Turk. J. Fish.& Aquat. Sci. 19(12), 1025-1038
http://doi.org/10.4194/1303-2712-v19_12_05

RESEARCH PAPER

Turkish Journal of FISHERIES and AQUATIC SCIENCES

Life History Parameters and Yield per Recruit Analysis for *Tachysurus nitidus* and *Plagiognathops microlepis* in Lake Dianshan and Their Management Implications

Richard Kindong[1], Jiangfeng Zhu[1,2,3,4], Xiaojie Dai[1,2,3,4,*], Siquan Tian[1,2,3,4]

[1] Shanghai Ocean University, College of Marine Sciences, Shanghai, China;
[2] National Engineering Research Center for Oceanic Fisheries, Shanghai, China
[3] Ministry of Agriculture, Oceanic Fisheries Resources and Environment, Scientific Observation and Experimental Station, Shanghai, China;
[4] Shanghai Ocean University, Collaborative Innovation Center for Distant Water Fisheries, Shanghai, China.

Article History
Received 05 October 2017
Accepted 04 December 2018
First Online 05 December 2018

Corresponding Author
Tel.: +8615692165351
E-mail: xjdai@shou.edu.cn

Keywords
Dianshan Lake
Growth
Mortality
Tachysurus nitidus
Plagiognathops microlepis
Yield per recruit

Abstract

This study was undertaken to estimate the life history parameters of the shining catfish (*Tachysurus nitidus*) and small-scale yellowfin (*Plagiognathops microlepis*) in Lake Dianshan using length–frequency data of 4070 specimens. Both species exhibited isometric growth. The von Bertalanffy growth constants for *Tachysurus nitidus* were L_∞=25.15 cm, K=0.19 yr^{-1}, and t_0=-0.378 yr with a derived growth performance index of Ø′ =2.08. The corresponding estimates for *Plagiognathops microlepis* were L_∞=36.5 cm, K=0.10 yr^{-1}, t_0= -0.40 yr and Ø′=2.125. The total mortality rate, Z, for *Pelteobagrus nitidus* was estimated as 1.51 yr^{-1}, with the fishing mortality, F, being calculated as 1.13 yr^{-1}. The mortality estimates for *Plagiognathops microlepis* were Z=0.54 yr^{-1} and F=0.33 yr^{-1}. The exploitation rates of both species (E=0.75 and E=0.61 for *Tachysurus nitidus*and *Plagiognathops microlepis* respectively) were higher than the optimum exploitation criterion (E_{opt}=0.5), which is indicative of over-fishing. The size-structured yield per recruit (YPR) analysis confirmed that both stocks are highly exploited, since current fishing mortality rates were higher than the biological reference points (BRPs) $F_{0.1}$ (0.16 for *Tachysurus nitidus* and 0.15 for *Plagiognathops microlepis*) and F_{max} (0.2 and 0.225 for *Tachysurus nitidus*and *Plagiognathops microlepis* respectively). The results further suggest that, for a sustainable management and an increase in yield, the current fishing effort for *Tachysurus nitidus*, be reduced to 0.2 and for *Plagiognathops microlepis* be decreased to 0.225. Other management action, such as gradual increase of fishing gears mesh sizes could also be considered necessary for sustainable exploitation of these stocks.

Introduction

Due to anthropogenic disturbance, many natural aquatic resources have suffered severe decline in abundance and yields, and some have even been driven to the point of collapse (Pauly *et al*., 2002; Myers & Worm, 2003; Welcomme *et al*., 2010; Huo *et al*., 2015; Lorenzen *et al*., 2016).

Geographically, the Dianshan Lake is found on Latitude 31^{0}11′N and longitude 120^{0}96′ E. It is the largest freshwater lake in Shanghai, with a total area of 63.7 square kilometers, an average depth of 2.5 m, with the deepest recorded depth to be 6.39 m. It is located in between Shanghai, Zhejiang and Kunshan of Jiangsu Province. Dianshan Lake is home to about 40 fish species, belonging to around 15 families (Kindong, Dai, Tian, & Gao, 2017b). This Lake supports a lucrative fishery in Shanghai, and fishermen involved in fishing usually procured commercially important fish species. Fishery in lake Dianshan is believed to be data poor, with no typical fishery data (e.g. catch and effort) being collected routinely. However, in recent years, the Shanghai government allocated a series of projects to monitor the fisheries of lake Dianshan.

Freshwater species *Tachysurus nitidus* and *Plagiognathops microlepis* are commercially important fish species in East Asia and Russia (Nguyen, 2013). They inhabit reservoirs, lakes, fast-flowing hill-streams and large rivers. *Tachysurus nitidus* is a species in the bagridae family of order Siluriformes (catfishes). The Bagridae is among the most speciose catfish groups in East Asia and it is distributed from Heilongjiang (Amur River) to Minjiang (Yangtze River tributary) (Carl, 2007). Population parameters such as growth and mortality rates are important information in population modeling and fishery management. However, few preliminary biological studies of this species have been reported in South Korea and China (Geng, Gao, Han, Dai, & Tian, 2014; Kim, Yoon, Won, Byeon, & Jang, 2015; Lee *et al*., 2015; Li *et al*., 2015; Yang *et al*., 2016; He, Yuan, Xiong, & Chen, 2016). Maximum reported length in Fishbase (Froese & Pauly, 2017) is 23.5 cm (Li *et al*., 2015). The second species *Plagiognathops microlepis* is a member of the Cyprinidae family (order Cypriniformes). They are distributed from eastern China and Russia; recorded from the Yangtze River, Amur basin, Ussuri River, Lake Khanka, and also recorded from northern Viet Nam (Nguyen, 2013). It's maximum reported length in Fishbase (Froese & Pauly, 2017) is 70 cm recorded in Russia by Berg (1964).

These species being commercial food fish, regulations on their harvests need to be administered and monitored. Though fish species constitute a fundamental component in the structure and function of Dianshan Lake's ecosystem, few documented studies have been conducted (Sun, Dai, Zhu, Ji, & Tian, 2007; Tao, Dai, Tian, & Ma, 2011; Han, Gao, Tian, & Dai, 2014; Hu *et al*., 2014; Kindong *et al*., 2017b). These studies did not directly target *Tachysurus nitidus* and *Plagiognathops microlepis*. Detailed studies on the life history parameters of *Tachysurus nitidus* and *Plagiognathops microlepis* have not yet been conducted worldwide (Froese & Pauly, 2017). Therefore, an evaluation of their life history parameters needs to be investigated in order to provide an insight on how these fisheries could be managed.

For an efficient use of a fishery, management guidance is provided by estimating two biological reference points (BRPs) $F_{0.1}$ and F_{max} from either the age-structured YPR or the size-structured YPR models (Chen, 1997; Chen, Xu, Chen, & Dai, 2007). $F_{0.1}$ and F_{max} are widely used for the management of most fisheries and under precautionary management they are commonly used for defining management target BRP ($F_{0.1}$) and threshold (F_{max}) BRP (Chen *et al*., 2007).

No previous study has focused on YPR and life history parameters such as growth and mortality of *Tachysurus nitidus* and *Plagiognathops microlepis* which are important target species in most waterbodies in East Asia and China in particular. The present study was undertaken to provide a better base for management decisions to be taken for this fishery.

Materials and Methods

Fish Sampling and Data Collection

Fish were sampled twice every month from 8 different sampling sites of lake Dianshan (Figure 1) as

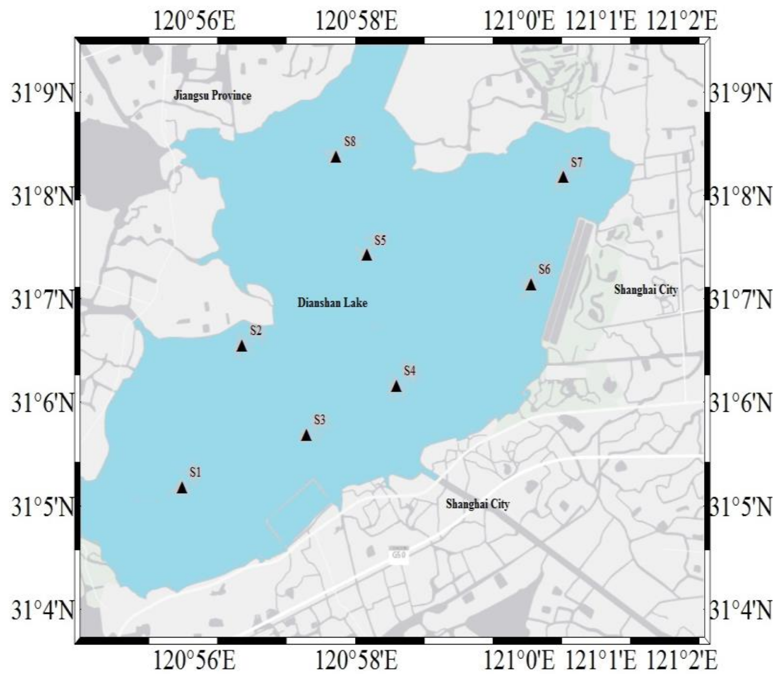

Figure 1: Map showing the sampling stations (S1-S8) in Dianshan Lake.

