Mapping the habitat of demersal fish resources to determine suitable fishing gear

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Abstract. Proper use of fishing gear is important in fishing operations. This study aimed to determine a suitable type of fishing gear to be implemented in seven coastal districts in Bengkulu Province based on the results of mapping and analysis of demersal fish habitats. The data used included: 1) bathymetry, 2) substrate type, 3) water brightness, and 4) demersal fish data from to 2019-2022. The methods applied involved classification and descriptive categories. Bathymetry and substrate type were classified and analyzed using mapping tools, while demersal fish catch data were analyzed using statisticals tools. The output was produced as thematic maps and infographics to illustrate the distribution of the three parameters. Interpretations were used to describe the relationship between demersal fish habitat and fishing gear type. The results showed that in the waters of Mukomuko, North Bengkulu, Central Bengkulu, Bengkulu City, Seluma, South Bengkulu and Kaur, demersal fish habitats dominated by Pampus argentus, Trachinotus carolinus, Lutjanidae sp., Epinephelus sp., and Ariidae sp. Suitable types of fishing gear include the Hand Line, Cash Net, Set Net, Bottom Long Line, Seine Net and Ocean-drift Gillnet.

1. Introduction

1.1 Background

Demersal fish is types of fish live most of their lives at the bottom or near the bottom of the water. Making formation of schools that are not too large, moving not too far, and relatively less movement [1], they occupy sea floors and lake beds, which usually consist of mud, sand, gravel, or rocks [2]. They divided into two main types: strictly benthic fish and benthopelagic

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fish. Benthic fish are denser than water and have negative buoyancy so they can rest on the sea floor. Benthopelagic fish have neutral buoyancy that can float just above the sea floor. They either live and wait as ambush predators, at times covering themselves with sand or otherwise camouflaging themselves, or move actively above the bottom in search for food. Most demersal fish are benthopelagic [2].

Catches from demersal fisheries contribute significantly for human consumption to developing countries [3] and worldwide [4] They make up a large proportion of the marine harvest in industry and have stimulated an increase in fishing activities. There are two management principles: 1) equal access between small and large fishermen by regulating routes and limiting fishing capacity, 2) the protection of biodiversity through the selectivity of fishing gear and the development of eco-friendly fishing gear. The deployment of fishing gear in Fishing Lanes in the WPPNRI and the High Seas is adjusted to the requirements of fishing gear, including 1) properties, 2) capacity, 3) selectivity level, type, and size, 4) fishing area, and 5) water characteristics [5]

Fishing operations are all activities carried out by a person or group of people at sea using various types of fishing gear with the aim of making a profit. There are several classifications of fishing gear types in terms of point of view, purpose, and water conditions. The basic principle of classification is based on fish catch [6]. In practice, the problem that arises is the mismatch between fishing gear specifications and the target species. It leads to overfishing and environment damage.

In order to achieve a sustainable blue economy vision, it involves good management supported by appropriate decision-making. Information on the availability of fish resources is very important as an indicator to describe the current conditions and potential of fisheries in a water area [7].

1.2 The aim of research

This study aims are

1. Produce fish-catch maps and fishing gear based on territorial boundaries, bathymetry, and sediment type
2. To examine the possible relationship of habitat profile to estimate suitable fishing gear in the study area.
3. To recommend the most suitable fishing gear for demersal fisheries in the study area

2. Methods

This study uses fishery production data based on fish species equipped with the type of fishing gear taken from statistical data provided by the Indonesian Ministry of Maritime Affairs and Fisheries (KKP) [8] data series from 2019 to 2022. Fisheries production is classified according to fish species and fishing gear. The assumptions used were estimating demersal fish habitats based on the existence substrate types and bathymetry. Data on the presence of bathymetry and substrate type were used as a basis for habitat estimates by creating partitions that indicate demersal fish movement areas.

