Using Yield per Recruit Analysis to Determine Fish Stock Status

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During the past decade, the fishing industry in Southeast Asia had been confronted with concerns on declining fishery resources due to overfishing, and more particularly because of the continued practice of illegal, unreported, and unregulated (IUU fishing) as well as degradation of the habitats that bring about negative impacts to the economic, social and ecological attributes of fisheries affecting food security. It has therefore become necessary that management measures should be established for the sustainable management of the fishery resources in general. However, attempts to establish such fisheries management measures have encountered problems on inadequacy of data for stock assessment that hinder the efforts to develop such measures. During discussions on the sustainable utilization and management of fishery resources in the Southeast Asian region, the need to improve data collection had always been raised on various occasions for the development of appropriate management measures of the fishery resources. Many studies have indicated that the use of Yield per Recruit Analysis could be an option in determining fish stocks, especially in situations where historical data in time series is insufficient. In this connection, a pilot study using Yield per Recruit Analysis was carried out in Sakon Nakorn Province, Thailand, to determine the stock status of the beardless barb in Nam Oun Reservoir. Results of such study could be used as model in the development of the appropriate management measures for the sustainability of the fishery resources of Southeast Asia.

In Southeast Asia, insufficiency of fisheries data is one of the main concerns in fisheries management and stock assessment (FAO, 2010). In a review of the information and data available during a regional workshop organized in 2009 by the WorldFish Center, FAO and SEAFDEC, and participated in by representatives from the ASEAN Member States (AMSs), it was noted that problems on data availability for short-time assessment were observed not only for cartilaginous fish stocks such as sharks but also for bony fish stocks. During the series of consultations organized by the SEAFDEC Training Department (TD), it was recommended that the "Yield per Recruit Analysis or Y/R Analysis" could be used to monitor the stock status of fishery resources in the Southeast Asian region considering the insufficiency of time series production data.

There are several models and concepts that could be adopted to determine the biomass of certain fish stocks, the most popular of which is the "Prediction Model" (Sparre and Venema, 1998), which involves predicting the stock biomass using a mathematical model that generates the possible number of catch, biomass and other related mortality parameters in the future based on the currently available data including economic data, such as price. For some models, the direct link between fish stock assessment and fish resource management as well as economic management, is eminent. The first Prediction Model proposed by Thompson and Bell in 1934 considered many assumptions but needed more data inputs. So, the model was not highly popular until computers were introduced. In the meantime, a simpler model known as "Yield per Recruit Analysis" was introduced by Beverton and Holt in 1957. Based on strict assumptions and requires less calculation, this model is more convenient to use in real situations. In this model, 'yield' refers to the amount of utilized fishery resource that focuses only on target species, different from 'catch" which includes yield, bycatch and catch from ghost fishing.

Yield per Recruit Analysis

Sparre and Venema (1998) provided the assumptions for the Yield per Recruit Analysis (Y/R Analysis) as shown in **Box 1**, and considered that during the early life span of fish, it is hatched from eggs in large numbers at the same time and also enter the fishing ground at the same time, as well as at the same age during recruitment (T_r). This is represented as "number of recruitment" or "R" while the rapidly increasing number is called "knife-edge recruitment" as shown in **Fig. 1**. During such time, R can

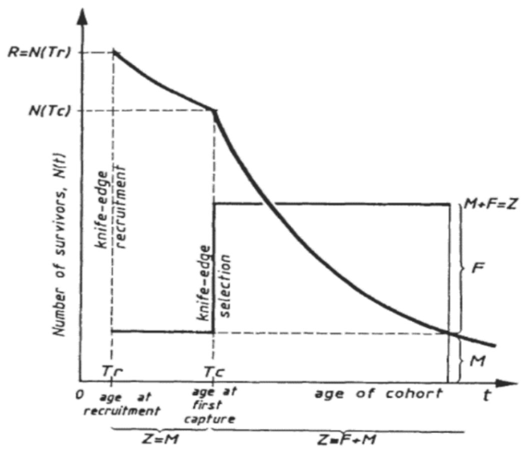

Fig. 1. Knife-edge pattern as knife-edge recruitment (*dashes*) and knife-edge selection (*dark line*) (Adapted from Sparre and Venema (1998))

