Productivity and susceptibility analysis of Indo-Pacific king mackerel in IFMA 711 waters

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Abstract. Indo-Pacific king mackerel has been long fished by traditional and modern fishers. The fish is a catch target species with high economic value in local and export markets. The fishing efforts for the fish have been increasingly intensive. The management for which is still lacking. The concern is, continuous exploitation will make indo-Pacific mackerel stock susceptible. The fish condition should be measured based on productivity and susceptibility parameters using productivity susceptibility analysis (PSA). The study aimed to analyze the sustainability of Indo-Pacific king mackerel and other species caught by gillnet and purse seine in IFMA 711 based on productivity and susceptibility scenarios. The study analyzed Indo-Pacific king mackerel and other species, i.e. whitefin wolf-herring, narrow-barred Spanish mackerel, longtail tuna, eastern little tuna, and bigeye scad. The results of the analysis suggest that Indo-Pacific king mackerel and whitefin wolf-herring were of moderate productivity and susceptibility, narrow-barred Spanish mackerel and longtail tuna were of high productivity and low susceptibility, and eastern little tuna and bigeye scad were of low productivity and high susceptibility, putting both at high risk from fishing activities. Also, the data quality of Indo-Pacific king mackerel was moderate, while the data quality of whitefin wolf-herring was the worst. Therefore, it is necessary to improve the quality and quantity of the data and scientific information on whitefin wolf-hearing in further studies.

Keywords: FMA 711; Indo-Pacific king mackerel; productivity; stock status; susceptibility

1. Introduction

In fisheries resource management, the most frequent challenge is how to exploit fisheries resources to generate economic benefit while sustainability is well maintained for future generations. The challenge is continuously increasing when various fish stocks are exploited at the same time, putting the stocks in intensive pressure and vulnerable state [1]. In addition to the uncertainty, the difficult condition of fisheries management is also related to the availability of scientific data, highly limiting the analysis of the fish resource and the information from which for the management was also minimum [2]. When the data is poor, one of the approaches used in fish stock management is combining the taxonomy, life
history, ecology, and fisheries condition [3]. Such a combination highly supports the management; with limited data, the fish resource management can be still carried out using various methods and applications that facilitate the management to assess fish stock conditions.

Indo-Pacific king mackerel (Scomberomorus guttatus) is one of the species from the genus Scombridae in Indonesia waters. The production of the species in the Indonesia Fisheries Management Area (IFMA) 711 in 2005–2016 was fluctuating, and in 2014 reached 21168 tons or approximately 58% of the total national production. The data indicate that the production of which in IFMA 711 is higher than in any other area [4]. The species in IFMA 711 is mostly fished using <10 gross tons (GT) small vessel with gillnet fishing gear. The catch from the fishers is then sold to a tangkahan. It is a landing site owned by individuals that are integrated with cold storage, workshop, and landing port for vessels to unload the catch from the fishers and to process the catch before export. Fishers’ landing sites in IFMA 711 are widely spread, i.e. at the ports and coastal areas of small islands.

Indo-Pacific king mackerel has been long fished by traditional and modern fishers. The fish is a catch target species with high economic value in local and export markets. The fishing efforts for the fish have been increasingly intensive. However, the management for which is still lacking. The concern is, continuous exploitation will make indo-pacific mackerel stock susceptible. Therefore, the fish condition should be measured based on productivity and susceptibility parameters using productivity susceptibility analysis (PSA). The study aimed to analyze the sustainability of Indo-Pacific king mackerel in IFMA 711 based on productivity and susceptibility scenarios.