The method includes techniques such as data clustering and combining data with spatial information. The data will be provided in a spatial distribution containing the distribution of the mean fish catch in each regency, distribution of sediment type, and depth distribution. By combining these data, we can determine suitable fishing gear for the study area. Fish production raw data contains fish catch data divided by species and fishing gear. Fish species data were sorted and selected based on dominance, represented by a higher total catch number and gentle fluctuation [9]. Each data type needs to produce a mean value in order to calculate

the Catch Per Unit Effort (CPUE) and effectivity. For oceanographic data, such as sediment type and water depth, need to be computed by using an interpolation technique. Sediment type data were collected from DKP (2017). The samples were converted into scores and classified into five categories. Water depth data sourced from Dishidros is provided image format and need to be converted to digital format. All dataset must be stored in spatial attributes. Both interpolation results of oceanographic data were combined with fish catch and fishing gear results to recommend suitable fishing gear use. The workflow of this study is illustrated in Figure 1.

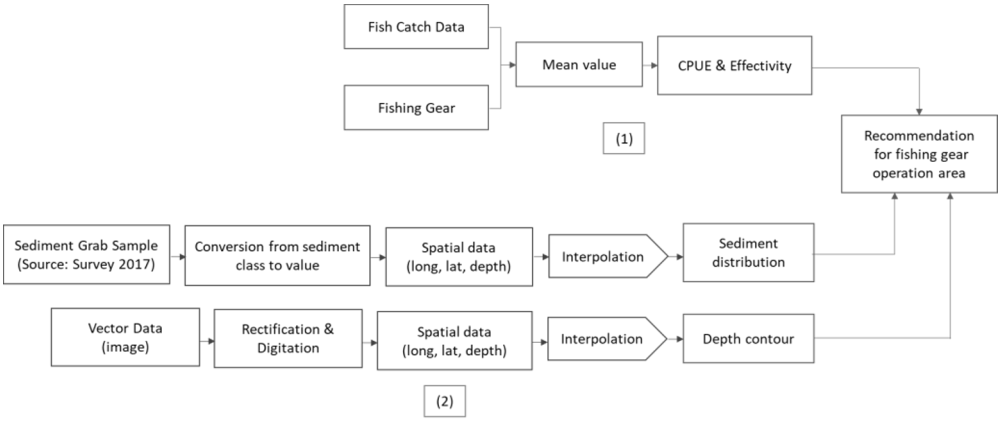


Figure 1. Research flow

Spatial analysis is the process of manipulating spatial information to extract new information and meaning from original data. Interpolation is a spatial analysis tool for calculating feature statistics and conducting geoprocessing activities. This technique uses a deterministic mathematical function to assume a closer value, which is more related than a further value, called Inverse Distance Weighting (IDW) interpolation. The IDW formula is as follows:

$$FZ_x = \sum_{i-1}^{n} \quad W_i Z_i \tag{1a}$$

$$W_i = \frac{\left(\frac{1}{d_i}\right)^p =}{\sum_{j=1}^{n} \left(\frac{1}{d_j}\right)^p} \tag{1b}$$

$$\sum_{i=1}^{n} \quad W_i = 1, p > 1 \tag{1c}$$

Fish catch data were sorted based on fish species as well as fishing gear data, and each was calculated using the formula shown below.

$$mean = \frac{\sum_{i=1}^{n} \quad catch}{n} \tag{2}$$

Fish catch and fishing gear data related to Catch Per Unit Effort. The CPUE is calculated by dividing the catch of each fishing trip by the number of hours fished during that trip. In this study, we assume that the effort is an overnight trip of 24 h.

$$CPUE = \frac{Total\ catch}{Total\ Effort} \tag{3}$$

Effectivity is efficient, suggesting an acting or a potential for action or use in such a way as to avoid loss or waste of energy in affecting, producing, or functioning.

