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ORIGINAL ARTICLE

Assessment of the fishery, growth, mortality and exploitation of Indo-Pacific tarpon, *Megalops cyprinoides* (Broussonet, 1782) from a microtidal tropical estuary, South West coast of India

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Abstract
Megalops cyprinoides is distributed in tropical and subtropical waters of Indo-Pacific Ocean. The population of the species have declined in recent years due to the over exploitation for commercial fisheries, habitat loss and alteration of freshwater flow from rivers and the species listed as Data Deficient (DD) in the IUCN red list. The present study reports on the fishery, length-weight relationships, growth, mortality and exploitation of *M. cyprinoides* from Kodungallur-Azhikode estuary, South West coast of India. Monthly catches of the species from the estuary varied from 135kg to 710kg. The length-weight relationship of the population was described by the equation: BW= $0.006TL^{2.98}$ (r= 0.99). The growth parameters, asymptotic length ($L\infty$) and growth coefficients (K) were 394.8mm and 0.87 year^{-1} respectively. The potential longevity (t_{max}) and the observed length at first capture (L_c) were estimated to be 3.44 years and 227.90mm respectively. Fishing mortality rate (F= 1.24 year^{-1}) of *M. cyprinoides* was higher than the natural mortality rate (M = 0.82 year^{-1}) and the present exploitation level (E=0.60) is 80% of the predicted maximum exploitation (E_{max}=0.75), which indicates that the stock is over exploited under current level of harvest. Therefore, the present investigation suggests reducing the fishing pressure for *M. cyprinoides* along the Indian coastal water that will be useful for their sustainable fisheries management.

Keywords: Kodungallur–Azhikode estuary, Fishery, Growth, Exploitation, Management.

INTRODUCTION

Tarpons belonging to the family Megalopidae, comprise only two species i.e., *Megalops cyprinoides* and *M. atlanticus* distributed in tropical and subtropical habitats of the Atlantic, Pacific and Indian Oceans (Adams et al. 2014). They have complex life cycles involving ontogenetic habitat shifts among geographically distinct marine and coastal habitats, the latter of which are vulnerable to destruction or alterations (Adams et al. 2014). *Megalops cyprinoides* is widely distributed in the Indo-Pacific from East Africa to the Society Islands, northward to Japan and southward to Australia (Adams et al. 2014). This species is more prevalent in wave-dominated estuaries that are located in higher rainfall catchments, having more constricted mouths, less mangrove area, and sandy substrate (Ley 2005). It is found in depths up to 50 m in coastal waters and ranges inland to hundreds of kilometres upstream in rivers and floodplains (Pusey et al. 2004). *Megalops cyprinoides* supports small scale fisheries in India and Papua New Guinea (Coates 1987) whereas they are landed commercially in the Philippines and Malaysia, occur as bycatch throughout their range, and are the target of a directed sport fishery in northern Australia (Wells et al. 2003). Fishery and biology data of this species is unavailable, which stymies stock assessments in countries where this species is exploited. *Megalops cyprinoides* supports the livelihood of small-scale fishermen who depend on the fishery in estuaries, rivers, lagoons, wetlands and coastal waters of maritime states in India. Increasing demand for exploitation of commercial and recreational fisheries, habitat loss due to fragmentation, alteration of freshwater flow from rivers and decline in water quality has led to the decline of the species in the wild and the species listed as Data Deficient (DD) in IUCN red list (Adams et al. 2014).

