PAPER • OPEN ACCESS

The dynamic system analysis of lemuru fishery in Bali strait by using biological parameter yield of some surplus production models

View the article online for updates and enhancements.

The dynamic system analysis of lemuru fishery in Bali strait by using biological parameter yield of some surplus production models.

Georgina Maria Tinungki, Nasrah Sirajang

Department of Mathematics, Faculty of Mathematics and Natural Science, Hasanuddin University, Jl Perintis Kemerdekaan KM 10, Tamalanrea, Makassar, Indonesia

Abstract. Stock assessment in any fisheries scientific study is an effort to determine the productivity of fishery resource, the effect of catch on resources and changes in catch patterns, for example due to implementation of management and development policies. It involves 3 (three) main aspects: the first, determine total biomass by using surplus production model; the second, determine recruitment (the number of fish that has reached the age during one recruitment season) can use Ricker model; the third, determine the equation of growth in the fishery can use Von Bertalanffy model. Mathematical models are mostly used to describe the dynamics of fish populations. In the use of appropriate models in stock assessment will result in a more appropriate basis in selecting fishing methods and advanced analysis of catches, hence required a plan in the sustainable management and utilization of fish resources. The study of sustainable dynamic of lemuru fisheries management in Bali strait is the dynamics of biomass of lemuru fishery by using the biological parameters yield of some surplus production models. By obtain the biological parameter values r, q and K, we obtain the dynamic trajectory between biomass and time, indicates that at the first year of observation, the biomass level is relatively high, but when several years later the biomass tends to decrease until it reaches the stable of biomass obtained for about 30 years and so on (t > 30).

1. Introduction

The main objective of this study was to analyze the dynamics of lemuru fishery biomass in Bali strait by using the biological parameter yield of some surplus production models [1]. Generally, the Surplus Production Model is used in fish stock assessments because this model group can be estimated only by using catch data and available efforts in common [2]. It ignores the complicated biological processes in a fish stock by assuming that the stock can be treated as aggregate biomass [3]. When all other factors remain constant, aggregate biomass from a fish stock will decrease as pressure is made on the resource by increases catch effort [4]. The surplus production model is a popular model in fisheries literature and has been used for over forty years [5]. This is due to not only is the model relatively simple to calculate, but it also requires only catch data and catch efforts time series as it available in most fishing centers [6].

In fact, according to [7], as the Graham-Schaefer model that not all biomass follows logistical growth. In this matter, the decrease of catch per unit effort ($CPUE_t$) yield against catch effort (E_t) follows the linear regression pattern, and the relationship between the catch yield and the symmetric parabolic-shaped biomass with the peak point (maximum) at the biomass level of *K/2* [8]. So, the Fox Model [9] has several different characteristics from the Graham-Schaefer model that the growth of biomass follows the Gomperz growth model and the decrease of *CPUE* against the catch effort [10].

[11] argues that the surplus production model as constructed by Graham (1935) and completed by Schaefer (1954) called as the Graham-Schaefer Method (1954) or logistic production models play an important role in the dynamics of fishery population. This model still has a disadvantage in which a model with only two parameters cannot predict three biological parameters so that there are several other surplus production models that can predict these three parameters [12]. [13] argues that *CPUE* is not only determined by the current catch effort (as in the Graham-Schaefer model) but also by the previous catch effort. Gulland assumes that there is a relationship between abundance and previous efforts, when recruitment and natural mortality is constant.

[14] completely abandoned the special properties possessed by the Gaham-Schaefer model, that by inserting a variable *m* into the Graham-Schaefer model, it would mean that *MSY* can be generated from various biomass sizes varying from *0* to *K*, where X_{opt} = *K/2*. [1] model is known as a different model because the use of a simple differential equation from the Schaefer model. The difference between the Walters and Hilborn models and the Schaefer is the Walters and Hilborn models using discrete versions of the biological model. In fact, this model can also show what is known in mathematical form as a *chaotic* behavior for a large value of *r* [15]. Moreover, the behavior of model is as true as the Schaefer model, especially for the low rates of *r*, *q* and *E* [16].