per suggestion of local fishermen during the period from January to December 2013. The fish species were captured with gillnets and trawls. Gillnets (10 m length; 1.5 m depth) ranging from 2.0 to 10.0 cm stretched mesh size were employed at each sampling point. Beam trawl nets (1.5 m height; 3.0 m length; 2.0 m width), 2.0 cm mesh size, was also used. Sampling was done during morning hours and the randomly captured samples were selected, morphometrically identified and measured. Totally, 544 and 3590 specimens of *Tachysurus nitidus* and *Plagiognathops microlepis* respectively were sampled. Specimens collected were quickly sorted out on species basis and identified to species level and then stored in coolers containing ice and later transported to the laboratory.

Fork length (FL) was measured to the nearest centimeter and the weight was taken on digital balance for each individual. Monthly length data collected from different sampling sites of the lake were converted into length frequencies with a constant class interval of 1 cm. The mean lengths and weights of the classes were used for data analysis using the format accepted by FiSAT (Gayanilo & Pauly, 1997).

Length Composition, Length-Weight Relationship, Condition Factor

The relation between length and weight of fish was analyzed by measuring lengths and weights of fish specimens collected from the study area. The statistical relationship between these parameters of fish was established by using the following parabolic equation (Froese, 2006):

$$W = aFL^b$$

Where, W=weight of fish (g); FL=fork length of fish (cm). This relationship, when converted into the logarithmic form, gives the following straight-line relationship.

$$\text{Log W} = \text{Log a} + \text{b Log FL}$$

(Beverton & Holt, 1957).

Where, *b* represents the slope of the line and Log *a* is the intercept.

The coefficient of determination (r^2) was used as an indicator of the quality of the linear regression. The value of *b* provides information on the fish growth type (isometric or allometric).

The condition factor is used for comparing the condition, fatness, or wellbeing (Kindong, Dai, Tian, & Gao, 2017a) of fish, based on the assumption that heavier fish of a given length are in better condition. The coefficient of the condition factor, K was calculated using Fulton (1904):

$$K = 100 * \frac{W}{L^3}$$

Where, W=weight in grams; L=length in cm; and 100 is a factor to bring the value of K near unity (Froese, 2006).

Growth and Mortality Parameters

The length frequency data collected for *Tachysurus nitidus* and *Plagiognathops microlepis* were used to determine growth parameters; these parameters were intended to be used for the estimation of mortality rates and stock status. Initial estimates of the von Bertalanffy growth parameters such as the asymptotic length (L_∞) and the growth coefficient (*K*) were obtained by using ELEFAN and Shepherd methods incorporated in FiSAT II software (Gayanilo & Sparre, 2005), which make direct use of size distributions to prepare an estimate of the growth parameters. Shepherd method was used to provide an initial estimate of the asymptotic length. With this initial estimate of (L_∞) as the seeded value the ELEFAN procedure was used to fit the non-seasonalized von Bertalanffy growth function (vBGF) to the length–frequency data. The growth of fish species was assumed to follow the vBGF which has the basic form:

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

Where, L_∞ is the asymptotic length; *K* is the growth coefficient; t_o is the theoretical age at which fish would have had at zero length; L_t is the length at age; and t is the age at length. This initial estimate of the asymptotic length was later used to determine the value of *K* (Silvestre & Garces, 2004).

The formula developed by Pauly and Munro (1984) was used to calculate the growth performance index Phi (Ø):

$$\text{Phi (Ø)} = Log_{10}K + 2Log_{10}L_\infty$$

The age at zero length (t_o) was calculated from Pauly's empirical equation (Pauly, 1979) given below:

$$Log(-t_o) = -0.392 - 0.275LogL_\infty - 1.0381K$$

The von Bertalanffy growth equation (Sparre & Venema, 1992) was used to find the lengths of the fish at various ages.

The lifespan (longevity T_{max}) was estimated following Pauly's equation T_{max}=3/*K* (Pauly,1979). The fitting of the best growth curve was based on ELEFAN (Pauly & David, 1981), which allows the fitted curve through the maximum number of peaks of the length–frequency distribution.

The total instantaneous mortality rates (Z) were estimated using length-converted catch curve method as implemented in FiSAT II. The instantaneous natural mortality rates (M), were estimated using seven different empirical equations (Pauly, 1980; Hoenig, 1983; Quinn & Deriso, 1999; Jensen, 1996; Hewitt & Hoenig, 2005; Then, Hoenig, Hall, & Hewitt, 2014) as shown in Table 1, their mean values were used for further analysis. The instantaneous fishing mortality rates, F, were deduced from the expression F=Z-M, and the exploitation ratio (E) from E=F/Z (Pauly, 1980).

Length at First Capture (Lc or $L_{50\%}$) and Length at First Maturity (Lm)

The length at first capture (*Lc*) is the length at which 50% of fish is retained by the fishing gear. It is estimated using the logistic curve (or running average) method implemented in the FiSAT II program.

To estimate the length at first maturity (L_m) for the assessed species, the following equation in (Hoggarth, Abeyasekera, Arthur, Beddington, & Burn, 2006) was used. The input parameters for the model included asymptotic length only (L_∞). Length at first maturity

$$L_m = L_\infty * 2/3.$$

Recruitment Pattern and Exploitation Rate

The vBGF parameters L_∞, K and t_o were used as inputs. Plots showing the seasonal patterns of recruitment into the fishery were obtained via backward projection of the frequencies onto the time axis of a time-series of samples along a trajectory defined by the vBGF (Dadzie, Abou-Seedo, & Moreau, 2007).

The exploitation rate (E) was derived by FiSAT II from the linearized length-converted catch curve of each species. An E close to 0.5 is considered to describe an optimal level of exploitation, whereas E>0.5 refers to a state of over exploitation as reported in (Tesfaye & Wolff, 2015).

Sized Structured Yield per Recruit (YPR) Analysis

According to Ricker (1975), vBGF was used to model the size data; the corresponding size structured. YPR model could be written as:

$$\frac{Y}{R} = \sum_{l=1}^{1}\left[\frac{W_l S_l F}{(S_l F + M)} \times \left(1 - e^{-(S_l F + M)\times \Delta T_l}\right) \times e^{-\sum_{k=1}^{l-1}(S_l F + M)\Delta T_k}(1 - D_l)\right]$$

The proportion of both species retained by fishing gears at a given length (S_l) was modelled by the following equation:

$$S_l = \frac{1}{1 + e^{-m(L_l - L_{50})}}$$

The probability of fish being discarded (D_l)can be written as:

$$D_l = \frac{1}{1 + e^{d_l(L_l - d_{50})}}$$

where l indexes size class, W_l is the average weight of fish in size class l, D_l the proportion of fish in size class l caught in the fishery that are discarded to the lake in the target fishery, Parameter *d* is the slope of the logistic curve. Parameter d_{50} describes age or size at which 50% of fish are discarded (in our study discards sizes were 8 cm). The nonlinear least squares method was used to estimate d and d_{50}. S_l is the proportion of fish in length L_l retained by fishing gears. The *m* and L_{50} are two parameters describing the rate of changes in S_l with size and size at which 50% of fish are retained by gears, respectively.

Results

Length Composition, Length-weight Relationship, Condition Factor

Monthly collected length frequency data from the *Tachysurus nitidus* and *Plagiognathops microlepis* were grouped into one-centimeter class interval (Figure 2). The size structure of the two species were not very similar. Length classes 13.5 cm and 12 cm was dominant for *Tachysurus nitidus* and *Plagiognathops microlepis* respectively. The highest length recorded throughout the study period for *Tachysurus nitidus* was 18.9 cm and 24.2 cm for *Plagiognathops microlepis*.

The length-weight regressions and condition factors for *Tachysurus nitidus* and *Plagiognathops microlepis* are reported in Table 2. The correlation (r^2) was strong for both species. This study's results showed that the slopes "*b*" of the regression equations for both species were not significantly different (t-test, P>0.05) from the isometric value of "3" showing an isometric growth for both species in lake Dianshan. The condition factor for both species were all above 1 signaling good wellbeing of species in lake.