Growth and mortality characteristics of fishes are one of the important parameters to take a serious decision on the scientific fisheries management issues of any fishery resources (Mahadevan et al. 2021; Renjithkumar & Roshni 2022). These parameters provide tools for scientific interpretation of population dynamics as well as formulation of conservation policies. Several methods were normally used to investigate the age and growth of the fish species in aquatic ecosystems, such as tagging and recapture experiments, observations of the mark on the various hard body parts like vertebrates, scales, otoliths and spines and length frequency analysis (Stequert et al. 1996). Fish stock assessment models assist fishery managers in understanding the dynamics of fish stocks and how fish populations respond to external stressors such as commercial fishing and predation (Hilborn et al. 2020; Sun et al. 2020). Appropriate data for length-based stock evaluations can be collected through sampling at commercial fish landings centre with no need for total removals from a target stock (Shephard et al. 2021). The length-frequency analysis is widely used and it is one of the best methods for determining age and mortality parameters for tropical and data deficient fish species. Although information is available on the food and feeding habits and reproductive biology of *M. cyprinoides* (Pandian 1969; Coates 1987), no studies have been reported on demographics and stock status of *M. cyprinoides* in any part of the species range which hindered their conservation. This study therefore examined the fishery, length-weight relationships, growth, mortality and exploitation of *M. cyprinoides* based on the length- frequency data collected from a microtidal monsoonal estuary (Kodungallur-Azhikode), South West coast of India.

MATERIALS AND METHODS

Study area: The fish were caught from Kodungallur–Azhikode Estuary (10°11'-10°12' N and 76°10'-76°13'E) in Kerala state, Southwest coast of India. Kodungallur–Azhikode Estuary is a microtidal estuarine system, forming part of Vembanad- Kol wetland ecosystem having an area of 700 ha with a ~180-m wide mouth opening to the Arabian Sea at the Munambam region. The estuary forms a confluence zone of the Periyar, Chalakudy and Karuvannur rivers originating from Western Ghats hotspot of India, thereby being affected by all upstream activities occurring in these river basins. It is a positive type of estuary, with the freshwater input varying from 10 to 21 m^3/s during the pre-monsoon, and 123 to 387 m^3/s during the Southwest monsoon (Revichandran & Abraham 1998), thereby being referred to as a monsoonal estuary (Jayachandran & Bijoy 2012; Jayachandran et al. 2012; Vijith et al. 2009).

Fishery: Data on the fishery for *M. cyprinoides* were collected monthly from April 2018 to March 2019. Stake nets and gill nets were the main fishing gears using for catching Indo-Pacific tarpon. Stake nets are fixed bag nets with rectangular mouth opening and mesh size varies from 20 to 60mm in the three front sections and 10 to 18mm at cod end. The gill nets used measured 100 to 200 metre in length and mesh size varies from 30 to 80mm. The catch (kg) from the haul of a stake nets and gill nets were recorded. Catch per unit effort (CPUE) was computed following Scaria et al. (1999). Daily landings from each type of gears were computed following Kurup et al. (1993); W= (w/n) X N, where W= total weight of fish, w= total weight of fish from gear sampled, n= number of gears sampled, N= total number of similar gears operated. Monthly catch was estimated by multiplying daily catch with total number of fishing days in a month (25 fishing days). The annual exploited quantity was calculated by summarising the landings of 12 months.

Growth and mortality parameters: Fish samples were collected randomly from small scale fishermen during April 2018 to March 2019. The total length (TL) was measured to the nearest 0.01 mm using digital sliding calliper and total body weight (BW) was taken using electronic weighting balance to the nearest 0.01g accuracy. The length- weight relationship of the species was determined by the least square method and monthly length-frequency data were grouped into 25mm class intervals. Length frequency distributions were used to estimate the growth, mortality and exploitation pattern of *M. cyprinoides*. The von

