Stock Assessment and Overexploitation Risk of Small Pelagic Fish in Fisheries Management Area 715 of Indonesia

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Abstract

This study presents updated stock assessments and risk analyses of overexploitation for the aggregate small pelagic fish complex and the dominant genus of the complex, *Decapterus,* for improving the management of the small pelagic fishery in Fisheries Management Area (FMA) 715. The analyses herein used non-equilibrium biomass dynamics models with available data on annual catch and catch per unit effort for 2005 to 2016. Fishing effort was standardised into the number of 20-meter length overall purse-seine vessels. The analyses show that the maximum sustainable yield (MSY) of the aggregate fish was about 121,600 tonnes, caught by 876 purse-seiners, while the MSY of the mackerel scad, *Decapterus macarellus* (Cuvier, 1833), was about 67,900 tonnes, caught by 805 purse-seiners. Since the mackerel scad and the aggregate fish stocks have been overexploited, a rebuilding strategy would be necessary to restore the stocks to a level capable of producing MSY (B_{MSY}). After achieving the B_{MSY}, it is recommended that a target reference point be implemented for the catch level with the maximum overexploitation risk level of 50 % in 10 years. The catch level meeting this requirement for mackerel scad would equal 80 % of its MSY, which could be achieved by controlling fishing effort at 427 purse-seiners. At this effort level, the fishery would produce 95,800 tonnes of aggregate fish catch with 54,300 tonnes of mackerel scad. These reductions in fishing efforts will be needed to maintain the future sustainability of the fish stocks in FMA 715.

Keywords: non-equilibrium biomass dynamic model, management reference points, *Decapterus macarellus*, small pelagic fish, fishery rebuilding strategy

Introduction

Fishery Management Area (FMA) 715 includes all or part of six provinces in eastern Indonesia across a large and diverse marine area with extensive fishery resources (Fig. 1). Small pelagic fish stocks in FMA 715 constitute an important fishery resource for the national economy, particularly among the six provinces, where coastal communities rely mostly on marine fishery resources for food and income. The Indonesian Constitution stipulates that the country's natural resources, including fishery resources, are basic assets for the people's prosperity and should be utilised to the greatest benefit of all Indonesians. Given the abundant small pelagic fish stocks in FMA 715, fishing pressure has increased considerably since the mid-1970s due to the motorisation of small-scale fishing boats, fishing gear improvements, and a growing human population (Dwiponggo, 1987). This small pelagic fishery supplies fish for food and processing industries supports marketing businesses and jobs, and contributed about 35.4 % of the total production of marine capture fisheries in FMA 715 from 2005 to 2016 (DGCF, 2017).

Maintaining the fishery's contribution to the economy depends on keeping the fish stock healthy. Unfortunately, the small pelagic fish stock in FMA 715 was fully-exploited in 2011 (MMAF, 2011), and in an overexploited state in 2016 (MMAF, 2016a). The overexploited stock results in lower production and lower economic benefits (Purwanto, 2003). The fishery resources must be actively managed to optimise their contribution to the Indonesian
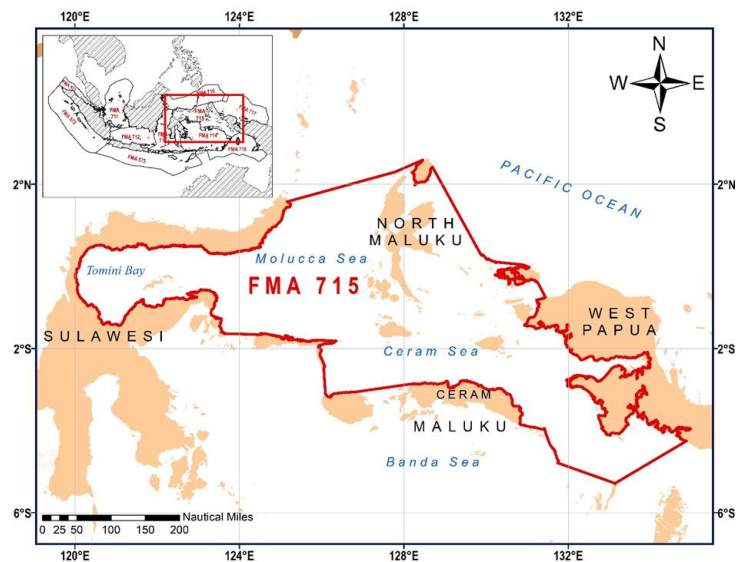
Fig. 1. Map of Fisheries Management Area (FMA) 715 of Indonesia.

economy. An appropriate and effective management strategy is required to sustain the small pelagic fish stock and optimise economic benefits from the fishery (MSS, 2004).

Since fisheries operate in aquatic ecosystems where their function and response to fishing and other human activities are not well-defined (Haddon, 2011), there will always be uncertainties in the estimates relating to fish stocks and their response to fishing efforts. A key issue is to ensure that the catch limits in the fisheries management strategies are fixed so that they are in a range of safety despite uncertainties (Buxton et al., 2014). In the past, fisheries management was directed to achieve the maximum sustainable yield (MSY). However, the classical fisheries management target of MSY is now recognised as being a risk-prone strategy, likely leading to declining stocks (Haddon, 2011).

As recommended by FAO (1995), agreed by UN member countries (UNGA, 1995), and stipulated in Indonesia's Government Regulation no. 60 of 2007 (MSS, 2007), a precautionary approach should be applied to the conservation, management, and utilisation of the fish stocks to achieve management objectives. Based on the development of fisheries management strategies in recent years, and in accord with UNGA (1995), the MSY is no longer used as a target reference point in fisheries management but as the limit reference point to minimise the risk of fish stock decline (Caddy and Mahon, 1995; FAO, 1997; Mace, 2001; Quinn and Collie, 2005). The uncertainties relating to the size and productivity of the stocks shall be taken into account in implementing a precautionary approach (Article 6(3) of UNGA, 1995). It is important to quantify the risk related to decision making associated with selecting limited reference points and target reference points to avoid undesirable outcomes and reduce the probability of stock collapse (De Anda-Montañez et al., 2017).