(4)

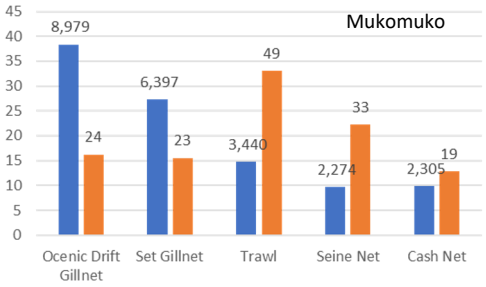
The CPUE is the main evaluation tool for fishing gear productivity. This study intended to make a recommendation for suitable fishing gear based on the national standard Permen-KP No. 71 2016 about Fishing Gear Deployment [10], but it is too general, so we need another parameter to specify the most suitable fishing gear in Bengkulu.

3. Results

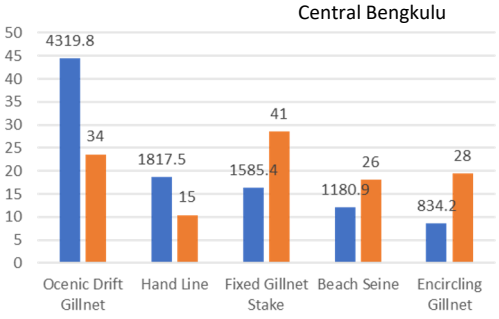
The CPUE results from a number of assumptions that can be made in various ways: (i) the fish vulnerability to the fishing gear [11], (ii) the spatial distribution of the stock which determines fishing effort distribution [12]. The distribution of fishing effort will be randomly distributed if the stock is randomly spaced; otherwise, the fisherman will search in a non-random way, functioning as an ideal predator; Every fishing operation is autonomous; otherwise, the process would be Markovian, with the fisherman repeating his activity in more abundant locations. The proportionality between CPUE and the actual circumstances in which CPUE was most likely to stay high while abundance decreased [13].

Figure 1 shows two bar charts represents catch volume (blue) in tons and five types of dominant fishing gear (orange) in units. Visually, the information that can be obtained is that high fishing productivity is indicated by the high blue and low orange bars. The resulting values differed because they were influenced by the effectiveness of each fishing gear. Under ideal conditions, catch volume increases as the number of fishing gear units increases because each fishing gear unit contributes to catching fish. The ideal condition is when fish resources are still abundant and there is no overfishing. If the number of fishing gear operations exceeds the optimal water capacity, the catch per fishing gear unit (catch per unit effort/CPUE) will decrease. For example, the use of trawls in Mukomuko is higher, but the catch obtained does not reach the same value as that of the ocean-drift gillnet. This can be caused by increased competition between fishing gear units, causing overfishing, but resources have been reduced.