Bertalanffy growth parameters; asymptotic length (L_∞) and the growth coefficient (K) were estimated using ELEFAN-1 (Electronic Length Frequency Analysis) module of FAO-ICLARM Stock Assessment Tools II (FiSAT-II) software (Gayanilo et al. 2005). The von Bertalanffy growth formula (VBGF) was fitted using $L_t = L_\infty$ [1- exp $^{-K\ (t-t_0)}$], where L_t is the growth at time t, L_∞ is the asymptotic length, K is the growth coefficient, t is the age of fish and t_0 is the age the fish at which the organism will have zero length. The potential longevity (t_{max}-3/K) and growth performance index, ϕ= Log10(K)+2+Log10 ($L\infty$) were calculated using the empirical equations of Pauly (1984). Total mortality (Z) was estimated from the length-converted catch curve method (Pauly 1984) and natural mortality (M) was determined 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 (30°C). Fishing mortality (F) was estimated using the following formula $F=Z-M$. Present level of exploitation rate (E) was estimated by the formula $E=F/Z$ given by Gulland (1970). Length at first capture (Lc or L_{50}) was calculated from length converted catch curves (Pauly 1984). Recruitment pattern was determined by reconstructing the recruitment pulses from a time series of length-frequency data (Gayanilo et al. 2005). The relative yield per recruit (Y/R) and relative biomass per recruit (B/R) analysis were estimated using knife selected method given by Beverton & Holt (1966), which help to understand whether populations are overexploited, E_{max} (exploitation rate with maximum yield) and E_{50} (exploitation that retains 50% of the biomass).

RESULTS

Chinese dip nets, stake nets and gill nets were the predominant fishing gears operated in Kodungallur-Azhikode estuary. Among them, stake nets and gill nets were the main gears used for catching *M. cyprinoides.* 20 numbers of stake nets and 50 numbers of gill nets actively engaging for fishing in the estuary. Typically, 10-15nos of stake nets and 25-30nos of gill nets were in operation at a time. Each net did one haul a day. Fishing occurred throughout the week except on Sunday, the traditional rest day for fishermen in the state Kerala, resulting in about nearly 25-26 fishing days a month. Annual exploited fishery of *M. cyprinoides* from the estuary was estimated to be 4.4 t. Monthly catches decreased from 710 kg in April 2018 to a trough of 135kg in July 2018 and increased to 580kg in March 2019 (Fig. 1a). The CPUE of gill nets and stake nets varied from 0.63kg/hr to 2.63kg/hr and 0.34 kg/hr to 2.88 kg/hr respectively. The CPUE of gill nets declined from 2.6 kg/hr in April 2018 to 0.63kg/hr in August 2019 and increased to 2.12kg/hr in March (Fig. 1b). The CPUE of stake nets also declined from 2.88kg/hr in April 2018 to 0.38 kg/hr in August 2018 and increased to 2.40kg/hr in March 2019.

Length-weight relationships: The *M. cyprinoides* specimens collected measured 13.00cm *TL* to 38.80cm *TL*, and weighted 32g to 450g. The fish showed isometric growth (i.e. the coefficient b was not significantly different from 3.0) in the length-weight relationships described by the equation BW= $0.006TL^{2.98}$ (r = 0.99, P>0.05).

Growth and mortality parameters: Analysis of the length-frequency data using ELEFAN software gave growth parameters of the population as asymptotic length (L_∞)= 394.80mm TL and growth coefficient (K)= 0.87 yr^{-1}. The growth curve showed that the population of *M. cyprinoides* comprised a single cohort originated during December to January (Fig. 2). The value of growth performance index (ϕ) and the longevity (t_{max}) were estimated as 4.54 and 3.44 years respectively. Total mortality (Z), natural mortality (M) and fishing (F) mortality coefficients of *M. cyprinoides* were 2.06 yr^{-1}, 0.82 yr^{-1} and 1.24 yr^{-1} respectively (Fig. 3). The fishing mortality rate of *M. cyprinoides* was greater than the natural mortality rate indicated a fairly high fishing pressure on the species in Kodungallur–Azhikode Estuary. The length at first capture (L_c) was estimated to be much higher (227.90mm). Based on the virtual population analysis (VPA), it was clear that juvenile (<176mm) of the *M. cyprinoides* population facing high natural