The Indonesian Government requires the information generated from fish stock assessments and risk analyses of fish stock overexploitation to improve small pelagic fishery management in FMA 715. This study aimed to i) assess and update the stock status of aggregate small pelagic fish complex, ii) determine the potential production of the fishery from utilising fish stock, iii) and quantify the risk concerning decision making associated with managing or rebuilding fish stocks to support better management planning.

Moreover, for monitoring and evaluation, other objectives of this study were to assess the predominant small pelagic species stock, i.e. mackerel scad, *Decapterus macarellus* (Cuvier, 1833), and its overexploitation risk. The results of those two assessments were compared to evaluate the possible use of mackerel scad as a key species to monitor the stock status of the aggregate species complex of small pelagic fishes.

Materials and Methods

A biomass dynamic model was implemented in this study using data aggregation approaches since the data available for assessing the small pelagic multispecies fish stock in FMA 715 are limited to catch data and indices of abundance. Accurate catch data are challenging to collect in Indonesia, making the time series in this paper quite valuable for advancing new ways to assess national stocks. Most fishery stocks in Indonesia are currently assessed in commodity groups that aggregate a species complex such as "small pelagic species". For this paper, an assessment was conducted for the small pelagic species complex as typically grouped by Indonesia's Ministry of Marine Affairs and Fisheries (MMAF). The results were compared with an evaluation of the dominant genus in the catch, *Decapterus*, which represented approximately 41 %

of the annual harvest. This comparison illustrated the potential for a single species assessment to be performed for the dominant catch component of this group. Since the next most harvested genus (*Rastrelliger*) only accounted for about 8 % of the catch and the others were even less, they were not considered for assessment. The paper demonstrates an approach that could be adopted for small pelagic stock assessment and expands this method to examine a dominant genus in the catch.

Model and method of analysis

Analyses for this study were conducted in two steps; the first was fish stock assessment, followed by risk assessment. In the assessment of fish stock, the analysis estimated surplus production parameters using a non-equilibrium biomass dynamics model (Haddon, 2011). A general formulation of the fish biomass dynamics model, as described or used by Polacheck et al., (1993), Chen and Montgomery (1999), and Walters et al. (2008), is:

$$B_{t+1} = B_t + g(B_t) - C_t \tag{1}$$

where:
B_t = the exploitable biomass at the beginning of year t;
B_{t+1} = the exploitable biomass at the beginning of year t+1;
$g(B_t)$ = surplus production as a function of biomass at year t;
C_t = the catch during year t.

The surplus production models $[g(B_t)]$ evaluated in this paper were the logistic model of Schaefer (1954, 1957) and the exponential Fox model (1970) as follows:

The Schaefer model:

$$g(B_t) = r.B_t.(1 - B_t/K) \tag{2}$$

The Fox model:

$$g(B_t) = r.B_t.[1 - \ln(B_t)/\ln(K)] \tag{3}$$

where:
r = the intrinsic growth rate parameter;
K = the average biomass level prior to exploitation.

Catch per unit effort at year t (U_t) is used as an index of relative abundance for year t (Schaefer, 1954; Fox, 1970, 1975), and the relationship between U_t and B_t is:

$$U_t = q.B_t \tag{4}$$

where: q = the catchability coefficient.

Estimation of the production parameters used a least-squares method with 20,000 trials of Monte Carlo simulations and 1,500 trials of bootstrapping. The analysis was undertaken using the ASPIC program developed by Prager (1994, 2002, 2016). The trajectory

of fish biomass and fishing mortality and confidence surfaces, created from bootstrap analysis, were presented using KobePlot software (Nishida et al., 2014).

Risk assessment was conducted to explore the impact of uncertainty (Watson and Sumner, 1999). The risk assessment estimated probabilities of overexploitation, i.e. when the biomass was less than the total biomass at MSY level (B_{MSY}), or fishing mortality was higher than the fishing mortality at MSY level (F_{MSY}), projected forward in 3 and 10 years. This was done using 10 different catch scenarios, including the previous catch and MSY levels. The bootstrap method provided uncertainty estimates using the residuals from the original best fit of biomass dynamic models (Prager, 1994; Haddon, 2011; Kell et al., 2014). The Risk Assessment software, developed by Odaira et al. (2017), was utilised to perform risk assessments using the residuals from fitting a biomass dynamic model with ASPIC Program (Prager, 1994, 2013; Nishida et al., 2014).

Data

The analysis used catch data published by the Indonesian Directorate General of Capture Fisheries (DGCF) (2002, 2003, 2004, 2005, 2006, 2016, 2017), unpublished fishing efforts estimated by the Indonesian Research Institute for Marine Fisheries (RIMF), and data on fishing activities, catch, fishing vessels and gears collected by the Ocean Fishing Port Authority of Bitung. The annual data on the catch of aggregate species and mackerel scad are from 2001 to 2016 and 2002 to 2016, respectively. The index of abundance of aggregate species and mackerel scad are from 2003 to 2016 and 2005 to 2016, respectively. After 2016, the catch data required for this study could not be obtained since the MMAF changed the design of its statistical data collection and has not published those data.

Small pelagic fish species were caught by fishers using various fishing gears, namely purse-seine, gillnet, troll-line, vertical hand-line, lift-net, and surrounding net. However, the main fishing gear used by the small pelagic fishery was purse-seine. Purse-seiners contributed about 73 % of the small pelagic fishery production from FMA 715 (MAFS-NMP, 2013; MAFS-NSP, 2013). The average vessel size of the purse-seiners was about 20-meters in length overall (LOA). Therefore, the fishing effort was standardised into the number of 20-meter LOA vessels operating purse seine during the year, referred to as "units" of fishing effort. The data on the annual landing of purse-seiners recorded by the Oceanic Fishing Port of Bitung was used to standardise fishing efforts. The average tonnage of the 20-meter LOA vessels was about 35 GT, categorised as a medium scale purse-seiner.

