Potential risks of tuna fishing conducted in Indonesia’s waters and its impact on tuna and shark

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Abstract. Bigeye tuna (BET), yellowfin tuna (YFT) and skipjack tuna stocks in the Pacific Ocean, in general, are underfished. However, according to Western and Central Pacific Fisheries Commission (WCPFC) who is mandated to assess the fishing impact on tuna and bycatch, the fishing impact on BET juveniles (including from Indonesia) were identified as high level impact. Productivity-susceptibility analysis (PSA) was used to assess the risk of tuna and sharks. The objectives of this study were to identify the types of tuna fisheries operated in Indonesias water (FMAs 713-715) which harm tuna and sharks species. Result shows that tuna was mainly caught by purse seine, pole and line, and longline. Purse seine fishing has a higher impact than the pole and line and longline fishing. Blue shark, hammerhead shark and silky shark in particular whale shark were at risk due to purse seine fishing, without proper management. Information regarding their niches and seasonal migrating patterns are required for further studies.

Keywords: archipelagic waters, risk assessment, sharks, tuna

1. Introduction

Tuna resources have been exploited all over the world including in the Pacific Ocean prior to 1950s, with skipjack tuna (Katsuwonus pelamis - SKJ) has been consistently the predominant species caught followed by yellowfin tuna (Thunnus albacares - YFT) (Miyake et al 2004). Purse seine (71% in 2017), longline (9% in 2017), and pole and line (7% in 2017) have been the main fishing gear to fish tuna resources in the ocean since the 1980s. Tuna catch from other fisheries (handline, troll line, and gillnet) increased up to 13% in 2017. These gear are operating in surface waters (except for deep longline and deep handline), which have high probability to interact with juveniles tuna that inhabits surface waters column. The pressure of these gear to the resources in the long term has been identified (Williams and Reid 2018). Furthermore, the use of fish aggregating devices (FADs) may increase impact of these fishing gear to the stocks.

Some initiatives have been undertaken by several bodies to ensure sustainable seafood supplies from these tuna resources, including regional tuna management bodies and fishery certification programs. Although, current stock assessment by the WCPFC suggests that BET, YFT, and SKJ stocks are not...
experiencing overfishing ($F < F_{MSY}$) and they are not in an overfished condition (SB/$SB_{F=0} < LRP$), some caveats were highlighted. Higher levels of impact on juveniles BET due to associated purse seine fisheries and the ‘other’ fisheries (Indonesia and Philippines) were identified during the 14th Scientific Committee (SC14) of the WCPFC, and it was recommended to continue measures to reduce fishing mortality of these juveniles (WCPFC 2018). Furthermore, it is mandated to assess the impact of fishing on target stock (tuna), but also non-target species (bycatch) (WCPFC Convention Article 5).

Productivity-Susceptibility Analysis (PSA) has been commonly used to assess the risk to target species due to fishing activities relative to other assessed stocks, which was initially developed by Milton (2001) and Stobutzki et al (2001). This analysis can be applied to both poor and rich data species within the same analysis and is useful for a baseline comparison among fisheries with varying levels of available information. However, this analysis is not attempted to provide information on the current stock status, but only the potential vulnerability to fishing, could not assess absolute risk and could not specify management actions. The risk is estimated through productivity (the rate at which the fished species can recover after potential depletion) and susceptibility (extent of the impact due to the fishing activity) characteristics.

Indonesia has a significant role in tropical tuna catch in the Western Pacific Ocean (Williams and Reid 2018). From eleven designated Indonesia’s Fisheries Management Areas (FMAs), FMAs 713, 714, 715, 716 and 717 are related to the Western and Central Pacific Fisheries Commission (WCPFC). FMAs 713, 714 and 715 are Indonesia archipelagic waters (IAW), whereas FMAs 716 and 716 are in the Indonesian Exclusive Economic Zone (IEEZ). The IAW, FMAs 713, 714 and 715 have been considered to have a higher contribution to the Indonesian tuna catch relative to the IEEZ, with proportion of around 60% came from the IAW (Satria et al 2014; Satria et al 2015; Satria et al 2016; Satria et al 2017). Fisheries operating in the IAW are mainly small scale commercial vessels using pole and line, purse seine, handline, troll line and gillnet, which highly influencing the livelihood for the small scale fishers. These vessels are mostly associated with fish aggregating devices (FADs) and targeting tropical tuna, which comprised of approximately 65% skipjack (*Katsuwonus pelamis* - SKJ), followed by 28% yellowfin (*Thunnus albacares* - YFT) and 6% bigeye tuna (*T. obesus* - BET) in 2006 (Satria et al 2017). These vessels also catch bycatch species, however, to date very limited studies and data collection on bycatch of tuna fisheries in the IAW.