Estimation of Growth Parameters (L_∞, K and t_o) and Longevity/Life Span (Tmax)

The FiSAT II growth curve output of the length frequency distribution of *Tachysurus nitidus* and *Plagiognathops microlepis* for the study period is shown in Figure 3. Table 2 present the estimated vBGF values of L_∞, *K* and t_o and derived growth performance index Phi (Ø). The growth performance index was higher for *Plagiognathops microlepis* than that for *Tachysurus nitidus*.

The lengths of the fish at various ages are presented in Table 3. This fish species for *Tachysurus nitidus* attain at least 50% of the asymptotic length in the fourth-year class, indicating rapid growth in length as compared to fish species of *Plagiognathops*

Table 1: Indirect estimation methods used to estimate natural mortality rates (M) based on different life history parameters.

Empirical model for estimation of M	Input parameters	Reference
$LogM = 0.0066 - 0.279\,Log10L_{\infty} + 0.6543\,Log10\,K + 0.4634\,Log10T$	$K, L_{\infty}, T = 15.5℃$	Pauly (1980)
$M = 4.899Tmax^{-0.916}$	$Tmax$	Then et al. (2014)
$M = 4.118K^{0.73}L_{\infty}{}^{-0.33}$	K, L_{∞}	Then et al. (2014)
$M = \exp[1.44 - 0.982 * \log 10(Tmax)]$	$Tmax$	Hoenig (1983)
$M = -log10(p)/Tmax$	$p = 0.01, Tmax$	Quinn and Deriso (1999)
$M = 4.22/Tmax$	$Tmax$	Hewitt and Hoenig (2005)
$M = 1.5 * K$	K	Jensen (1996)

Tmax, maximum age; *p*, proportion of animals that reach maximum age; *K*, von Bertalanffy growth coefficient (per year); L_{∞}, asymptotic maximum carapace length (mm) from the von Bertalanffy growth model; T, temperature range (°C) for lake Dianshan during survey ((Mei, Zhang & Shi, 2010; Gao, Tian & Dai, 2014).

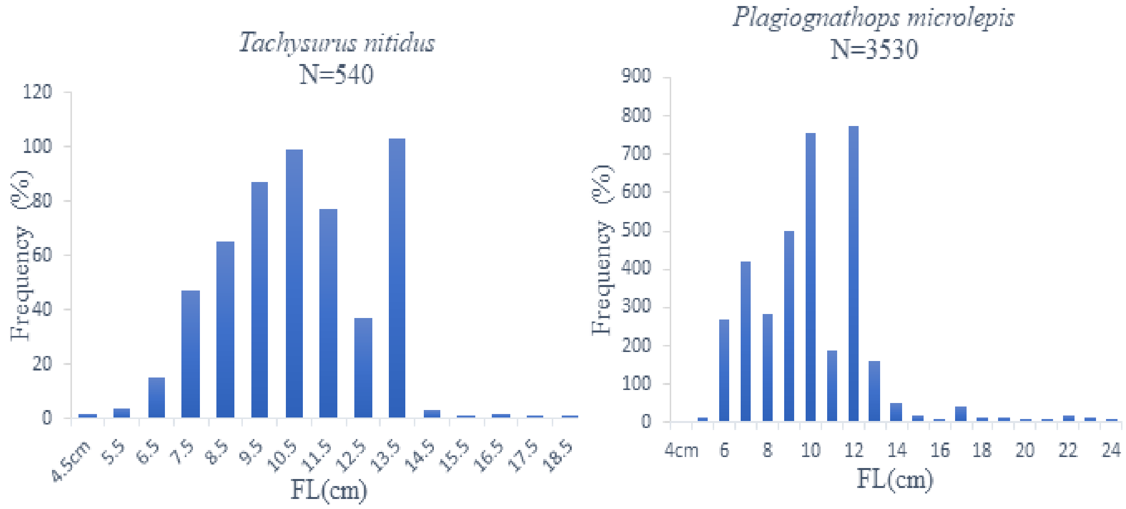

Figure 2: Overall length frequency distributions of *Tachysurus nitidus* (left) and *Plagiognathops microlepis* (right).

Table 2: Estimated growth parameters, length–weight relationships parameters and condition factors of *Tachysurus nitidus* and *Plagiognathops microlepis* from Dianshan lake

Parameters	*Tachysurus nitidus*	*Plagiognathops microlepis*
Number of fish	540	3530
Asymptotic fork length (cm)	25.15	36.5
Growth coefficient K (yr^{-1})	0.19	0.10
Age at zero length t_o (yr)	-0.378	-0.40
growth performance index (Ø′)	2.080	2.125
FL range (cm)	4.5-18.9	4.2-24.2
Slope (*b*)	3.01	3.007
95% CI of *b*	2.99-3.03	2.99-3.04
Intercept (*a*)	0.0113	0.0145
95% CI of *a*	0.0108-0.0116	0.0137-0.0148
Determination coefficient (r^2)	0.71	0.89
Condition factor (K)	1.51	1.55

P<0.001 for all regression slopes.

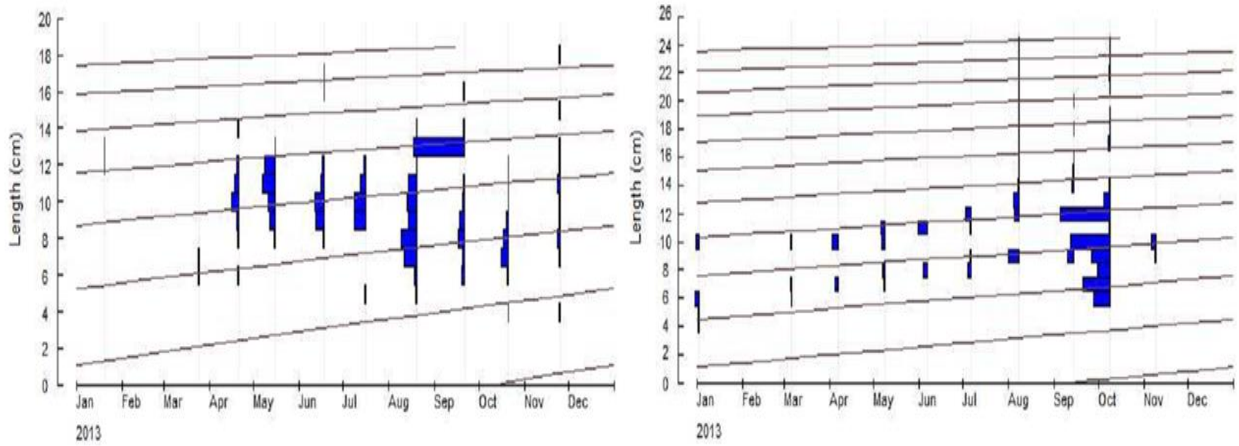

Figure 3: Length frequency distribution output from FiSAT II with superimposed growth curves for *Tachysurus nitidus* (left) and *Plagiognathops microlepis* (right).

Table 3: Calculated age-length data for *Tachysurus nitidus* and *Plagiognathops microlepis* on their von Bertalanffy growth equation

Year class (yr)	FL (cm) *Tachysurus nitidus*	FL (cm) *Plagiognathops microlepis*	Year class (yr)	FL (cm) *Tachysurus nitidus*	FL (cm) *Plagiognathops microlepis*
1	5.79	4.76	6	17.66	17.25
2	9.14	7.78	7	18.96	19.08
3	11.91	10.52	8	20.03	20.74
4	14.2	12.99	9	20.92	22.24
5	16.09	15.23	10	21.65	23.60

microlepis that attain 50% of the asymptotic length in the eighth-year class. Both fish species indicates less rapid growth at their early ages. Longevity (Tmax) calculated was 15.79 years for *Tachysurus nitidus* and 30 years for *Plagiognathops microlepis.*

Estimation of Mortality Parameters (M, F and Z)

The instantaneous total mortality rate, Z estimated from the linearized length-converted catch curve (Figure 4) was 1.51 yr^{-1} for *Tachysurus nitidus* and 0.54 yr^{-1} for *Plagiognathops microlepis*.

The instantaneous natural mortality was obtained by taking the mean value of the results obtained from the seven empirical methods to estimate M (Table 1). For *Tachysurus nitidus*, the mean M and corresponding fishing mortality rate F obtained were 0.38 yr^{-1} and 1.13 yr^{-1} respectively, and 0.21 yr^{-1} and 0.33 yr^{-1} respectively for *Plagiognathops microlepis*.