2. Material and methods

2.1. Time and location of the study

This study was carried out in IFMA 711, covering Karimata Strait, Natuna Sea, and the South China Sea. Another study on the fisheries condition, fishing operation, and the biological aspects of Indo-Pacific king mackerel were previously carried out in 2014-2017 in Riau Islands waters as part of IFMA 711, with Indo-Pacific king mackerel and whitefin wolf-herring as the study’s specific objects. In this study, other species were analyzed as well using PSA. Secondary data of the fish species were acquired from scientific journals and papers. The species were used as comparisons in PSA. The materials and objects of the research included six species, namely Indo-Pacific king mackerel (Scomberomorus guttatus), whitefin wolf-herring (Chirocentrus nudus), narrow-barred Spanish mackerel (Scomberomorus commerson), longtail tuna (Thunnus tonggol), eastern little tuna (Euthynnus affinis), and bigeye scad (Selar crumenophthalmus). See figure 1 for the location of the study.

PSA was initially developed to evaluate shrimp bycatch in Australia by assessing the productivity of the bycatch stock and the susceptibility of which against fisheries [5, 6]. In 2004, the Australian Ecological Risk Assessment (AERA) team adapted the PSA for broader purposes in assessing the susceptibility of an ecosystem [7]. The PSA has also been adapted for various assessment/evaluation of the sustainability of an ecosystem or stock [8-12].

The analysis is also used in the Right Base Fisheries (RBF). Its semi-quantitative approach assesses several attributes of each species that contribute to the productivity or susceptibility of which. The purpose is to provide a relative measurement between risk and the assessment elements of fisheries activity. The PSA is required when the RBF is used to assess the target species, and it may also be used to assess protected species or bycatch. Each identified species (assessment element) has its respective PSA value.

The assessment of fish stock status based on the productivity and susceptibility against the pressure from the fisheries activity is one of the approaches used to understand how strong a species is to survive in an ecosystem impacted by the intensity of fishing activity in the waters. The PSA has been used to assess fish stock status up to species level to allow a management action to be taken for the sustainability of the fisheries. The required data inputs were the species’ biological parameters including the age at first maturity, maximum age, fecundity, natural mortality, and behavior. All the data were easily
accessible from local fishers, scientific kinds of literature, and online databases (e.g. FishBase), while the information on fisheries was from the fishers, the fisheries experts, and stakeholders.

The attributes in the productivity analysis were the population parameters of the fisheries; the range of each parameter category was determined based on the discussion with the experts (table 1). On the other hand, parameters for the sustainability analysis were based on the availability and catchability, i.e. the overlaps among species and fishing gears, the fishing chance, i.e. the fish size or mesh size, and the probability of the resource survival after capture (table 2). A total of 22 attributes were selected for analysis (10 productivity attributes and 12 susceptibility attributes) [11]. Hobday stated that assessment with PSA analysis uses scores 1 to 3, where score 1 indicates low productivity or susceptibility, and score 3 high (table 2) [13].

![Figure 1. The location of the PSA study in IFMA 711.](image)

| No | Productivity Attribute                  | High (3) | Moderate (2)                      | Low (1) |
|----|----------------------------------------|----------|----------------------------------|---------|
| 1  | Intrinsic growth \((r)\)              | >0.5     | 0.5-0.16 (mid-point 0.10)        | <0.16   |
| 2  | Max age                                | <10 years| 10-30 years (mid-point 20)       | >30 years|
| 3  | Max size                               | <60 cm   | 60-150 cm (mid-point 105)        | >150 cm |
| 4  | Von Bertalanffy growth coefficient \((k)\) | >0.25   | 0.15-0.25 (mid-point 0.20)       | <0.15   |
| 5  | Estimated natural mortality \((M)\)    | >0.40    | 0.20-0.40 (mid-point 0.30)       | <0.20   |
| 6  | Measured fecundity                     | >10^4 (100 000) | 10^2-10^3 (1000-10 000) | <10^2 (1000) |
| 7  | Breeding strategy                      | 0        | between 1 and 3                  | >4      |
| 8  | 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) |
| 9  | Age at maturity                        | <2 years | 2-4 years (mid-point 3.0)        | >4 years|
| 10 | Mean trophic level                     | <2.5     | 2.5-3.5 (mid-point 3)            | >3.5    |

