The spatial vulnerability of fisheries resources for sustainable management

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Abstract. Professional management and promoting sustainability have not been well applied in the Sunda Strait waters. Accurate data and information will determine the success of an optimal and sustainable pelagic capture fisheries management model. The purpose of this study was to explore spatial fisheries and analyze the spatial vulnerability of fisheries resources for sustainable management. This research was conducted in the Sunda Strait waters. Data on catches and the distribution of fishing grounds indicate that fisheries conditions in the Sunda Strait are not in good economic and ecological conditions. Excess capacity in a small-scale fisheries area will disrupt the sustainability of fish resources in the area and affect the biomass supply. Management must be carried out by considering sustainability for the long term and contributing to ecological sustainability, economic efficiency, and the efforts of the local fishing fleet.

1. Introduction
Fisheries resources are under pressure from the increasing demand for protein, then driven by a rapidly growing human population [1]. Fishery biomass is often extracted from areas that are known only to the fishermen themselves, and are recorded from the landing point or the location of the first sale the catch was made. It is the reason that fishing sites are often difficult to know for certain, are out of radar and difficult for supervisors to carry out surveillance [2].

Understanding fishing ground is sometimes something that is considered less important. The number of fishing efforts and potential fishing areas is an important step for successful fisheries management and makes realistic predictions about the broader ecological consequences of fishing [3]. Although for some scenarios, fisheries are not always the case. These steps provide important details for management, specifically explicit spatial approaches, such as protected areas or fisheries closures [4].

The Sunda Strait waters are unique because they are a mixture of water masses from the Indian Ocean and the Java Sea. Fish density in the Sunda Strait waters varies greatly. This variation is thought to be due to the fish characteristics and the oceanographic factors of the Sunda Strait. Selecting five types of fish observed in this study was based on the abundance of these fish stocks throughout the season.
Fishermen and fisheries business people are hoping for abundant catches [5]. The maximum catch can only be achieved if the important factors that influence fishing are met properly. These factors are good and fast fishing vessels, good fishing equipment, good and accurate knowledge of fish behavior, and what is not less important is adequate knowledge of the conditions of the aquatic environment in which the fish live. Professional management models and promoting sustainability have not been well applied in the Sunda Strait waters. Accurate data and information will determine the success of an optimal and sustainable pelagic capture fisheries management model. This study aims to explore spatial fisheries and analyze the spatial vulnerability of fisheries resources for sustainable management.

2. Materials and methods

2.1. Study area
This research was carried out in the waters of the Sunda Strait, primary data collection and secondary data were carried out from April 2018 to September 2018. Sampling locations and production data are in four locations, namely: (1) Karangantu Fisheries Port, Serang, Banten, (2) Labuan Fisheries Port, Pandeglang, Banten, (3) Lempasing Fisheries Port, Lampung, and (4) Kalianda Fisheries Port, Lampung.

2.2. The data
Primary data collection was obtained through observation, questionnaires, and interviews with related parties. In addition, primary data in the form of biological data such as measurements of total length and height of fish, wet weight, gender and gonad maturity level, were collected on average as many as 125 fish samples from each location. The selection of interview respondents was 60 people using purposive sampling method. Temporal information is also needed as a follow-up step from the results of spatial analysis in different periods so that patterns of spatial change can be dynamically obtained.

2.3. Data analysis
The data processing software used is ArcGIS 10.2.6 and the Image Processing Program. Some aspects that need to be considered in making a database design, including (a) describing objects; (b) analyze available data; (c) physical design; (d) connecting spatial data with the database, and (e) implementing. The method used is an overlay of several different data sources of scale and time. Digitize existing maps such as Earth maps, bathymetry maps, maps of the marine environment to obtain spatial data or graphical data. Creating a digital database from oceanographic data was done, such as data on sea surface temperature, chlorophyll, salinity, and results of in situ data collection.

There are substantial differences between areas maintained by small (coastal) and industrial (offshore) fleets in the Sunda Strait. The distance traveled by fishermen to fishing areas can vary widely and is determined by factors including target species, time of year, coastline complexity, water depth, and weather. The average linear distance traveled by one-day fishing-to-fishing grounds in the Sunda Strait waters is 25 km [6]. The grid cells built to calculate the Predicted Fishing Effort (PFE) refer to these linear distances to create a buffer that describes the area of capture by small-scale fleets. Areas with potential fishing grounds are referred to as areas of influence, according to other estimates based on secondary data and evaluation in the field for small-scale fishing activities in the Sunda Strait.