Length at First Capture (Lc or $L_{50\%}$) and Length at First Maturity (Lm)

Figure 5 shows the probability of fish capture and gives the length at first capture *(Lc or $L_{50\%}$)* for the two targeted fish species. The probability of capture for *Tachysurus nitidus* and *Plagiognathops microlepis* at 25%, 50% and 75% were estimated as:

Tachysurus nitidus: $L_{25\%}$=7.29 cm; $L_{50\%}$=7.78 cm; $L_{75\%}$ =8.26 cm.

Plagiognathops microlepis: $L_{25\%}$=4.72 cm; $L_{50\%}$=5.08 cm; $L_{75\%}$=5.44 cm.

The length at first maturity (*Lm*) was estimated at 16.77 cm for *Tachysurus nitidus* and 24.33 cm for *Plagiognathops microlepis*.

Recruitment Pattern and Exploitation Rate E

Figure 6 shows the recruitment pattern of the two targeted fish species. The months for the major recruitment peaks were June for *Tachysurus nitidus* and May for *Plagiognathops microlepis*.

The results obtained from the length-converted catch curve (Figure 4) estimated the exploitation rate for *Tachysurus nitidus* to be 0.75 and 0.61 for *Plagiognathops microlepis.* According to Pauly and Munro (1984), optimum exploitation rate E_{opt}=0.5; relating this to our result indicates that both species from lake Dianshan were over exploited.

Sized Structured Yield per Recruit (YPR) Analysis

The parameters used and the results obtained from the YPR analyses are summarized in Table 4.

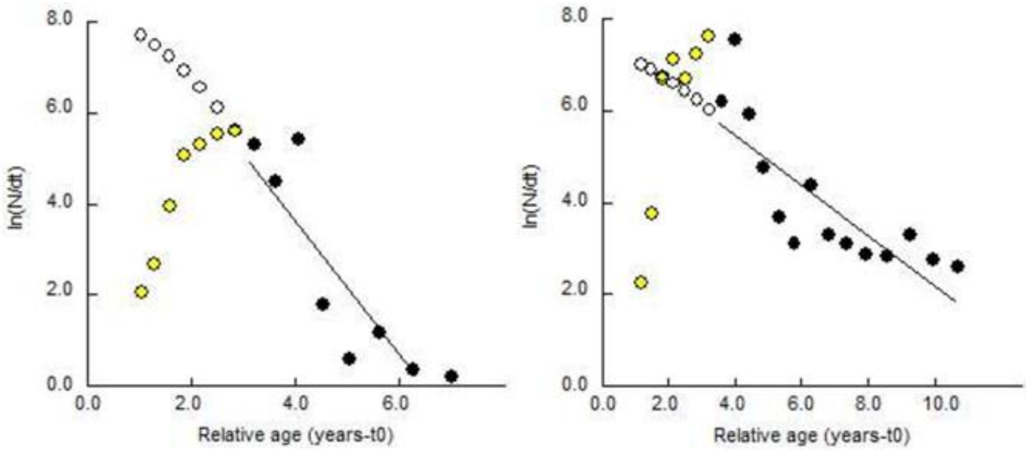

Figure 4: FISAT II output of linearized length-converted catch curve for *Tachysurus nitidus* (left) and *Plagiognathops microlepis* (right).

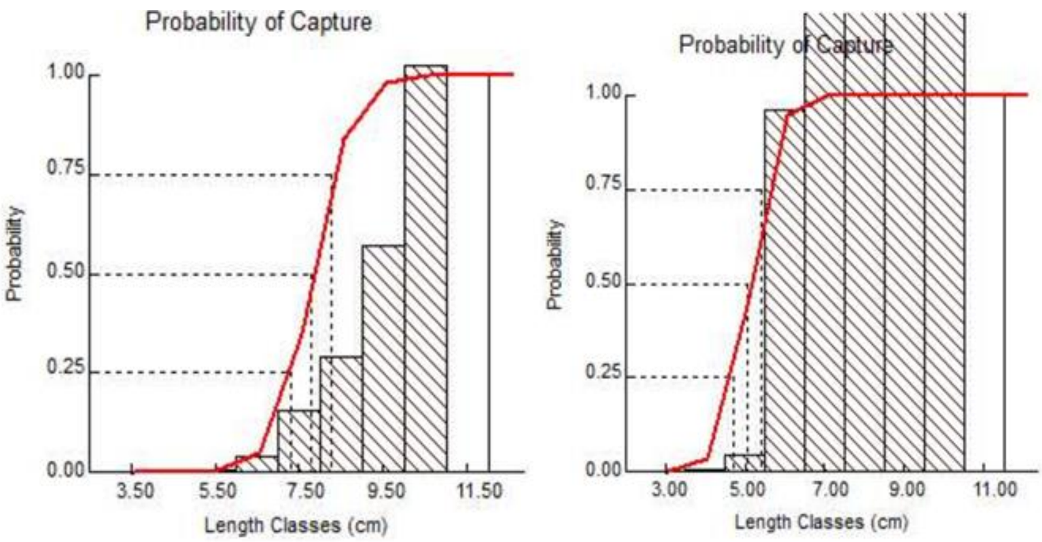

Figure 5: FiSAT II output of the probability of capture of *Tachysurus nitidus* (left) and *Plagiognathops microlepis* (right).

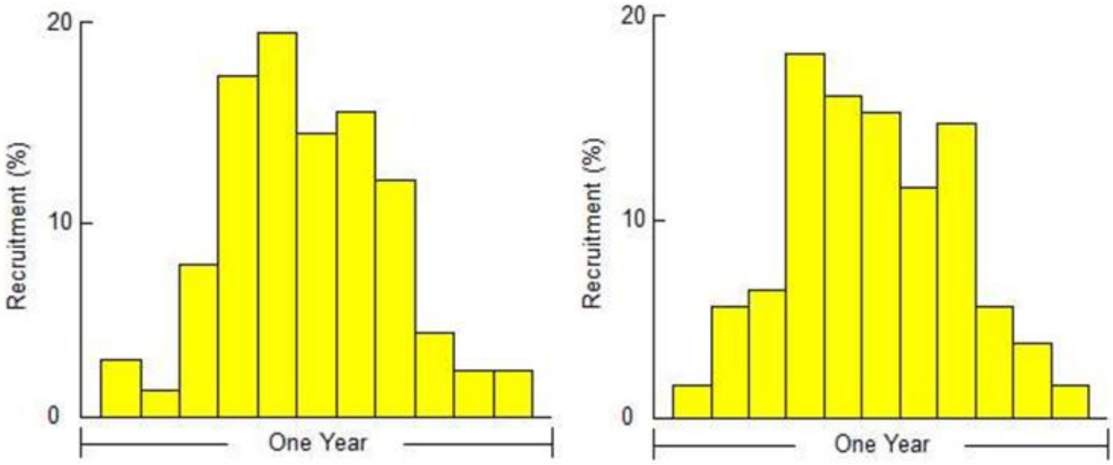

Figure 6: FiSAT II output of recruitment patterns of *Tachysurus nitidus* (left) and *Plagiognathops microlepis* (right).

Figure 7 depicts resulting selectivity and discard curves of *Tachysurus nitidus* and *Plagiognathops microlepis*. Yield per recruit curves for both species are presented in Figure 8. The yield per recruit estimated by the size structured YPR analysis were 3.37 kg/R for *Tachysurus nitidus* and 16.1 kg/R for *Plagiognathops microlepis* under the current fisheries. Maximum YPR for both species was not attained at the current F (Fcur) but at F_{max} values for both species. At lower F values, up to $F_{0.1}$ (0.16 for *Tachysurus nitidus* and 0.15 for *Plagiognathops microlepis*), sustainable YPR are predicted to occur over a range of length of first capture (Lc). The current fishing mortalities for both species were all higher than the values of the biological reference points (BRPs) $F_{0.1}$ and F_{max} obtained in this study, as can be seen in Table 4. It is clear from the BRP values obtained that the stocks for both species in this study area were highly exploited. These results also suggest that, for optimum YPR to be obtained, the current fishing effort would have to be reduced.