Table 1. Parameter/attribute and productivity score in risk analysis.
| No | Susceptibility Attribute | Low (1)                                                                 | Moderate (2)                                                                 | High (3)                                                                 |
|----|--------------------------|--------------------------------------------------------------------------|-----------------------------------------------------------------------------|--------------------------------------------------------------------------|
| 1  | Management strategy      | target stocks have catch limits and proactive accountability measures;    | target stocks have catch limits and reactive accountability measures;         | target stocks do not have catch limits or accountability measures;         |
|    |                          | non-target stocks are closely monitored                                   | non-target stocks are not closely monitored                                  | non-target stocks are not closely monitored                                 |
| 2  | Areal overlap            | <25% of the stock is in the fishing area                                   | 25–50% of the stock is in the fishing area                                    | >50% of the stock is in the fishing area                                    |
| 3  | Geographic concentration | stock is distributed in >50% of its total range                          | stock is distributed in 25–50% of its total range                           | stock is distributed in <25% of its total range                            |
| 4  | Vertical overlap         | <25% of the stock is in the fishing depths                                | 25–50% of the stock is in the fishing depths                                 | >50% of the stock is in the fishing depths                                  |
| 5  | Fishing rate relative to M | <0.5                                                                    | 0.5–1.0                                                                    | >1                                                                        |
| 6  | Biomass of spawner (SSB) or other proxies | B is >40% of B0 (or max observed from time series of biomass estimates) | B is 25–40% of B0 (or max observed from times series)                       | B is <25% of B0 (or max observed)                                         |
| 7  | Seasonal migrations      | seasonal migrations decrease fishery production                         | seasonal migrations do not substantially affect the fishery                  | seasonal migrations increase fishery production                           |
| 8  | Schooling/Aggregation    | fish behavior decreases fishing gear catchability                         | behavioral responses do not substantially affect the catchability of the gear | fish behavior increases fishing gear catchability (i.e., hyperstability of CPUE) |
| 9  | Morphology affecting capture from fishing gear | low affect                  | moderate affect                                                             | high affect                                                              |
| 10 | Survival after capture and release | probability of survival >67%                                           | probability of survival 33–67%                                              | probability of survival <33%                                               |
| 11 | Desirability/value of the fishery | low value                  | moderately value                                                            | highly value                                                              |
| 12 | Fishery impact to fish habitat | adverse effects absent, minimal, or temporary                           | adverse effects more than minimal or temporary but are mitigated             | adverse effects more than minimal or temporary and are not mitigated       |
2.2. Data quality index

Uncertainty related to fish stock data can lead to errors in the analysis of risks from the fishing activity impacts [14]. When there is a lack of data, ecological risk analysis often generates a higher score, and mistakenly identifies a high-risk stock as a low-risk one [5, 15, 14]. Incomprehensive data set will result in high risk because the lacking number of data or the risk assessment of the available data leads to a higher score in the assessment [7].

The data quality index was developed to provide the uncertainty estimate of the five individual sustainability scores, i.e. from the best data or score with high confidence to the no data or score with low confidence (table 3). The data quality of both productivity and susceptibility scores were calculated as the weighted average of quality score for each attribute of each fish species, and the results from which indicated the quality of the overall data or confidence. The data quality scores were group into three, i.e. low (> 3.5); moderate (2.0-3.5); and high (< 2.0) [11]. See table 3 for the five data quality scores used to evaluate the productivity and susceptibility of fish stock.

Table 3. The five data quality scores used in the PSA.

| Data Quality Score | Description                                                                 |
|--------------------|-----------------------------------------------------------------------------|
| 1                  | Best data, substantial information based on the collected data on stock and in the determined study area. |
| 2                  | Adequate data, corroborating information with limited coverage, or information considered not as reliable as the best data due to a particular reason |
| 3                  | Limited data, an estimate with high variation and low confidence, may be based on the same taxon or life history strategy |
| 4                  | Very limited data, expert's opinion or information based on the kinds of literature in general on various species, or information about the other locations |
| 5                  | No data, no information available to determine the score – included in data quality index score, not included in PSA |