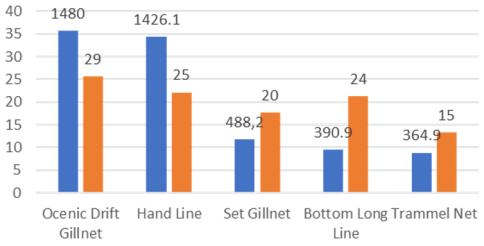
North Bengkulu

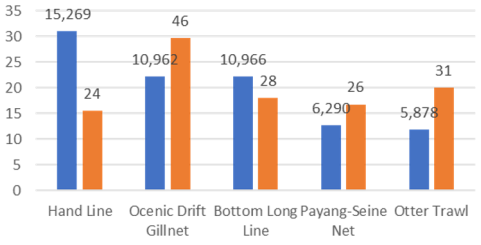


Central Bengkulu



Bengkulu City





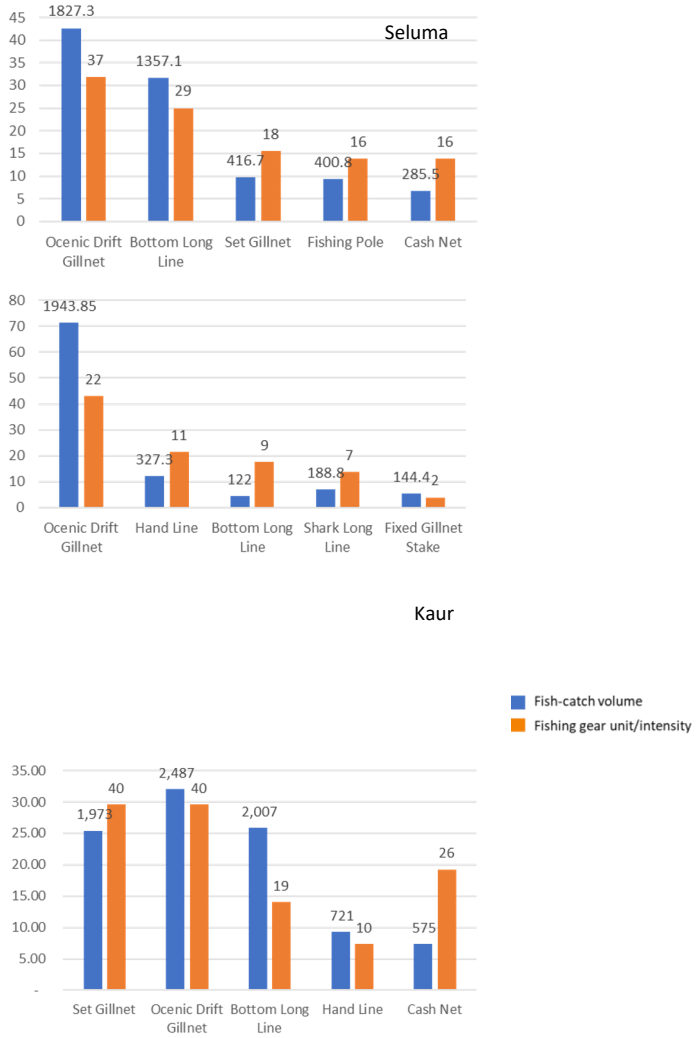


Figure 1. Bar diagram of Fish-catch Volume and Fishing Gear Unit

Catch-per-unit effort (CPUE) methods [14][15][6][17][18] can be applied to calculate the absolute abundance of closed populations when removal occurs one after the other. Catch-per-unit-effort (cpue) is frequently used as a source of stock size estimation. This approach is particularly helpful when there is a linear relationship through the origin between the catch and effort [19][20][21]. Ocean-drift gillnets had the highest catch, with a mean catch of 6,100 tons. If we look at the CPUE, Hand line has the highest value of 8.82 tons/year but the lowest value of effectiveness compared between fish catch number and fishing gear utility. Fixed gillnets are highly effective in terms of the number of catches produced with an average of 11 fishing gear units. The 5 (five) most commonly used fishing gears in Bengkulu waters are listed in Table 1

Table 1. CPUE and Effectivity

No	Fishing Gear type	Catch Volume (ton)	Fishing gear (unit)	CPUE	Effectivity
1	Ocean-drift Gillnet	6100	58	4.38	20.25
2	Hand Line	4497.75	21	8.82	-60.50
3	Bottom Long Line	3754.75	27	5.74	-4.48
4	Set Gillnet	4043.5	25	6.72	-21.43
5	Fixed Gillnet Stake	396.25	11	1.53	72.04
	total	18792.25	142		

Changes in catch per unit effort were inferred to signify changes in the true abundance of the target species. A decreasing CPUE indicates overexploitation, whereas an unchanging CPUE indicates sustainable harvesting [22]. As the cumulative catch increases, CPUE decreases linearly [20].

As show in Table 2, the average fish catch based on the five dominant demersal fish species in the seven coastal districts. It is consisted of 11 dominant fish species that are always available, with relatively stable fluctuations during 2019-2022. The demersal fish species are Pomfret, Ariid catfish, Yellowfin mojarras, Leaftail croaker, Toli shad, Doublespot queenfish, Pompano, snapper fish, Mullet, Grouper fish, and soles.

