
Growth, Population Dynamics and Optimum Yield of Indian Mackerel, *Rastrelliger kanagurta* (Cuvier, 1816), in the Eastern Gulf of Thailand

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Koolkalya, S., Matchakuea, U. and Jutagate, T. (2017). Growth, Population Dynamics and Optimum Yield of Indian Mackerel, *Rastrelliger kanagurta* (Cuvier, 1816), in the Eastern Gulf of Thailand. International Journal of Agricultural Technology 13(7.1): 1065-1075.

Thailand's marine fisheries have been intensively developed since 1950s. Catches are comprised of the pelagic and demersal fishes as well as other aquatic animals. Among the pelagic species, Indian mackerel *Rastrelliger kanagurta* (Cuvier, 1816) is one of species that has created significant economic value in the country. Meanwhile the precise information on population dynamics, stock assessment and optimum yield of *R. kanagurta* were still rare, especially in the Eastern-Gulf of Thailand. The objectives of this study was to estimate the growth and mortality rates to optimize the fishing pressure of the stock of the Indian mackerel in the Eastern-GoT, base on an otolith approach. In this study, the age-based approach of growth and mortality estimation and the relative yield per recruit were analyzed using the FiSAT II software. For the results, the growth parameters of von Bertalanffy growth model were $K=4.24 \text{ year}^{-1}$ and $L_{\infty} = 214.37$ millimeters, respectively. The total mortality coefficient (Z) was estimated at 6.09 year^{-1} and the natural mortality coefficient (M) was estimated as 2.70 year^{-1} . The current fishing mortality (F) was calculated as 3.39 year^{-1} and the actual value of exploitation rate (E) = 0.56. The relative yield per recruit was estimated from the knife-edge selection of size at first capture yielded the E_{max} and $E_{0.5}$ values at 0.49 and 0.32 respectively and the actual value of exploitation rate was higher than both E_{max} and the $E_{0.5}$, implying the overfishing situation of the stock. The possible fisheries management regime for this situation is increase size at first capture (L_c) and decrease fishing pressure, i.e. E -value. From this study, the length at first capture (L_c) between 150.06 and 214.37 millimeters and the 0.50 optimum level of exploitation (E) were recommended. For conclusion, this study illustrated the information on population dynamics and stock assessment of the *R. kanagurta* resources in the Eastern-GoT, as well the way forward for optimum exploitation. These findings can be further applied in the sustainability of Indian mackerel in the Eastern-GoT

Keywords: Fish stock assessment, mackerel, otolith, age and growth, mortality

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Introduction

The Indian mackerel, *Rastrelliger kanagurta* (Cuvier, 1816), is the tropical pelagic fish that commonly found in the Indian and the West Pacific Oceans and widespread in Southeastern Asia, in particular the Gulf of Thailand (GoT) (Luther, 1995; Khrueniam, *et al.*, 2013; Amin, *et al.*, 2014; Thongsila, *et al.*, 2012). This fish species is among the commercially important marine fishes and supports economically throughout its distribution range as well as considered as the common seafood for people (Khrueniam, *et al.*, 2013; Amin, *et al.*, 2014; Thongsila, *et al.*, 2012). The fisheries on *R. kanagurta* in the GoT have been developed since 1950s (Marine Fishery Laboratory, 1965). It is, then, become the main target species, in which, the highest yield of *R. kanagurta* from the Gulf of Thailand was found in 1994 at 50,898 metric tons, compared to 30,790 metric tons in 2014 (Fishery Statistics Analysis and Research Group, 2016). The yield of *R. kanagurta* between 1984 and 2009 in the GoT was found continuously decreased (Koolkalaya *et al.*, 2015) which consequence by the concerns on stock status and the quantifying of optimum fishing intensity that should be recommended to sustain the resource.

The population parameters of the interesting fish stock, such as growth and mortality must be known to quantify the optimum fishing intensity, because they are the input parameters for the number of the stock assessment models. There are two main methods for determining fish growth i.e. direct and indirect methods. Among the direct methods, counting the otolith's ring was common for ageing and long been shown to provide a good approach for reconstructing the growth of fishes because of the constancy increment pattern during otolith growth, which can be related to fish age and fish length (Wilson and Larkin, 1980; Campana and Neilson, 1985; Morales-Nin, 1992; Chambers and Miller, 1995). In addition, since the daily increment technique of otolith was developed in the early 1970's, this technique has gained wide acceptance (Jones, 1992).