Modified PSA is the best approach to analyze stock vulnerability [5, 6, 15-17]. Several organizations and working groups also recommended the modified PSA as the most reasonable approach to determine risks [7-9, 18]. The two-dimensional characteristics of PSA can be calculated directly to generate the overall vulnerability (v) score of a species. Values for 'p' and 's' are determined by giving a score starting at 1 to 3 for the standard set of attributes associated with each index (productivity and susceptibility attributes). The 'p' value as the 'x' axis with the highest productivity value is given a score of 3, then for medium and low productivity, it is given a score of 2 and 1 respectively, while the 's' value is given a 'y' score. The axis value with the lowest susceptibility value is given a score of 1 and the highest was given a score of 3. The 'p' and 's' scores, namely 3 and 1 are the original coordinates (x,y). This score is the average value of each index and graphically on the x-y scatter plot, is a two-dimensional picture of the Euclidean distance from the productivity and susceptibility scores in calculating the value of species vulnerability (v). The formula is as follow:

\[
v = \sqrt{[(p-3)^2 + (s-1)^2]} \tag{1}
\]

Note: v = vulnerability, p = productivity, and s = susceptibility

The v score is used to determine the vulnerability reference point in fisheries resource management [12]. See table 4 for the category of the vulnerability scores.
3. Results

3.1. Productivity and susceptibility parameters
PSA was carried out on 6 dominant species, i.e. (1) Indo-Pacific king mackerel, (2) whitefin wolf-herring, (3) narrow-barred Spanish mackerel, (4) longtail tuna, (5) eastern little tuna, and (6) bigeye scad. Productivity attributes are parameters to examine how fast a species recovers after being impacted by fishing activity. Also, susceptibility attributes indicate the potential of a fish resource after being impacted by fishing activity. See Table 5, 6 and 7 for the results of PSA on Indo-Pacific king mackerel and other species.

Table 4. The vulnerability (v) score to determine the reference point.

| Category | Vulnerability Score (v) |
|----------|-------------------------|
| low      | v < 1.8                 |
| medium   | 1.8 ≤ v > 2.0           |
| high     | 2.0 ≤ v > 2.2           |
| major    | v ≥ 2.2                 |

Table 5. The productivity attributes of fish species caught in IFMA 711 based on PSA.

| No. | Productivity Attribute | Indo-Pacific king mackerel | Whitefin wolf-herring | Narrow-barred Spanish mackerel | Longtail tuna | Eastern little tuna | Bigeye scad |
|-----|------------------------|----------------------------|-----------------------|-------------------------------|---------------|---------------------|-------------|
| 1   | Intrinsic growth (r)   | 0.600<sup>a</sup>          | 2.348<sup>a</sup>     | ND                            | ND            | ND                  | ND          |
| 2   | Max age (years)        | 6.9                        | 7.3                   | 12                            | 9.1           | 9.4                 | 4<sup>b</sup> |
| 3   | Max size (cm)          | 76                         | 85                    | 105<sup>d</sup>              | 92.5<sup>c</sup> | 73.5<sup>c</sup>  | 25<sup>b</sup> |
| 4   | k (growth coefficient) | 0.37<sup>e</sup>           | 0.35                  | 0.3                           | 0.33          | 0.32                | 0.9         |
| 5   | Natural mortality (M)  | 0.59<sup>e</sup>           | 0.56                  | 0.34                          | 0.64          | 0.67                | 1.8         |
| 6   | Annual fecundity       | 28,082 – 1,506,075<sup>f</sup> | 30,394 – 89,524<sup>d</sup> | 320,000 – 950,000<sup>d</sup> | ND            | ND                  | ND          |
| 7   | Breeding strategy      | 0                          | 0                     | 0                             | 0             | 0                   | 0           |
| 8   | Recruitment pattern    | moderate (<75% success)     | moderate (<75% success) | moderate (<75% success)       | moderate (<75% success) | moderate (<75% success) | moderate (<75% success) |
| 9   | Age at first maturity (year) | 2-4 years               | 2-4 years             | 2-4 years                     | 2-4 years     | 2-4 years           | < 2 years<sup>b</sup> |
| 10  | Mean trophic level     | 4.3<sup>b</sup>            | 4.2<sup>b</sup>       | 4.5<sup>b</sup>              | 4.5<sup>b</sup> | 4.5<sup>b</sup>     | 3.8<sup>b</sup>  |

