Abstract. Spawning Potential Ratio (SPR) could be used to investigate stock indicators in terms of data-limited fisheries assessment. This study was aimed to assess the Length-based SPR of Indian scad \textit{(Decapterus russelli, Rupell, 1928)} in South China Sea. The length-frequency data were collected from 2015 to 2019, with approximately 250 fish sampled monthly. Fish samples were obtained from the catch of purse seiner which landed at Pemangkat fishing port. LB-SPR model required length-frequency and life history parameters i.e growth and maturity. The parameters \(L_\infty\), \(K\), \(M\), \(L_{50}\), and \(L_{95}\) were 23.92 cm, 0.60 year\(^{-1}\), 1.00, 15.80, and 22.00 respectively. The estimated LB-SPR from static life-history parameters was 41%, while the stochastic SPR about 22% with a wide confidence interval, due to uncertainty of \(L_\infty\) and \(K\). According to the LB-SPR model considering the uncertainty, the estimated stochastic SPR is more acceptable in the condition of poor data. Besides, the high fishing pressure (\(F/M\geq1\)) indicated that SPR was lower than the target reference point (40%). However, in terms of the length at first capture (\(SL_{50}\)) was greater than a length at first maturity (\(L_{50}\)), it should be a consideration to estimate the SPR. Therefore, SPR was determined by 20%-40% or stock status on fully-exploited.

Keywords: \textit{Decapterus russelli}; indian scad; life-history parameters; South China Sea; spawning potential ratio

1. Introduction
The exploitation of small pelagic fish in the South China Sea has been continuously for a long time, especially by purse seiner based in Pemangkat and Riau Islands (Batam, Tanjung Balai Karimun) [1]. The high exploitation rate of the resources could be lead to overfished and then reduced biomass, particularly for targeted species. In term of fishery management, is necessary to have the latest information of stock status as a reference to determine management rules [2].

Currently, the stock status of small pelagic in FMA 711 includes the South China Sea was over-exploited, refers to the maximum sustainable yields and exploitation rates was 330,284 tons/year and 1.41 respectively [3]. However, the management options would be relatively difficult to implement in multi-species fisheries such as small pelagic according to stock status aggregately.
Regarding that, it is necessary to assess stocks specifically, in particular to dominant and targeted species, applied the best scientific method based on reliable data. Therefore, management measures clearly could be carried out immediately.

In FMA 711, the catch composition of purse seiner dominated by targeted species, i.e Indian Scad (Decapterus russelli) and Mackerel Scad (Decapterus macrosoma) were about 67.3%. The other species are Indian Mackerel (Rastreliger kanagurta), Spotted Sardinella (Amblygaster sirm), Bigeye Scad (Selar crumenophthalmus), and Sardinella [4]. Also, the catch composition of purse seines in Pemangkat Fishing Port was dominated by scad (\(D. \text{russelli}\) and \(D. \text{macrosoma}\)) was 40%, Bigeye Scad (24%), tuna-like species, and others [1]. According to the multispecies fishery, \(D. \text{russelli}\), the dominant species which was caught by main fishing gear, could be a representative species for the small pelagic fisheries. Therefore, the single species assessment could be applied to this species, to determine stock status.

Regarding the time series of catch-effort data not available since 2017, as well as assumed bias due to IUU fishing in the South China Sea, the stock status is estimated by the length-based assessment on the data-limited method. The spawning potential ratio (SPR) was recommended to assess the stock status of data-limited fisheries [5].

SPR is the ratio of current reproductive capacity (\(\text{SPR}_{\text{ct}}\)) in exploited stock to maximum potential reproductive capacity (\(\text{SPR}_{100\%}\)) when the population is unfished, can be used as a reference point for stock status to regulate fishing mortality in an attempt to maintain sustainable yields [6]. Currently, SPR was a length-based approach (LB-SPR) to establish a biological reference point, that supported management rules for data-poor fisheries The LB-SPR model requires length distribution and life history parameters (growth and maturity) as input on the model [7]. This study estimated the SPR of \(D. \text{russelli}\), as a species indicator on small pelagic in the South China Sea.

2. Materials and methods

Biological sampling was carried out on several \(D. \text{russelli}\) that were obtained from purse seiner which has fishing ground in the Natuna Sea and the South China Sea and landed at PPN Pemangkat, the largest port of purse seiner around FMA 711 (figure 1). They operated with light fishing without FADs, using fishing gear with mesh size 1 inch. It assumed that the fish size of the catch could represent the population and/or catch composition was independent data.