Discussion

Length Composition, Length-Weight Relationship, Condition Factor

The estimated asymptotic length recorded for *Tachysurus nitidus* and *Plagiognathops microlepis* (i.e. 25.15 cm and 36.5 cm respectively) shows the catch of relatively smaller sized specimens of both species' exploited stock from lake Dianshan. Table 5 shows reported length variations for both species. In Fishbase (Froese & Pauly, 2017), Li *et al*. (2015) reported the largest individual size for *Tachysurus nitidus* to be 23.5 cm TL_{max}; largest individual sizes for *Plagiognathops microlepis* were registered by Nichols (1943) (67.5 cm common length) and 70 cm TL_{max} recorded by Berg (1964). This disparity in lengths from reported lengths and those reported in this study shows the dominance of juveniles in catches for both species. This maybe due to the use of different size meshes in catches at different fishing areas. Berg (1964) recorded high catches for this species in Russia.

Length-weight relationship in this study showed that both species exhibited isometric growth implying that the fish length and body weight are both directly proportional in growth to each other. Values of *b* equal to 3 indicate that the fish grows isometrically; values other than 3 indicate allometric growth (Tesch, 1971). The *b* values in fish is species specific and therefore varies with sex, age, seasons, physiological conditions, growth increment and nutritional status of fish (Ricker, 1975; Bagenal & Tesch, 1978). Table 5 shows different values reported for *Tachysurus nitidus*. This dissimilarity in results from other authors may possibly be due to reasons related to ecosystem and biological phenomena like seasons, feeding behavior, competition for food, maturity stages. However, *Plagiognathops microlepis* has no reported length-weight relationship in FishBase (Froese &Pauly, 2017), so the result obtained in this study would probably be the first.

Condition factor indices have been widely used as indicators of relative health (Brown & Murphy, 1991). Species condition factor values less than one (<1) are considered as being low while those greater than one (>1) are considered as high (Mir *et al*., 2012). LeCren (1951) had reported that environmental factors, food supply, and parasitism have great influence on the health of the fish; he also added that, difference in condition factor has been interpreted as a measure of histological events such as fat reservation, adaptation to the environment, and gonadal development. In the present study, the condition factors recorded were K=1.51 and K=1.55 for *Tachysurus nitidus* and *Plagiognathops microlepis* respectively, showing that environmental variables, eutrophication and environmental pressures (reduced) favors the wellbeing of both species.

Growth Parameters (L_∞, K and t_0) and Longevity/Life Span (Tmax)

While using FiSAT II for the estimation of growth parameters, uncertainties do exist as several combinations of the $L\infty$ and *K* values might lead to the same results (Moreau, Bambino, & Pauly, 1986; Pauly & Morgan, 1987). $L\infty$ and *K* are negatively correlated, when $L\infty$ is high, the *K* is low (Narges, Preeta, Jasem, Gholam-reza, & Yahid, 2011; Mirza, Nadeem, Beg, & Qayyum, 2012; Murugan, Rahman, Lyla, & Khan, 2014; Delgado *et al*., 2017). Growth characteristics may differ a lot for the same species found in different water bodies, however, (Bartulovic *et al*., 2004; Gulland, 1970) reported that there must be some differences between growth characteristics among localities because of the diversity and availability of dietary items, hydrographical and climatic conditions.

Growth and mortality rates are very much interrelated. Growth affects the fish's openness to both predation and fishing and it mostly determines the food necessities of each individual fish (Allen & Hightower, 2010). And it is the growth of individual fish that provides the catch and prey potential for the fishery and the natural predators (Pauly, 1984). Pauly (1980), assumes that small and fast-growing fishes have higher natural losses (more predators), and that natural mortality also increases with environmental temperature. Significant contributions from growth studies have been made by Schaefer (1954), Beverton and Holt (1957), Ricker (1975) and Gulland (1969).

The asymptotic lengths estimated for the two species in the present study were lower than reported corresponding maximum lengths in FishBase (*Tachysurus nitidus* to be 23.5 cm TL_{max} and 70 cm TL_{max} for *Plagiognathops microlepis*). This assertion could

Table 4: Parameters used in the YPR analysis

Parameters	*Tachysurus nitidus*	*Plagiognathops microlepis*
VBG parameters		
$L_{\infty}(cm)$; *K* (*yr*$^{-1}$); t_o (yr)	25.15; 0.19; -0.4	36.5; 0.1; -0.4
Length-Weight relationship		
Ln(*a*); *b*	-4.5; 3.01	-4.234; 3.007
Natural Mortality		
M	0.38	0.21
Selectivity curve		
m (cm^{-1})	0.682	0.782
L50 (cm)	7.78	5.08
Discard curve		
d ((cm^{-1})	0.4	0.46
d50 (cm)	8	8
Fcurrent	1.13	0.33
Yield at Fcur.	3.37	16.1
F0.1	0.16	0.15
Yield at F0.1	13.019	16.3
Fmax	0.2	0.225
Yield at Fmax	13.661	17.4

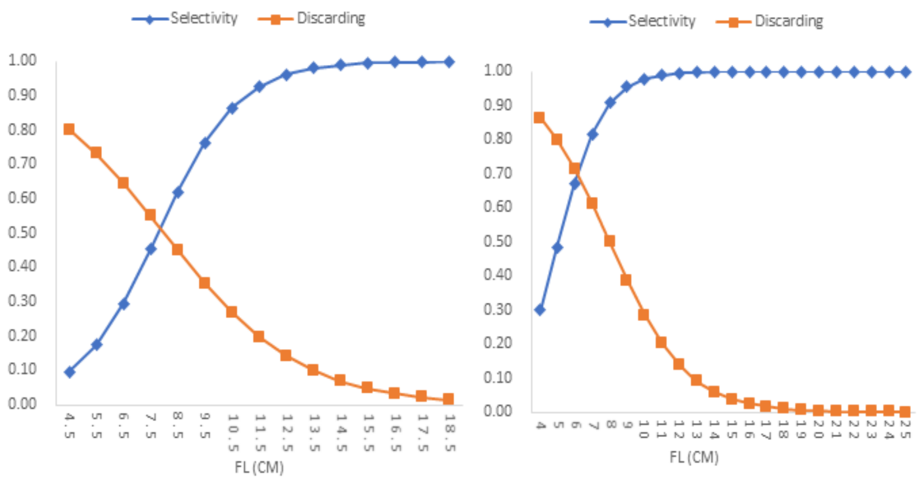

Figure 7: Discard and selectivity curves for*Tachysurus nitidus* (left) and *Plagiognathops microlepis* (right).

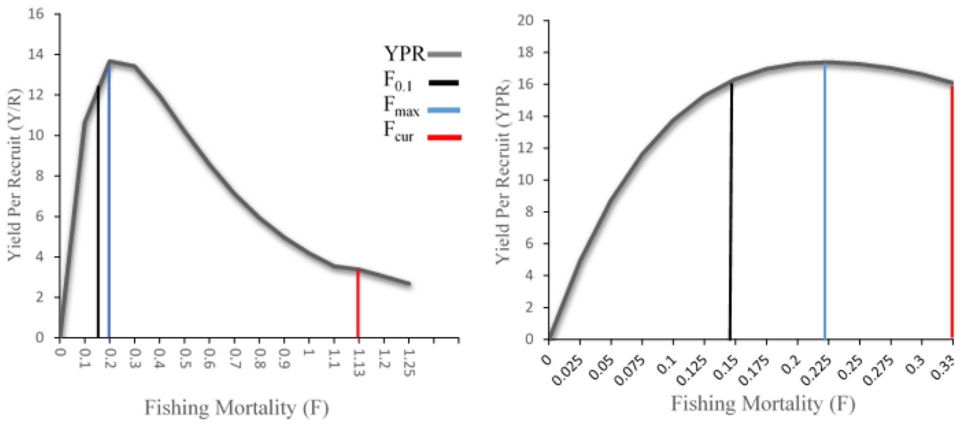

Figure 8: Yield per recruit analysis for the base case for *Tachysurus nitidus* (left) and *Plagiognathops microlepis* (right).

Table 5: Length-weight relationships reported by other authors

Species	Length range (cm)	*a*	*b*	Author	Country
Tachysurus nitidus	4.7-16.0 (FL)	0.0390	2.57	Geng et al. (2014)	China
	5.2-23.5 (TL)	0.0062	3.10	Li et al. (2015)	China
	8.5-19.0 (TL)	0.0105	2.87	Lee et al. (2015)	South Korea
	7.7-18.9 (TL)	0.0054	3.11	Kim et al. (2015)	South Korea
	8.5-16.5 (TL)	0.0243	2.82	He et al. (2016)	China
	4.5-18.9 (FL)	0.0113	3.01	Current study	China
*Plagiognathops microlepis**	-	-	-	Froese & Pauly (2017)	FishBase
	4.2-24.2 (FL)	0.0145	3.007	Current study	China

*No LWR reference in FishBase.

imply that the stocks of these two economically important species being exploited in lake Dianshan mostly constitutes juveniles as shown by length composition data.