Source: <sup>a</sup>[22], <sup>b</sup>[23], <sup>c</sup>[20], <sup>d</sup>[19], <sup>e</sup>[24], <sup>f</sup>[25], <sup>g</sup>[26], <sup>h</sup>[21], ND (no data)
| No. | Susceptibility Attribute | Indo-Pacific king mackerel | Whitefin wolf-herring | Narrow-barred Spanish mackerel | Longtail tuna | Eastern little tuna | Bigeye scad |
|-----|--------------------------|---------------------------|----------------------|-------------------------------|--------------|---------------------|------------|
| 1   | Strategy management      | Strategy does not have catch and size limits; non-target stocks are not closely monitored | Strategy does not have catch and size limits; non-target stocks are not closely monitored | Strategy does not have catch and size limits; non-target stocks are not closely monitored | Strategy does not have catch and size limits; non-target stocks are not closely monitored | Strategy does not have catch and size limits; non-target stocks are not closely monitored | Strategy does not have catch and size limits; non-target stocks are not closely monitored |
| 2   | Areal overlap            | 25–50% of the stock is in the fishing area | 25–50% of the stock is in the fishing area | 25–50% of the stock is in the fishing area | 25–50% of the stock is in the fishing area | 25–50% of the stock is in the fishing area | 25–50% of the stock is in the fishing area |
| 3   | Geographic overlap       | stock is distributed in >50% of its total range | stock is distributed in >50% of its total range | stock is distributed in >50% of its total range | stock is distributed in >50% of its total range | stock is distributed in >50% of its total range | stock is distributed in >50% of its total range |
| 4   | Vertical overlap         | 25–50% of the stock is in the fishing depths | 25–50% of the stock is in the fishing depths | 25–50% of the stock is in the fishing depths | 25–50% of the stock is in the fishing depths | 25–50% of the stock is in the fishing depths | 25–50% of the stock is in the fishing depths |
| 5   | Fishing rate relative to M | 0.5–1 | 0.5–1 | 0.5–1d | 0.5–1 | 0.5–1 | > 1b |
| 6   | Biomass of spawner (SSB) | 25–40% of B0 | 25–40% of B0 | 25–40% of B0 | 25–40% of B0 | 25–40% of B0 | 25–40% of B0 |

b [23]  
d [19]
Table 7. Continued from table 6.

| No. | Susceptibility Attribute          | Indo-Pacific king mackerel | Whitefin wolf-herring | Narrow-barred Spanish mackerel | Longtail tuna | Eastern little tuna | Bigeye scad |
|-----|---------------------------------|---------------------------|-----------------------|--------------------------------|---------------|---------------------|-------------|
| 7   | Seasonal migrations             | seasonal migrations affect the catch | seasonal migrations affect the catch | seasonal migrations affect the catch | seasonal migrations affect the catch | seasonal migrations affect the catch | seasonal migrations affect the catch |
| 8   | Schooling/aggregation           | do not substantially affect the catchability of the gear | do not substantially affect the catchability of the gear | do not substantially affect the catchability of the gear | do not substantially affect the catchability of the gear | do not substantially affect the catchability of the gear | do not substantially affect the catchability of the gear |
| 9   | Morphology affecting capture   | species shows high selectivity to the fishing gear | species shows high selectivity to the fishing gear | species shows high selectivity to the fishing gear | species shows high selectivity to the fishing gear | species shows high selectivity to the fishing gear | species shows high selectivity to the fishing gear |
| 10  | Survival after capture and release | probability of survival <33% | probability of survival <33% | probability of survival <33% | probability of survival <33% | probability of survival <33% | probability of survival <33% |
| 11  | Desirability/value of the fishery | stock is highly valued or desired by the fishery | stock is highly valued or desired by the fishery | stock is highly valued or desired by the fishery | stock is highly valued or desired by the fishery | stock is moderately valued or desired by the fishery | stock is moderately valued or desired by the fishery |
| 12  | Fishery impact on essential fish habitat | adverse effects minimal or temporary and are not mitigated | adverse effects minimal or temporary and are not mitigated | adverse effects minimal or temporary and are not mitigated | adverse effects minimal or temporary and are not mitigated | adverse effects minimal or temporary and are not mitigated | adverse effects minimal or temporary and are not mitigated |
PSA also can be applied for multispecies fisheries using biological and ecological parameter data [27]. See table 8 for the result of the calculation of productivity, susceptibility, and vulnerability attributes.