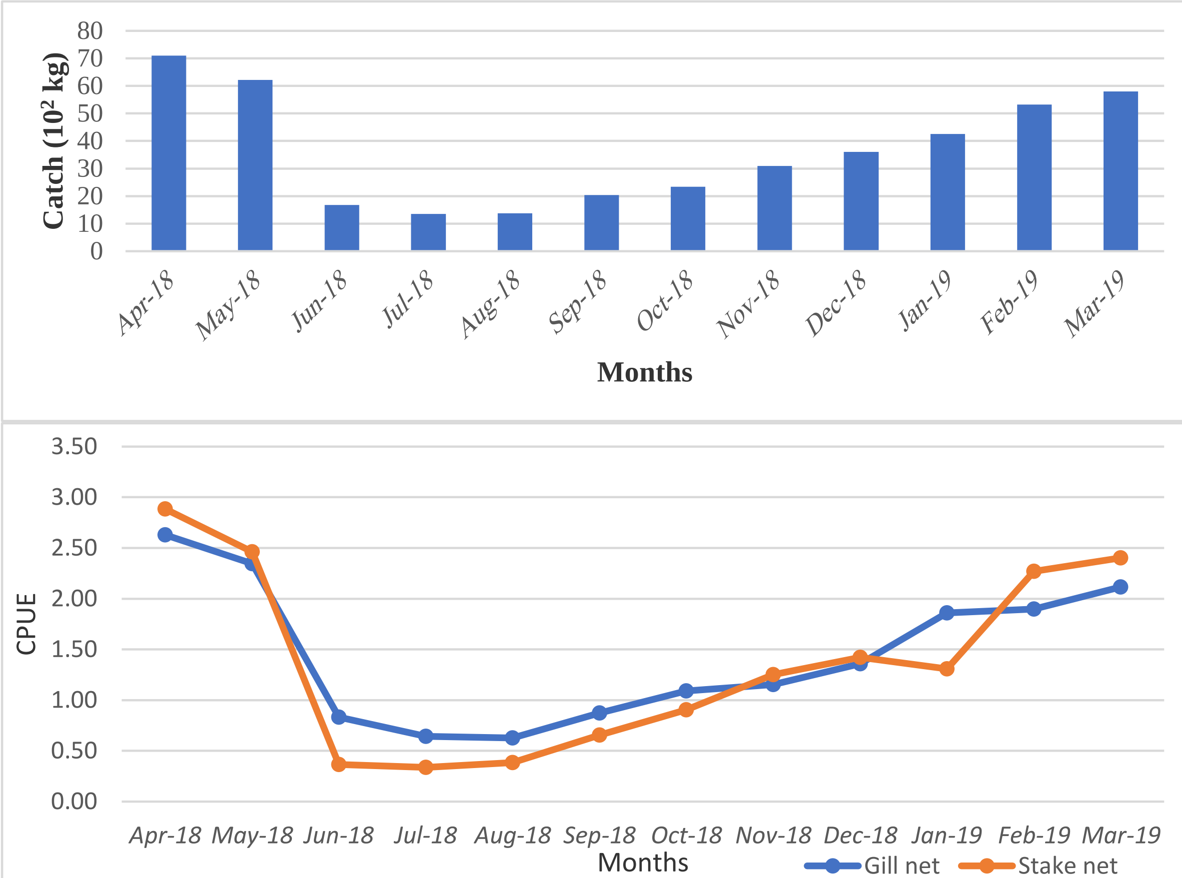

Fig.1. Monthly (*a*) total catch, and (b) mean CPUE of gill nets and stake nets of *M. cyprinoides* from Kodungallur-Azhikode estuary.

Table 1. Growth and mortality parameters of *M. cyprinoides* from Kodungallur-Azhikode estuary.

