the current fishing gill net. Hence, the findings of present study state that there is a potential of exploiting *P. disjunctivus* population in Victoria and Kalawewa reservoirs can be effectively exploited. This finding is in consistent with Sumanasinghe and Amarasinghe (2014) who stated that *P. pardalis* in Polgolla reservoir Y'/R can be significantly increased by increasing exploitation ratio up to about 0.7 while increasing L50 up to about 23 cm.

In the present analysis, although length frequency data were collected from gill net catches, the estimates of growth and mortality parameters were reliable as there is a fair consistency of the estimates from Powell-Wetherall and ELEFAN methods. Sumanasinghe and Amarasinghe (2014) also stated similar results for

P. pardalis in Polgolla reservoir. Present analysis has shown that the *P. disjunctivus* population in Victoria and Kalawewa reservoirs is presently underexploited with current fishing gear (gill nets with mesh size 84 mm). When consider the virtual population analysis (Figure 6) it showed that smaller fishes were not susceptible in harvesting using the current fishing gear and gill net. But, there is a possibility for further increase of exploitation level especially smaller sized fish using smaller meshed gill nets with prior permission however further study should be conducted to evaluate the efficiency of small meshed gill nets to harvest small individuals of the population. Amarasinghe *et al.* (2002) stated that small cyprinid species can be differentially exploited using small-mesh gillnets. Further, it can be proposed that suitable fishing traps can be used to exploit near nesting burrows (Nico *et al.,* 2009) of *P. disjunctivus* may be an effective way for eradication of this species.

CONCLUSION AND RECOMMENDATION

Present analysis has shown that the *Pterygoplichthys disjunctivus* population in Victoria and Kalawewa reservoirs is presently underexploited and there is a potential for further increase of exploitation level. Hence, by creating a market for value added products of these fish species fishermen can be motivated to exploit it. It can be recommended that suitable fishing gear such as fish trap near its nesting burrows may be an effective way for eradication of this species. As management practices, improving awareness of invasive fish species and their impacts to local aquatic environment while coordination among responsible authorities, fish community stakeholder groups and volunteers to identify controlling measures for this species can be implemented.

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