![Figure 1. Map of sampling site and fishing ground of small pelagic purse seiner.](image)
2.1. Material
Data collection i.e. length distribution and gonad maturity level were carried out from 2015-2019. Fish sampled were taken randomly, and 300 fish was measured each month approximately. The individual length measured were fork length (FL) were tabulated monthly into a length-frequency distribution with 1 cm class interval.

Life history parameters based on these data were estimated (table 1). Data analysis is detailed in another paper on “Biological aspects and population dynamics of Indian scad in the South China Sea” [8]. We assume that the length composition data is representative of the exploited population at a steady state. Growth parameters (L∞ and K) analysis was performed by pooled length data (without differentiating the sex) and M was estimated from L∞ and K. According to the constant of individuals growth (b) for males and females were relatively not different 3.40 and 3.45 respectively, it assumed that they have equal catchability [9]. Further considering there was a little yearly variation of growth parameter, we assumed D. russelli in the South China Sea have constant growth, therefore the data of 5 years were analyzed jointly aggregated across all months [10]. However, the length maturity (L50 and L95) obtained from data distribution of female length based on gonad maturity level.

Table 1. The life history parameters for analysis of the LB-SPR model.

| Parameters | Estimated | Methods          | References |
|------------|-----------|------------------|------------|
| L∞         | 23.92     | Powell-Wetherall | [11]       |
| K          | 0.60      | ELEFAN-SA        | [12]       |
| t0         | -0.29     | Pauly            | [13]       |
| M          | 1.00      | Pauly            | [14]       |
| L50        | 15.80     | Logistic curve   | [15]       |
| L95        | 22.00     | Logistic curve   |            |

2.2. Methods
The LB-SPR model [16] was applied to estimate SPR based on length-frequency distribution with pooled male and female, which requires life history ratios M/K and L∞/L∞ [9] and follow the formula:

$$SPR = \frac{\sum(1-L_x)^{(M/K)(F/M)+1})p}{\sum(1-L_x)^{M/K} L_x}$$  \hspace{1cm} \text{for } x_m \leq x \leq 1 \hspace{1cm} (1)$$

Where $\tilde{L}_x$ is standardized length ($L_m/L_\infty$); M is natural mortality; K is growth rate; F is fishing mortality and b is exponent usually close to 3.

The open-source software ‘R’ version 4.0.3 [17] with package LBSPR (version 1.0.5) was applied to estimate selectivity, relative apical fishing mortality, and SPR [18]. This formula resulting from the SPR which is not considering the uncertainty of the data (SPR deterministic).

Regarding life history (L∞, K, and M) plausible causing the uncertainty due to the poor data quality, it is necessary to estimate uncertainty in LB-SPR through life history parameters to define stochastic SPR. Parameters L∞ and K distributions were establish using Natural Mortality Tool in the site of The Barefoot Ecologist’s Toolbox (http://barefootecologist.com.au/apps) developed by Shiny [19], for obtaining the estimated prior of M from a range of life-history based methods. To describe the uncertainty of SPR, we used Monte Carlo simulation with 1000 bootstrapped iterations, and covariance of CV-L∞ and CV-M/K is 0.1 and 0.2 as the default value and assumed that CV could fix without error [9].

A consideration that stock of small pelagic with average resilience or productivity, therefore to describe the stock status, we set limit reference point (LRP) at 20% [20] and a target reference point (TRP) at 40% [21, 22]. This reference point has become the default value and applied by The Marine Stewardship Council.
3. Result and discussion

3.1. Length frequency distribution
Fish sampled from 2015 to 2019 ranged from 10.5-24.5 cmFL (figure 3). The mean length were 17.4 ± 1.9, 17.7 ± 1.8, 17.2 ± 1.8, 17.7 ±1.9, and 17.4 ± 2.0 cmFL respectively during the sampling period, in which length-frequency distribution male and female are pooled. All the fitted of size curves match the size data reasonably well, suggests the normal distribution of one cohort with the modes were equal to the mean length.

In 2019, the mode of length-frequency (18.5 cm) was higher than the mean length (17.4 cm), hence the curve fitting appears to be slightly negatively skewed. That indicated the composition of larger fish more caught this year. However, this still needs to be reconsidered, given the uncertainty (standard deviation ) for mean length from every year was quite high, which 2019 have the highest standard deviation (± 2).