Table 2. Mean Fish Catch by Species 2019-2022

No	Regency	Mean Volume of Fish Species (kg)				
1	Mukomuko	Pomfret	Ariid catfish	Yellowfin mojarras	Leaftail croaker	Toli shad
		995,168.5	781,316	542,291.75	522,050	354,535
2	North Bengkulu	Doublespotted -queenfish	Pomfret	Pompano	Toli shad	Yellowfin mojarras
		503,345.25	492,777	434,350	407,482.5	349,443.25
3	Central Bengkulu	Snapper fish	Pompano	Pomfret	Mullet	Toli shad
		192,120.8	161,057.5	132,900	105,331.8	76,552.5
4	Bengkulu City	Pomfret	Grouper fish	Snapper fish	Ariid catfish	Pompano
		3,153,345	2,687,601.75	1,932,421	1,452,437.5	1,273,446
5	Seluma	Grouper fish	Pompano	Snapper fish	Mullet	Doublespotted queenfish
		197,027.5	121,065	120,677.5	82,630.75	55,925.5
6	South Bengkulu	Ariid catfish	Snapper fish	Grouper fish	Leaftail croaker	Sole
		315,866.8	264,114.25	191,495	187,077.5	89,498.25
7	Kaur	Pompano	Ariid catfish	Yellowfin mojarras	Mullet	Doublespotted queenfish

		351,224.5	273,385.5	171,972.3	160,990.3	124,252.5

The average fish catch based on three types of fishing gear is most widely used in each of the seven coastal districts. The types of fishing gear most often used in the waters of the Bengkulu Province are drift nets, fixed nets, trawls, handlines, gill nets, and bottom longlines. Table 3 is a list of catches based on fishing gear:

Table 3. Mean Fish Catch by Fishing Gear 2019-2022

No	Regency	Mean Fish Catch by Fishing Gear (kg)		
1	Mukomuko	Oceanic Drift Gillnet	Set Gillnet	Trawl
		93,535	69,533.75	17,550
2	North Bengkulu	Oceanic Drift Gillnet	Hand Line	Fish Gillnet Stake
		1,079,939	454,367.5	396,361.3
3	Central Bengkulu	Oceanic Drift Gillnet	Hand Line	Set Gillnet
		369,992.8	356,527.5	122,049.3
4	Bengkulu City	Hand Line	Oceanic Drift Gillnet	Bottom Long Line
		3,817,259	2,740,494	2,741,623
5	Seluma	Oceanic Drift Gillnet	Bottom Long Line	Set Gillnet
		456,825.8	339,287	104,179
6	South Bengkulu	Oceanic Drift Gillnet	Hand Line	Bottom Long Line
		485,962.5	81,833.75	30,505
7	Kaur	Set Gillnet	Oceanic Drift Gillnet	Bottom Long Line
		493,178.8	621,810.8	501,808.3

The relationship between water depth, bottom substrate, and fishing gear is very close and mutually influential. The depth and type of substrate are crucial in choosing the appropriate fishing gear since they affect both the target fish's habitat and the fishing gear's efficiency. The results from two parameters for determining the right fishing gear in this study are presented in Table 4.