Population parameter	Value
Asymptotic length (L_∞, mm)	394.80
Growth coefficient (K; year^{-1})	0.87
Growth performance index (ϕ)	4.54
Longevity (t_{max}; years)	3.44
Total mortality rate (Z)	2.06
Natural mortality rate (M)	0.83
Fishing mortality rate (F)	1.24
Length at first capture (Lc; mm)	227.90
Annual exploitation (E)	0.60
E_{50}	0.39
E_{max}	0.75

mortality in the study area (Fig. 4). The relative yield per recruit (Y'/R) and biomass per recruit (B'/R) determined based on knife-edge selection estimated the exploitation rate (E) was 0.60. The current level of exploitation was found to be almost 80% that gives the maximum level of exploitation (E_{max}= 0.75) and almost twice than E_{50} (0.387) that is maintained 50% of the spawning biomass (Fig. 5). The recruitment pattern of *M. cyprinoides* indicates two recruitment peaks from April to June and November to December.

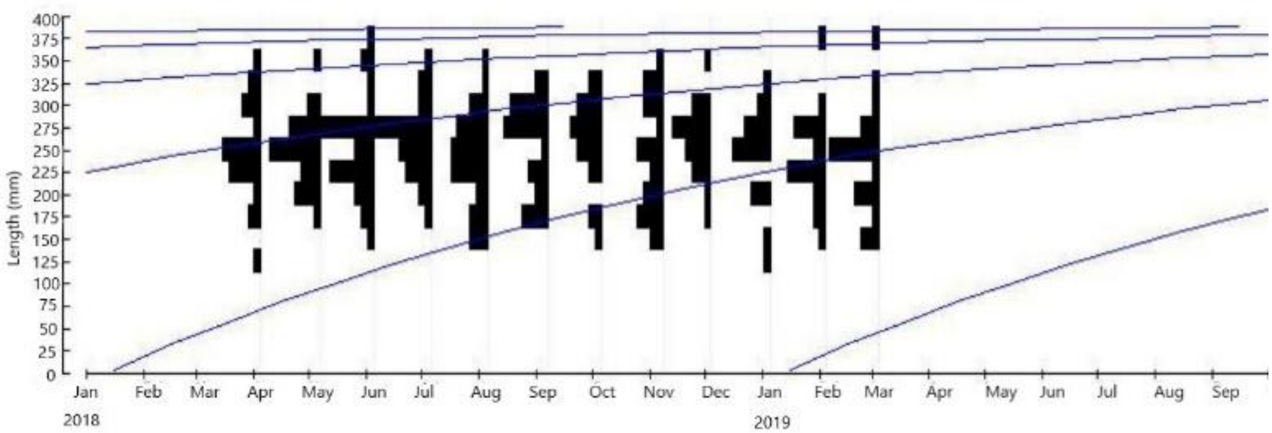

Fig.2. Growth curves fitted by ELEFAN I to length-frequency of *M. cyprinoides* from Kodungallur-Azhikode estuary.

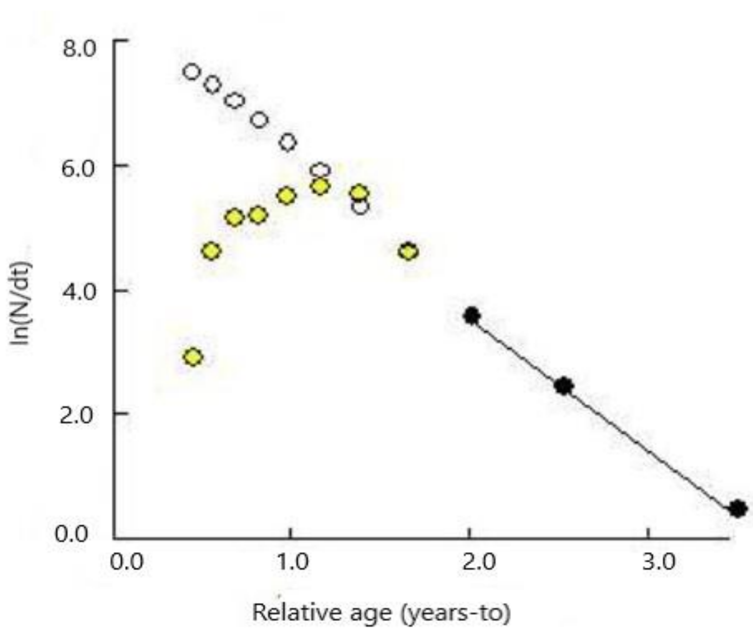

Fig.3. Length converted catch curve for the estimation of mortality of *M. cyprinoides* from Kodungallur-Azhikode estuary.