The small pelagic fishery catch in FMA 715 consists of

several genera. However, genus composition reported is different from year to year, and only data of 17 genera always appeared in the capture fisheries statistic published by the DGCF from 2001 to 2016 (DGCF, 2016, 2017). Only data of 17 genera were used to avoid bias in the analysis due to different genus composition (see Supplementary Table 1).

Results

Fishing effort, catch, and catch per unit effort

The fishing effort of the small pelagic fishing fleet in FMA 715 increased from 2005 to 2015, and then declined afterwards (Fig. 2). The levels of fishing effort in 2005, 2015 and 2016 were about 485, 1037 and 965 units, respectively.

The small pelagic fishery production landed from FMA 715 consisted of at least 17 genera, contributing about 78.3 % of the total production of the small pelagic fishery. However, about 40.9 % of the total small pelagic fishery production consisted solely of mackerel scad. The quantity of the 17 genera of small pelagic fishes landed increased from 2005 to 2016 was about 91,200 and 135,600 tonnes, respectively. The amount of mackerel scad landed was similar to the trend of the 17 genera. The mackerel scad landed in 2005 and 2016 were about 51,800 and 79,700 tonnes, respectively.

The catch per unit effort (CPUE) of the 17 small pelagic genera and mackerel scad increased before 2009, but declined afterwards until 2015, then increased again in 2016 (Fig. 2). The CPUE of the 17 small pelagic genera in 2009 and 2016 were about 221 and 141 tonnes.unit^{-1} year^{-1}, respectively. Meanwhile, the mackerel scad CPUE in 2009 and 2016 were 126 and 83 tonnes.unit^{-1} year^{-1}, respectively.

Fishery production model and optimal production

This study analysed the combined production of species belonging to 17 genera, referred to as the aggregate species, and the individual production of mackerel scad. The values of parameters resulting from analyses of the production of aggregate species of small pelagic fish and mackerel scad are presented in Table 1. As indicated by coefficients of determination (R^2), the goodness of fit to the data of the Fox model was higher than the Schaefer model for the production of aggregate species and mackerel scad. Therefore, the Fox model was used in this study.
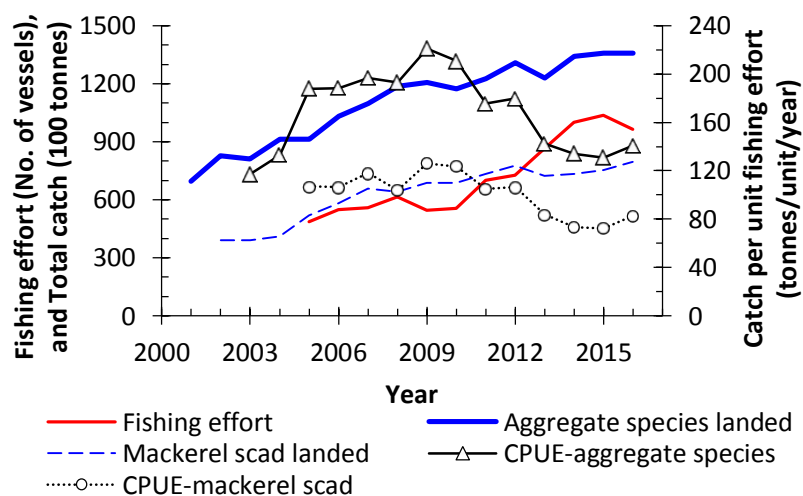

Fig. 2. Fishing effort, total catch, and catch per unit effort (CPUE) of aggregate species belong to 17 genera and mackerel scad, *Decapterus macarellus,* landed by the small pelagic fishery in Fisheries Management Area 715, for 2001 to 2016.

Table 1. The estimated values of parameters and determination coefficients of the fishery production model of the aggregate species and the mackerel scad, *Decapterus macarellus,* in Fisheries Management Area 715.

Parameter	Unit	Aggregate species		*Decapterus macarellus*	
		Schaefer Model	Fox Model	Schaefer Model	Fox Model
r	–	1.6208	0.8955	0.9170	0.6817
q	10^{-3}	1.01	1.02	0.65	0.85
K	10^3 tonnes	299.9	369.0	288.1	270.7
R^2	–	0.752	0.774	0.694	0.715

Note: r = 2*F_{MSY} for Schaefer model (Prager, 1994); r = F_{MSY} for Fox model (Fox, 1970); F_{MSY} fishing mortality at maximum sustainable yield.

The estimated optimum value of the aggregate species of small pelagic fish biomass and production and the estimated optimum level of fishing mortality of the small pelagic fishery in FMA 715 are presented in Table 2. The results indicated that the aggregate species of small pelagic fish stock in FMA 715 could produce sustainable production at a maximum level, or MSY, of about 121,600 tonnes.year^{-1} resulting from fishing effort of 876 units. Fishing activities that resulted in the MSY caused fishing mortality of about 0.9 on the aggregate species small pelagic fish stock and caused the fish biomass to be around 135,700 tonnes. Meanwhile, the MSY of mackerel scad was 67,900 tonnes.year^{-1} resulting from the fishing effort of 805 units (Table 2). Fishing activities that resulted in the MSY caused fishing mortality of about 0.68 and fish biomass of about 99,600 tonnes.

The MSY of mackerel scad production was achieved using smaller fishing effort than the aggregate

species of small pelagic fish production (Table 2). Based on the parameters in Table 1, it was estimated that the fishing effort of 876 units is required to achieve the MSY of aggregate species. However, this would result in the overexploitation of mackerel scad stock, as indicated by its relative fishing mortality of 1.09. The MSY level of mackerel scad production can be achieved by reducing the fishing effort of small pelagic fishery to 805 units.

