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Original Article

Population dynamics of two sympatric native and exotic cichlids in a tropical microtidal estuary, India

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Abstract: Population dynamics of two sympatric cichlids, the native *Etroplus suratensis* and the alien *Oreochromis mossambicus*, were determined from the Vembanad Lake, the largest estuarine system of southern peninsular India. Based on annual length-frequency data, the results revealed that *E. suratensis* has a higher asymptotic length (L_∞) (302 mm vs. 262mm), but a lower growth constant (K) (0.68 year^{-1} vs. 1.1 year^{-1}) than *O. mossambicus*, suggesting the faster growth rate of the alien species. Natural mortality (M) rates recorded for *E. suratensis* (0.69 year^{-1}) indicate lower levels of predation and other natural stressors in the lake. The exploitation ratio (E) was estimated to be 0.83 for *E. suratensis* and 0.78 for *O. mossambicus*, both values greater than the predicted optimum and suggestive of overexploitation. Our study provides the first information on the demography of wild *E. suratensis,* which would help inform future management strategies in the Vembanad Lake.

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Introduction

Biological invasion is the second-most important threat to global biodiversity after habitat loss (Welcomme, 1988; Courtenay and Robins, 1989). The invasion and establishment of non-native species can impair ecosystem functioning through adverse impacts at the individual, population and community levels of native species, eventually leading to their population decline or extinction (Nyman, 1991; Sato et al., 2010). Ecological risks caused by alien fish species are difficult to be estimated in the initial stages, though the impacts are far-reaching and irreversible (Stapp and Hayward, 2002). Despite the high rate of global biological invasion, the ecological, economic and social impacts of alien species are poorly known to effectively address and manage the issue (Gu et al., 2015; Xia et al., 2019).

Mozambique tilapia, *Oreochromis mossambicus* (Peters, 1852) is a benthopelagic, eurytopic and salt-tolerant mouth-brooding cichlid inhabiting slow-flowing rivers and streams, as well as the lakes and lagoons of Eastern Africa (Skelton, 1993). Due to its perceived utility as a candidate aquaculture species, it is one of the world's most translocated and widely distributed alien fish species (Canonico et al., 2005). The species survives in many unsuitable environments due to its huge ecological plasticity characterized by adaptable life-history traits, trophic flexibility, tolerance to extreme and unfavorable environmental conditions, immense breeding potential, sound parental care, high growth rate, and aggressive and territorial behaviour (Pérez et al., 2006; Maddern et al., 2007). Considering its ecological impacts, *O. mossambicus* has been listed as one of the 100 most invasive species in the world (Global Invasive Species Database, 2019) and is believed to create the most adverse ecological effects (Lowe et al., 2000).

The Pearlspot, *Etroplus suratensis* (Bloch, 1790),

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is a medium-sized euryhaline substrate-spawning fish inhabiting estuaries, coastal lagoons, and natural and man-made freshwater habitats of peninsular India and Sri Lanka (Munro, 1955; Baensch and Riehl, 1985). This species is a major contributor to inland fisheries in Peninsular India (Padmakumar et al., 2012) and Sri Lanka (Jones et al., 2018), supporting the livelihoods of thousands of subsistence fishers. *Etroplus suratensis* has high acceptance in domestic and international markets and has recently been considered an ideal aquaculture species (Padmakumar et al., 2009). Though assessed as 'Least Concern' on the IUCN Red List of Threatened Species™, localized population declines of this species have been recorded (Abraham et al., 2019).

Vembanad Lake is the largest tropical estuarine system located on the southwest coast of India, harboring a rich ichthyodiversity (Maitra et al., 2018). *Etroplus suratensis*, one of the most abundant species in the lake ecosystem (Samuel, 1969), has shown drastic population reductions due to a synergy of anthropogenic stress in the habitat (Kurup et al., 1995; Padmakumar et al., 2012). The landing of the species decreased from 1252 tonnes in the 1960s (Samuel, 1969) to 458 t in the middle 1980s (Kurup et al., 1995) and 135.28 t in 2012-2013 (Roshni et al., 2017).