Growth data and the mathematical description of growth of fish are important informations for the field of fish stock assessment and fisheries management (Morales-Nin, 2000; Mehanna, 2001; Cadima, 2003; Lombarte *et al.*, 2003). The growth parameters obtain from fitting the observed growth data into the mathematical models are the basic data into the analytical models used in assessing and managing the status of the exploited fish stocks (Mehanna, 2001). Other than growth, the rate of mortality, which is cause of change in abundance of fish in any defined population, is also needed for the analytical stock assessment models, in which most of the mortality estimation models are also required growth parameters as the inputs. This study, therefore, firstly aims to examine growth parameters based on the otolith studies. The obtained growth parameters, then, further used for estimation of mortality rates and

examining the optimum length at first capture and fishing pressure of *R. kanagurta* in the Eastern-GoT for further recommendation to the wise-use of the resource.

Materials and methods

Fish sampling and otolith preparation

The samples of *R. kanagurta* were collected from the fish landing sites along the Eastern Gulf of Thailand (Fig. 1). Total length, body weight and sex of 103 individuals were recorded and the sample size distribution was showed in Figure 2. The pair of otolith (i.e. sagitta) from individual sample was extracted. Each sagitta was rinsed with water, cleaned from adhering tissue, dried and stored in plastic micro-centrifuge tubes. Then, each sagitta was embedded in epoxy resin. Each embedded sagitta was cut through the mid-plane, i.e. a transverse section, by using a slow-speed diamond wheel saw (SBT650, South Bay Technology), which continuously lubricated with coolant solution. The sections were polished down using silicon carbide paper (P2000 to P2500), rinsed with distillate water, until primodium was found. The right sagitta of each individual sample was used for ageing, meanwhile the left one was kept as spare if the right sagittal was broken or unreadable.

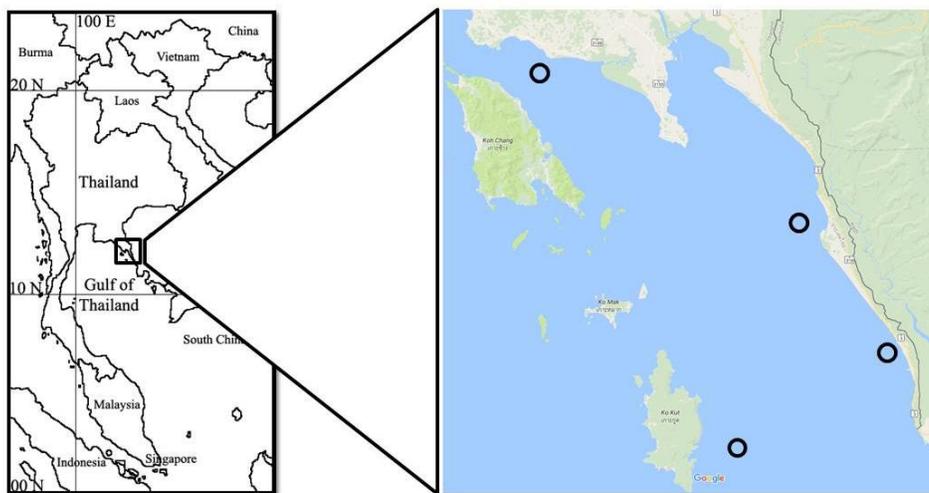


Figure 1. Collected locations (○) of *Rastrelliger kanagurta* in the Eastern Gulf of Thailand

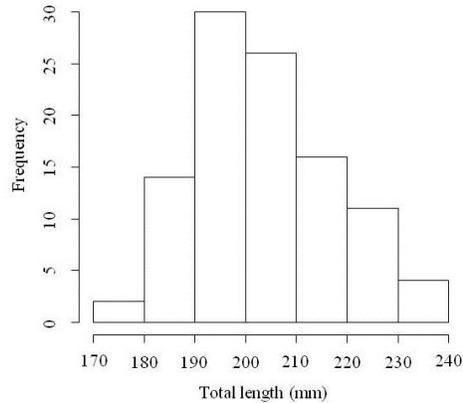


Figure 2. Sample's size distribution of *Rastrelliger kanagurta* from the Eastern Gulf of Thailand