Development of fishery and fish stock abundance

The development of the fishery and affected fish stock in FMA 715 are shown from the plot of relative fishing mortality and fish biomass presented in Figures 3 and 4. In 2005, the fishing pressure on aggregate species and mackerel scad stocks was sub-optimal since the fishing mortality (F_{2005}) was lower than that at MSY (F_{MSY}) or $F_{2005}/_{MSY} < 1$ (Figs. 3,

Table 2. The optimum biomass and production of mackerel scad, *Decapterus macarellus,* and aggregate species, and the optimum fishing mortality of the small pelagic fishery in Fisheries Management Area 715.

| Parameter | Symbol | Unit | Aggregate species | | | Mackerel scad | | |
			Point estimate	Bias-corrected approximate confidence limits		Point estimate	Bias-corrected approximate confidence limits	
				80 % lower	80 % upper		80 % lower	80 % upper
Maximum sustainable yield	MSY	10^3 tonnes	121.6	118.3	128.8	67.9	61.1	70.9
Fishing mortality at MSY	F$_{MSY}$		0.896	0.656	1.148	0.682	0.299	1.101
Catchability coefficient	q		1.02E-03	0.82E-03	1.26E-03	8.47E-04	4.33E-04	1.19E-03
Fishing effort at MSY	E$_{MSY}$	Number of 20 m LOA vessels	875.6	751.7	1103	805	589	1176
Estimated yield in 2017	Y$_{2017}$	10^3 tonnes	120.3	112.0	128.2	66.4	59.3	74.3
Biomass at MSY	B$_{MSY}$	10^3 tonnes	135.7	107.8	180.1	99.6	64.6	208.2
Relative fishing mortality at MSY	F$_{2016}$/F$_{MSY}$		1.23	0.88	1.53	1.37	0.81	1.97
Relative biomass at MSY	B$_{2017}$/B$_{MSY}$		0.86	0.69	1.17	0.80	0.55	1.29
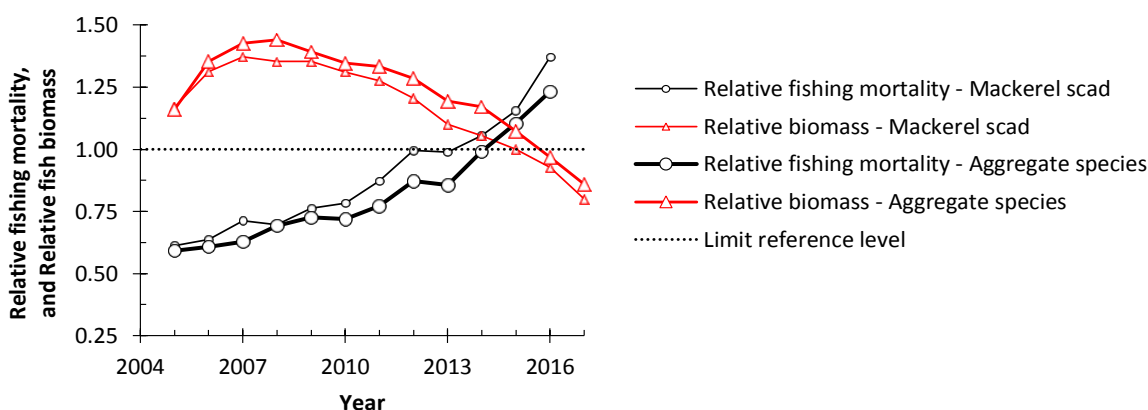
Fig. 3. Time series of fishing mortality and biomass of mackerel scad, *Decapterus macarellus,* and aggregate small pelagic fish species in Fisheries Management Area 715 from 2005 to 2017.
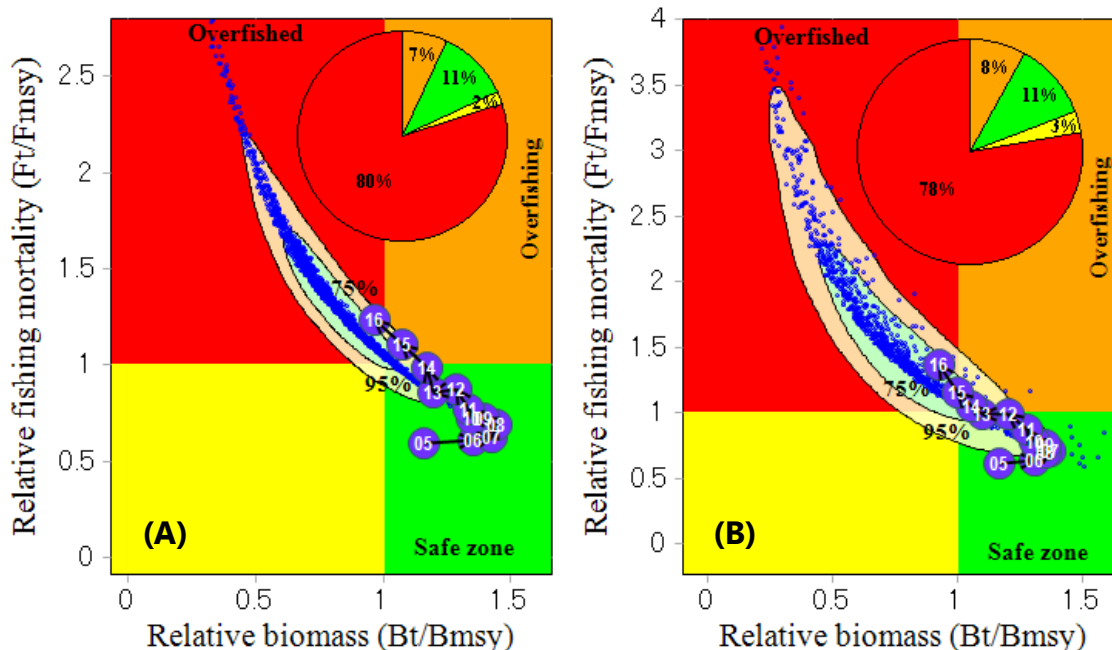
Fig. 4. Estimated trajectory of fish biomass and fishing mortality of (A) aggregate species of small pelagic fishes and (B) mackerel scad, *Decapterus macarellus,* in Fisheries Management Area 715, 2005–2016.