**Table 8.** The vulnerability scores of Indo-Pacific king mackerel and other species.

| No. | Species                  | Productivity Score | Susceptibility Score | Vulnerability Score |
|-----|--------------------------|--------------------|----------------------|---------------------|
| 1   | *Scomberomorus guttatus* | 1.37               | 1.93                 | 1.88                |
| 2   | *Chirocentrus nudus*     | 1.42               | 2.11                 | 1.93                |
| 3   | *Scomberomorus commerson*| 2.27               | 2.04                 | 1.27                |
| 4   | *Thunnus tonggol*        | 2.42               | 2.41                 | 1.53                |
| 5   | *Euthynnus affinis*      | 1.25               | 2.41                 | 2.25                |
| 6   | *Selar crumenophthalmus* | 1.22               | 2.39                 | 2.26                |

The results of the analysis on the vulnerability attributes (table 8) suggest that Indo-Pacific king mackerel (1) and whitefin wolf-herring (2) were of moderate productivity and susceptibility, narrow-barred Spanish mackerel (3) and longtail tuna (4) were of high productivity and low susceptibility, and eastern little tuna (5) and bigeye scad (6) were of low productivity and high susceptibility. See figure 2 for the results of the scoring on the productivity and susceptibility attributes of the 6 species.

**Figure 2.** The results of the scoring on the productivity and susceptibility attributes.

**Figure 3.** The data quality plot of the 6 species caught in IFMA 711.
From the data quality plot, a higher score both for productivity and susceptibility means the data is poor. The higher the score is, or the more the score leans towards the right side of the x-axis and the upper side of the y-axis, the worse the data is (figure 3). Table 9 shows the data quality plot of the 6 species, i.e. the data quality of species 2 (whitefin wolf-herring) was the worst; species 1 (Indo-Pacific king mackerel) and species 3 (narrow-barred Spanish mackerel) were moderate; and species 4 (longtail tuna), species 5 (eastern little tuna), and species 6 (bigeye scad) was the best.

Cope suggested that a data quality score of higher than 3 indicates the data is poor [12]. Such a data quality plot is highly useful to determine the most conservative score to indicate the information gap [12]. See figure 3 for the data quality plot of the 6 species caught in IFMA 711.

**Table 9.** The result of the data quality scoring on the 6 species in the study.

| No. | Common Name                        | Scientific Name            | Productivity Score | Susceptibility Score |
|-----|------------------------------------|----------------------------|---------------------|----------------------|
| 1   | Indo-Pacific king mackerel         | Scomberomorus guttatus     | 2.74                | 2.89                 |
| 2   | Whitefin wolf-herring              | Chirocentrus nudus         | 2.71                | 5                    |
| 3   | Narrow-barred Spanish mackerel     | Scomberomorus commerson    | 3.41                | 2.35                 |
| 4   | Longtail tuna                      | Thunnus tonggol            | 3.11                | 1.66                 |
| 5   | Eastern little tuna                | Euthynnus affinis          | 2.5                 | 1.67                 |
| 6   | Bigeye scad                        | Selar crumenophthalmus     | 2.85                | 1.86                 |

3.2. Vulnerability reference point

The result of the PSA is a species vulnerability score that can be used to determine the vulnerability reference point. This study used the species vulnerability reference points [12]. Figure 4 shows that the vulnerability score of Indo-Pacific king mackerel and whitefin wolf-herring was 1.9 and they belonged to medium vulnerability; narrow-barred Spanish mackerel and longtail tuna were 1.3 and 1.5, respectively, and they were of low vulnerability; and eastern little tuna and bigeye scad was 2.3, and they were of major vulnerability.