[15] provides a dynamic time model ("*discrete in time*"), and stochastic in which it contrary to the Graham-Schaefer model that is static time and deterministic and continuous. Thus, [15] reconstituted the surplus production model in the form of dynamic, time-specific and stochastic models, which made it superior to the traditional Graham-Schaefer model [17]. The Clarke Yoshimoto Pooly (CYP) (1992) model estimates the biological parameters of *r* (natural growth rate), *q* (catch capability coefficient), and *K* (environmental carrying capacity). Reliable and realistic model that can describe *Maximum Carrying Capacity* (MCC), and *Maximum Sustainable Yield* (MSY) and other variables related only Cushing's model, where CPUE   is obtained from CPUE of sustainable surplus production model [12].

2. Materials and Methods

This study is a desk study using primary and secondary data. Primary data were obtained from direct interviews with local fisheries,in Bali on May 2013. While, secondary data were obtained from Central Bureau of Statistics, and other related institutions. The method used is dynamic system approach, which is able to analyze a system dynamically and change according to time.

2.1. The Aplication of Fishery Population Dynamic Equation

Following [11] in analyzing dynamic systems is not necessarily quantitative analysis because by conducting qualitative analysis, the nature of dynamic equations and its stable can also be studied with graphic assistance that will be very helpful in analyzing the dynamic model qualitatively.

For example, the dynamics function of the fish resources stock is often written as a model called the *lumped* parameter model in which fish stock (*X*) is often written as:

$$\frac{dX}{dt} = \dot{X} = F(X) \tag{1}$$

The most common example of this model is logistic model or Verhulst, where the above model is written as:

$$\dot{X} = rX\left(1 - \frac{X}{K}\right) \tag{2}$$

Where :

   r   = growth rate (net) and
   K   = carrying capacity

The above equation can be described as follows:

As figure 1, it appears that stock (*X*) will grow (X > 0)

- On interval 0 < X < K. This is indicated by the arrow to the downward right of the *F(X)* curve.

- On the contrary, in region where $X > K$, function X will decrease so that the stock will also decrease. This is indicated by the arrow of upward left of the $F(X)$ curve.
- Point $X = K$ is called the equilibrium point. In this case the function $F(X)$ will also be equilibrium at $X = 0$. From these two equilibrium points, only at $X = K$ the equilibrium will be stable (indicated by the opposite arrow counter) [11].
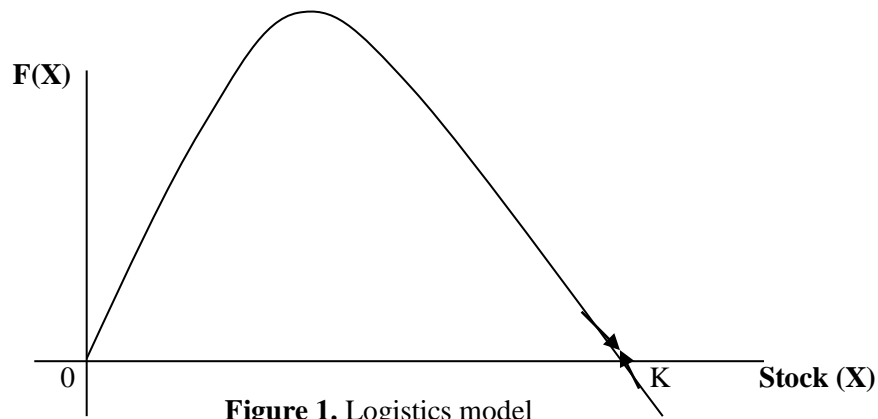

Figure 1. Logistics model

An example of a logistic curve with the equation : $\dfrac{dX}{dt} = aX - bX^2 - y$ can be depicted in Figure 1