Table 4. Contribute Parameters for Fishing Gear Determination

Regency	Fishing Area (Nm)	Fishing Gear (based on deployment and effectivity)	Depth range (m)	Substrate
Mukomuko	0-4	Set Gillnet	5-50	Sandy mud
	4-12	Ocean-drift Gillnet	10-785	Sandy mud
North Bengkulu	0-4	Encircling Gillnet	5-15	Muddy sand
	4-12	Hand Line	10-220	Muddy sand
Central Bengkulu	0-4	Hand Line	0-20	Gravel-mud sand
	4-12	Ocean-drift Gillnet	20-125	Gravel-mud sand
	0-4	Bottom Long Line	5-85	Gravel Sand

Regency	**Fishing Area (Nm)**	**Fishing Gear (based on deployment and effectivity)**	**Depth range (m)**	**Substrate**
Bengkulu City	4-12	Hand Line	15-285	Gravel Sand
Seluma	0-4	Bottom Long Line	5-105	Gravel Sand
	4-12	Ocean-drift Gillnet	20-270	Gravel Sand
South Bengkulu	0-4	Fixed Gillnet Stake	5-25	Gravel Sand
	4-12	Ocean-drift Gillnet	15-530	Gravel Sand
Kaur	0-4	Bottom Long Line	5-205	Sand
	4-12	Hand Line	25-1350	Sand

As shown in Figure 3a, depth was divided into five classes, and Figure 3b, substrate type was divided into five classes. The depth in the 12 nautical mile area ranges from 0 to 1400 m from minimum to maximum. The substrate type that was successfully obtained and scored consisted of sand, gravelly sand, sand-gravel-mud, sandy mud, and muddy sand. This justification is based on statistical data [8] and national standards [10].

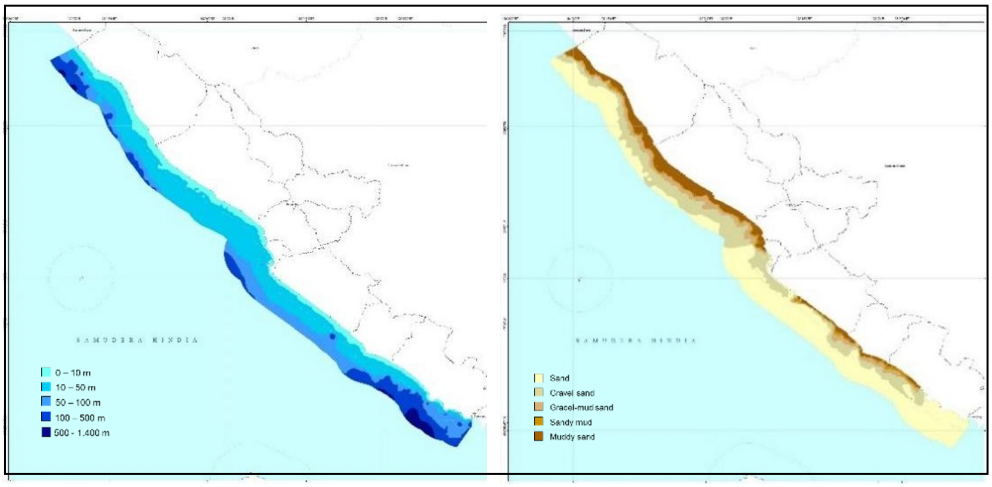


Figure 3. Map of (a) Bathymetry and (b) Sediment Type

The fishing area can be mapped based on the catch results, as shown in the two images of the distribution of demersal fish. Figure 4a shows the distribution of the average value of demersal fish catch in each district. Figure 4b shows the dominant fishery resource. The sediment type is a characteristic of the fish habitat. Based on this, we examined two categories to predict the distribution of fish habitats.