![Figure 2](image2.png)

**Figure 2.** The size distribution (bar) and curve fitting (solid line) of *D. russelli* were caught by purse seiner and landed at Pemangkat Fishing port from 2015-2019.

![Figure 3](image3.png)

**Figure 3.** The specified size of the maturity curve (black line) and yearly estimated selectivity curve (colored line).

3.2. Length selectivity and maturity
The selectivity analysis was determined using the logistic function to estimate length at capture in the level 50% (SL$_{50}$) and 95% (SL$_{95}$) by year. The selectivity parameters during 2015-2018 look compatible with what is seen in the fishery (figure 4a and table 2), therefore the estimates of F/M are probably reasonable in the South China Sea.
However, the estimate in 2019 looks far too high (table 2). This probably means that this initial estimate of $F/M = 6.12 \pm 2.17$ is a considerable over-estimate. The ogive curve of estimated selectivity and maturity showed that the length at first capture was higher than the length at first maturity during 2015-2019 (figure 3 and figure 4a). As well as length at maturity $L_{50}$ and $L_{95}$ were estimated at 15.80 and 22.00 cmFL respectively (table 1).

Table 2. The estimated length selectivity ($SL_{50}$, $SL_{95}$), fishing pressure ($F/M$) and spawning potential ratio (SPR) with a 95% confident interval.

| Years | $SL_{50}$  | $SL_{95}$  | $F/M$   | SPR       |
|-------|------------|------------|---------|-----------|
| 2015  | 16.94 ± 0.33 | 19.95 ± 0.48 | 2.22 ± 0.40 | 0.41 ± 0.03 |
| 2016  | 17.50 ± 0.28  | 20.43 ± 0.39  | 2.50 ± 0.41  | 0.43 ± 0.03  |
| 2017  | 16.83 ± 0.31  | 19.68 ± 0.45  | 2.61 ± 0.45  | 0.38 ± 0.03  |
| 2018  | 17.17 ± 0.27  | 20.17 ± 0.40  | 1.89 ± 0.29  | 0.45 ± 0.03  |
| 2019  | 19.42 ± 0.70  | 23.67 ± 0.83  | 6.12 ± 2.17  | 0.40 ± 0.08  |

3.3. Spawning potential ratio

The length selectivity ($SL_{50}$ and $SL_{95}$), relative fishing mortality ($F/M$), and SPR were estimated by year with 95% confidence intervals (figure 4). The SPR in 2019 was estimated at (40 ± 8%)%, mostly met to the TRP as a sustainability reference point (40%). However, the estimated fishing pressure ($F/M$) in 2019 was 6.12 ± 2.17 could be unrealistically high compared to other years, due to the highest length selectivity with widely the confidence interval this year (table 2).

According to that, and assumed the length composition data was at a steady-state, We determined the average of SPR during 2015-2018 (41%) as of current SPR. The revised estimates appear more reasonable, with as expected produced estimate of fishing pressure ($F/M$).

Figure 4. The estimated size of selectivity relative maturity (a), fishing pressure (b), and deterministic SPR (c).

Estimating uncertainty in LB-SPR through life history values, We applied two methods developed by Cope (2019) which used the Monte Carlo simulation. Before estimating uncertainty, We draw N sample values (1000 bootstrapped) for $L_\infty$ and K from a multivariate random normal distribution and plot the $L_\infty$ and K to make sure random draws are consistent with median values (figure 5a).

The first step, establish $L_\infty$, K, and M distributions to get M/K. The parameters value $L_\infty$ and K were set up 23.92 (CV=0.1) and 0.6 (0.1) respectively, the correlation between $L_\infty$ and K was -0.9, and resulted in the median of M/K was 0.94 (figure 5b). Second, establish multivariate $L_\infty$ and median M/K (from the first way) with CV M/K was set at 0.2 and resulted in M/K 0.94 (figure 5c) as well. The estimation M/K (0.94) considering uncertainty through life parameters was different regarding M/K (1.66) through static life history values (table 1).
Figure 5. The median value of L∞ and K from a random normal distribution (a), the median of M/K generated from L∞, K, and M distributions (b), and median of M/K generated from L∞ and median of M/K on the first way (c), used Monte Carlo simulation (n sampel=1000).