In figure 1, the logistic curve with the equation : $\dfrac{dX}{dt} = aX - bX^2 - y$,

where :

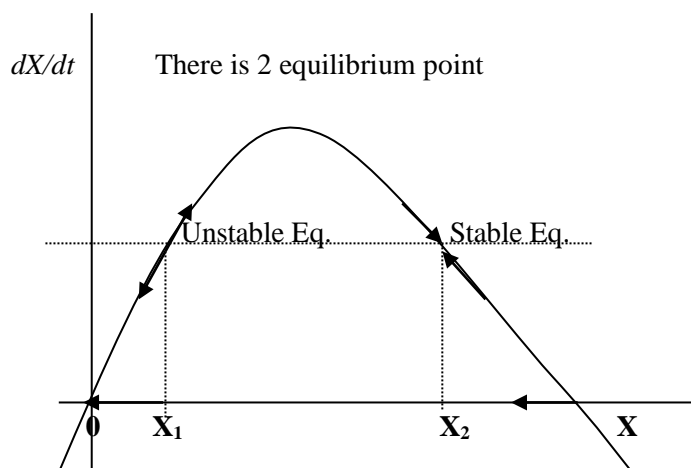|				
$0 < X < X_1$	: $f(X) < y$	→	$dX/dt \downarrow$ →	$X \uparrow$
$X_1 < X < X_2$	: $f(X) > y$	→	$dX/dt \uparrow$ →	$X \uparrow$
$X_1 > X_2$	: $f(X) > y$	→	$dX/dt \downarrow$ →	$X \downarrow$ (3)

Figure 2. Logistic curves with there are two equilibrium points

2.2. Surplus Production Model

The surplus production model is a method that can be used in estimates fish stock, by using catch yield data, which require simple data containing one variable that is Y_t in ton/year as independent variable,

and E_t in days/year as dependent variable. In addition, there are three parameters of the natural growth rate r, the carrying capacity K and the catch capability coefficient q.

Also, this model is used in estimating the size of population, based on the large of catch yield for a particular catch effort in water. It can depict the presence of fish stocks in the past and can predict future yield based on catch per unit effort ($CPUE_t$) data. In determining the optimum level of effort, efforts that can produce a maximum sustainable yield catch without affecting long-term stock productivity. The surplus production model to be examined in this case is an overall stock, total effort and total catch yield obtained from the stock, without including details of such things as growth and mortality parameters or the effect of mesh size on aged fish captured other.

The surplus production model allows for an analysis where little information, especially on yields, stock abundances, and the amount of fishing available. Unfortunately, these models cannot be adapted to detailed biological information about the fish in question, or provide detailed advice on fishing patterns. The estimation of optimum catch effort (E_{opt}) and maximum sustainable catch (MSY) is approximated by the Surplus Production Model, as it is known that between catch per unit effort ($CPUE_t$) and effort can be either linear or exponential (Gulland, 1983).

The Surplus Production Model consists of two basic models: the Schaefer Model (linear relationship) and the Gompertz Model as developed by Fox (exponential relationship) (Gulland, 1971). With parameters and variables as defined previously, the procedures for estimating the parameters as described by Schaefer, Fox, Gulland, Pella & Tomlinson, Walter & Hilborn, Schnute and Clarke, Yoshimoto and Pooley are as follows :

Schaefer   : $U_t = a - bE_t$

Where a = qK and b = q²K/r

Fox   : $ln\ U_t = a - bE_t$
Where a = ln(qK) and b = q/r

Gulland   : $U_t = a + b\overline{E}_t$

Where a = qK and b = q²Kr

Pella & Tomlinson: $U_t = a - bE^{m-1}$,

Where a = qK, b = qᵐK / rᵐ⁻¹

Walter & Hilborn : $$\frac{U_{t+1}}{U_t} - 1 = r - \frac{r}{Kq}U_t - qE_t$$
Where $a = r$ and $b = r/qK$