Fish ageing

The sagitta sections (in total 103 samples, Fig. 2) were observed through a compound microscope at $\times 4$, $\times 10$ and $\times 40$ magnification. At the highest magnification, the sagitta was taken photograph with a digital camera (ZEISS, AxioCam ERc 5s). The captured image was then used for daily ring count by using ImageJ program (Rasband, 2016). The age (days) of the individual fish (\hat{T}) was, then, estimated by the following equations

$$\log_e \left(\frac{dl}{dt} \right) = \alpha - \beta l + \varepsilon, \text{ and}$$

$$\hat{T} = (e^\alpha \beta)^{-1} (e^{\beta L} - 1),$$

where, dl is the distance along the counting area, dt is the number of daily ring between the distance between counting area, l is the distance from otolith core to mid sampling area, L is the total distance from core to edge, α and β are the coefficients of the regression equation (Morales-Nin, 1992).

Age and growth analysis

The length-at-age dataset of *R. kanagurta*, from otolith reading, was fitted by using non-linear least-squares to estimate the growth parameters *viz.*, the asymptotic length (L_∞), and the growth coefficient (K). Then, the growth equation of *R. kanagurta* was presented by the von Bertalanffy's growth function (VBGF; Bertalanffy, 1938).

$$L_t = L_\infty(1 - e^{K(t-t_0)}),$$

where, L_t is the length at time t . t_0 is the age when the fish would have had length zero.

The growth performance index (ϕ), a species-specific parameter to indicate the unreliability in the accuracy of estimated growth parameters was calculated with function as,

$$\phi = \log_{10}(K) + 2 \log_{10}(L_\infty).$$

Mortality, exploitation rates and relative yield per recruit analysis

The total mortality rate (Z) was calculated by Hoenig's formula (Hoenig, 1982) as,

$$Z = \frac{1}{(c_1 \times (T_{max} - T_c))}$$

where; t_{max} is the maximum age in years, t_c is mean age at first capture and c_1 is a function of the sample size from which t_{max} was estimated (pre-programmed in FiSAT II (Gayani *et al.*, 1996)).

Natural mortality rate (M) from Pauly's empirical formula (Pauly, 1980) which incorporated the growth parameters and taken mean temperature into account (set as 29.17 °C in this study).

$$\ln(M) = -0.0152 - 0.279 \ln(L_\infty) + 0.6543 \ln(K) + 0.463 \ln(T),$$

where; L_∞ is the asymptotic length, K is the growth coefficient and T is the mean annual habitat temperature.

The fishing mortality rate (F) was determined by subtracting M from Z . The exploitation rate (E) was calculated using the formula $E = F/Z$. The relative yield per recruit analysis (Y'/R), introduced by Beverton and Holt (1957) as the alternative of yield per recruit model, suggested by Gulland (1969), is used to examine the optimum fishing intensity, which required less input parameters and can be written as,

$$Y'/R = EU \frac{M}{K} \left\{ 1 - \frac{3U}{(1+m)} + \frac{3U^2}{(1+2m)} + \frac{3U^3}{(1+3m)} \right\}$$

where, $U = 1 - (L_c/L_\infty)$, L_c = length at first capture, $m = (1-E)/(M/K) = (K/Z)$

Results

Age composition of *R. kanagurta* samples from the Eastern GoT, ranged from size 175-235 mm (Fig. 2), was between 0.44 and 1.25 years old, with average 0.78 ± 0.18 years old. The VBGF was fitted to size of length-at-age data using non-linear least-squares, which yielded the L_{∞} as 214.37 mm. Meanwhile, the curvature (K) parameter of the VBGF was 4.24 yr^{-1} (Table 2; Fig. 3). The ϕ -values was 3.29, as also showed in Table 2.