The reported reduction in *E. suratensis* has been concomitant with an increase in catches of the exotic *O. mossambicus* (Kurup et al., 1993; Padmakumar et al., 2012). This co-existence of *E. suratensis* and *O. mossambicus* results in competition for food and nesting habitats since both species belong to the same family (Cichlidae) and have similar habitat preferences (benthopelagic), feeding behaviour (omnivores) and reproductive requirements (mouth and substrate brooders requiring sufficient space for spawning) (Ward and Samarakoon, 1981; Bindu and Padmakumar, 2008; Russel et al., 2012; Froese and Pauly, 2019) leading to the potential competitive displacement of *E. suratensis* (Odum, 1971). In this context, this work aims to estimate the population characteristics of native *E. suratensis* and alien *O. mossambicus* in Vembanad Lake to inform appropriate management plans.

Materials and Methods

The Vembanad Lake (9°28′, 10°10′N, 76°13′, 76°31′E) is a shallow, complex bar-built micro-tidal estuary covering an area of 241 km^2 with a catchment area of 14500 km^2, depth range of 1-12 m and total length of 80 km, stretching from Munambam in the north to Alappuzha in the south in the state of Kerala having open permanent connections with Arabian Sea (Martin et al., 2011). It is listed as a Ramsar site (No. 1214) by the Convention of Wetlands of UNESCO in 1981, considering its ecological significance and global conservation importance. It is one of the fast-degrading estuaries in India, and its fish fauna is under severe depletion pressure due to lake reclamation, bottom dredging, pollution, overexploitation of fishery resources and alien species introductions (Maitra et al., 2018).

Samples of *E. suratensis* and *O. mossambicus* were collected from commercial catches at major fish landing centers along the Vembanad Lake monthly from June 2017 to May 2018. Fish were caught using gillnets of different mesh sizes ranging from 2-9 cm and cast nets with a mesh size of 1.5 cm. Data were collected randomly from well-mixed catches to avoid size-based bias in the population estimation. The total length of each individual fish was measured (L_T, to the nearest 0.01 mm), and data were grouped into 10 mm intervals for further analysis. The growth and mortality parameters were estimated for the pooled population.

Asymptotic length (L_∞) and growth coefficient (K) were estimated using von Bertalanffy growth formula (VBGF) (Von Bertalanffy, 1938; Gayanilo et al., 2005) using ELEFAN-1 (Electronic Length Frequency Analysis) incorporated in FiSAT-II (FAO-ICLARM Stock Assessment Tools) (see http://www.fao.org/fishery/topic/16072/en#4) software (Gayanilo et al., 2005). Based on the L_∞ and K values, growth performance index (ϕ) and potential longevity ($3/K$) were estimated (Munro and

