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# Vulnerability analysis of pelagic and demersal fisheries in the Indian Ocean, Fisheries Management Area 572, Indonesia

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# Vulnerability analysis of pelagic and demersal fisheries in the Indian Ocean, Fisheries Management Area 572, Indonesia

**Firdha Iresta Wardani[1], N Nadiarti[2], Alfa FP Nelwan[3], and Muhammad Jamal[4]**

[1]Fisheries Science Study Program, Universitas Hasanuddin, Makassar 90245, Indonesia
[2]Aquatic Resources Management Study Program, Universitas Hasanuddin, Makassar 90245, Indonesia
[3]Utilization of Fisheries Resources Study Program, Universitas Hasanuddin, Makassar 90245, Indonesia
[4]Utilization of Fisheries Resources Study Program, Universitas Muslim Indonesia, Makassar 90231, Indonesia

Email: nadiarti@unhas.ac.id

**Abstract**. Indonesian Fisheries Management Area (FMA) 572 situated in the Indian Ocean, includes the coastal waters of Bengkulu City, has great potential in terms of pelagic and demersal fisheries. However, the exploitation of these fisheries resources has been intensified due to the growing demand for human consumption. Unfortunately, information related to the susceptibility and productivity of fisheries resources in this area is still negligible. The purpose of this study was to determine the level of vulnerability to potential fishery impacts of several pelagic and demersal fisheries in FMA 572. The study was conducted in Bengkulu City from July to December 2019. Analysis of the productivity and susceptibility level of the fisheries used several productivity and susceptibility parameters through the Productivity and Susceptibility Analysis (PSA) method. The results of the study revealed that the vulnerability level of yellow stripe scad (*Selaroides leptolepis*) was higher than that of other target fishes. However, in general, the vulnerability of pelagic and demersal fisheries to potential overfishing in FMA 572 was still low.

## 1. Introduction

The waters of Bengkulu City in the Indonesian Fisheries Management Area (FMA) 572 as a part of Indian Ocean, support rich pelagic and demersal fisheries. The potential fishery resources of FMA 572 in 2015 were estimated to be around 1.228 million tons per year [1]. Unfortunately, fish stocks are now facing risks locally and globally, and even serious threats of extirpation, due to direct and indirect fishing effects [2]. Fishing activities have caused changes in the structure of fish communities and stock depletions [3]. It is considered by [4] that the capture fisheries in Indonesia face risks with increasing threats and declining catches, where the small pelagic and demersal fish stocks are mostly fully exploited while the status of most large pelagic fishes is overexploited.

To help manage the risks posed to species caught in a range of fisheries, several frameworks and approaches have been developed, such as Ecological Risk Assessment [5,6], Ecological Risk Screening Technique [7], Potential Risk Assessment [8], and Ecological Method for Qualitative Risk Assessment [9]. Productivity and Susceptibility Analysis (PSA) is an alternative approach to the fisheries risk assessment [10]. PSA is a semi-quantitative and rapid risk assessment tool that relies on the use of life-

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history characteristics of a stock (i.e., productivity) and its level of susceptibility to the fishery to determine a relative inherent vulnerability [11].

Several advisory and management bodies, as well as other studies, have used PSA in assessing the vulnerability of fisheries for various taxa, e.g. (Georgeson et al., 2018; Lucena-Frédou et al., 2017; Peng et al., 2015; W. Patrick et al., 2009; Stobutzki, Miller, & Brewer, 2001). Several studies in Indonesia using PSA e.g. [3,17,18]. However, none of these studies covered FMA 572, especially the waters of Bengkulu City. Therefore, this study applied the PSA approach to analyze the vulnerability of the pelagic and demersal fisheries in FMA 572, in particular the waters around Bengkulu City, to support fisheries management in this important fishing area.

## 2. Methods

### *2.1. Data Collection*

This study was conducted in Bengkulu City from July to December 2019. Primary data were collected through measuring the total length and determining the stage of gonad development of sampled fish, as well as conducting interviews. The fish specimens used as samples in this study were collected from the fish landing site (PPI Pulau Baai) and fish auction site (TPI Pasar Bengkulu) and comprised a selection of the pelagic and demersal fishes of various sizes which were available at the sampling locations. Fish specimens were identified based on FishBase, the global database of fish [19]. The fishes were measured and then divided into three groups (small, medium, and large size). Interviews were conducted with respondents (n = 69) including fishermen (n = 61) and fishmongers (n = 8). Secondary data were obtained from the desk study. The data collected also included fish fecundity, fish behaviour, fisheries production, and marketing aspects.