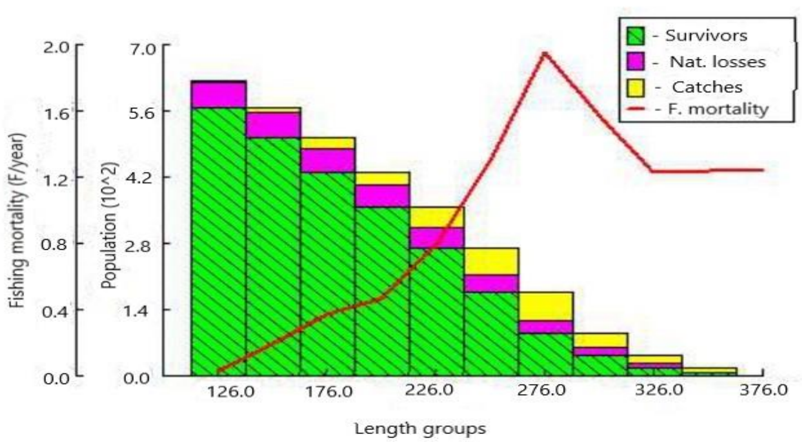

Fig.4. Length-structured virtual population analysis (VPA) of *M. cyprinoides* from Kodungallur-Azhikode estuary.

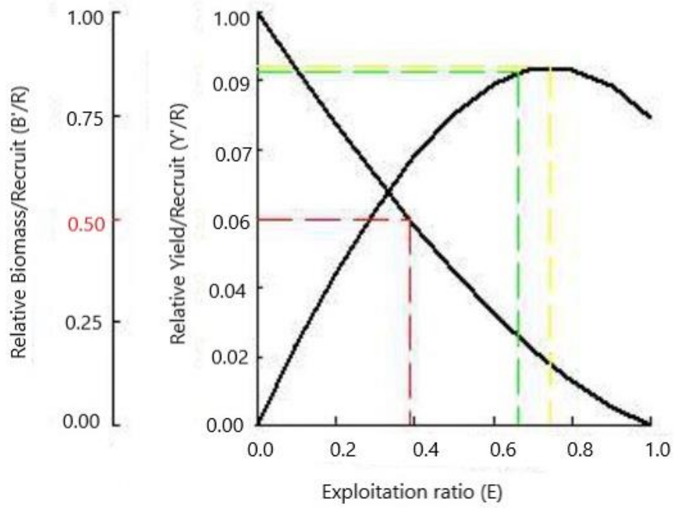

Fig.5. Relative yield per recruit (*Y'/R*) and relative biomass per recruit (*B'/R*) plots of *M. cyprinoides* from Kodungallur-Azhikode estuary.

DISCUSSION

Information on the age and growth of migratory fishes is essential to understand the effects of threats on species and their influence on stock structure (Shanmughan et al. 2022). This is the first study on the growth, mortality and exploitation levels of Indo-Pacific tarpon, *M. cyprinoides* from its distributional range. The fishery of *M. cyprinoides* from Kodungallur-Azhikode Estuary was declined from 5.5 t in 2007 (Harikrishnan et al. 2011) to 4.4 t in the present study. The decreased landing of tarpons may be due to temporal changes in fish landing pattern of the estuary mainly due to the changes in the environmental variability, habitat destruction and fish migration etc. (Bijoy et al. 2012). The decrease in the fish catch in the estuary significantly reduced during monsoon period due to the environmental stressors such as salinity changes, depleted oxygen level due to turbidity and also due to decreased fishing days at heavy rains (Bijoy et al. 2012).