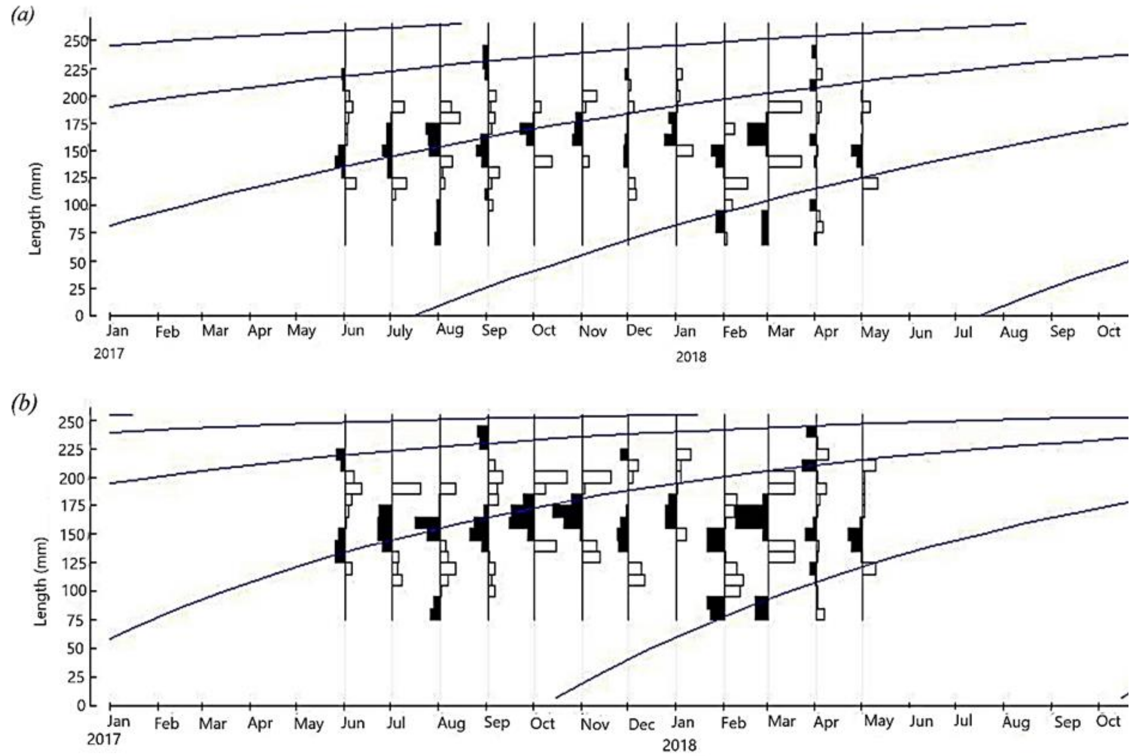

Figure 1. (a and b). von Bertalanffy growth curve of *Etroplus suratensis* and *Oreochromis mossambicus* from Vembanad Lake, India.

Pauly, 1983) using the formula: $\phi = \text{Log } 10\ (K) + 2 + \text{Log } 10\ (L\infty)$.

Total mortality (Z) was estimated using the length-converted catch curve method (Pauly, 1984). Natural mortality (M) was calculated using the empirical formula of Pauly (1980): In M = 0.0152-0.279 In (L_∞) + 0.6543 In (K)+0.4634 In (T), where L_∞ is the asymptotic length in mm, K is the growth constant in year^{-1} and T is the annual mean temperature (29°C). The instantaneous fishing mortality rate (F) was computed as $F = Z\text{-}M$. The exploitation rate (E) was estimated as $E = F/Z$ (Gulland, 1970). E_{max} (maximum yield per recruit) and E_{50} (exploitation that retains 50% of the biomass) were calculated from relative yield per recruit (Y/R) and relative biomass per recruit (B/R) analysis using the knife-edge selection method (Pauly and Soriano, 1986). The recruitment pattern was determined by reconstructing the recruitment pulses from a time series of length-frequency data (Gayanilo et al., 2005).

Results

A total of 745 specimens of *E. suratensis* (67-300 mm) and 865 specimens of *O. mossambicus* (62-260 mm) were analysed during the study period. Using ELEFAN-II, the growth parameters, i.e. asymptotic length (L_∞), growth constant (K) and age at which length equals 0 (t_0) were estimated as 302 mm, 0.68 year^{-1} and -0.01527 year for *E. suratensis*, and 262 mm, 1.1 year^{-1} and -0.0041 year for *O. mossambicus*, respectively (Fig. 1a, b). The growth performance index (ϕ) was estimated as 4.87 and 4.79 for *E. suratensis* and *O. mossambicus*, respectively. Based on the growth equation, *E. suratensis* attained a length of 151 mm and 225 mm at the end of the first and second years of growth, respectively, while *O. mossambicus* reached 175 mm and 233 mm during the same period.

Total (Z), natural (M) and fishing (F) mortality coefficients estimated for *E. suratensis* were 4.04 year^{-1}, 0.69 year^{-1} and 3.35 year^{-1}, and Z, M and F for *O. mossambicus* were estimated as 4.42 year^{-1}, 0.99 year^{-1} and 3.44 year^{-1} (Fig. 2a, b). The exploitation rate (E) of *E. suratensis* was estimated as 0.83 and for *O. mossambicus* as 0.78. The exploitation rate at which marginal increase in relative yield per recruit

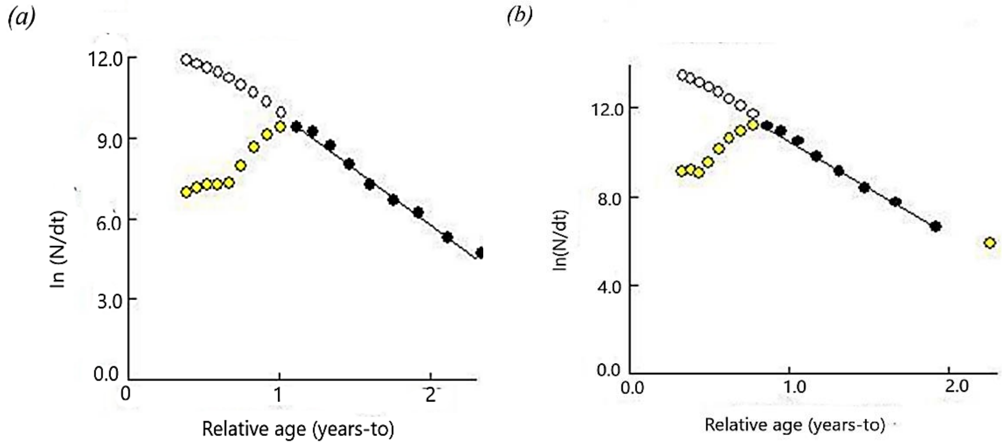

Figure 2. (a and b). Length-converted catch curve for *Etroplus suratensis* and *Oreochromis mossambicus* from Vembanad Lake, India.