Total mortality rate (Z) was estimated at 6.09 yr^{-1} by the Hoenig' formula. Natural mortality (M)- and fishing mortality (F)- rates were 2.70 and 3.39 respectively (Table 2). The M/K value, which will used as the input parameter for the relative yield per recruit analysis was 0.64 and the current exploitation rate (E) was 0.56 (Table 2) respectively.

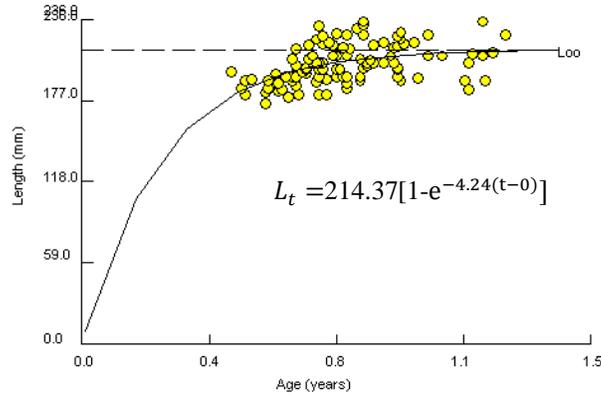


Figure 3. The von Bertalanffy growth model of *R. kanagurta* in the Eastern Gulf of Thailand

Table 2. Estimated population parameters of *R. kanagurta* in the Eastern Gulf of Thailand

Population parameters	Result
Asymptotic length (L_{∞}) in mm	214.37
Growth coefficient ($K \text{ yr}^{-1}$)	4.24
Growth performance index (ϕ)	3.29
Natural mortality ($M \text{ yr}^{-1}$)	2.70
Fishing mortality ($F \text{ yr}^{-1}$)	3.39
Total mortality ($Z \text{ yr}^{-1}$)	6.09
Exploitation level (E)	0.56
Sample size (N)	103

The relative yield per recruit as a function of length at first capture (L_c) and M/K value was estimated for *R. kanagurta* in the Eastern part of Thailand and the results were showed in Fig. 4. The results indicated that, at the present situation, the relative yield per recruit was estimated to be around 0.10 g with the maximum exploitation rate (E_{max}) at 0.49, which implied that the present level of exploitation rate (0.56) was higher than both E_{max} and the exploitation rate with maintain 50% of the stock biomass as spawning stock ($E_{0.5}$) at 0.32.

The graphically relative yield per recruit isopleths diagram of *R. kanagurta* from the Eastern Gulf of Thailand was showed in Fig. 5. From the diagram, it is suggested that a suitable L_c of *R. kanagurta* was between 150.06 and 214.37 mm. Meanwhile the fishing pressure, i.e. E -value, should have been between 0.60 and 1.00 yr^{-1} , which consequently indicated that the F -value should lied between 3.65 and 6.09 yr^{-1} . Under this condition, the Y^*/R was estimated to be closely the maximum Y^*/R .

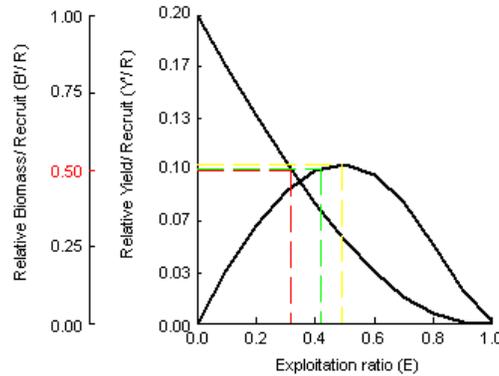


Figure 4. Two dimension relative yield per recruit of *R. kanagurta* from the Eastern Gulf of Thailand.

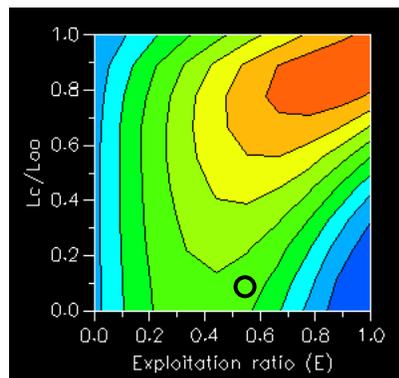


Figure 5. Relative yield per recruit isopleths diagram and the actual value (o) of *R. kanagurta* from the Eastern Gulf of Thailand.