The maximum observed length (L_{max}) of 38.8cm TL of the species from Azhikode estuary was close to the maximum length reported for the species in Chalakudy river (39.4cm), India (Renjithkumar et al. 2021) and Sepik River, Northern Papua New Guinea (44 cm) (Coates 1987), but significantly lower than the maximum length of 150cm TL (Rahman 1989). The LWR equation *M. cyprinoides* shows an isometric growth pattern which indicates that fishes become more round and heavier as length increases. Depending on the value of '*b*' of LWR, the growth in fishes can be as isometric (b= 3), positive allometric growth (b>3) and negative allometric growth (b<3) (Tesch 1971). The coefficient of determination (r^2) was higher than 0.95 indicates high correlation between total body length and weight. The normal r^2 value for the ideal growth of fish is typically between 0.90 and 1.0, which was observed for tarpons indicates the proper fitness of the model for growth and good health status of the species. The estimated *b* values of the regression for all species were within the expected range of 2.5-3.5 (Froese 2006).

The high growth coefficient (*K*) (0.87 yr^{-1}) value of *M. cyprinoides* indicated that, the species attained asymptotic length ($L\infty$) rapidly which is in agreement with Pauly & Munro (1984), that species having shorter life span have higher '*K*' value and reach their $L\infty$ within one or three years of life history. There is no published information available on the growth and mortality parameters of Indo-Pacific tarpons, *M. cyprinoides*, making it impossible to compare data between geographical populations. Nevertheless, the estimated growth rate of *M. cyprinoides* is higher and the asymptotic length (L_∞) lower than that of *M. atlanticus* (*K*= 0.103-0.123, L_∞= 1556-1817mm) from South Florida waters (Crabtree et al. 1995). Lack of information on growth performance index of the species restricts the comparison between populations in different geographical ranges.

The decrease in the size of a fish population can be attributed to two factors: natural death (*M*) (disease, predation, pollution etc.) and fishing pressure (*F*). For this study, the mortality study was based on concepts defined by Beverton & Holt (1957) and Gulland (1963). The fishing mortality rate of *M. cyprinoides* was greater than the natural mortality rate indicated a fairly high fishing pressure on the species in Kodungallur–Azhikode Estuary. The information on the mortality rate of fish species was important for formulating exploitation strategies to harvest and manage the fishery resources at optimum level. A ratio between total mortality and growth coefficient (*Z/K*) of < 1.0 indicates a growth dominated population, whereas a ratio of > 1.0 indicate a mortality-dominated population (Etim et al. 1999). The population of *M. cyprinoides* in Kodungallur–Azhikode Estuary were dominated by mortality (*Z/K*= 2.36). It indicates that this overexploitation of fishes may lead to a gradual loss in recruitment and development, resulting in severe stock decline in future. While the size at first maturity for *M. cyprinoides* is known to be 180-190 mm (Padmaja & Rao 2001), the length at first capture (L_c) was estimated to be much higher (227.90mm). Based on the virtual population analysis (VPA), it is clear that juvenile (<176mm) of the *M. cyprinoides* population facing high natural mortality in the study area. Such high natural mortality of juveniles could be due to various factors such as predation, disease, pollution etc (Roshni & Renjithkumar 2021). On the contrary, mortality of larger size individuals (>226) indicating greater fishing pressure. In the present study the value of the fishing mortality (1.24) for *M. cyprinoides* is close to twice as compared to natural mortality (0.83) and exploitation (0.60) indicating that the species is being heavily exploited in the study area. The present level of exploitation (*E*= 0.60) is almost 80% that gives the maximum level of exploitation (E_{max}= 0.75) and is twice than E_{50} (0.39) that is maintained 50% of the spawning biomass. For conservation of the species in the study area, it is necessary to maintain at least 50% of the spawning stock and the current level of exploitation from 0.60 to 0.39 which is approximately 65%. For an exploited optimally utilized fish stock, the rate of fishing mortality (*F*) should be equal to 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*) was 0.60 which is higher than 0.5, which predicted, a higher fishing pressure on the tarpons stock along the Kodungallur–Azhikode Estuary.