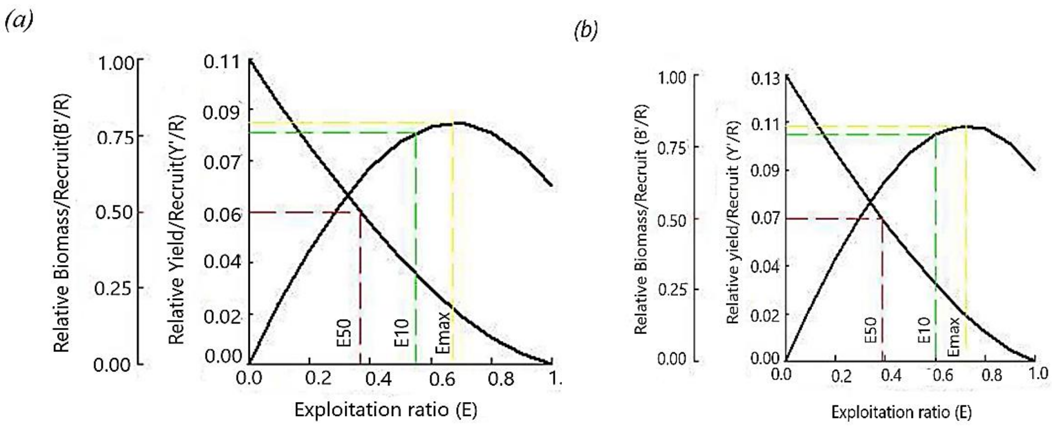

Figure 3. (a & b). Relative yield-per- recruit (*Y/R*) and relative biomass- per-recruit (*B/R*) analysis using knife-edge method for *Etroplus suratensis* and *Oreochromis mossambicus* from Vembanad Lake, India.

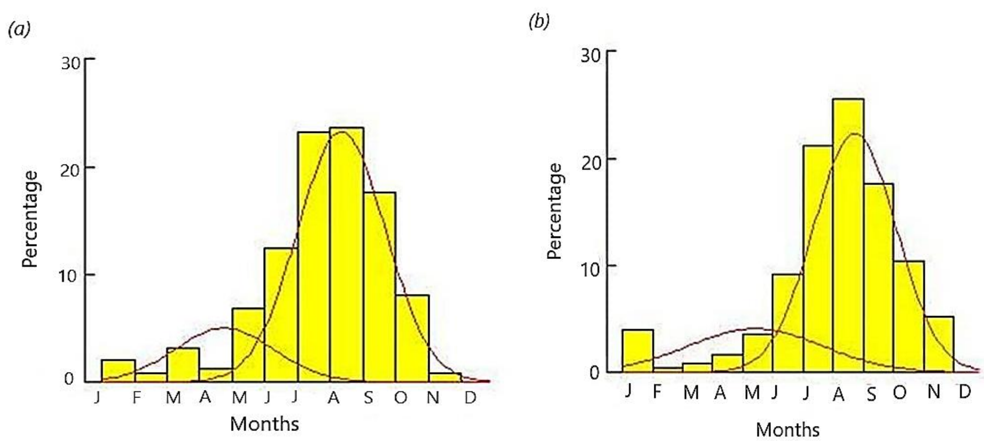

Figure 4. (a & b). Recruitment pattern for *Etroplus suratensis* and *Oreochromis mossambicus* from Vembanad Lake, India.

becomes $1/10^{th}$ of its value (E_{10}), the exploitation rate at which the stock would be reduced to 50% of its unexploited biomass (E_{50}), and exploitation rate at which yield per recruit reaches maximum (E_{max}) were estimated as 0.550, 0.368 and 0.675 for *E. suratensis,* and 0.600, 0.386 and 0.722 for *O. mossambicus* (Fig. 3a, b). The size at first capture for *E. suratensis* was estimated as L_{25} = 136.38 mm, L_{50} = 153.25 mm and L_{75} = 170.12 mm, and for *O. mossambicu* as L_{25} = 136.30 mm, L_{50} = 149.48

mm and L_{75} = 162.12 mm. Recruitment of *E. suratensis* and *O. mossambicus* to the fishery was continuous and took place throughout the year, with around 64% of the recruitment occurring between July and September for both species (Figs. 4a, b).