Within the IAW, risk assessments using PSA have been conducted for live bait fishery for Indonesian pole and line tuna fishery (International Pole and Line Foundation Indonesia (IPNLF) and Centre for Environment, Fisheries and Aquaculture Science (CEFAS) in consultation with Center for Fisheries Research, Ministry for Marine Affairs and Fisheries of Indonesia (CFR), and preliminary PSA for handline tuna fishery in the IAW by Masyarakat dan Perikanan Indonesia (MDPI). Since comprehensive stock assessments for tuna in the Western and Central Pacific Ocean (WCPO), have been done by the WCPFC, PSA for the tuna stock (SKJ, YFT, and BET) might be redundant, as the tuna species are believed to be one stock in the whole WCPO. Therefore, within this study PSA was conducted to investigate which gear/fishery that has the highest impact on the tuna stock (instead of investigating the potential risk of stock being a subject to overfishing) and identify which bycatch (sharks) species are in high risk by the identified fishery (gear).

2. Materials and methods

2.1. Materials

Several steps were done in the analysis, started from identifying issues based on lesson learned from the trial EAFM application in Sikka, desk study to on tuna fishing practices in the IAW by various gear and its impacts to tuna resources, conducting PSA using template developed by NOAA, involving
relevant key stakeholders and experts in consultative workshops and discussing the initial results of PSA.

Biological information and life history of the species of interest were obtained through a literature review on relevant scientific papers and fish base (Frose and Pauly 2019) to investigate the product attributes. Information regarding the impact of the fishery on the fish stock (susceptibility attributes) was gathered through desk study and/or consultations with CFR and RIMF scientific experts (for tuna and shark species).

2.2. Methods
PSA was used to measure potential risk of fishing activities by various gear i.e. pure seine (PS), pole and line (PL) long line (LL), hand line (HL), and troll line (TL) on tropical tuna species (BET, YFT, and SKJ) and determine gear which has the highest risk to the stock. PSA was also used to identify potential risk of this selected gear on shark species. The PSA template developed by NOAA was used in this study. The productivity of a stock and its susceptibility to the fishery were evaluated to calculate vulnerability of the species to the impacts of fishing, and are given a score (1 to 3 for high to low productivity, respectively; and 1 to 3 for low to high susceptibility, respectively). The vulnerability is calculated using equation 1 (Patrick et al 2009) as the Euclidean distance from the origin of a PSA scatter plot.

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

where \( p \) is productivity score and \( s \) is the susceptibility score. The most vulnerable to overfishing indicated by a low productivity score and a high susceptibility score, whereas the least vulnerable reflected by a high productivity score and a low susceptibility score (Patrick et al 2009). The vulnerability scores were identified as having low (<1.8), moderate (2.0 < \( v \) > 1.8), high (2.2 < \( v \) > 2.0), and very high (>2.2) concern.

Productivity is defined as the ability of a stock to recover from depletion state (Stobutzki et al 2001). Productivity attributes consisted of intrinsic rate of population growth (\( r \)), maximum age, Von Bertalanffy growth coefficient (\( k \)), estimated natural mortality (\( M \)), measured fecundity, breeding strategy, recruitment pattern, age at maturity and mean trophic level (definition and ranking of productivity attributes are adopted from Patrick et al (2009)). These attributes are obtained through a literature review on relevant scientific papers and fish base (Frose and Pauly 2019).

Susceptibility is defined as the probability of species to capture and mortality from the fishery (Stobutzki et al 2001). Susceptibility attributes, its definition, and ranking are referred from Patrick et al (2009). Susceptibility attributes were investigated through literature study on relevant references and/or consultations with CFR and RIMF scientific experts (for tuna and shark species). Data quality category shows qualitatively score the data used as inputs to the PSA which reflecting the uncertainties and reliability of the information/data used when evaluating the productivity and susceptibility of an individual stock (Patrick et al 2009).

3. Results and discussion

3.1. PSA on tuna species
The vulnerability values of BET, YFT, and SKJ caught by PL, PS and LL are less than 1.8 due to their high productivity scores (2–2.4) and lower susceptibility scores (1.67–2.17) (Figure 1, Table 1). This means that these three tuna species caught by the three gear have a low risk of being overfished. It is consistent with the latest stock assessment published by WCPFC, which showed BET, YFT, and SKJ stocks are not experiencing overfishing where F<\( F_{\text{MSY}} \) and SB/\( SB_{\text{Fad}} \) < LRP (WCPFC 2018). Among
the three types of gear being investigated, PS has the highest impact on the three tuna species, with BET caught by PS have the highest vulnerability score among the other eight units of analysis.

![Figure 1](image-url)

**Figure 1.** Results of the PSA analysis conducted for BET, YFT and SKJ stock from PL, PS and LL fisheries in Indonesia’s archipelagic waters. The three contour lines differentiate areas of different vulnerability classes (i.e. from low concern bottom left corner to high concern top right corner). Note that SKJ – PL (7) and SKJ – PS (8) have the same vulnerability score. Data quality high (■); medium (■); low (■).