The recruitment pattern of *M. cyprinoides* revealed two peaks of recruitment from April to June and November to December indicating two or extended spawning periods per year. Our observations are consistent with that of Pauly (1980), who found that tropical fish species mostly exhibit double recruitment pulses. The two peaks of recruitment are observed during rainy period and in particularly during the period of South West Monsoon and North East Monsoon in Kerala state, India. This suggests that abundance of food during rainy seasons favour juvenile's recruitment in to the population. Detailed investigation of various reproductive characteristics such as spawning periods, length at first maturity, sexual dimorphism and fecundity is suggested for *M. cyprinoides*.

CONCLUSION

This is the first report on the population characteristic and stock status of *M. cyprinoides* from the coastal waters. Considering this study, it is evident that the stock of *M. cyprinoides* is overexploited. *M. cyprinoides* is a fast-growing species having an annual *K* of 0.87, with a short life span that may be completing its life cycle within four years. The exploitation ratio (*E*) was 0.60, which is very much on the higher side of optimum exploitation (*E*= 0.5); therefore, fishing pressure should be reduced using regulatory approach to have a sustainable catch. The present study would be the basic study for the scientists and conservation managers to manage and sustainably harvest the species with optimal exploitation.

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مقاله کامل

ارزیابی شیلاتی، رشد، مرگ و میر و بهره‌برداری از تارپون هند-آرام، *Megalops cyprinoides* (Broussonet 1782)، در یک مصب استوایی ریزکشندی، سواحل جنوب غربی هند

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چکیده: *Megalops cyprinoides* در آب‌های گرمسیری و نیمه گرمسیری اقیانوس هند و اقیانوس آرام پراکنش دارد. جمعیت این گونه در سال‌های اخیر به‌دلیل بهره‌برداری بیش از حد برای صید تجاری، نابودی زیستگاه و تغییر جریان آب شیرین از رودخانه‌ها، به‌عنوان گونه‌هایی با فقدان یا کمبود اطلاعات (DD) در لیست قرمز IUCN ذکر شده‌اند، کاهش یافته است. مطالعه حاضر در مورد وضعیت شیلاتی، روابط طول وزن، رشد، مرگ و میر و بهره‌برداری از *M. cyprinoides* از خور Kodungallur-Azhikode، سواحل جنوب غربی هند گزارش ارائه می‌کند. صید ماهیانه این گونه از خور از ۱۳۵ کیلوگرم تا ۷۱۰ کیلوگرم متغیر بود. رابطه طول و وزن جمعیت به‌صورت توصیف شد: $BW= 0.006TL^{2.98}$ (r= 0.99). پارامترهای رشد، طول بی‌نهایت (L∞) و ضرایب رشد (K) به‌ترتیب ۳۹۴/۸ میلی‌متر و ۰/۸۷ سال در ۱ سال بود. طول عمر بالقوه (tmax) و طول مشاهده شده در اولین صید (Lc) به‌ترتیب ۳/۴۴سال و ۲۲۷/۹۰ میلی‌متر برآورد شد. میزان تلفات شیلاتی (F=۱/۲۴ در سال) *M. cyprinoides* بالاتر از میزان مرگ و میر طبیعی (M=۰/۸۲ در سال) بود و سطح بهره‌برداری فعلی (E=۰/۶) ۸۰ درصد حداکثر بهره‌برداری پیش‌بینی شده (Emax=۰/۷۵) است که نشان می‌دهد در سطح فعلی برداشت از ذخیره بیش حد است. بنابراین، تحقیق حاضر کاهش فشار شیلاتی و بهره‌برداری از *M. cyprinoides* را در امتداد آب ساحلی هند پیشنهاد می‌کند که برای مدیریت پایدار شیلاتی مفید خواهد بود.

کلمات‌کلیدی: مصب کوچین، شیلات، رشد، بهره‌برداری، مدیریت.