Discussion

Though *O. mossambicus* attains a maximum length of 390 mm (Wohlfarth and Hulata, 1983), no fish in this size range were obtained in the present study. It has been suggested that *O. mossambicus* can alter the life history traits in favour of the surrounding environment; hence, a standard growth pattern with respect to a particular ecosystem or geographical area is difficult to fix (Pérez et al., 2006; Maddern et al., 2007). Menon (1999) estimated a maximum attainable length of 400 mm for *E. suratensis*; however, individuals encountered in the present study showed a significantly lower length range which may be due to the high levels of anthropogenic stress and their subsequent impacts limiting the growth of the species (Padmakumar et al., 2012). Bindu and Padmakumar (2014) reported a maximum length of 340 mm for *E. suratensis* from Vembanad Lake, comparable with the maximum estimated length observed in the present study.

There is no published information on the growth (K, L_∞ and ϕ) and mortality parameters (Z, M and F) of *E. suratensis* which makes comparing different geographic populations impossible. The estimated asymptotic length of *E. suratensis* is higher and the growth coefficient lower than that of *O. mossambicus* indicating that *O. mossambicus* grows much faster than *E. suratensis* facilitating its rapid colonization in the lake (Table 1). Slow-growing species are more vulnerable to collapse, especially when climatic variability and harvest dynamics contribute unfavorably to fish survival rates (Pinsky and Byler, 2015). The slow growth of *E. suratensis* could probably increase the depletion pressure of the species if extreme climatic variations and severe overexploitation continue in their natural habitat. The L_∞ estimated in the present study is almost similar to that of *O. mossambicus* populations in African waters (Weyl and Hecht, 1998), while the species showed their highest growth rate in Vembanad lake than any other region, which suggests that the lake provides the best habitat requirement for *O. mossambicus*, facilitating its range expansion and population explosion. The growth performance index value (ϕ) values observed for *E. suratensis* (4.87) and *O. mossambicus* (4.79) is high, reflecting excellent environmental conditions and high food availability in the habitat, favouring rapid growth of the species. The growth performance (ϕ) values recorded for *O. mossambicus* was higher than those observed in previous studies (Moreau et al., 1986; de Silva et al., 1988; de Silva and Amarasinghe, 1989), which may be attributable to the ability of the species to utilize a wide range of food items (Maitipe and de Silva, 1984) in the Vembanad Lake.

The higher natural mortality of *O. mossambicus* in the present study could be due to active fish predators in the lake (Gosavi et al., 2019), and the higher fishing mortality suggests high exploitation (Glamuzina et al., 2007; Panda et al., 2018). Overfishing is a major threat to inland waters (Allan et al., 2005). In the present study, a higher fishing mortality was observed for *O. mossambicus* compared to populations from Sri Lanka (Amarasinghe and De Silva, 1992; Amarasinghe, 2002; Amarasinghe et al., 2017). For an exploited fish stock of optimal utilization, the rate of fishing mortality (F) should be equal to the rate of natural mortality (M), giving an exploitation rate (E) of 0.5 (Gulland, 1970). The relative yield per recruit (Y/R) and biomass per recruit (B/R) determined based on knife-edge selection estimated the exploitation rate (E) of *E. suratensis* and *O. mossambicus* to be greater than 0.5. Also, the computed value of exploitation was greater than the predicted E_{max}, indicating that both the fishes are under excessive fishing pressure. *Etroplus suratensis* is exploited more intensively, particularly due to a targeted fishery due to their high economic value and market demand.

Bindu and Padmakumar (2014) reported that

Table 3. Growth, mortality and exploitation parameters of *Oreochromis mossambicus* and *Etroplus suratensis* from various geographical regions.