Box 1. Assumptions used for the Yield per Recruit Analysis (Sparre and Venema, 1998)
• Fish population is assumed to be exploited in steady state
• Every individual in the same unit stock is assumed to be hatched at the same date and time, also called 'same cohort'
• Recruitment and selectivity patterns are 'knife-edge' also called 'big bang recruitment pattern' wherein the large number of recruitment will enter the fishing ground at the same time and the number of fish size in the selectivity range will increase rapidly at the same time
• During exploitation stage, natural mortality (M) and fishing mortality (F) are constant so that the environmental condition and fishing effort should be constant
• Fishing mortality will change naturally depending on the size and age of fish but there will be very minor change in the low selectivity gear such as trawlers
• There is a perfect random mixing within stocks, where the individual born in the early and late hatching period is assumed to be the same cohort by ignoring the length of that period
• Isometric growth pattern is observed directly from the length-weight relationship equation, $W=qL^b$, when b = 3, but it is also possible to use species having allometric growth pattern (b ≠ 3), in which case the equation could be adjusted in terms of some values using some mathematical methods

be decreased only by natural mortality (M), generating in the process the number of the remaining stock which is shown as "N". After the fish gets bigger reaching a size at first capture (L_c) and age at first capture (T_c), N will be affected by fishing pressure, and the mortality of fish will become Z (total mortality) which is equal to M (natural mortality) + F (fishing mortality) causing rapid decrease of the stock, known as "knife-edge selection."

To determine the Yield per Recruit (Y/R), Beverton and Holt (1957) developed the Y/R equation which requires weight and age-based biological parameters together with mortality parameters as shown below:

$$\frac{Y}{R} = Fe^{(-M(t_c-t_r))}W_\infty\left[{}^{1}/_{Z} - {}^{3S}/_{(Z+K)} + {}^{3S^2}/_{(Z+2K)} - {}^{S^3}/_{(Z+3K)}\right]$$

Where Z=Total mortality (F+M per year);
F=Fishing mortality (per year);
M=natural mortality (per year);
t_c=age at first capture (year);
t_r=age at first recruitment (year);
W_∞=asymptotic weight (g); and
S=constant, which is derived using the equation:

$$S = e^{K(t_c-t_0)}$$

Where K=curvature parameter (per year),
t_c=age at first capture (year), and
t_o=hatching period (year)

The result of the Y/R equation could be interpreted as the yield (measured in weight) per number of recruitment (recorded in number). For example, if 1.0 million fish recruited give a yield about 1,000 metric tons (mt), then 2.0 million fish recruited should give yield of about 2,000 mt or yield of about 1.0 kg per one fish. The graph of Y/R equation reflecting different ages at first capture is shown in **Fig. 2**.

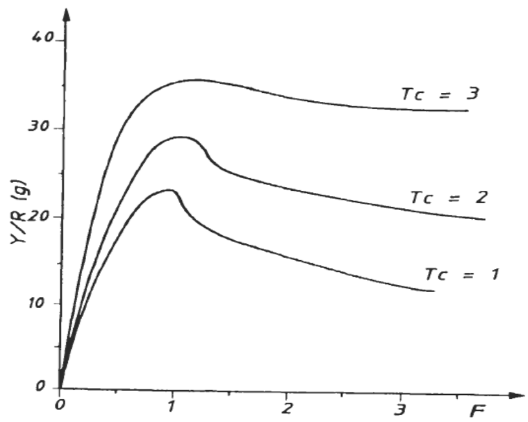

Fig. 2. Different curves of Y/R reflected by different ages at first capture (Adapted from Sparre and Venema (1998))

The graph of the Y/R could be presented in a curve showing the relationship between the yield per recruit (y-axis) and the fishing mortality (x-axis) as shown in **Fig. 3**. The optimum fishing mortality is represented by the Y/R forming a peak of the curve which is the 'MSY' level (Sparre and Venema, 1998). The peak of the curve is reflected by age at first capture (t_c).

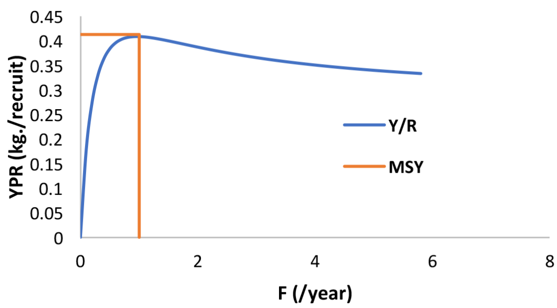

Fig. 3. Yield per recruit curve showing the peak of curve and MSY level

In monitoring the stock status of fishery resources, the main concern raised by fisheries researchers and managers during stock assessment is 'overfishing' which can be divided into two (2) levels, such as:

(1) *Growth overfishing:* Can occur when increase in fishing effort is too high, and fish is caught before they can grow old enough to be considered as a recruitment. Such situation is known as "overfishing in biological concept."