This study presented lower values of growth coefficient *K* (y^{-1}) and considerable values for age at zero length t_o (yr) for both species (Table 2) signifying slow growth rate. Both species slowly attain their respective maximum sizes.

The growth performance index (Ø′) of both species obtained in this study ranged from 2.080 to 2.125 (Table 2). Results shows both species grow at relatively same rate. Generally, growth performance index(Ø′) are species specific parameters, meaning their values within related taxa are usually alike and have narrow normal distributions. Sparre and Venema (1992) stated that the value of *K*=1.0 is fast growth, *K*=0.5 is medium growth and *K*=0.2 is slow growth. The growth coefficient *K* for both species were lower than 0.2, indicating that, *Tachysurus nitidus* and *Plagiognathops microlepis* are slow growing species, confirmed by their long-life span of 15.79 and 30 years respectively.

The lengths of both species at various ages presented in Table 3 shows that these species exhibited faster growth before they could mature than when they reached their first sexual maturity stage. They attained their first sexual maturities at late ages (6.21 years for *Tachysurus nitidus* and 10.83 years for *Plagiognathops microlepis*). In general, their growth rate was slow.

Estimation of Mortality Parameters (M, F and Z)

Beverton and Holt (1959) pointed out that the natural mortality coefficient of a fish is directly related to the growth coefficient and inversely related to the asymptotic length. The data set for estimating the total mortality Z by the length converted catch curve method should satisfy the primary assumption that the stock is in equilibrium.

The instantaneous total mortality rate, Z estimated was 1.51 yr^{-1} with (95%CI of Z=0.70-2.32) for *Tachysurus nitidus* and 0.54 yr^{-1} with (95% CI of Z=0.30-0.79) for *Plagiognathops microlepis*. The equivalent fishing mortality F for both species are 1.13 yr^{-1} for *Tachysurus nitidus* and 0.33yr^{-1} for *Plagiognathops microlepis.*

Seven empirical methods (Table 1) for determining the instantaneous natural mortality, M were used and the corresponding mean value was estimated and used in this study. This parameter is very vital for stock assessment but difficult to estimate. The estimated values of M for *Tachysurus nitidus* ranged from 0.267-0.48 yr^{-1}, estimated mean M was 0.38 yr^{-1}; similarly, M estimates for *Plagiognathops microlepis* in the range of 0.14-0.29 yr^{-1} with a corresponding mean M of 0.21 yr^{-1}. Adams (1980) documented that natural mortality has a positive correlation with growth rates and negatively correlated to age at maturity, life span, fish body size. Consequently, the estimated mean M values recorded in the present study could be acceptable bearing in mind their long-lived nature.

The reliability of the estimated natural mortality rate, M, was established using the M/*K* ratios because this ratio has been reported to be within the range 1.0-2.5 for most fish species (Beverton and Holt, 1957). M/*K* values were 2 for *Tachysurus nitidus* and 2.1 for *Plagiognathops microlepis*.

Recruitment Pattern, Length at First Capture (Lc or $L_{50\%}$) and Length at First Maturity (Lm)

The recruitment patterns of both species suggested that there was one main pulse of annual recruitment (Figure 6). The major pulse appeared in June for *Tachysurus nitidus* and May for *Plagiognathops microlepis*. The small lengths observed for both species confirms the use of small mesh sized trawls and gillnets for fishing operations by fishermen in lake Dianshan.

The length at first capture for both species were: *Tachysurus nitidus*: $L_{50\%}$=7.78 cm and *Plagiognathops microlepis*: $L_{50\%}$=5.08 cm. The length at first capture was the length at which 50% of the fish are vulnerable to be captured by fishermen. This is the average size of fish vulnerable to be fished or enter the fishing ground, in the Dianshan lake.

The length at first maturity (*Lm*) estimated was 16.77 cm for *Tachysurus nitidus* and 24.33 cm for *Plagiognathops microlepis*. Results shows *Lc*<*Lm* for both fish species, indicating high probability catches of juveniles by employed fishing gears, since these species were caught without reaching their first sexual maturity stage characterizing growth overfishing. Growth overfishing is mostly characterized by small size fish species within the harvested catch (Wehye, Ofori-Danson, & Lamptey, 2017).

The estimated Lc/L_{∞}ratios using the relationships between the Length at first capture (Lc) and the asymptotic length (L_{∞})for the two-treated species were 0.31 and 0.14 for *Tachysurus nitidus* and *Plagiognathops microlepis* correspondingly. These values were all less than 0.5 indicating high presence of juvenile fish species in the landed catch during the study period. The presence of many small-sized fish species in the catches could be explained by the unselective use of small mesh sized fishing gears.

Probability of Capture and Exploitation Rate E

The probability of capture doesn't just enable fishery managers to determine sustainable minimum sizes of target fish species in a fishery but also give real size indications of fish species that are being caught in the fishing area by specific gears. Backward extrapolation of descending limb of the length-converted catch curve is often used to estimate the probability of capture (Sparre, 1987). Considering the optimum exploitation rate criterion of E_{opt}=0.5, values obtained for *Tachysurus nitidus* (0.75) and *Plagiognathops microlepis* (0.61) were all higher than E_{opt}. This shows that both species were highly overexploited ($E>E_{opt}$) in lake Dianshan. The value of the exploitation rate is based on the fact that sustainable yield is optimized when the fishing mortality coefficient is roughly equal to natural mortality (Pauly, 1983). With this situation, specimens captured during their spawning periods could hinder recruitments; also, a decline in catch for both species in lake Dianshan could be observed in the future since the size at first capture is lesser than the size at first maturity. Therefore, immediate management measures need to be taken for this species fishery in lake Dianshan in order to avoid drastic decline of these economic fish species.

Sized Structured Yield per Recruit (YPR) Analysis

Size structured YPR was calculated to assess the status of stocks of both species by using the analysis of their current biological parameters (Quinn & Deriso, 1999; Novoa-Pabon, Barros, Krug, Silva, & Pinho, 2015). $F_{0.1}$ and F_{max}, estimated from size-structured YPR analyses, being two of the most commonly used biological reference points in fisheries management; were used in this study as management target (i.e., $F_{0.1}$) and threshold/limits (F_{max}) under the context of precautionary management (Chen *et al*. 2007).

From Table 4, it can be seen that minimum yields for both fisheries were obtained at the current high F values and increased rapidly at low levels of fishing mortalities. The stocks for both species at the current fishing mortalities are considered unsustainable because these values are greater than $F_{0.1}$ and F_{max}. This may explain why most fish species are caught at the time period when they enter the fisheries, and this could also be one of the reasons why most of the fish for both fisheries were caught without fully attaining their maturity stages.

To maximize the YPR for *Tachysurus nitidus* from 3.37kg/R to 13.661kg/R, the fishing mortality rate should be decreased from 1.13 to 0.2 (about 80% of fishing effort reduction and a 75% increase of yield), and for *Plagiognathops microlepis* the optimum YPR could be reached if the current fishing mortality is decreased from 0.33 to 0.225, equivalent to a fishing effort reduction of 31.8% and 18% yield increase. These increases in yield would increase substantially the fishery productivity.

Conclusion

We have attempted to evaluate the life history parameters and carried out a yield per recruit analysis for *Tachysurus nitidus* and *Plagiognathops microlepis*. Our results revealed that the stock of both species in the Dianshan lake is currently overexploited, with a risk in the nearest future of recruitment failure. However, the continual use of fishing gears with small-sized meshes in addition to high fishing effort can result in diminished economic benefits, reduced catch per effort, and the collapse of the fisheries for the current target species. So, there is a need for fishery managers and scientists to undertake stock assessment studies for these species in the future in order to take long lasting measures for sustainable harvest of this fish species fishery. Nevertheless, immediate management measures such as monitoring fishing efforts if not a reduction in fishing effort to acquire optimum yields; and mesh size regulation (to increase length at first capture) are needed to safeguard these commercially important fish species from possible collapse. The present study appears to be the first work done on *Tachysurus nitidus* and *Plagiognathops microlepis* stocks inhabiting East Asian water bodies, therefore information obtained here will serve as a foundation for further research relating to this commercially important fish species.

Acknowledgement

Authors are thankful to the college of Marine Sciences of Shanghai Ocean University for laboratory assistance and the Shanghai Municipal Governments' Agricultural Committee for providing the necessary finances. We are also grateful to the editor and three anonymous reviewers; whose comments improved the quality of the paper. Special thanks also go to the CSC (Chinese Government Scholarship program) for funding the first author's studies in China. Authors declare no conflict of interest.