Only grid cells that intersect with the area of influence entered are analyzed further. The estimated Kernel Density Estimation (KDE) is used for data distribution for the human population, the number of vessels and annual catch rates, as well as the average area of influence. KDE is calculated using the Spatial Analyst Extension method in the ArcGIS 10.2 builder model using the following equation [7]:

\[ f(u) = \frac{1}{nh} \sum K(u) \]
Where, n represents the total number of input points, showing the search radius (capture range) of the fisherman from the departure point (set as far as 12 miles) by entering the input variable (human population, number of vessels, and total catch (ton)). The output of this function has the same unit as the input variable but is normalized per unit area (parameter cell size = 1 km$^2$). The kernel function is described as follows [7]:

$$K(u)=\frac{3}{4}(1-\mu^2) \quad |x-x_i| \leq h$$

$$K(u)=0 \quad |x-x_i| > h$$

This function explains that for each data point with the $x_i$ coordinates of the original dataset, KDE sets the density around it according to the square distribution to a distance equal to h (12 miles) in grid interpolation with x coordinates for each cell. All analyses were carried out using Universal Transverse Mercator (UTM) projections.

3. Results and discussions

Pelagic fish used as examples in this study include six types, *Leiognathus equulus*, *Rastrelliger faughni*, *Upeneus moluccensis*, *Nemipterus japonicus*, and *Priacanthus tayenus*. The types of fish analyzed are of different types and families, so they have different physiological and morphological characteristics. During the study, six species of fish were observed which were quite easy to obtain because they were fish that always existed every year and were mostly landed in Fisheries Port (TPI) located in the Sunda Strait, such as Labuan, Lempasing, and Karangantu TPI.

3.1. Productivity and susceptibility parameters

Productivity is the capacity of species to recover after the population is used up [8]. The results of the productivity attribute analysis in this study are shown in Table 1.

**Table 1. The productivity of five types of small pelagic fish.**

| Attribute                  | Unit     | *Leiognathus equulus* | *Rastrelliger faughni* | *Upeneus moluccensis* | *Nemipterus japonicus* | *Priacanthus tayenus* |
|----------------------------|----------|------------------------|------------------------|------------------------|------------------------|------------------------|
| Intrinsic growth rate (r)  | ton/year | 1.12$^2$               | 2.54$^3$               | 6.58$^4$               | 3.16$^4$               | 2.61$^1$               |
| Maximum age                | year     | 4.81                   | 4.87                   | 2.44                   | 4.89                   | 4.89                   |
| Maximum size               | mm       | 230                    | 310                    | 185                    | 371                    | 336.5                  |
| Growth coefficient (K)     | /year    | 0.51                   | 1.01                   | 1.01                   | 0.51                   | 0.51                   |
| Natural mortality (M)      |          | 0.52                   | 0.74                   | 0.81                   | 0.48                   | 0.48                   |
| Catch mortality (F)        |          | 0.8                    | 6.4                    | 1.82                   | 3.18                   | 6.66                   |
| Fecundity                  | grain    | 9,904                  | 30,205                 | 36,700                 | 3,408                  | 31,554                 |
| Recruitment pattern t0    | %        | 22.38                  | 18.25                  | 34.54                  | 16.93                  | 20.66                  |
| The first measure of the  | mm       | 154.12                 | 203.14                 | 138.47                 | 208.98                 | 233.23                 |
| mature gonad (Lm)          |          |                        |                        |                        |                        |                        |

Source: [9-12]
Table 1 shows that the five types of fish have different intrinsic growth rates (r). From the results of the analysis, *U. moluccensis* has the highest r-value, and *L. equulus* has the lowest r-value. Masud [13] states that the intrinsic growth rate can provide information about a higher growth rate than others [13]. The highest capture mortality was found in *P. tayenus* with natural mortality of 0.48. This shows a higher utilization of fishing compared to natural deaths. Mortality in a population can occur due to natural and arrests factors. Natural factors that affect mortality include the condition of the aquatic environment, space and feed competition, disease, and predation. Natural mortality has a negative correlation with the maximum age of fish [14]. Meanwhile, arrest factor that affect mortality are generally closely related to fishing gear used by fishermen. The results of Heriawan’s [15], study of fishing gear that was made the top priority by fishermen in catching small pelagic fish based on their technical aspects were purse seine.

Susceptibility is one parameter that shows the tendency of fish to be caught by fishermen. The value of susceptibility attributes is shown in Table 2.