The fishing grounds for pelagic fishes were mostly in offshore waters. For demersal fishes, the fishing grounds were located around Tikus Island, Enggano Island, and Mega Island, all of which have fringing coral reefs (Figure 1).

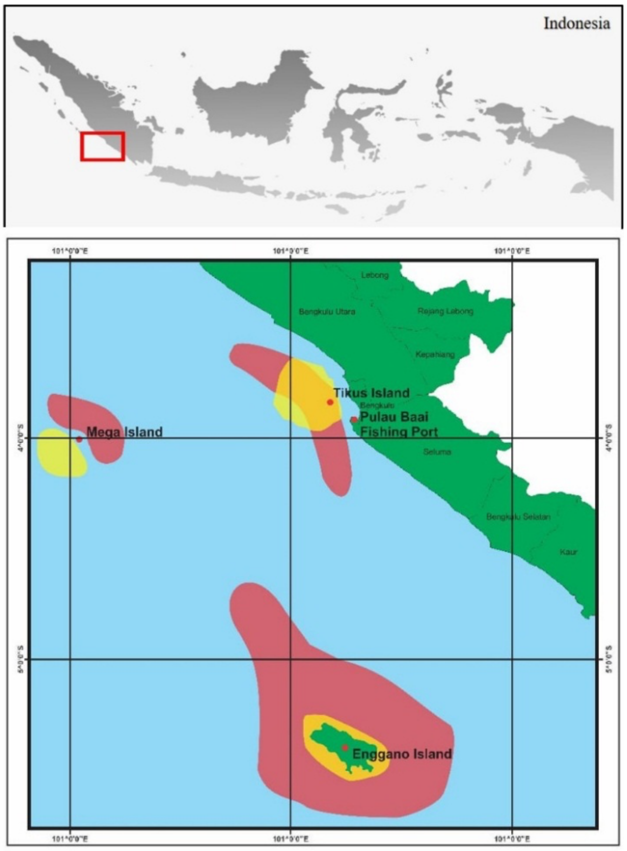


**Figure 1**. Map of fishing grounds for pelagic and demersal fishes in Bengkulu City. Key: land (green), ocean (blue), pelagic fishing ground (red), demersal fishing ground (yellow)

*2.2. Data Analysis*

Growth parameters were estimated based on the von Bertalanffy equation [20] through the ELEFANT Program in the software FISAT II [21]. The Von Bertalanffy equation: $L_t = L_\infty (1 - e^{[-K(t-t_0)})$, was used, where Lt is the total length of fish (cm) at t age, L∞ is the maximum fish length (cm), K is the growth coefficient, and $t_0$ is the theoretical age when the fish length is zero.

The theoretical age of a fish could be estimated separately using the empiric formulation of Pauly [22]: $Log\,(-t) = 0.3922 - 0.2752\,(Log\,L_\infty) - 1.038\,(Log\,K)$, while the total mortality (Z) was calculated using the length-converted catch curve in the FiSAT II package [20], and the natural mortality (M) was estimated using Pauly's empiric formula [21] as follows: $Ln\,M = -0.0152 - 0.279\,x\,Ln\,L_\infty + 0.6543\,x\,Ln\,K + 0.463\,x\,Ln\,T$, where M is natural mortality, and T is mean water temperature (°C). Fishing mortality rate (F) was determined by$(F = Z - M)$. Exploitation rate was determined as the ratio of the fishing mortality (F) to the total mortality (Z): $E = \frac{F}{Z}$ [23].

Productivity and Susceptibility Analysis (PSA), a method developed by the National Oceanic and Atmospheric Administration (NOAA) National Marine Fisheries Service, was used to estimate the vulnerability [16,24] of several pelagic and demersal fishes to overfishing based on a combination of biological productivity and interactions with overfishing fleets [25,26].

The PSA outlines vulnerability in two parameters: (1) productivity (P), characterized by the life history of each pelagic and demersal fish, and (2) susceptibility (S), characterized by how the species are likely to be affected by the fishery in question. The present study considered the pelagic and demersal fishes caught from the Bengkulu waters within the Indonesian Fisheries Management Area (FMA 572).