(2) *Recruitment overfishing:* Occurs when the resource reaches 'growth overfishing' but the fishing effort is still maintained or gets higher, and the fish caught gets smaller and the number of parental stock declines. In this level, if no appropriate management measures are in place, the species stock biomass could collapse or becomes extinct from the ecosystem.

In practice, Y/R Analysis is mainly used for evaluating the situation of a stock, *i.e.* whether it is in a state of 'growth overfishing' or not. Nevertheless, considering that data is limited over a long period of time, the occurrence of small amount of yield per recruit could imply that there is 'growth overfishing'. Therefore, Y/R Analysis could be an appropriate tool for this kind of situation and still be able to estimate the stock status and subsequently come up with the necessary management measures.

Y/R Analysis had been used in many studies aimed at determining the fish stock situation. For example, Peixer and Petrere Júnior (2007) mentioned in their study of the South American ray-finned fish "pacu" (*Piaractus mesopotamicus*) in Pantanal, Brazil. As one of the most important target species in Pantanal, Brazil, "pacu" had been reported to be over-exploited in Brazilian waters. Using the biological data and other biological parameters collected from sports fishing and teams of researchers, the length-weight relationship of "pacu" had been developed, while the mortality parameters were derived from fishery statistics during 1999-2000. The results based on the value of F confirmed that "pacu" in Pantanal waters was over-exploited.

In the Y/R study for greasy grouper (*Epinephelus tauvina*) carried out by Barr *et al*. (2010) in the Arabian Gulf waters of Qatar, the results provided that the catch of greasy grouper was over the MSY level. The study also confirmed that the increase in age at first capture is reflected directly with the peak of the Y/R graph and fishing mortality level as well. Therefore, the management strategy for this species of grouper focused on gear selectivity by age and size of target, while the management measure was based on the result of the Y/R Analysis.

In the case study carried out by Barbieri *et al*. (1997) on the Atlantic croaker (*Micropogonias undulatus*), a quick assessment was made by estimating the current F compared with F_{MSY} provided in the Y/R. The results indicated that the different size compositions in different study areas had also affected the result of the Y/R Analysis.

The use of Y/R Analysis is therefore quite useful in situations where the data is limited, such as those in Southeast Asia, as the model requires less input parameters which can be observed and collected easily through annual field surveys. However, this model should be interpreted carefully considering its assumptions while the data inputs should be collected carefully in order to get more significant results. Nonetheless, the Y/R Analysis remains one of the important choices for conducting regional stock assessment as reference point for the development of fishery management measures in the future.

Yield per Recruit Analysis of Beardless Barb (*Anematichthys repasson* (Bleeker, 1853)) in Nam Oun Reservour, Sakon Nakorn, Thailand: A Case Study

In a case study conducted by the SEAFDEC Training Department (TD) for the development of management measure for the beardless barb (*Anematichthys repasson*) in Nam Oun Reservoir, Sakon Nakorn, Thailand, the Y/R Analysis was adopted. Beardless barb is one of the most economically important species in Nam Oun Reservoir.

Beardless barb (*Anematichthys repasson*)

A member of Cyprindae family, this species is mainly distributed in Southeast Asia from Mae Khlong to Maekong River basin in areas between Thailand, Lao PDR, Cambodia and adjacent waters of Myanmar, while its southern range reaches part of Peninsular and Sarawak Malaysia, and Sumatra in Indonesia (Vidthayanon, 2012; Froese and Paully, 2018). This species is usually caught for household consumption and local market by artisanal fisheries. The status and trend of the fisheries of this species have not yet been determined, therefore, this report will be the first stock assessment of the beardless barb in Nam Oun Reservoir, Sakon Nakhorn Province, Thailand.