### Table 2. Parameters of susceptibility to fish resources.

| Attribute                              | Name of fish          |
|----------------------------------------|-----------------------|
|                                        | *Leiognathus equulus* | *Rastrelliger faughni* | *Upeneus moluccensis* | *Nemipterus japonicus* | *Priacanthus tayenus* |
| Strategy management                    | There is no restriction on stock and monitoring is not carried out properly |
| Geographic concentration               | Stock distribution    | Stock distribution    | Stock distribution    | Stock distribution    | Stock distribution    |
|                                        | 48.23% of the total range | 42.73% of the total range | 33.40% of the total range | 49.92% of the total range | 47.12% of the total range |
| Area overlap                           | 68.17% in the catch area | 52.11% in the catch area | 74.63% in the catch area | 73.09% in the catch area | 82.24% in the catch area |
| Vertical distribution                  | 57.87% in the same depth of catch |
| F/M                                    | 1.86                   | 2.87                   | 2.14                   | 3.02                   | 5.44                   |
| SSB (Spawning Stock Biomass)           | 26.07%                 | 18.11%                 | 10.26%                 | 43.72%                 | 9.57%                  |
| Season Migration                       | Seasonal migration affects the reduction in the number of fish in the fishing area |
| Schooling aggregation                  | Habitual responses improve catch yields |
| Morphology affecting                   | Species morphology indicates medium fishing gear selectivity |
| Desirability/Value of the Fishery      | The price of fish is low value, which is Rp. 5,000 – 10,000/kg |
|                                        | The price of fish is high value, which is Rp. 25,000 – 35,000/kg |
|                                        | The price of fish is low value, which is Rp. 5,000 – 10,000/kg |
|                                        | The price of fish is medium value, which is Rp. 10,000 – 25,000/kg |
|                                        | The price of fish is medium value, which is Rp. 10,000 – 25,000/kg |
| Fishery impact to essential fish habitat | Does not disturb the habitat or is classified as friendly to the habitat |

Based on the results of the susceptibility parameter analysis of fish resources in Table 2, the rate of exploitation of the five fish has exceeded the optimum exploitation rate (0.5), so that the small pelagic fish stocks indicated have experienced more capture. The occurrence of more arrests is suspected due to fishing activities in the Sunda Strait waters have not yet had a strict application of regulations, as well as supervision that has not run properly. High overlap and vertical overlap can be caused by a
large number of ships and fishing activities carried out in the Sunda Strait waters. Then also, with the habit of small pelagic fish that live in groups, making it easier for fishermen to do fishing.

Study states that small pelagic fish from various groups generally occupy the same habitat, namely in surface waters that have a depth of > 200 meters [16]. Generally, the fish caught in the waters of the Sunda Strait is captured from several fishing grounds, including Banten Bay, Panaitan Island, Sebesi Island, Rakata Island, Sangiang Island, Lampung Bay, Semangka Bay, and Ujung Kulon. Fish caught from a fishing location could be landed in different places to make fish stocks mixed [17].

4. Vulnerability index

The results of the analysis obtained from the parameters of productivity and susceptibility were scored by considering the weights, attribute values, and data quality so as to produce a graph that connects productivity and susceptibility. Graphs of the relationship between productivity and susceptibility are shown in Figure 1.

Figure 1. Graph of the relationship between productivity and susceptibility.

Based on Figure 1, it can be seen that the red line illustrates the level of vulnerability of high fish stocks, the green line illustrates the level of vulnerability of medium fish stocks, and the blue line illustrates the low vulnerability of fish stocks. The number in the circle in the figure shows the type of fish observed during the study, namely (1) *L. equulus*, (2) *R. faughni*, (3) *U. moluccensis* (4) *N. japonicus*, and (5) *P. tayenus*. Whereas, the colors of the circle contained in the image shows the quality of data and numbers analyzed. Five types of fish observed during the study were categorized as low susceptibility with vulnerability index values that differed from one fish to another. The values of productivity and susceptibility and vulnerability indices are shown in Table 3.

| Fish species          | Productivity value | Susceptibility value | Vulnerability index |
|-----------------------|--------------------|----------------------|---------------------|
| *Leiognathus equulus* | 2.07               | 2.03                 | 1.39                |
| *Rastrelliger faughni*| 2.21               | 2.39                 | 1.60                |
| *Upeneus moluccensis* | 2.21               | 2.15                 | 1.40                |
| *Nemipterus japonicus*| 2.14               | 2.15                 | 1.44                |
| *Priacanthus tayenus* | 2.14               | 2.52                 | 1.74                |

The value of fish productivity in Table 3 shows that *U. moluccensis* have a higher value than other fish. This is due to the value of fecundity, recruitment pattern, and intrinsic growth rate of high *U. moluccensis*. The susceptibility value of *R. faughni* shows a high value because the score is based on production data and the results of interviews with fishermen who catch fish in the Sunda Strait waters. *R. faughni* has higher economic value compared to other fish, so *R. faughni* is more threatened due to fishing activities.