Schnute   : $ln\ (U_{t+1}/U_t) = a + b[(U_t+U_{t+1})/2]-c[(E_t+E_{t+1})/2]$
Where $a = r$, $b = rqK$ and $c = q$

CYP   : $ln(U_{t+1}) = a\ ln\ (qK) + b\ ln(U_t) - c(E_t + E_{t+1})$

Where a = 2r/(2+r), b = (2+r) and c = q/(2+r)

Cushing   : $ln\ (S_{t+1}+Y_t) = ln\ a + b\ ln\ S_t$;

Where $a>1$ and $0<b<1$ (4)

3. Results and Discussions

The Dynamic System Analysis of Lemuru Fishery in Bali Strait

Fishery resources are dynamic natural resources as explored in the preceding section, resulting in the dynamics of biomass from lemuru fisheries in Bali strait by using the biological parameters yield of some surplus production models as follows:
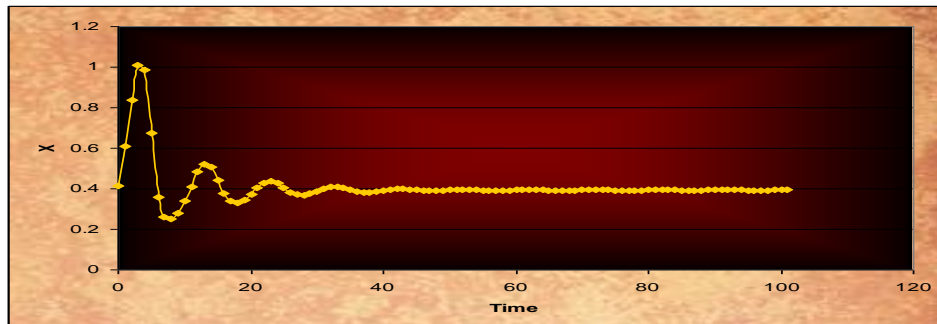
1. Schaefer model

Figure 3. Dynamic trajectory of fish biomass (vertical axis, X_t) (100.000 tons) of lemuru in   Bali strait, Year (horizontal axis/time), Schaefer model 2013-2017.

In figure 3, shows equilibrium after almost 30 years, at a production rate less than 40.000 tons, it is obtained by entering the following initial values:

$$X_0 = \frac{h}{qE} = 481.762,047 \text{ ton} \qquad \rightarrow \text{ initial value}$$

$$X_t = (1+r)X_0 - rX_0^2 \qquad \rightarrow \text{ biomass at time } t$$
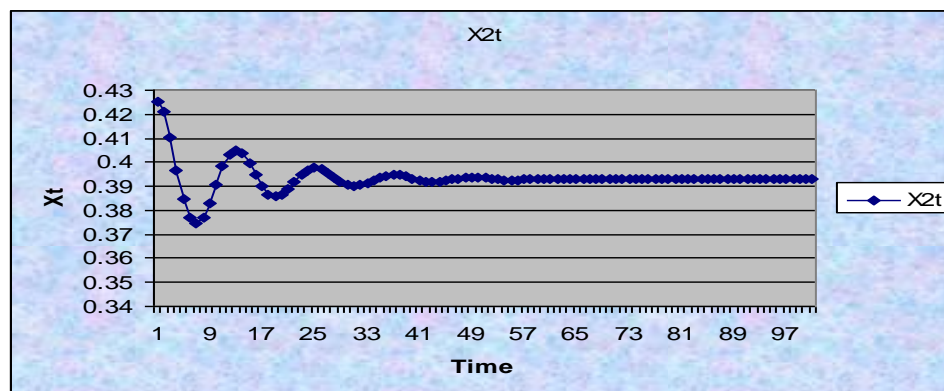
2. Fox model

Figure 4. Dynamic trajectory of fish biomass (vertical axis, X_t) (100.000 tons) of lemuru   in Bali strait, Year (horizontal axis/time), Fox model 2013-2017.