4A and 4B). Meanwhile, the aggregate species, including the mackerel scad stock was underexploited. The fish biomass indicates the under-exploitation of the stock in 2005 (B_{2005}) that was lower than that at MSY (B_{MSY}), or $B_{2005}/B_{MSY} > 1$. From 2005 to 2007, the fish biomass of aggregate species and mackerel scad grew while fishing mortality rose. Unfortunately, further increases in fishing mortality decreased the abundance of mackerel scad and aggregate species from 2008 to 2016.

The relative fishing mortality on the aggregate species stock in 2015 and 2016 was greater than 1.00, i.e. 1.11 and 1.23, respectively (Fig. 3). The fishing mortality on aggregate species stock was estimated to be about 1.1 in 2016, which was higher than the F_{MSY} (Table 2). On the other hand, the relative fish biomass was about 1.07 and 0.97 in 2015 and 2016, respectively. The estimated aggregate species biomass in 2016 was 131,000 tonnes, which was lower than the B_{MSY}, indicating that the stock was overexploited (Table 2). It is in accord with the confidence surface of the 2016 stock exploitation estimates exhibiting that about 89 % of the estimates fell in the unsafe zone (red, orange and yellow) (Fig. 4A). Furthermore, the fish biomass was projected to decline to 117,000 tonnes, and the relative fish biomass (B_{2017}/B_{MSY}) was about 0.86 in 2017 (Fig. 3).

On the other hand, the relative fishing mortality of the mackerel scad increased to a level greater than 1.00 in 2014, and increased further later (Fig. 4B). The relative fishing mortality on the mackerel scad stock in 2015 and 2016 was 1.16 and 1.37, respectively (Fig. 3). Meanwhile, the relative biomass of mackerel scad in 2015 and 2016 was 1.00 and 0.93, respectively. The relative biomass of mackerel scad in 2016 exhibited

the overexploitation of the stock (Table 2). It corresponds to the indication provided by the confidence surface of the 2016 stock exploitation estimates that about 89 % of the estimates fell in the unsafe zone (Fig. 4B). Moreover, it was projected that the fish biomass would decrease to 79,700 tonnes, and the relative fish biomass would be about 0.8 in 2017 (Fig. 3).

Risk assessment of overexploitation

The result of the risk assessment is presented in Tables 3 and 4. The probabilities of the FMA 715 small pelagic fish stock and fishing mortality to violate B_{MSY} and F_{MSY} reference levels decreased with decreases in the targeted catch levels.

In the previous 3 years (2014–2016), the previous average catch of the aggregate fish species was about 135,200 tonnes. The risk assessment result suggested that if the previous catch was continued, the probability of violating B_{MSY} and F_{MSY} in 3 years would be about 91 % and 96 %, respectively. Moreover, the probability of violating B_{MSY} and F_{MSY} would be even higher in 10 years at 98 % (Table 3). A continuation of recent average catch levels for the aggregate species would lead to a high risk of overfishing ($F_t > F_{MSY}$) and the fish stock to be overfished ($B_t < B_{MSY}$) in 3 and 10 years.

Meanwhile, the previous catch level of the mackerel scad was about 76,000 tonnes. If the previous catch continued, the risks of violating B_{MSY} and F_{MSY} on mackerel scad stock in 3 years would be about 78 % and 79 %, respectively, categorised as medium-high risk. Both the risks of violating B_{MSY} and F_{MSY} would be even higher in 10 years, i.e. 89 % and 84 %,

Table 3. Probabilities (%) of the Fisheries Management Area 715 small pelagic fishery to violate biomass and fishing mortality at maximum sustainable yield (B_{MSY} and F_{MSY}) reference levels in 3 and 10 years, at various targeted levels of aggregate species catch.

Targeted catch relative to the MSY (%)		70	80	90	MSY	110	111*)	120	130	140	150
Catch scenarios (1000 tonnes)		85.1	97.3	109.4	121.6	133.8	135.2	145.9	158.1	170.2	182.4
Risk of over-exploitation	$B_3 < B_{MSY}$	59	71	80	87	91	91	94	96	98	98
	$F_3 > F_{MSY}$	19	37	62	86	95	96	98	100	100	100
	$B_{10} < B_{MSY}$	13	24	42	80	96	98	100	100	100	100
	$F_{10} > F_{MSY}$	13	22	40	80	96	98	100	100	100	100

Notes: *) The previous catch level, which is the average catch in the previous 3 years (2014-2016); B_3 and B_{10} = biomass in 3 and 10 years; F_3 and F_{10} = fishing mortality in 3 and 10 years.
Color legend:

Risk levels	Low risk	Medium-low risk	Medium-high risk	High risk
Probability (%)	0–20	> 20–50	> 50–80	>80–100

Table 4. Probabilities (%) of the Fisheries Management Area 715 small pelagic fishery to violate biomass and fishing mortality at maximum sustainable yield (B_{MSY} and F_{MSY}) reference levels in 3 and 10 years, at various targeted levels of mackerel scad, *Decapterus macarellus*, catch.