Nine attributes were used to calculate productivity P (Table 1), as proposed by [24]. Likewise, eleven attributes were used to estimate the susceptibility S (Table 2) as originally proposed by [16,24]. All these attributes were then scored on a three point scale: 1–3 (low, medium and high categories, respectively), based on the contribution of the relative value to the overall productivity or susceptibility score [27]. To determine the value of most attributes, the criteria identified by [16] were used.

**Table 1.** Productivity attribute data

| Parameters | High (3) | Medium (2) | Low (1) |
|---|---|---|---|
| r | >0.5 | 0.16-0.5 | <0.16 |
| Maximum Age | <10 years | 10-30 years | >30 years |
| Maximum Size | <40 cm | 40-80 cm | >80 cm |
| von Bertalanffy Growth Coefficient (k) | >0.20 | 0.10-0.20 | <0.10 |
| Estimated Natural Mortality | >0.20 | 0.10-0.20 | <0.10 |
| Measured fecundity | $>10^4$ | $10^2$-$10^4$ | $<10^2$ |
| Recruitment pattern | Highly frequent recruitment success (>75% of year classes are successful) | Moderately frequent recruitment success (between 10% and 75% of year classes are successful) | Infrequent recruitment success (<10%of year classes are successful) |
| Age at Maturity | <2 year | 2-4 years | >4 years |
| Mean Trophic level | <2.5 | 2.5-3.5 | >3.5 |

**Table 2.** Susceptibility attribute data

| Parameters | Low (score= 1) | Medium(score=2) | High (score=3) |
|---|---|---|---|
| Areal Overlap | <25 | 25-50 | >50 |
| Geographic concentration | >50 | 25-50 | <25 |
| Vertical Overlap (%) | <25 | 25-50 | >50 |
| Seasonal Migrations | Seasonal migrations decrease the overlap with the fishery | Seasonal migrations do not substantially affect the overlap with the fishery | Seasonal migrations increase affect the overlap with the fishery |
| Schooling/aggregation and other behavioural responses | Behavioural responses decrease the catchability of the gear | Behavioural responses do not substantially affect the catchability of the gear | Behavioural responses increase the catchability of the gear |
| Morphology Affecting Capture | Species shows low selectivity to the fishing gear | Species shows moderate selectivity to the fishing gear | Species shows high selectivity to the fishing gear |
| Desirability/Value of the fishery | Stock is not highly valued or desired by the fishery | Stock is moderately valued or desired by the fishery | Stock is highly valued or desired by the fishery |
| Management Strategy | Targeted stocks have catch limits and proactive accountability measures; non-target stock are closely monitored | Targeted stocks have catch limits and reactive accountability measures | Targeted stocks do not have catch limits and proactive accountability measures; non-target stock are closely monitored |

| | | | |
|---|---|---|---|
| Fishing rate relative to M | <0.5 | 0.5-1.0 | >1 |
| Survival after Capture and Release | >67% | 33%-67% | <33% |
| Fishery Impact to EFH or habitat in general for Non-targets | Adverse effects absent, minimal or temporary | Adverse effects more than minimal or temporary but are mitigated | Adverse effects more than minimal or temporary but are not mitigated |

The PSA assessment determined weighting scores, attribute scores, and data quality. The weighting scores indicate the relative importance of each parameter, ranging from 0 (the least important) to 4 (the most important). The attribute scores of productivity and susceptibility comprise level 1 (low), level 2 (medium) and level 3 (high). Data quality was in the range of 1 to 5, where 1 is complete data, 2 is limited data (temporally and spatially), 3 is data based on the same genus or family, 4 is new data (unpublished information), and 5 is no data.

According to [14,16], the vulnerability analysis is a combination of productivity and susceptibility based on a Euclidean distance approach. Each attribute of productivity and susceptibility according to [28] has three possible risk scales: low risk (3), medium risk (2), or high risk (1). All data were then analysed and presented as a scatter x-y plot using the following equation [24]: $V = \sqrt{\sqrt{(p-3)^2 + (s-1)^2}}$, where p is productivity score and s is susceptibility score. When the v value is beyond or equal to 1.8 this indicates overfishing [24].