**Figure 4.** The vulnerability reference points of species: (1) Indo-Pacific king mackerel, (2) whitefin wolf-herring, (3) narrow-barred Spanish mackerel, (4) longtail tuna, (5) eastern little tuna, and (6) bigeye scad caught in IFMA 711.
PSA is a method that can be used to evaluate stock vulnerability based on stock's biological productivity and susceptibility in fisheries management. The method can be used in the main study effort focusing on fish species with the highest vulnerability and poor information on its biology (poor data quality) as well as fish species with low vulnerability to obtain intensive assessment data [28]. Several studies used the method mainly for bycatch species that the information on the biology and fisheries of which is still lacking [28]. PSA can also be used to determine the reference point for the management of fish species vulnerable against high exploitation, as shown by figure 4. The color quadrant interpretation can be seen in table 4. The reference point can also be used to determine the reference point for the harvest strategy.

4. Discussion
In the PSA, the productivity of a species/stock is analyzed based on the life history of the species that determine whether the species is capable of surviving or recovering after being impacted by fishing activity, while the susceptibility is based on the impact of specific fishing activity. The PSA can help prioritize fisheries management using quantitative and transparent means based on species vulnerability against fishing pressures. The results of the PSA suggest that Indo-Pacific king mackerel and whitefin wolf-herring were at medium risk (1.8 < \( v < 2.0 \)). Narrow-barred Spanish mackerel and longtail tuna were of high productivity and low susceptibility, putting them at low risk to run out, or the vulnerability scores of both species were low (\( v < 1.8 \)). Also, eastern little tuna and bigeye scad were of low productivity and high susceptibility, putting them at high risk (2.0 \( \leq v < 2.2 \)). Fish resources at low and medium risks are safe to fish so long as the vulnerability score is maintained at < 2.

These results are similar to the study in Palabuhanratu who stated that neritic tuna has a low vulnerability, particularly narrow-barred Spanish mackerel and longtail tuna [29]. Cope suggested using PSA to determine the vulnerability reference points [12]. By collecting data on the biological aspect, population dynamics, and productivity, the vulnerability of Indo-Pacific king mackerel and several other species can be determined. Both Indo-Pacific king mackerel and whitefin wolf-herring were of medium vulnerability; narrow-barred Spanish mackerel and longtail tuna were of low vulnerability; eastern little tuna and bigeye scad was of major vulnerability. The fact that Indo-Pacific king mackerel and whitefin wolf-herring were of medium susceptibility and productivity means the effect of fishing activity results in medium productivity but the species susceptibility does not indicate overproduction. Therefore, it is recommended that the productivity increase through fishing activity is maintained at the current condition because the vulnerability scores of both species are between moderate and major.

Both eastern little tuna and bigeye scad were at major vulnerability or red quadrant. Therefore, productivity and susceptibility must be lowered. Fauzi stated that the bigeye scad in IFMA 711 is highly exploited and has high mortality due to fishing [30]. Such high mortality causes its exploitation rate to exceed the optimum limit (0.5/year) and its productivity high. The species is dominantly caught by purse seine [30], while eastern little tuna by gillnet [31]. Fauzi also stated that eastern little tuna is also often caught along with bigeye scad by purse seine [30]. Both species have undergone growth overfishing as the mean size of the catch is lower than the size at first maturity [23]. The possible measures to mitigate this are reducing fishing efforts that use purse seine during the species’ spawning seasons, i.e. at the beginning of east monsoon (June–July) and west monsoon (December–January) for bigeye scad. During those months, it is recommended to stop or reduce the fishing efforts for the species.