Based on the findings of Peixer and Petrere Júnior (2007), Y/R Analysis is the alternative model most applicable in cases where long time series data of catch and effort are unavailable. The Y/R equation of Beverton and

Holt Yield (Gulland, 1969, cited in Sparre and Venema, 1998) which explains about the relationship between the number of recruitment (expressed as number) and the possible yield that can be derived after recruitment or when virgin stock grows into exploited stock (as weight), was therefore used to generate the Y/R Analysis in the said case study. Following Sparre and Venema (1998), the result is reflected as the relationship between Y/R and other related models as biomass per recruit and fishing mortality (F) in each level. In this connection, Y/R offers a simple and clear way for managers involved in fisheries to take decisions regarding, for example, the advantages of reducing mortality rates and/or increasing the minimum age of recruitment for fisheries management, as suggested by Holden (1995 cited in Peixer and Petrere Jŭnior, 2007).


Fishing activity in Nam Oun Reservoir (left) and beardless barb yield (right)

Features of the Case Study

This study was aimed at generating the Y/R Analysis to monitor the status of the beardless barb in Nam Oun Reservoir, Sakon Nakhorn, Thailand, the result of which could be used as reference point for fisheries management of this important resource at Nam Oun Reservoir. The study made use of the Nam Oun fishery patrol monthly survey conducted under the collaborative resource enhancement project of the Department of Fisheries of Thailand, Nam Oun Fishery Patrol Unit and SEAFDEC/TD. The biological parameters as asymptotic length (L_∞) and curvature parameter (K), size at first capture, total mortality, and natural mortality were determined using


Data collection for stock assessment study

the FAO-ICLARM Stock Assessment Tool version 2 or FiSAT II (Gayanilo *et al*., 1998). For the age-length key, von Bertalanffy's growth equation was used, as shown below:

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

Where L_t=Length at age t (cm);
L_∞=asymptotic length (cm);
K=curvature parameter (per year);
t=age (year); and
t_o=hatching period (year), which could be calculated using the modified von Bertalanffy equation:

$$t_0 = \frac{1}{K}\ln\left(1 - \frac{L_0}{L_\infty}\right)$$

Where L_o=size at first hatching (cm)

The fishing mortality and natural mortality was derived from the function between monthly total mortality (Z) and total fishing effort. The trend was established using the equation:

$$Z=M+F$$

Where M=natural mortality coefficient (per year);
F=fishing mortality

The yield per recruit as a function of fishing mortality F, was calculated using Beverton and Holt (1957) as shown below:

$$\frac{Y}{R} = Fe^{(-M(t_c-t_r))}W_\infty\left[{}^{1}/_{Z} - {}^{3S}/_{(Z+K)} + {}^{3S^2}/_{(Z+2K)} - {}^{S^3}/_{(Z+3K)}\right]$$

Where t_c=age at first capture (year);
t_r=age at first recruitment (year); and
W_∞=asymptotic weight (g)

Results and Discussion

Growth

The length-weight equation of beardless barb was determined using unseparated sex, the result of which indicated that $W = 0.0351L^{2.908}$. The growth parameters calculated by FiSAT II gave the asymptotic length (L_∞) and curvature parameter (K) as 23.42 cm and 0.33 per year, respectively. The age-length parameter provides the growth curve for each data set which could be used to adjust the size at first capture from the record.

Using the samples of the beardless barb, the computation for age-length parameter indicated 10.04 cm which is a little bit bigger than the size at first maturity reported by Nuangsit and Chansri (2008) which was at 10.02 cm (**Table**). As of the moment however, only the growth parameter is available for this species, and there is still no exact information on age determination for the beardless barb. Therefore, age determination was considered based on the biological parameter, size at hatching time and hatching period, which was used as input in the computation of the age-length equation using the von Bertalanffy's equation.

Mortality estimation

For mortality estimation of the beardless barb, the equation of Jones and van Zalinge (1984) (cited in Sparre and Venema, 1998) was used to determine the total mortality while for natural mortality the equation of Pauly (1980) was used and both functions are presented in FiSAT II. The results showed the total mortality of the beardless barb at 1.88 per year and the natural mortality at 30°C surface temperature was 1.27 per year. However, beardless barb was not included in the species list of Pauly's research for natural mortality (Pauly, 1980). Therefore, the natural mortality for this species should make use only of 1 or 2 digits to avoid uncertainties. The fishing mortality was 0.92 per year.

Size at first capture

The size at first capture of beardless barb landed in Nam Oun Reservoir and nearby area was closed to the size at first maturity reported by Nuangsit and Chansri (2008), although the current information of this species is still limited. Therefore, further study should be carried out for better understanding of the status of the stock of this species.