## 3. Results

Overall, the total fish sample (n = 1198) obtained from 12 sampling frequencies in this study comprised pelagic fishes (n = 645) and demersal fishes (n = 553). The pelagic fish samples consisted of yellow striped scad (*Selaroides leptolepis*) (n = 305), mackerel scad (*Decapterus macarellus*) (n = 120), and mackerel tuna (*Euthynnus affinis*) (n = 220). The demersal fish samples were largehead hairtail (*Trichiurus lepturus*) (n = 329), white pomfret (*Pampus argenteus*) (n = 60), and threadfin bream (*Nemipterus japonicus*) (n = 164). All these samples were divided into three size categories, i.e. small size fish (<40 cm), medium size fish (40-80 cm), and large size fish (>80 cm).

Table 3 shows results of productivity analysis for pelagic and demersal fish species in Bengkulu waters. The highest intrinsic growth rate (r) was found in the yellow striped scad. This fish also had the highest longevity and the lowest growth coefficient of all the fishes in this study. Among demersal fishes, the largehead hairtail was found to have the highest intrinsic growth rate (r) as well the highest longevity. Fecundity values of all fishes in the study area were categorized as high level since the fecundity values were mostly above 10,000 (Table 3). Recruitment patterns of all evaluated fish ranged from 16.25 – 23.14 which were in the medium scale category. Mean trophic level of the pelagic and demersal fishes in the study area (Table 3) were comparable and ranged from 3.3 to 4.5. Table 4 shows the results of susceptibility analysis for pelagic and demersal fish species in Bengkulu Waters.

**Table 3.** Results of productivity analysis for pelagic and demersal fish species in Bengkulu Waters

| Parameters | Pelagic | | | Demersal | | |
|---|---|---|---|---|---|---|
| | Yellow striped scad | Mackerel scad | Mackerel tuna | Largehead hairtail | White pomfret | Threadfin bream |
| r | 1.6 | -0.36 | -0.017 | 1.21 | 0.872 | 0.73 |
| Maximum Age | 4.92 | 2.58 | 2.58 | 2.67 | 0.91 | 2.5 |
| Maximum Length | 30.5 | 34 | 67.1 | 83.4 | 38.5 | 35.5 |

| | | | | | | |
|---|---|---|---|---|---|---|
| von Bertalanffy Growth Coefficient (k) | 0.26 | 0.51 | 0.51 | 0.52 | 1.51 | 0.51 |
| Estimated Natural Mortality | 0.72 | 1.1 | 0.29 | 0.96 | 2.39 | 1.07 |
| Measured fecundity | 762-24,906[a] | 5,669-120,752[b] | 210,000-680,000[c] | 12,928-294,700[d] | 40,610-221,849[c] | 13,900-139,200[c] |
| Recruitment pattern (%) | 16.73 | 20.03 | 19.26 | 16.25 | 23.14 | 17.54 |
| Age at Maturity | 1 | 0.16[e] | 0.083 | 0.25 | 0.083[c] | 1.4[c] |
| Mean Trophic level | 3.8[c] | 3.4[c] | 4.5[c] | 4.4[c] | 3.3[c] | 4.1[c] |

Sources: [a][29], [b][30]. [c][19], [d][31], [e][32]

**Table 4.** Results of susceptibility analysis for pelagic and demersal fish species in Bengkulu Waters

| Parameters | Pelagic | | | Demersal | | |
|---|---|---|---|---|---|---|
| | Yellow striped scad | Mackerel scad | Mackerel tuna | Largehead hairtail | White pomfret | Threadfin bream |
| Areal Overlap | 66% | 33% | 50% | 40% | 50% | 33% |
| Geographic concentration | 75% | 75% | 75% | 75% | 75% | 75% |
| Vertical Overlap (%) | 33% | 33% | 25% | 20% | 50% | 33% |
| Seasonal Migrations | Seasonal migrations decrease the overlap with the fishery | | | | | |
| Schooling/aggregation and other behavioural responses | Behavioural responses decrease the catchability of the gear | | | | | |
| Morphology Affecting Capture | High selectivity (Drifting gill net) | High selectivity (Fixed gill net) | High selectivity (Purse Seine) | High selectivity (Fixed gill net) | Low selectivity (*Payang* seine) | High selectivity (Drifting gill net) |
| Desirability/Value of the fishery | High IDR 20,000-23,000 | High IDR25,000-30,000 | High IDR25,000-30,000 | Moderate IDR10,000-250,00 | High IDR 40,000-120,000 | Moderate IDR 10,000-150,000 |
| Management Strategy | Adverse effects more than minimal or temporary but are not mitigated | | | | | |
| Fishing rate relative to M | 0.67 | 0.73 | 0.28 | 0.22 | 0.02 | 0.68 |
| Survival after Capture and Release | <33% | | | | | |
| Fishery Impact to EFH or habitat in general for Non-targets | Adverse effects more than minimal or temporary | Adverse effects more than minimal or temporary | Adverse effects more than minimal or temporary | Adverse effects more than minimal or temporary | Adverse effects absent, minimal or | Adverse effects more than minimal or |