Discussion

Information on age and growth of fishes are important input data for fish population dynamic, stock assessment and fisheries management (Morales-Nin, 2000; Campana, 2001; Mehanna, 2001; Cadima, 2003; Lombarte *et al.*, 2003). The study on age and growth in tropical fishes was commonly performed by length frequency data, i.e. length based calculation, because the difficulty of identifying age and growth directly on otolith or other hardpart of tropical fishes (Srinoparatwatana, 2009). However, the length based method *per se* required continuous data, i.e. at least 12 months of data collection, and also needed high number of fish samples. In addition, the length based method also difficulty to proceed, according to complexity of assessed protocols (Hoenig *et al.*, 1987). Nonetheless, challenging by the advance technique, such as cutting machine, high resolution microscope and computer program, the age based calculation in tropical fishes was increased rapidly (Campana, 2001). In this study, age calculation of *R. kanagurta* can be performed by polishing the thin cross-section otoliths of *R. kanagurta* with micro-sand paper until daily ring was appeared. Then, the ageing method based on increment thickness, coupled with the ImageJ picture analysis program, was applying to calculated age of individual fish.

The growth performance indice (ϕ) from this study (3.29) was lied within other ϕ -values from both age and length based calculation, i.e. 2.76-3.31 (Lavapie-Gonzales *et al.*, 1997; Mehanna, 2001; Al-Mahdawi and Mehanna, 2010; Sumontha *et al.*, 2010; Thongsila *et al.*, 2012), implying that the estimated growth parameters were reliable. The mortality rates, obtained in this study, were similarity with the study from the whole Gulf of Thailand, i.e. $Z=5.32 \text{ yr}^{-1}$, $M=2.56 \text{ yr}^{-1}$ and $F= 2.76 \text{ yr}^{-1}$ (Thongsila *et al.*, 2012) but Z and F were slightly lower than the study from the Andaman Sea, $Z=8.18 \text{ yr}^{-1}$, $M=1.40 \text{ yr}^{-1}$ and $F= 6.78 \text{ yr}^{-1}$ (Sumontha *et al.*, 2010). The difference mortality rates in these two areas were caused by different stocks with different fishing pressure and consequent to the population parameters.

Pauly and Soriano (1986) used four-quadrant models to describe fish yield related to fish size. Quadrant A represents under fishing ($L_c/L_\infty=0.5-1.0$ and $E=0.0-0.5$). Quadrant B represents eumetric fishing ($L_c/L_\infty=0.0-0.5$ and $E=0.0-0.5$). Quadrant C represents developed fishery ($L_c/L_\infty=0.0-0.5$ and $E=0.5-1.0$). Quadrant D represents overfishing ($L_c/L_\infty=0.0-0.5$ and $E=0.5-1.0$). The relative yield per recruit isopleths of *R. kanagurta*, in this study, showed the position of actual value of *R. kanagurta* in the area of quadrant D (Fig. 5), since the ratio of L_c and L_∞ was 0.14 and the exploitation rate (E) was 0.56. The fishing characteristic in the quadrant D was explained by the small fish were

caught at high effort levels and the possible management regime for this quadrant were increase size at first capture (L_c) and decrease fishing pressure, i.e. E -value (Pauly and Soriano, 1986).

From the results, the possible fisheries management regime, for *R. kanagurta* stock in the Eastern-GoT, is increase size at first capture (L_c) and decrease fishing pressure, i.e. E -value. From this study, the length at first capture (L_c) between 150.06 and 214.37 millimeters and the 0.50 optimum level of exploitation (E) suggested by Gulland (1971) were recommend. Meanwhile the length at first maturity, spawning biology and the regulation for protect mature parental stock during spawning season need to further investigate for sustaining the *R. kanagurta* stock in this fishing ground.

Acknowledgement

The authors would like to thank to the Rambhai Barni Rajabhat University (RBRU) for funding for this study.

The authors would like to offer particular thanks to the students at the aquaculture technology program, Faculty of agricultural technology, Rambhai Barni Rajabhat University, responsible for the field and laboratory work.

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(Received: 9 October 2017; accepted: 25 November 2017)