Targeted catch relative to the MSY (%)		70	80	90	MSY	110	112*)	120	130	140	150
Catch scenarios (1000 tonnes)		47.5	54.3	61.1	67.9	74.7	76.0	81.5	88.2	95.0	101.8
Risk of over-exploitation	$B_3 < B_{MSY}$	71	73	76	77	78	78	79	80	80	81
	$F_3 > F_{MSY}$	32	55	70	76	78	79	80	82	83	83
	$B_{10} < B_{MSY}$	32	47	69	80	88	89	90	92	93	94
	$F_{10} > F_{MSY}$	21	29	49	75	83	84	84	85	85	85

Notes: *) The previous catch level, which is the average catch in the previous 3 years (2014-2016); B_3 and B_{10} = biomass in 3 and 10 years; F_3 and F_{10} = fishing mortality in 3 and 10 years.
Color legend:

Risk levels	Low risk	Medium-low risk	Medium-high risk	High risk
Probability (%)	0–20	>20–50	>50–80	>80–100

respectively, categorised as high risk (Table 4).

When the fishery targeted the aggregate species at the MSY level, the probabilities of violating B_{MSY} in 3 and 10 years were about 87 % and 80 %, respectively, while the risks of violating F_{MSY} would be about 86 % and 80 %, respectively (Table 3). The risk of violating B_{MSY} and F_{MSY} reference levels as consequences of fishing targeting catch at the MSY level were lower than those of continuing fishing targeting the previous catch level. However, the risk level of fishing at MSY was medium-high in 10 years. Furthermore, the effort level at the aggregate species MSY was 876 units leading to overexploitation of mackerel scad.

Similarly, a decreased catch level to achieve MSY of mackerel scad would result in a lower risk of overexploitation of mackerel scad and the aggregate species group. At the MSY level of mackerel scad, the probabilities of violating B_{MSY} and F_{MSY} in 3 years would be about 77 % and 76 %, respectively, while the risks

of violating B_{MSY} and F_{MSY} in 10 years would be 80 % and 75 %, respectively (Table 4). If the fishery harvested mackerel scad at its MSY level, the catch of aggregate fish species would be lower than its MSY level, i.e. about 117,400 tonnes, and CPUE would be about 146 tonnes.unit^{-1} year^{-1} (Table 5). The risk of violating B_{MSY} and F_{MSY} reference levels in 3 years would be about 84 % and 78 %, respectively, while the risks of violating B_{MSY} and F_{MSY} in 10 years would be lower, i.e. 67 % and 66 %, respectively (Table 5).

If the small pelagic fishery targeted the catch of the aggregate species to 80 % of MSY, it would reduce the risk to 24 % probability to violate the B_{MSY} and 22 % probability to violate the F_{MSY} reference levels in 10 years (Tables 3 and 5). This risk level was categorised as medium-low risk. At that catch level, the fishery would also land 56,900 tonnes of mackerel scad, and the CPUE would be about 125 tonnes.unit^{-1} year^{-1}, which is greater than the CPUE at MSY (Table 5).

Table 5. Probabilities (%) of the Fisheries Management Area 715 small pelagic fishery to violate biomass and fishing mortality at maximum sustainable yield (B_{MSY} and F_{MSY}) reference levels in 3 and 10 years, at various levels of fishing effort and targeted catch levels of mackerel scad, *Decapterus macarellus*, and aggregate species.

Target			Mackerel scad MSY	80 % of aggregate species MSY	80 % of mackerel scad MSY
Fishing effort (units)			805	455	427
Aggregate species	Fishing mortality		0.82	0.47	0.44
	Relative fishing mortality		0.92	0.52	0.49
	Total catch (1000 tonnes)		117.4	97.3	95.8
	Relative catch (Y/MSY)		0.97	0.80	0.79
	Catch per unit effort (tonnes/unit/year)		146	214	225
	Risk of over-exploitation	$B_3 < B_{MSY}$	84	71	70
		$F_3 > F_{MSY}$	78	37	35
		$B_{10} < B_{MSY}$	67	24	22
		$F_{10} > F_{MSY}$	66	22	21
Mackerel scad	Fishing mortality		0.68	0.39	0.36
	Relative fishing mortality		1.00	0.57	0.53
	Total catch (1000 tonnes)		67.9	56.9	54.3
	Relative catch (Y/MSY)		1.00	0.84	0.80
	Catch per unit effort (tonnes/unit/year)		84	125	127
	Risk of over-exploitation	$B_3 < B_{MSY}$	77	74	73
		$F_3 > F_{MSY}$	76	61	55
		$B_{10} < B_{MSY}$	80	56	47
		$F_{10} > F_{MSY}$	75	37	29

Notes: B_3 and B_{10} = biomass in 3 and 10 years; F_3 and F_{10} = fishing mortality in 3 and 10 years.
Colour legend:

Risk levels	Low risk	Medium-low risk	Medium-high risk	High risk
Probability (%)	0 - 20	> 20 - 50	> 50 - 80	> 80 - 100

Furthermore, the risks of violating B_{MSY} and F_{MSY} on mackerel scad stock in 3 years would be about 74 % and 61 %, respectively, categorised as medium-high risk, while the risks of violating B_{MSY} and F_{MSY} in 10 years would be lower, i.e. 56 % and 37 %, respectively, categorised as medium-high risk and medium-low risk (Table 5).

A decrease in targeted catch to 80 % of MSY of mackerel scad would decrease the risk on mackerel scad and aggregate species (Table 5), and the CPUE of the small pelagic fishery would increase, benefiting the fleet. In general, when the catch level is higher than the MSY level, the risk rises with time (Tables 3 and 4). On the contrary, the risk would decrease with time when the catch level is lower than the MSY level.

Discussion

One major constraint in assessing fish stocks in Indonesia is the availability of data. The time series data required for the assessment were catch and effort published by DGCF and catch per vessel collected by fishing ports. The high coefficient of determinations that resulted from the surplus production model analyses indicated acceptable goodness of fit of the models to the data. These promising results show the feasibility of the statistical data collected and published by DGCF to assess the small pelagic fishery in FMA 715 (Table 1).