In figure 4, shows equilibrium after almost 40 years, at a production rate less than 40.000 tons, it is obtained by entering the following initial values:

$$X_0 = \frac{h}{qE} = 31.349,894 \text{ ton} \qquad \rightarrow \text{ initial value}$$

$$X_t = (1+r)X_0 - rX_0^2 \qquad \rightarrow \text{ biomass at time } t$$
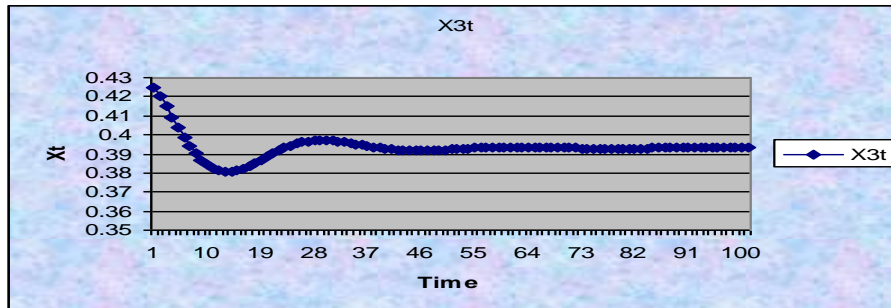
3. Schnute model

Figure 5 Dynamic trajectory of fish biomass (vertical axis, X_t) (100.000 tons) of lemuru in Bali strait, Year (horizontal axis/time), Schunte model 2013-2017.

In figure 5, shows equilibrium after almost 40 years, at a production rate less than 39.000 tons, it is obtained by entering the following initial values:

$$X_0 = \frac{h}{qE} = 201.415,62 \ \text{ton} \quad \rightarrow \quad \text{initial value}$$

$$X_t = (1+r)X_0 - rX_0{}^2 \quad \rightarrow \quad \text{biomass at time } t$$
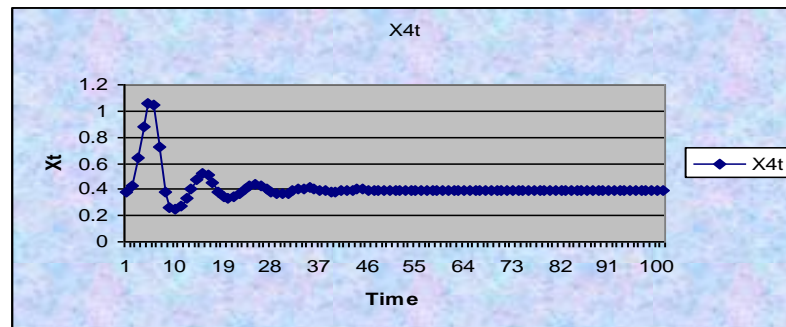
4.   Walter-Hilborn Model

Figure 6. Dynamic trajectory of fish biomass (vertical axis, X_t) (100.000 tons) of lemuru in Bali strait, Year (horizontal axis/time), Walter-Hilborn model 2013-2017

In figure 6, shows equilibrium after almost 30 years, at a production rate less than 40.000 tons, it is obtained by entering the following initial values:

$$X_0 = \frac{h}{qE} = 797.676,16 \ \text{ton} \quad \rightarrow \quad \text{initial value}$$

$$X_t = (1+r)X_0 - rX_0{}^2 \quad \rightarrow \quad \text{biomass at time } t$$
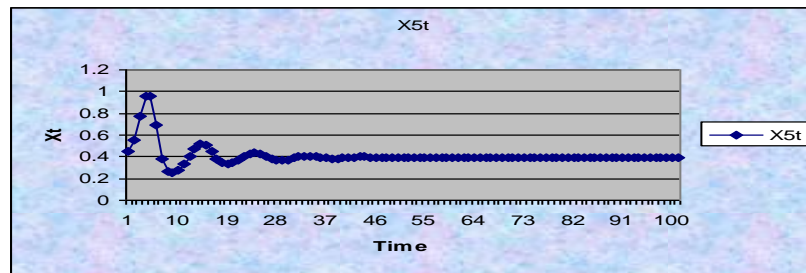
5.   Clarke Yoshimoto Pooly Model