References

Adams, P.B. (1980). Life-history patterns in marine fishes and their consequences for fisheries management. *Fishery Bulletin, 78*, 1–12.

Allen, M.S., & Hightower, J.E. (2010). Fish Population dynamics: mortality, growth and recruitment. In W.A. Hurbert & M.C. Quist (Eds.), *Inland fisheries management in North America* (pp. 43-79). Berthesda, Maryland: American fisheries Society.

Bagenal, T.B. & Tesch, F.W. (1978). Age and growth. In T.B. Bagenal. (ed.). Methods for assessment of fish production in fresh waters. *Blackwell Science Publications*: Oxford, UK, 101-136.

Bartulovic, V., Glamuzina, B., Conides, A., Dulcic, J., Lucic, D., Njire, J., & Kozul, V. (2004). Age, growth, mortality and sex ratio of sand smelt, Atherina boyeri, Risso,1810 (Pisces: Atherinidae) in the estuary of the Mala Neretva River (Middle-Eastern Adriatic). *Croatia Journal of Applied Ichthyology, 20*, 427-430. https://doi.org/10.1111/j.1439-0426.2004.00560.x

Berg, L.S. (1964). Freshwater fishes of the U.S.S.R. and adjacent countries. volume 2, 4th edition. *Israel Program for Scientific Translations Ltd*, Jerusalem. (Russian version published 1949).

Beverton, R.J.H. & Holt, S.J. (1957). On the dynamics of exploited fish populations. *Chapman and Hall*, London, 533 pp.

Brown, M.L., & Murphy, B.R. (1991). Standard weight (Ws) development for striped bass, white bass and hybrid Striped Bass. *North American Journal of Fisheries Management, 11*, 451-467. http://doi.org/10.1577/1548-8675(1991)011<0451:SWWSFS>2.3.CO;2.

Carl, F.C.J. Jr. (2007). Checklist of catfishes, recent and fossil (Osteichthyes: Siluriformes), and catalogue of Siluriformes primary types. *Zootaxa, 1418*, 1-628. http://dx.doi.org/10.11646/zootaxa.1418.1.1.

Chen, Y. (1997). A comparison study of age- and length-structured yield-per recruit models. *Aquatic Living Resources, 10,* 271–280. https://doi.org/10.1051/alr:1997030.

Chen, Y., Xu, L.X, Chen, X.J., & Dai, X.J. (2007). A simulation study of impacts of at-sea discarding and bycatch on the estimation of biological reference points F0.1 and Fmax. *Fisheries Research, 85,*14–22. https://doi.org/10.1016/j.fishres.2006.11.033.

Dadzie, S., Abou-Seedo, F. S., & J. Moreau. (2007). Population dynamics of *Parastromateus nigerin* Kuwaiti waters as assessed using length–frequency analysis. *Journal of Applied Ichthyology, 23,* 592–597. http://doi.org/10.1111/j.1439-0426.2007.00903.x.

Delgado, M., Silva, L., Gómez, S., Masferrer, E., Cojan, M., & Gaspar, M.B. (2017). Population and production parameters of the wedge clam *Donax trunculus* (Linnaeus, 1758) in intertidal areas on the southwest Spanish coast: Considerations in relation to protected areas. *Fisheries Research, 193*,232–241. http://dx.doi.org/10.1016/j.fishres.2017.04.012

Froese, R. (2006). Cube law, condition factor, and weight-length relationships: History, meta-analysis, and recommendations. *Journal of Applied Ichthyology, 22*, 241-253. http://doi.org/10.1111/j.1439-0426.2006.00805.x.

Froese, R., & D. Pauly. Editors. (2017). FishBase. Retrieved from. www.fishbase.org, (18/06/2017).

Fulton, T.W. (1904). The rate of growth of fishes. Twenty-Second Annual Report Part III. *Fisheries Board of Scotland, Edinburgh,3*, 141-241.

Gao, C.X., Tian, S.Q., & Dai, X.J. (2014). Estimation of biological parameters and yield per recruitment for *Coilia nasustaihuensis* in Dianshan Lake, Shanghai, China. *Chinese Journal of Applied Ecology, 25(5),* 1506-1512.

Geng, L, Gao, C.X., Han, C., Dai, X.J., & Tian, S.Q. (2014). Primary biological study of *Pelteobagrus nitidus* in Dianshan Lake. *Journal of Shanghai Ocean University, 23(3),* 435-440.

Gulland, J.A. (1969). Manual of methods of Fish Stock Assessment. Part 1. Fish Population analysis. *FAO Manual in Fisheries Science,* No. 4, Rome, 154 pp.

Gulland, J.A. (1970) The fish resources of the ocean. *FAO Fisheries Technical Paper*, No. 97, FAO, Rome, p 425.

Gayanilo, F.C., & Pauly, D. (1997). The FAO-ICLARM Stock Assessment Tools (FiSAT) Reference manual. (Eds.), *FAO Computerized Information Series (Fisheries)*, FAO Rome, 8, pp. 262.

Gayanilo, F.C., Sparre, P., & Pauly, D. (2005). FAO-ICLARM Stock Assessment Tools II (FiSAT II). User's guide. *FAO Computerized Information Series (Fisheries)*. No. 8, Revised version, FAO, Rome, 168pp.

Han, C., Gao, C.X., Tian, S.Q., & Dai, X.J. (2014). Analysis of annual variations for fish community structures in Dianshan Lake. *Journal of Shanghai Ocean University.*

He, M.F., Yuan, D.Q., Xiong, W., & Chen Y.F. (2016). Length–weight relationships for four fish species upstream in the Minjiang River, southeastern China. *Journal of Applied Ichthyology, 1–2*. http://doi.org/10.1111/jai.13156

Hewitt, D.A., & Hoenig, J.M. (2005). Comparison of two approaches for estimating natural mortality based on longevity. *Fishery Bulletin,103*, 433–437. http://aquaticcommons.org/id/eprint/9631

Hoenig, J.M. (1983). Empirical use of longevity data to estimate mortality rates. *Fishery Bulletin, 81,* 898–903.

Hoggarth, D.D., Abeyasekera, S., Arthur, R.I., Beddington, J.R., & Burn, R.W. (2006). Stock Assessment for fishery management. *A framework guide to the stock assessment tools of the Fisheries Management Science Programme (FMSP)*. Rome pp: 261.

Hu, Z.J., Wang, S.Q., Hao, W., Chen, Q.J., Ruan, R.L., Chen, L.Q., & Liu, Q.G. (2014). Temporal and spatial variation of fish assemblages in Dianshan Lake. *Chinese Journal of Oceanology and Limnology 32*, 799–809. https://doi.org/10.1007/s00343-014-3193-4

Huo, B., Ma, B.S., Xie, C.X., Dua, Y.J., Yang, X.F., & Huang, H.P. (2015). Stock assessment and management implications of an endemic fish, *Oxygymnocypris stewartii*, in the Yarlung Zangbo River in Tibet, China. *Zoological Studies, 54*, 53. http://doi.org/10.1186/s40555-015-0129-4.

Jensen, A.L. (1996). Beverton and Holt life history invariants result from optimal trade-off of reproduction and survival. *Canadian Journal of Fisheries and Aquatic Sciences, 53*, 820–822. https://doi.org/10.1139/f95-233.

Kim, J.H., Yoon, J.D., Won, D.H., Byeon, M.S., & Jang, M.H. (2015). Length-weight relationships of 19 fish species from Saemangeum reservoir in South Korea. *Journal of Applied Ichthyology, 31*, 951-953. http://doi.org/10.1111/jai.12825.

Kindong, R., Dai, X.J., Tian, S.Q., & Gao, C.X. (2017a). Estimation of Length-Weight Relationships and Condition Factor of Five Cultrinae Fish Species from Dianshan Lake, Shanghai, China. *Current Research Journal of Biological Sciences*. http://doi.org/10.19026/crjbs.9.3420.

Kindong, R., Dai, X.J., Tian, S.Q., & Gao, C.X. (2017b). Ichthyofaunal Assemblage of the Dianshan Lake, Shanghai, China: Implications for Management. *Proceedings of the Zoological Society*. http://doi.org/10.1007/s12595-017-0220-4.

Le Cren, E.D. (1951). The length-weight relationships and seasonal cycle in gonad weight and condition in perch (*Perca fluviatilis*). *Journal of Animal Ecology, 20*, 201-219.