**Table 1.** Productivity and susceptibility scores, and vulnerability of BET and YFT by gear type. Level of concern is classified by its vulnerability (low ($v < 1.8$), moderate ($2.0 < v > 1.8$), high ($2.2 < v > 2.0$), and very high ($>2.2$) concerns).

| Species Name       | Gear | Productivity score ($p$) | Susceptibility score ($s$) | Vulnerability ($v$) | Concern |
|--------------------|------|--------------------------|----------------------------|---------------------|---------|
| *Thunnus obesus*   | PL   | 2.2                      | 1.5                        | 0.94                | low     |
| *T. obesus*        | PS   | 2.2                      | 2.17                       | 1.41                | low     |
| *T. obesus*        | LL   | 2.2                      | 1.92                       | 1.22                | low     |
| *T. albacares*     | PL   | 2.4                      | 1.5                        | 0.78                | low     |
| *T. albacares*     | PS   | 2.4                      | 2.17                       | 1.31                | low     |
| *T. albacares*     | LL   | 2.4                      | 1.92                       | 1.1                 | low     |
| *Katsuwonus pelamis* | PL  | 2.5                      | 2.08                       | 1.19                | low     |
| *K. pelamis*       | PS   | 2.5                      | 2.08                       | 1.19                | low     |
| *K. pelamis*       | LL   | 2.5                      | 1.58                       | 0.77                | low     |

### 3.2. PSA on shark species

Based on consultation with scientific experts from CFR, shark species that have potential interaction with tuna fisheries operate in the IAW included silky shark, hammerhead sharks, thresher sharks, oceanic whitetip shark, blue shark, and whale shark. PS fishery has interaction with the six shark...
species. Similarly, LL interact with those shark species, except whale shark. Deep HL (dHL) may interact with thresher sharks and blue shark. On the other hand, PL, surface HL (sHL) and TL may not interact with these six shark species (Table 2).

**Table 2.** Potential tuna fisheries interaction with sharks within Indonesia’s archipelagic waters (FMAs 713, 714 and 715).

| Fisheries | Silky shark (*Carcharhinus falciformis*) | Hammerhead sharks (*Sphyrna spp.*) | Thresher sharks (*Alopias spp.*) | Oceanic whitetip shark (*Carcharhinus longimanus*) | Blue shark (*Prionace glauca*) | Whale shark (*Rhincodon typus*) |
|-----------|----------------------------------------|-----------------------------------|---------------------------------|-----------------------------------------------|-----------------------------|-----------------------------|
| PL        | -                                      | -                                 | -                               | -                                             | -                           | -                           |
| sHL       | -                                      | -                                 | √                               | -                                             | -                           | -                           |
| dHL       | -                                      | -                                 | √                               | -                                             | √                           | √                           |
| PS        | √                                      | √                                 | √                               | √                                             | √                           | √                           |
| LL        | √                                      | √                                 | √                               | √                                             | √                           | -                           |
| TL        | -                                      | -                                 | -                               | -                                             | -                           | -                           |

The vulnerability values of the six shark species analyzed are varied ranging from 1.51 – 2.36 (from low to very high concern). *R. typus* has the highest vulnerability score among the others, with a very high risk of being subjected to overfishing (Figure 2, Table 3). Except blue shark, hammerhead and silky sharks in particular whale shark are at risk, and the risk may increase without proper management in place.

![Figure 2](image_url) **Figure 2.** Results of the PSA analysis conducted for *C. falciformis*, *P. glauca*, *R. typus*, *S. lewini*, *C. longimanus*, *A. superciliosus* and *A. pelagicus* stocks from PS fishery in Indonesia’s archipelagic waters. The three contour lines differentiate areas of different vulnerability classes (i.e. from low concern bottom left corner to high concern top right corner). Data quality high (■); medium (■); low (■).
Table 3. Productivity and susceptibility scores, and vulnerability of each shark species that interacts with tuna purse seine fishery in the IAW. Level of concern is classified by its vulnerability (low ($v < 1.8$), moderate ($2.0 < v > 1.8$), high ($2.2 < v > 2.0$) and very high ($>2.2$) concerns).

| Scientific/common name | Gear | Productivity score ($p$) | Susceptibility score ($s$) | Vulnerability ($v$) | Concern |
|-------------------------|------|--------------------------|---------------------------|-------------------|---------|
| *Carcharhinus falciformis* | PS   | 1.2                      | 2.17                      | 2.15              | high    |
| *Prionace glauca*       | PS   | 1.5                      | 1.17                      | 1.51              | low     |
| *Rhincodon typus*       | PS   | 1                        | 2.25                      | 2.36              | very high |
| *Sphyrna lewini*        | PS   | 1.1                      | 1.75                      | 2.04              | high    |
| *C. longimanus*         | PS   | 1.1                      | 1.83                      | 2.07              | high    |
| *Alopias superciliosus* | PS   | 1.2                      | 1.83                      | 1.98              | moderate|
| *Alopias pelagicus*     | PS   | 1.1                      | 1.83                      | 2.07              | high    |

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