Figure 7. Dynamic trajectory of fish biomass (vertical axis, X_t) (100.000 tons) of lemuru in Bali strait, Clarke Yoshimoto Pooly model   2013-2017.

In figure 7, shows equilibrium after almost 30 years, at a production rate less than 40.000 tons, it is obtained by entering the following initial values:

$$X_0 = \frac{h}{qE} \;=\; 76.355{,}682 \text{ ton} \qquad \longrightarrow \quad \text{initial value}$$

$$X_t = (1+r)X_0 - rX_0^{\,2} \qquad\qquad \longrightarrow \quad \text{biomass at time } t$$
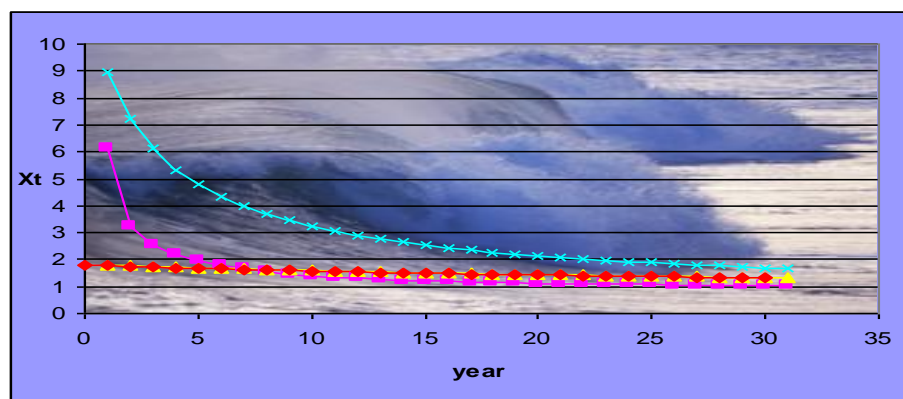

Figure 8. The Graph of dynamic trajectory of Lemuru fish stock in Bali strait, 2013-2017.

The results show that the most statistically appropriate model for estimating biological parameters in Bali strait are the Fox and CYP models. This is in line with previous studies related to fish resources in tropical regions such as Indonesia, the use of Fox and CYP models is considered the most appropriate compared to using other models such as Walters Hilborn and Schnute [3].

4. Conclusion and Recomandation
4.1. Conclusion
In this study, By obtaining the values of biological parameters r, q and K, then the dynamic trajectories between biomass and time are shown in Fig. 9 which is, that at the beginning of the first year of observation, the biomass of 105..000 tons is relatively high, but when several years later biomass appears to decrease until then reach a stable biomass obtained about 30 years and so on (t > 30) at a biomass level of about 27.000 tons/year, can be seen at figure below which shows equilibrium after almost 30 years.
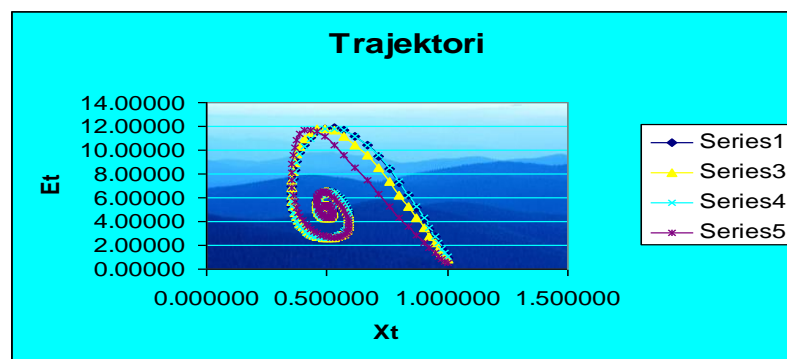
Figure 9. The relationship of fish stock (X_t (100.000 tons)) with catch effort (E_t) of Lemuru fishery in Bali strait, 2013-2017.