The result of this study, covering 2005 to 2016, showed that fishing mortality tended to increase from 2005 to 2016 and the biomass abundance of mackerel scad and aggregate species decreased from 2008 to 2016 (Table 2; Figs. 3 and 4). As a possible consequence of overfishing from 2015 to 2016, the abundances of mackerel scad and aggregate species were at levels unable to produce MSY in 2016. Moreover, it was estimated that the stocks of mackerel scad and aggregate species would be further diminished in 2017 (Fig. 3). Given the overexploited state of the fishery in 2016, a critical immediate need is additional data collection to evaluate the current stock status. Additionally, strict fisheries management will be required to maintain and, if necessary, rebuild stock abundance and restore sustainable productivity of the small pelagic fishery. Better fisheries management is expected to increase fisheries productivity and efficiency, which should result in optimum sustainable fish production.

The data and information available on the FMA 715 small pelagic fishery were sufficient to perform the stock assessments and risk analyses but were incomplete and limited in scope. The data used in the

analysis were statistical data of the fishery utilising a multispecies small pelagic fish stock. Unfortunately, the fish stock lives in complex and interrelated aquatic ecosystems, with considerable natural variations where no ecological process is known perfectly. The limited research activity also exacerbated the condition to provide additional data for the analyses and illegal and unreported fishing practices in the fishing area. However, the absence of adequate scientific information should not be a reason for postponing or failing to identify and initiate fishery conservation and management measures (FAO, 1995; UNGA, 1995). Rather, the uncertainties resulting from the lack of exact knowledge need to be explicitly considered during the stock assessment, risk analysis, and fishery management (Uusitalo et al., 2015).

The MSY is a risk-prone target for fisheries management (Haddon, 2011). This study indicated that the probabilities of the fish stock and fishing mortality to violate B_{MSY} and F_{MSY} reference levels declined with decreases in the targeted catch levels below MSY (Tables 3 and 4). When the fishing regime is changed, the stock will not move immediately to different stable biomass, but gradually, since the system takes time to respond to changed conditions (Haddon, 2011). Therefore, the risk of overexploitation would gradually change over time, even when the catch has been changed to comply with the targeted catch level. When fishing occurred above MSY, the results indicated that the risk escalated over 3 to 10 years (Tables 3 and 4). On the contrary, the risk would lessen with time when the catch was reduced below MSY. These dynamics in the risk level of overexploitation were also reported by Nishida (2017) and Winker et al. (2019) from the risk assessment of Kawakawa, *Euthynnus affinis* (Cantor, 1849), and Longtail tuna, *Thunnus tonggol* (Bleeker, 1851), stocks in the Southeast Asian waters and Yellowfin tuna, *Thunnus albacares* (Bonnaterre, 1788), stock in the Indian Ocean, respectively. Walter et al., (2019) and Walter and Winker (2020) also reported the same relationships in the risk of overexploitation of Atlantic Bigeye tuna, *Thunnus obesus* (Lowe, 1839), and Atlantic Yellowfin tuna stocks, respectively.

Fishing efforts should be managed to ensure that the fish stock and the fishing pressure are at a sustainable level. There are two ways to control the fishery, by implementing input and output controls. Considering Indonesia's complexity and limited capacity to undertake fisheries monitoring required to support the implementation of output controls such as catch limits, it would be more appropriate to institute input controls by controlling fishing effort, which affects the level of fishing mortality. Input controls also present a challenge since many smaller-scale operators do not participate in reporting and data collection. Thus, a large portion of the fishing effort in Indonesia is not adequately documented. A short-to medium-term policy in managing the small

pelagic fishery in FMA 715 would be to stop granting new fishing licenses as input control. Furthermore, two consecutive strategies need to be taken to manage fish stocks to produce an optimum yield at an acceptable level of risk, namely a stock rebuilding strategy and a fishery optimising strategy. Additional data collection would also be necessary to monitor and evaluate the stock status and the effect of fishery management actions.

The stock rebuilding strategy would be developed and implemented to restore the stock abundance and the sustainable productivity of the small pelagic fish stock in FMA 715 at levels capable of producing MSY within the target years (FAO, 1995; UNGA, 1995). Purwanto et al. (2014) estimated the recovery time of the small pelagic fish stock in the Java Sea from overfished to B_{MSY} was about 2 years when the fishing effort was reduced from its overfished level, i.e. 1.59 E_{MSY}, to E_{MSY}. For the rebuilding plan of the overexploited stock of aggregate small pelagic fish species, with relative fishing mortality of 1.23, a 3-year recovery time would be necessary. This is longer than the recovery time in the Java Sea since the implementation of the management strategy in FMA 715 is confounded by having many more small islands than the Java Sea, which increases the challenges of ensuring compliance of fishers to new regulations.

Uncertainties in the population biomass estimates are typical (Buxton et al., 2014). Therefore, fishery management strategies must ensure that the risk of exceeding reference points, such as the MSY, is very low (Annex II of UNGA, 1995). There is a high risk of exceeding B_{MSY} when the fishery targets the aggregate species MSY. Thus, it would be more difficult to recover the fish stock by using the rebuilding target aggregate species B_{MSY}, since the risks of violating B_{MSY} in 3 years would still be 87 % (Table 3). If B_{MSY} of mackerel scad was used as the rebuilding target, the risks on the mackerel scad and aggregate species in 3 years would be lower, i.e. 77 % and 84 % (Tables 4 and 5). However, those risks are higher than 50 %, which is recommended as a target threshold for uncertainty (Restrepo et al. 1998). This rebuilding target could still be achieved, but the stock rebuilding strategy must have appropriate management measures and enhanced monitoring to review fishery performance, the fish stock status, and the efficacy of conservation and management actions. Data collection and analysis are required to support the stock rebuilding program. Adaptive management processes should be implemented with a management strategy developed and regularly revised based on enhanced monitoring and review result.