| | | | | | | |
|---|---|---|---|---|---|---|
| | but are mitigated | but are mitigated | but are mitigated | but are mitigated | temporary but are not mitigated | temporary but are mitigated |

Among the species evaluated within the study area, yellow striped scad was found to be potentially the most vulnerable, with a mean vulnerability score of 1.69 and white pomfret was found to be the least vulnerable, with a mean score of 1.24. All vulnerability scores across all zones fell into the low category (Table 5, Fig. 2), where threadfin bream had the highest vulnerability score among the demersal fishes (1.48). Mackerel tuna and mackerel scad had comparable vulnerability scores (1.37 and 1.31, respectively), both lower than the yellow striped scad.

**Table 5.** Productivity, susceptibility and vulnerability values of pelagic and demersal fishes in Bengkulu Waters

| Fish Group | Productivity Value | Susceptibility Value | Vulnerability Value |
|---|---|---|---|
| **Pelagic fish** | | | |
| • Yellow striped scad | 2.71 | 2.67 | 1.69 |
| • Mackerel tuna | 2.82 | 2.30 | 1.37 |
| • Mackerel scad | 2.57 | 2.30 | 1.31 |
| **Demersal fish** | | | |
| • Largehead hairtail | 2.43 | 2.14 | 1.27 |
| • White pomfret | 2.82 | 2.23 | 1.24 |
| • Threadfin bream | 2.71 | 2.46 | 1.48 |

Figure 2 shows the productivity and susceptibility scores of all the studied fish species, showing that the data for all the species studied qualified as high quality data.

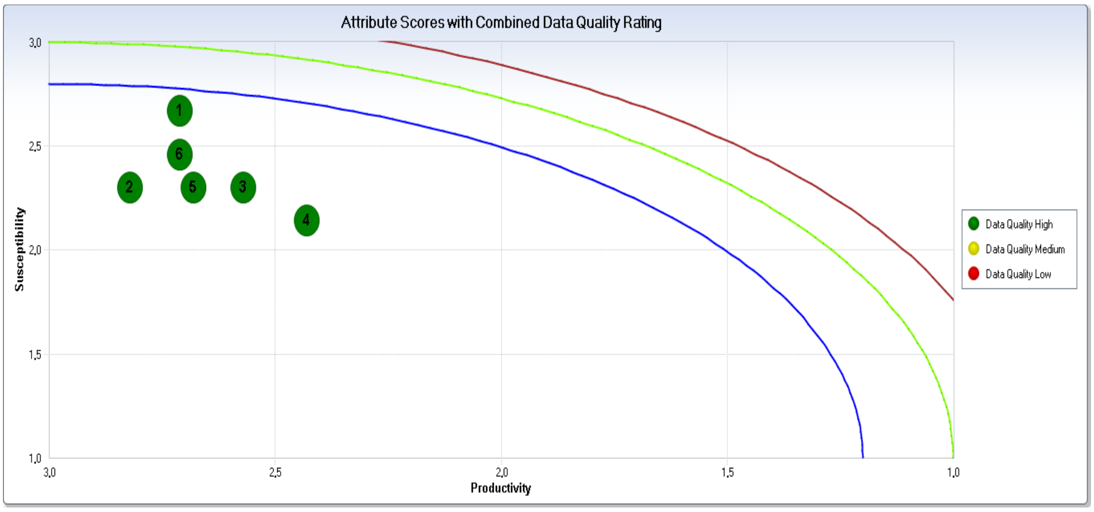


**Figure 2**. Productivity and susceptibility scores of six fish species in Bengkulu waters within FMA 572: yellow striped scad (1), mackerel scad (2), mackerel tuna (3), largehead hairtail (4), white pomfret (5), threadfin bream (6).

## 4. Discussions

The variation in fish growth might be influenced by the external factors and the inherent internal factors of the fish [33]. The external factors may include environmental conditions and food availability, while the inherent internal factors possibly include offspring, sex, age and disease.