The longtail tuna in IFMA 711 still can be fished so long as the fish size and fishing time and area are taken into account [32]. On the other hand, that the main catches of gillnet are eastern little tuna, longtail tuna, and narrow-barred Spanish mackerel; while Indo-Pacific king mackerel was the least caught by the gear [31]. Because of the composition and the low vulnerability status of the longtail tuna and narrow-barred Spanish mackerel (at green quadrant), the fishing activity for the two species can continue.

The trophic levels (TL) based on the gillnet were TL 4.2, 4.3, and 4.5. The TL of the whitefin wolf-herring was 4.2; Indo-Pacific king mackerel 4.3; and narrow-barred Spanish mackerel, longtail tuna, and eastern little tuna 4.5, indicating the 5 species are predators for small fish. Odum explained that in
general, in marine ecosystem predation, all mature nektons are carnivores or predators that prey on smaller or other nektons [33]. One of the most consistent feeding characteristics of nektonic fish is they do not select their prey as all fish of all sizes are their foods. Considering all the facts, there is a possibility that all fish caught by gillnet eat the same food, and if so, a niche overlap is highly possible. Such overlap can happen to the predators as well as the prey. The vulnerability happens if two or more predators are competing over the same or similar prey. In the long term, the competition makes the losing species die and look for alternative food and leads to population decrease, dominance, and extinction.

The catch composition of purse seine in IFMA 711 consists of shortfin scad, bigeye scad, eastern little tuna, longtail tuna, large head hairtail, Indian scad, torpedo scad, Bonga shad, Indian mackerel, squid, and black pomfret; with bigeye scad as the dominant catch [30]. The results of the study showed that the TL based on the purse seine TL 3.2, 3.7, and 4.2, or higher. TL 3.2 was from squid that preys on smaller fish such as anchovies and several shrimp species. TL 3.7 was from Indian mackerel (Rastrelliger kanagurta), torpedo scad (Megalaspis cordyla), Indian/shortfin scad (Decapterus russelli, Decapterus macrourus), and bigeye scad (Selan crumenophthalmus) that usually eat phytoplankton, zooplankton, nektan, detritus, and juvenile crustaceae. Species bigeye scad eats almost all small biotas in the fishing ground. TL 4.2 was from eastern little tuna (Euthynnum affinis), longtail tuna (Thunnus tonggol), black pomfret (Parastromateus niger). Also, TL 4.4 was from a large head hairtail (Trichiurus sp.). In this study, only bigeye scad as the most dominant species caught by purse seine was included in PSA. The results of PSA suggested that bigeye scad and eastern little tuna were the most vulnerable. Catch from gillnet is dominated by predator species, while from purse seine prey.

This indicates that bigeye scad and other small pelagic fish as prey are caught by different fishing gears from those for the predators, except for eastern little tuna and longtail tuna that are also caught by purse seine. They are 4 possible competitions in catch fisheries’ multispecies and multivessel cases with ecological and technological dependencies [34]. In this study, the cases belong to the 2nd and 4th competition scenario where there are 2 competing vessels and vessel 1 captures species 1 as the prey species, while vessel 2 captures species 2 as the predator species. However, vessel 1 with purse seine also captures eastern little tuna and longtail tuna that is the target catch of vessel 2 with gillnet. Compared to other species, this puts bigeye scad and eastern little tuna at the highest vulnerability and risk as to the impact of fishing activities using purse seine and gillnet.

5. Conclusion
The results of PSA suggested that Indo-Pacific king mackerel and whitefin wolf-herring were of moderate productivity and susceptibility, while eastern little tuna and bigeye scad were of low productivity and high susceptibility, putting both at high risk from fishing activities. In addition, the data quality of Indo-Pacific king mackerel was moderate, while the data quality of whitefin wolf-herring was the worst. Therefore, it is necessary to improve the data and scientific information on whitefin wolf-hearing for the future fisheries management plan.

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