The vulnerability index analyzed from productivity and susceptibility parameters show that each fish belongs to the low vulnerable category. This is caused by many factors, both internal and external. Internal factors that affect them are the low ability of fish to regenerate and survive with existing
environmental conditions while external factors that influence them are arrest pressure due to high market demand, space or food competition, and predation.

5. Spatial fisheries
The mileage of fishermen to the fishing ground can vary depending on several factors, including target species, fishing time (year), coastline complexity, water depth, and weather. Akmal's research (2015) showed that the average linear distance traveled by small-scale fishermen (one-day fishing) to fishing grounds in the Sunda Strait waters is 25 km [6]. The grid cell built to calculate the prediction of fishing efforts refers to the linear distance to create a buffer that describes the catchment area by a small fleet.

The results of the research in the field by collecting data on coastal communities can be assumed that there are 4 to 7 fishermen working as one-day fishing, representing 67% to 97% of this sector. The final estimate of the prediction of fishing efforts in the Sunda Strait shows that high fishing efforts occur in areas close to the coast and small islands. The results of the analysis of the prediction of fishing efforts are presented in Figure 2.

Small-scale fishing boats for six months of observation are equipped with GPS Garmin GPSMAP 78s. From the results of the spatial analysis, it was found that most of the one-day fishing caught fish in coastal areas and were close to small islands in the Sunda Strait region. Fishermen generally catch fish at night then return in the morning to the original port. Based on the results of a deep discussion with the fishermen who were given a hand GPS loan, it was found that fishermen generally stopped or turned the boat to clean fish during their return trip to the port, so this made replication of the same movement as before they went fishing in the fishing ground area. Small-scale fisheries do have problems if they are not equipped with tracking devices such as GPS. After the ship leaves the port to look for fish, the ship cannot be tracked the locations and where the area they are fishing [18].

This study uses annual fisheries data (2010-2018) from the Sunda Strait compiled by the Department of Marine and Fisheries (DKP), Banten Province. KDE analysis is used to estimate the explicit spatial values of the total annual fisheries catch data (2010-2018). The results of the KDE analysis are presented in Figure 3.
Figure 3. Prediction of fisheries efforts presented in 25 km$^2$ of grid cells.

The results of the spatial analysis indicate that fishing efforts by small-scale fishermen are more commonly found around the coastal areas and small islands of the Sunda Strait. The fishing areas that are mostly visited by fishermen are Pandeglang waters, Serang division, Cilegon waters, and South Lampung waters.

Through KDE's analysis, we can find out how many fishing attempts in a particular area. The highest predictive value of fisheries efforts is in areas that have a high population density. The more population in the coastal area, the more the number of ships is indicated, especially for small fishing boats (one-day fishing).

The design of predictive analysis of fisheries efforts to predict fishing efforts and evaluate fisheries growth can be based on two factors, namely: 1) the human population with the number of vessels; and 2) prediction of fisheries efforts and total catches. The increased catch is a result of increased efforts, the most plausible assumption of this condition is that when a stock is overexploited, there will be a vulnerability to fish resources [19].

Although this analysis only requires a simple step, the estimated accuracy of the number of vessels tends to vary depending on how the fishermen’s data and the number of vessels are collected. During the study also benefited from the participation of fishermen to help collect data and carry GPS during fishing. Therefore, predictions of small-scale fisheries can be indicated as a better general reflection. The results of overlaying a map of ship tracks with KDE analysis maps are presented in Figure 4.

Data on catches and the distribution of fishing grounds indicate that fisheries conditions in the Sunda Strait are not in good economic and ecological conditions. This is caused by the number of vessels that catch quite a lot in one fishing area. Excess capacity in a small-scale fishing area will disrupt the sustainability of fish resources in the area, and affect the biomass supply. Fisheries growth in the Sunda Strait must be handled carefully with a reliable and accurate spatial and temporal database. Management must be carried out by considering sustainability for the long term and contributing to ecological sustainability, economic efficiency, and the efforts of the local fishing fleet.
6. Conclusion

1) Five types of fish observed during the study were categorized as low susceptibility with vulnerability index values that differed from one fish to another. This is caused by many factors, both internal and external. Internal factors that influence them are the low ability of fish to renew themselves and survive with existing environmental conditions while external factors that influence them are arrest pressure due to high market demand, space or food competition, and predation.

2) Fishing by small-scale fishermen is more commonly found around the coastal areas and small islands of the Sunda Strait waters. The fishing areas visited by fishermen are Pandeglang waters, Serang division, Cilegon waters, and South Lampung waters. The fleets of ships that operate and are the focus of the research are vessels measuring 5-15 GT. The final estimate of the prediction of fishing efforts in the Sunda Strait shows that high fishing efforts occur in areas close to the coast and small islands.

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