In figure 9, it shows that if catch effort is increased, then the trajectory toward balance will be faster (from blue to red). Appear stable focus on the fish stock level of 50.000 tons, while the catch effort is more than 40.000 days.

4.2. Recommendation

This study still needs further research focusing on the the biological parameter dynamics of any fish species present in these for sustainable management. In addition, there should also be an optimal measurement of input and output for each species of fish in the Bali strait , so that the management can be directly conducted on each species of fish to obtain the optimal and sustainable conditions.

REFFERENCES

[1]   Wudianto 2001 *Analisis Sebaran dan Kelimpahan Ikan Lemuru di Perairan Selat Bali: Kaitannya Dengan Optimasi Penangkapan*. Dissertation. Program Pascasarjana-IPB. Bogor. [Indonesian]

[2]   Saha A K, Setegn S G 2015 *Ecohydrology for sustainability of IWRM: A tropical/subtropical perspective. In: Sustainability of Integrated Water Resources Management* Springer, Switerzerland.

[3]   Tinungki G M 2005 *Evaluation of Production Model in Expecting Maximum Sustainable Yield to Support Lemuru Fisheries Management Policy in Bali Strait* Dissertation. Institut Pertanian Bogor, Bogor. [Indonesian].

[4]   Anna Z 2017 *BIODIVERSITAS journal* **18** (4) October 2017 p. 1468-1474.

[5]   Ghofar A and Mathews C P 2000 The Significance of Environmental Information in The Management of Oil Sardine Fishery in the Bali Strait. *Workshop on Inter-annual Climate Variability and Pelagic Fisheries* Noumea, New Caledonia.

[6]   Asep Sholahuddin 2015 *The Application of ANN-Linear Perceptron in the Development of DSS for a Fishery Industry* Journal Elsevier, Available online at www.sciencedirect.com.

[7]   Widodo 1986-1987 *Models of Population Dynamics for Fisheries*. A Serial Seminars Published by Oseana. Jakarta.

[8]   King R S Tsai C M 2017 *Sustainability* **9** (8) p.1387.

[9]   Fox W W 1970 *Trans. Am. Fish. Soc.*, **99** (1) 80-88.

[10]   Mace P M 2001 *A New Role for MSY in Single Species and Ecosystem Approaches to Fisheries Stock Assessment and Management*. National Marine Fisheries Service, Woods Hole, MA, USA.

[11]   Fauzi A 2001 *An Econometric Analysis of the Surplus Production Function: An Application for Indonesian small pelagic fishery*. IPB Darmaga Bogor.

[12]   Tinungki G M, Boer M, Monintja D R, Widodo J, Fauzi A 2004 *Jurnal Ilmu-ilmu Perairan dan Perikanan Indonesia* **11** (2) 135-138. [Indonesian]

[13]   Walters C and Hilborn R 1976 *Journal Fish Resource. Board Can* **33** 145-159.

[14]   Anderson L G, Seijo J C 2010 *Bioeconomics of Fisheries Management* John Willey and Sons,
           New York, USA.
[15]   Schnute J 1977 *J. Fish. Res. Board Can* **34** 583-663.
[16]   Anurani P, Andreas L, Wendel K, Chris F, Peter D, John G, Tom J 2015 *Polar Biol* **38** 651-664.
[17]   Anna Z 2016 *Marine and Fisheries Socio-Economi Journal* **11**(2) 161-172. [Indonesian].