Species	L_∞	K	ϕ	Z	M	F	E	E_{50}	L_c	Location	Source
O. mossambicus	448	0.52	2.8	1.39	1	0.394	0.282	-	18.8	Kadulla Reservoir, Sri Lanka	Amarasinghe and De Silva (1992)
O. mossambicus	460	0.45	2.77	3.03	0.955	2.076	0.685	-	19.6	Minneriya Reservoir,Sri Lanka	Amarasinghe and De Silva (1992)
O. mossambicus	266.	0.23	-	-	-	-	-	-	-	Chicamba lake, Mozambique	Weyl and Hecht (1998)
O. mossambicus	378	0.51	2.69	2.83	1.1	1.73	0.61	-	15.9	Tabbowa Reservoir, Sri Lanka	Amarasinghe (2002)
O. mossambicus	314	0.84	-	-	-	-	-	-	-	Salton Sea, California, USA	Caskey et al. (2007)
O. mossambicus	402	0.42	2.64	2.15	0.93	1.22	0.57	0.75	22.4	Minneriya Reservoir,Sri Lanka	Amarasinghe *e*t al. (2017)
O. mossambicus	424	0.31	2.55	2.34	0.75	1.59	0.68	0.75	22.5	Udawalawe Reservoir, Sri Lanka	Amarasinghe et al. (2017)
O. mossambicus	432	0.29	2.54	1.96	0.69	1.27	0.68	0.75	23.7	Victoria Reservoir, Sri Lanka	Amarasinghe et al. (2017)
O. mossambicus	262	1.1	4.79	4.42	0.99	3.44	0.78	0.368	149.5	Vembanad lake, India	Present study
E. suratensis	302	0.68	4.87	4.04	0.69	3.35	0.83	0.386	153.3	Vembanad lake, India	Present study

L_∞, asymptotic length (mm); K, growth coefficient (year^{-1}); ϕ, growth performance index; Z, total mortality (year^{-1}); M, natural mortality (year^{-1}); F, fishing mortality (year^{-1}); E, current exploitation rate, $E_{50,}$ exploitation rate where stock is reduced to half its virgin biomass; $L_{c,}$ length at first capture (mm).

E. suratensis attains maturity at a length of 195 mm in males and 200 mm in females in Vembanad Lake. The length at first capture (*Lc*) of *E. suratensis* was estimated as 153.25 mm in the present study, indicating that the exploited stock mainly comprises immature individuals. The capture of smaller-sized individuals before reaching maturity can affect population stability and recruitment (Gwinn et al., 2015; van Overzee and Rijnsdorp, 2015). However, Allen et al. (2002) reported *O. mossambicus* reaches sexual maturity at a length of 150 mm, and the length at first capture (*Lc*) estimated for the species in the present study was 149.48 mm, almost reaching reproductive maturity. For *E. suratensis,* the overexploitation of immature fishes could be a major threat in the lake, affecting recruitment and leading to population decline. Meanwhile, the overexploitation of near-mature individuals of *O. mossambicus* is unlikely to threaten its population size due to the species continuous spawning, stable recruitment, and rapid growth. Recruitment of both *E. suratensis* and *O. mossambicus* was continuous throughout the year, with a major pulse during July-September producing 64.30 and 64.24% recruitment, respectively. Spawning and recruitment of the two fish species occurring in the same month could lead to severe inter-specific competition for available food resources and space due to overcrowding of fingerlings.

Our study indicates the presence of a well-established population of *O. mossambicus* in Vembanad Lake, contributing significantly to the total annual fishery. This will lead to the rapid occupation of a vacant spatial and trophic niche by the species resulting in the competitive displacement of many native fishes, especially those sharing similar ecological resources like *E. suratensis* and *Pseudetroplus maculatus* (Raghavan et al., 2008).

Conclusion

Currently, *E. suratensis* in Vembanad Lake is experiencing severe fishing pressure, as evident from the high rate of exploitation, including a greater proportion of juveniles in the catch. This is in addition to threats from alien species such as *Atractosteus spatula*, *Clarias gariepinus*, *Pangasianodon hypophthalmus, Piaractus brachypomus* and *Pterygoplichthys multiradiatus* (Krishnakumar et al., 2011; Roshni et al., 2014; Bijukumar et al., 2019). There is an urgent need to reduce the fishing effort and the mesh sizes of fishing gears to avoid the future collapse of this fish species. Also, a more detailed investigation is recommended to understand the life history traits and threats to

E. suratensis for implementing proper conservation plans. Reward-based encouragement to the local fishers for collecting large quantities of *O. mossambicus*, detailed scientific research on the impacts on native species, and the development of novel eradication measures are also required for managing the fast-growing population of *O. mossambicus*.

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