The high fecundity values imply high population productivity [34]. Recruitment patterns of all evaluated fishes were in the medium category which implies relatively steady recruitment [16]. Age at maturity tends to be positively correlated with maximum age ($t_{max}$) as long-lived, lower productivity stocks will have higher ages at maturity relative to short-lived stocks [16]. Since the age at maturity for all fish species in this study was in the low category (<2 years), it can be suggested that these species are short-lived stocks and belong to the higher productivity stocks group. Based on the value of mean trophic level, the target fishes in the study area were categorized as belonging to the 4$^{th}$ level and predominantly piscivorous [35], which can be considered a relatively high trophic level [16].

Susceptibility is the potential for the stock to be impacted by the fishery [24]. The attribute of areal overlap was found to be high in the yellow striped scad, while other species had medium areal overlap. This indicates higher susceptibility in the yellow striped scad, as according to [16] the higher the areal overlap, the greater the susceptibility. Geographic concentration in general had a low score (>50). Although the demersal fishes are not migrating as far as the pelagic fishes, all these fish stocks are schooling fishes and categorized as highly aggregated stocks [36–40], which may potentially lead to increases in catchability, so that they have high susceptibility [16].

Yellow striped scad was found to be potentially the most vulnerable fish in this study, although the score was still below the overfished status [24]. The higher the vulnerability score, the higher the likelihood that fishing threats faced by fish could affect the ability of the stock to recover from pressure. A study in the Java Sea [41] found that *Decapterus* sp. (Carangidae) had been overfished with a vulnerability score of 2.18. This is higher than the vulnerability score of yellow stripe scad in this study, and indicates that fishes belong to the Family Carangidae are potentially vulnerable; however, the fish in the Indian Ocean were still less vulnerable compared with those in the Java Sea. Higher exploitation rates for pelagic fisheries in the Java Sea, including Carangidae, is supported by [42] who explained that rapid development of pelagic fisheries in the Java Sea has occurred since the mid 1970's, after the introduction of the purse seine fleet and the trawl ban in 1980. Nonetheless, more detailed studies are required to support this suggestion.

The mackerel tuna and mackerel scad had comparable vulnerability scores (1.37 and 1.31, respectively), lower than for the yellow striped scad. A vulnerability study on neritic tuna in Palabuhanratu waters (Suryaman *et al.*, 2017) found the most vulnerable fish there was the mackerel tuna with a vulnerability score of 1.49 which was higher than for this species in our study. Different vulnerability values for the same species may relate to intraspecific variations in life history patterns [43] and the use of different weighting values in the vulnerability analysis [34]. Variation of vulnerability values among the pelagic and demersal fishes maybe due to different characteristics, such as their behaviour relative to the gears used by fishermen. These characteristics will of course affect the vulnerability scores obtained.

The highest vulnerability score among the demersal fishes studied suggests that the threadfin bream is more vulnerable compared to the other two demersal fishes (largehead hairtail and white pomfret). In general, all the vulnerability scores for the fish studied in the Bengkulu area were below 1.8, indicating that the vulnerability level of the pelagic and demersal fish to overfishing is still low (Patrick *et al.* 2010).

The high quality of the data (shown by green circles in the graphs) used in this study was due to the predominantly primary data applied in this study taken from direct observations and measurements in the field. Logitudinal lines in the graph of productivity and susceptibility indicating vulnerability level [25], where the longitudinal red line in the graph indicates high vulnerability, the longitudinal green line indicates medium vulnerability, and low vulnerability is indicated by the longitudinal blue line [25,44]. Since all fish data were distributed below the blue line (Figure 2), this suggests that the vulnerability for all fish species evaluated in this study was still at a low level. These results was confirmed by Table 6 where all the productivity values were larger than the vulnerability values, suggesting the level of fish productivity is higher than the threat to fish from fishing.

Although the vulnerability analysis showed low impacts from fishing on the fish stocks, minimizing the fishing impact on the ecosystems will support sustainable fisheries production through proper fisheries management [45]. This is especially relevant for the yellow striped scad which had the highest vulnerability level.

## 5. Conclusion

All fish species in this study were in the low vulnerability level category. However, controls on fishing effort, especially for the yellow stripe scad, are still required to ensure long-term sustainable fisheries production.

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