Table. Size at first capture compared with size at first maturity

Size (TL, cm)	Sample	L_m (TL, cm)	References
$L_{25\%}$	9.25		
L_c	10.04	10.02	Nuangsit and Chansri (2008)
$L_{75\%}$	10.83		

Yield per Recruit Analysis

Results from the Y/R Analysis are shown as the Y/R curve and Kobe plot that made use of the ratio between F/F_{MSY} and TB/TB_{MSY}. For the beardless barb, the results indicated that the fishing mortality and Y/R at current level (orange dot) were 0.92 per year and 2.339 kg/recruit, respectively, while the value of MSY (green dot) was 4.40 per year and Y/R at 11.46 kg/recruitment (**Fig. 4**).

The values of F/F_{MSY} and TB/TB_{MSY} for the beardless barb were 0.21 and 3.98, respectively. Therefore, F is 79% lower than the MSY level, and TB is 298% higher than the MSY level, as shown in **Fig. 5**. The results also indicated that the growth parameters as asymptotic length (L_∞) and curvature parameter (K) were 23.42 cm and 0.33 per year, respectively. Furthermore, the results also showed that the size at first capture of the beardless barb landed in Nam Oun Reservoir and nearby area was 10.04 cm, which is closed to previously established size at first maturity of this species which was at 10.02 cm.

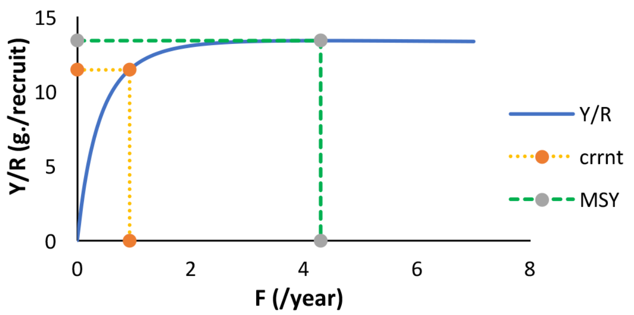

Fig. 4. Yield per recruit estimation with current situation (crrnt) and MSY level (MSY) for the beardless barb

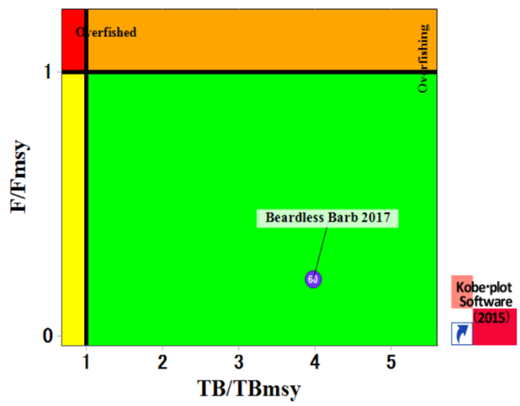

Fig. 5. Result from Kobe plot showing the current status of beardless barb based on the Y/R analysis

Results of the Y/R Analysis show that the population of beardless barb in Nam Oun Reservoir is in deep green zone (very good condition, TB/TB_{MSY} = 3.98 and F/F_{MSY} = 0.21). In Nam Oun Reservoir, the beardless barb is one of the important species for house-hold consumption and local market together with other barbs and inland fish species. The results from this study can therefore provide the appropriate reference point for the development of resource management measures for the fishery resources in this area.

Other Uses of Yield per Recruit Analysis

Considering that Yield per Recruit Analysis could be used not only for stock assessment of bony fishes but also for cartilaginous species such as sharks, the "Technical Consultative Meeting on Shark Data Collection and Stock Assessment and Improvement Data Collection in Southeast Asian Region" arranged by SEAFDEC/TD in September 2017, agreed to select "Yield per Recruit Analysis" as the most appropriate model to analyze the stock status of sharks caught in the Southeast Asian region by making use of the one-year data available at the moment. Four (4) species of economically-important species of sharks, namely: brown-banded bamboo shark (*Chiloscyllium punctatum*); grey bamboo shark (*C. hasseltii*); pelagic thresher (*Alopias plagicus*); and the bigeye thresher (*A. superciliosus*) had been identified for the proposed pilot study. Initially, the brown-banded bamboo shark would be considered for the pilot study not only in view of its importance for household consumption but also because the status and trend of the production of the species have not been determined yet (Krajangdara, 2017) and the species has been recognized by Dudgeon *et al*. (2016) as "near threatened" since 2003.

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