Lee, J.W., Yoon, J.D., Kim, J.H., Park, S.H., Baek, S.H., Yu, J.J., Jang, M.H., Min, J.I. (2015). Length-weight relationships for 18 freshwater fish species from the Nakdong River in South Korea. *Journal of Applied Ichthyology, 31*, 576-577. http://doi.org/10.1111/jai.12757

Li, L., Wei, W.Q., Wu, J.M., Xie, X., Ren, L., & Du, H. (2015). Length-weight relationships of 11 fish species from the Yibin reach of the Yangtze River, southwest China. *Journal of Applied Ichthyology, 31*, 242-243. http://doi.org/10.1111/jai.12622.

Lorenzen, K., Cowx, I.G., Entsua-Mensah, R.E.M., Lester, N. P., Koehn, J.D., Randall, R.G., So N., … Cooke, S. J. (2016). Stock assessment in inland fisheries: a foundation for sustainable use and conservation. *Reviews in Fish Biology and Fisheries, 26*, 405–440. http://doi.org/10.1007/s11160-016-9435-0

Mei, X.Y., Zhang, X.F., & Shi, L.J. (2010). Regime shift of water nitrogen and chlorophylla. *Journal of Hydroecology, 3(6),*1-4 (in Chinese).

Mir, J.I., Shabir, R., & Mir, F.A. (2012). Length-weight relationship and condition factor of *Schizopyge curvifrons* (Heckel, 1838) from River Jhelum, Kashmir, India. *World Journal of Fish and Marine Sciences*, *4,*325-329. DOI: 10.5829/idosi.wjfms.2012.04.03.6315

Mirza, Z.S., Nadeem, M.S., Beg, M.A., & Qayyum, M. (2012). Population Status and Biological Characteristics of Common Carp, *Cyprinus carpio*, in Mangla Reservoir (Pakistan). *Journal of Animal Plant Science*, *22*, 933–938.

Moreau, J., Bambino, C., & Pauly, D. (1986). Indices of overall growth performance of 100 tilapia (Cichlidae) populations. In: Maclean J.L., Dizon L.B., Hosillos L.V. (eds) The 1st Asian fisheries forum. *Asian Fisheries Society*, Manila, pp 201–206.

Murugan, S., Rahman, M.A.U., Lyla, P.S., & Khan, S.A. (2014). Growth and Population dynamics of flathead grey mullet, *Mugil cephalus* (Linnaeus, 1758) from Parangipettai waters (Southeast coast of India). *Thalassas,30(2),*47–56.

Myers, R.A., & Worm, B. (2003). Rapid worldwide depletion of predatory fish communities. *Nature, 423*, 280-283. http://doi.org/10.1038/nature01610

Nguyen, T.H.T. (2013). Plagiognathops microlepis. The IUCN Red List of Threatened Species 2013:e.T166128A1847631.http://dx.doi.org/10.2305/IUCN.UK.20131.RLTS.T166128A1847631.en. Downloaded on 19 June 2017.

Narges, A., Preeta, K., Jasem, M., Gholam-reza, E., & Yahid, Y. (2011). Stock assessment of Silver Pomfret *Pampus argenteus* (Euphrasen, 1788) in the Northern Persian Gulf. *Turkish Journal of Fisheries and Aquatic Sciences, 11(1)*, 63-68. http://doi.org/10.4194/trjfas.2011.0109

Nichols, J.T. (1943). The freshwater fishes of China. Natural history of Central Asia: Volume IX. *The American Museum of Natural History*, New York, USA, 322 p

Novoa-Pabon, A., Barros, P., Krug, H., Silva, P., & Pinho, M.R. (2015). Yield per recruit analysis for the red blackspot seabream (*Pagellus bogaraveo*) stock from the Azores (ICES area Xa2). *ICES CM 2015/A*:33.

Pauly, D. (1979). Theory and management of tropical multispecies stocks: a review with emphasis on the Southeast Asian demersal fisheries. *ICLARM Studies and Reviews 1, 35 p*.

Pauly, D. (1980). On the interrelationships between natural mortality, growth parameters, and mean environmental temperature in 175 fish stocks. *Journal du Conseil, 39(2)*, 175–192. http://doi.org/10.1093/icesjms

Pauly, D., & David, N. (1981). ELEFAN I a basic program for the objective extraction of growth parameters from Length frequency data. *Meeresforschung, 28(4)*, 205–211.

Pauly, D. (1983). Some simple methods for assessment of tropical fish stock. *FAO Fisheries Technical Paper*, no. 234, pp. 52.

Pauly, D. (1984). Fish population dynamics in tropical waters: a manual for use with programmable calculators. *ICLARM Studies & Reviews, 8*, 1–325. https://doi.org/10.1086/414824.

Pauly, D., & J.L. Munro. 1984. Once more on the comparison of growth in fishes and invertebrates. *Fishbyte, 2(1)*, 21.

Pauly, D., & Morgan G. (1987). Length-based methods in fisheries research. *ICLARM Conference Proceedings 13*: International Center for Living Aquatic Resources and Management (ICLARM)

Pauly, D., Christensen, V., Guénette, S., Pitcher, T.J., Sumaila, U.R., Walters, C.J., Watson, R., … Zeller, D. (2002). Towards sustainability in world fisheries. *Nature 418*, 689–695. http://doi.org/10.1038/nature01017

Quinn, T.J., & Deriso, R.B. (1999). Quantitative Fish Dynamics. *Oxford University Press*, New York. 126pp.

Ricker, W.E. (1975). Computation and interpretation of biological statistics of fish populations. *Bulletin of the Fisheries Research Board of Canada*, 315–318.

Schaefer, M.B. (1954). Some aspects of the dynamics of populations important to the management of commercial marine fisheries. *Bulletin of the Inter-American Tropical Tuna Commission 1(2)*, 26–56.

Silvestre, G.T., & Garces, L.R. (2004). Population parameters and exploitation rate of demersal fishes in Brunei Darussalam (1989–1990). *Fisheries Research, 69*,73–90. https://doi.org/10.1016/j.fishres.2004.03.004

Sparre, P. (1987): Computer programs for fish stock assessment: Length-based Fish Stock Assessment (LFSA) for Apple II Computers. *FAO Fisheries Technical Paper*, 101(Suppl. 2), 218.

Sparre, P., & Venema, S.C. (1992). Introduction to tropical fish stock assessment. Part1. *Manual, FAO Fisheries Technical paper*, 306. No 1, Review 1, FAO Rome 376 pp.

Sun, J.Y., Dai, X.J., Zhu, J.F., Ji, W.B., & Tian, S.Q. (2007). Analysis of fish species diversity in Dianshan Lake. *Journal of Shanghai Ocean University, 16*, 454–459.

Tao, J., Dai, X.J., Tian, S.Q., & Ma, C. (2011). Community diversity and growth characteristics of wild fishes in Dianshan Lake. *Hunan Agricultural Sciences, 7,* 137–141.

Tesch, F.W. (1971). Age and Growth. In: Methods for Assessment of Fish Production in Fresh Waters, Ricker, W.E. (Ed.). *Blackwell Scientific Publications, Oxford, UK*., pp: 98-103.

Tesfaye, G., & Wolff, M. (2015). Stock assessment of fishery target species in Lake Koka, Ethiopia. *Revista de Bioliogia Tropical (International Journal of Tropical Biology*, ISSN-0034-7744) Vol. *63 (3),* 755-770.

Then, A.Y., Hoenig, J.M, Hall, N.G., & Hewitt, D.A. (2014). Evaluating the predictive performance of empirical estimators of natural mortality rate using information on over 200 fish species. *ICES Journal of Marine Sciences, 72(1),*1–6. https://doi.org/10.1093/icesjms/fsu136.

Welcomme, R.L., Cowx, I.G., Coates, D., Be´ne´, C., Funge-Smith, S., Halls, A.S., & Lorenzen, K. (2010). Inland capture fisheries. *Philossophical Transactions of the Royal Society B, 365*, 2881–2896. http:// doi.org/10.1098/rstb.2010.0168.

Wehye, A.S., Ofori-Danson, P.K., & Lamptey, A.M. (2017). Population Dynamics of *Pseudotolithus Senegalensis* and *Pseudotolithus Typus* and their Implications for Management and Conservation within the Coastal Waters of Liberia. *Fisheries Aquaculture Journal, 8*, 201. http:// doi.org/10.4172/2150-3508.1000201.

Yang, Z., Tang, H.Y., Que, Y.F., Xiong, M.H., Zhu, D., Wang, X., & Qiao, Y. (2016). Length weight relationships and basic biological information on 64 fish species from lower sections of the Wujiang River, China. *Journal of Applied Ichthyology, 32*, 386-390. http:// doi.org/10.1111/jai.13016.