The estimated LB-SPR based stochastic (Monte Carlo bootstrapped) from 2015 to 2019 was 21%, 23%, 19%, 24%, and 21% respectively, which were have a wide range of confidence intervals. The median values of stochastic SPR were systematically lower than LB-SPR estimated from deterministic (static) life history parameters (figure 6).

Figure 6. LB-SPR deterministic and LB-SPR stochastic (MC) of D. russelli in the South China Sea from 2015 – 2019.
3.4. Discussion

According to the deterministic LB-SPR model, the current SPR was estimated at 41% reach to the TRP (40%), that SPR on the point of a sustainability reference point or sustainable utilization. The 41% SPR indicated that the exploitation rate almost under-exploited [9], and illustrates there was about 41% of D. russelli populations in the South China Sea have opportunities to spawn. However, the LB-SPR from the stochastic model was about 22%, mostly met the LRP (20%). By this indicator showed that the stock status has been fully-exploited reach over-exploited [9]. The other SPR assessment of small pelagic fish shows that the stock status of short mackerel (R. brachysoma) in the Northern Coast of Java has fully exploited with 30% SPR [23], and overfishing (SPR<20%) for Bali Sardinella (S. lemuru) in Prigi Bay [24].

The estimated stochastic SPR was very different from deterministic SPR, due to uncertainty of the life history parameters i.e L∞ and K which were causing underestimates to M. The LB-SPR models are especially sensitive to the under-estimation of L∞ [16] since the largest length fish in a sample start to reach L∞, the estimates of SPR will increase rapidly [9].

Considering the L∞ (23.92) was estimated by Powell-Wetherall method has a wide range of confident interval (8.13-39.77), and K (0.60) was determined using ELEFAN with highest of fitting scores (Rn=0.27) has been low value [8]. The estimated M value based on L∞ and K [14] is also influenced by the uncertainty of these two parameters. Therefore, considering the uncertainty of L∞ and K, the covariance of M/K was set at 0.2 even Monte Carlo simulation to obtain the median of new M/K. The result was very different compared to M/K calculated based on L∞ and K static without considering uncertainty (figure 5).

According to the LB-SPR model considering the uncertainty, the estimated stochastic SPR is more acceptable. Moreover, the ratio F/M > 1 (table 2) indicates that the fishing pressure was high relatively, thus SPR 41% was unacceptable directly. The ratio F/M > 1 is more likely to lead to recruitment overfishing. The length-frequency distributions represent that 75% of the catch composition matured with fork length > 16 cm (L50). Nevertheless, the length at first capture (SL50) was greater than the length at first maturity (L∞) (figure 3), at least fish have spawned once before getting caught, hence the principle of sustainability is still occurring [25]. Otherwise, SL95 < L95 (table 2) indicates that fish at mature-adult were caught before reaching the length or age of mega spawner. The length-frequency distribution represents that the mega spawner which is > 22 cmFL (L95) has less in number (0.5%), that occurring the recruitment overfishing. The mega spawner was less than 20% availability indicated over-exploitation [25].

Therefore it necessary not fixated on the median of stochastic LB-SPR value (22%). Besides, a confident interval of stochastic SPR was quite wide, it could be assumed that the current SPR is between 20% to 40% or above the LRP but also below the TRP. Consequently, the stock status of D. russelli in the South China Sea is fully exploited based on the SPR indicator as a biological reference point. Regarding the high uncertainty of life-history parameters (L∞ and K) and the estimation of performance indicators (SPR), a more precautionary approach is required to develop harvest control rules for fisheries management.

According to the stock status of fully exploited and recruitment overfishing, it is necessary making fisheries management controls more restrictive considering precautionary management. The close of the fishing season needs to be applied within a certain period when more adult and mega spawners are caught. It could protect the spawner reaching to spawn. This option is not so simple given the high uncertainty of reproductive biology and spawning habits.

4. Conclusion

According to some aspects to be concerned, i.e terms of uncertainty in the life history parameters L∞ and K, highly fishing pressure F/M >1 and considering the use of fishing gear were under control which is SL50 > L50. Therefore, the SPR of D. russelli in the South China Sea was determined in a range of 20%-40%, or the stock status is fully exploited. Considering the precautionary approach for harvest control rule, the current fishing effort still could be maintained and should be accompanied by monitoring the
catch-effort and collecting length-frequency continuously to obtain high-quality data to reduce the uncertainty of the analysis results.

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