The fishery should be maintained at a target reference point needed to sustain fishery resources and optimise economic benefits from utilising the fishery resource (MSS, 2004; Annex II (Para 2) of UNGA, 1995). Considering the risk of setting targeted

catch at the MSY level, ranging from medium-high to high-risk levels (Tables 3 and 4), the MSY should not be used as the target reference point. Instead, the MSY should only be used as the limit reference point the fishery optimising strategy in controlling fishing effort.

Referring to Restrepo et al. (1998), the targeted catch level for managing the small pelagic fishery in FMA 715 is a maximum risk level of 50 % probability of the stock being overfished in 10 years. The targeted catch level of aggregate species equal to 80 % MSY has a risk level of 24 % in 10 years (Table 5). At that catch level, the quantity of the mackerel scad landed by the fishery was about 84 % of its 2016 MSY level, and the risk for the mackerel scad stock was about 56 %. To ensure that the risk level of the fishery to violate B_{MSY} and F_{MSY} would not exceed 50 %, the target reference point for the management of small pelagic fishery in FMA 715 should be the catch of the mackerel scad equal to 80 % MSY. With this target reference point, the overexploitation risk of mackerel scad and aggregate species stocks would be about 47 % and 22 % in 10 years, respectively (Table 5). The 80 % MSY of the mackerel scad could be achieved by controlling fishing effort at 427 purse-seiners. At this effort level, the fishery would produce 95,800 tonnes of aggregate fish catch with 54,300 tonnes of mackerel scad.

With imperfect knowledge about the function and the response of an aquatic ecosystem to fishing and other human activities and the inherent challenge in using population dynamic models, there will always be uncertainties resulting from stock assessments (Haddon, 2011). A key issue is to ensure that the catch limits in the fisheries management strategies are set in a range of safety despite the uncertainty (Buxton et al., 2014). This study presents alternative targets and limits reference points at various levels of risk. The proposed limit and target reference points with the proposed acceptable level of risk resulting from this study are required to develop a harvest control rule for the management of the fishery. The harvest control rules have become an important tool and are increasingly adopted in the practice of modern fisheries management (Kvamsdal et al., 2016), including management of fisheries adopting an ecosystem approach (Quetglas et al., 2017).

The ecosystem approach to fisheries management is in accord with fisheries management goals and sustainable utilisation of fishery resources in Indonesia, as implicitly stated in the 1945 Indonesian Constitution (People's Consultative Assembly of the Republic of Indonesia, 1945) and Indonesian Fisheries Act No 31 of 2004 (MSS, 2004). Article 33(3) of the 1945 Constitution and Article 6(1) of Act no. 31 year 2004 clearly state that fish stocks as part of natural resources in Indonesia should be sustainable and utilised in an optimal and sustainable way for the welfare of Indonesians. These national goals imply that fisheries management should ensure ecological

and human well-being. The ecosystem approach to fisheries is a means to implement sustainable development concepts into fisheries by addressing both human and ecological well-being (FAO, 2003; Bianchi, 2008). Indonesia's MMAF has adopted an ecosystem approach in the preparation of the Fisheries Management Plan (FMP) for FMA 715 issued in 2016 (MMAF, 2016b). To be effectively implemented, an FMP must include reference points for performance measures, management measures/actions and decision rules that control the intensity of fishing activity and/or catch (FAO, 2003; Garcia and Cochrane, 2005; Bianchi, 2008). Unfortunately, the key elements of the FMP are not yet completed, including harvest strategies, reference points, and management measures and control rules (DAFF, 2007; Sloan et al., 2014). A harvest strategy should be developed that includes clear actions for responsible authorities to implement the FMP.

Conclusion

The results indicate that the stocks in Fishery Management Area 715 of mackerel scad, *Decapterus macarellus*, and aggregate small pelagic fish species are overexploited, while the small pelagic fishery is at an overfished level. Any increase in the targeted catch will result in higher risks of violating B_{MSY} and F_{MSY} on mackerel scad and aggregate species of small pelagic fish stocks. Based on these results, a stock rebuilding strategy is recommended and would be implemented with fishery input controls to restore the stock abundance and productivity at levels capable of producing MSY. Given that these recommendations are based on information from 2016, additional data collection is also necessary to monitor and evaluate stock status and the effect of fishery management actions. Considering that the risk of violating B_{MSY} and F_{MSY} on the mackerel scad stock is lower than that on the aggregate small pelagic fish stock at any level of small pelagic fishing effort, it is suggested to use the B_{MSY} of mackerel scad as the stock rebuilding target. A fishery harvest strategy should be adopted and enforced by fishery managers to maintain stock status at or above B_{MSY}. It is recommended that a level of effort corresponding to a catch of mackerel scad equal to 80 % of its maximum sustainable yield be implemented to manage the fishery with a target reference of 50 % risk of overexploitation.

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Supplementary Table 1. List of 17 genera of small pelagic fish that were always reported in the Statistical Yearbook of Capture Fisheries during 2005–2015.

No.	Genus	Common English name
1	*Decapterus* spp.	Scad, Round-scad
2	*Selar* spp.	Oxeye scad/Bigeye scad
3	*Selaroides* spp.	Trevallies
4	*Atule* spp.	Trevallies
5	*Elagatis* spp.	Rainbow runner
6	*Megalaspis* spp.	Torpedo scad
7	*Scomberoides* spp.	Queen fish
8	*Dussumieria acuta* Valenciennes, 1847	Rainbow sardine
9	*Amblygaster* spp.	Spotted sardinella
10	*Sardinella* spp.	Fringescale/Deepbody/ Goldstripped sardinella
11	*Anodonstoma* spp.	Chacunda gizzard shad
12	*Tenualosa* spp.	Hilsa shad
13	*Rastrelliger* spp.	Indian mackerel and short-bodied mackerel
14	*Mugil* spp.	Mangrove/Blue-spot/ Blue-tail mullet
15	*Tylosurus* spp.	Needle fish
16	*Hemirhampus* spp.	Garfish and halfbeaks
17	*Cypselurus* spp.	Flying fish

Source: DGCF (2016); www.fishbase.org