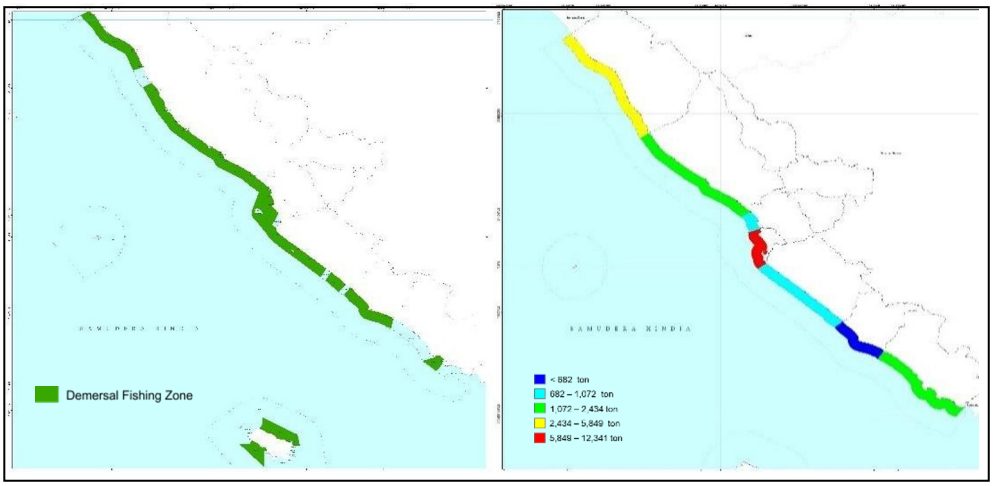


Figure 4. Map of (a) fisheries zones (source: RZWP3K, 2020) (b) fish catch distribution

A map that recommends fishing gear suitable for the substrate type in conjunction with KKP [10] [5] can be created based on the overlay findings between the depth variables and sediment type. Specifically, Fishing Lanes and Placement of Fishing Gear in the Fisheries Management Area of the Republic of Indonesia and Placement of Fishing Gear and Fishing Aids in the Fisheries Management Area of the Republic of Indonesia and the High Seas, as well as the Arrangement of Fishing Andons.

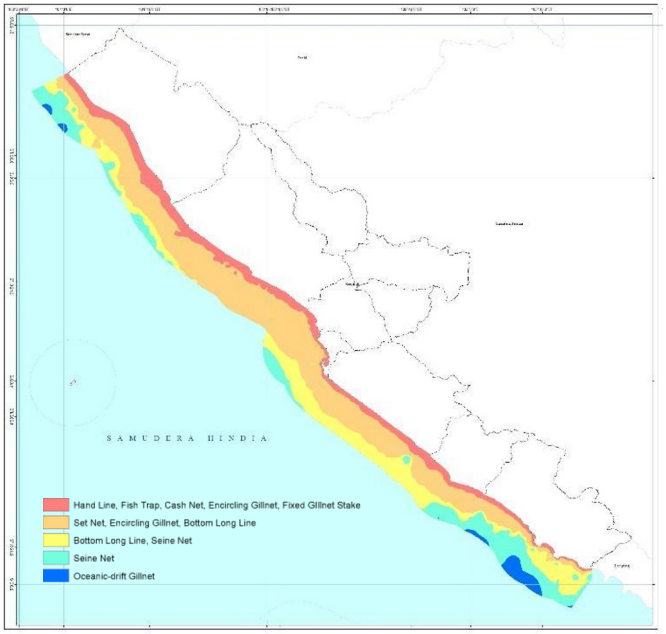


Figure 5. Map of Recommended Fishing Gear Use Based on Depth and Substrate Type

Based on the results shown in Figure 5, there are five recommended lanes for fishing gear use based on sediment type and depth. The coastal area from the coastline to 4 Nm is a cruising area for vessels with a tonnage of less than 5 GT, indicating that this area should be dominated by traditional fishermen who use traditional fishing gear.

4. Discussion and Conclusion

In coastal areas, passive fishing gear is often found in the form of handlines, cash nets, encircling gillnets, and fishing traps [23]. Meanwhile area of 4-12 Nm dominated by bottom longlines, set nets, encircling gillnets, seine nets, fixed gillnets, and ocean-drift gillnets. The type of fishing gear known to have been used in fishing operations is not only special demersal fishing gear, but also pelagic gear. This refers to demersal species frequently occur in mid-water and pelagic species occur close to the seabed, so that 'demersal' species are frequently caught in 'pelagic' fisheries and 'pelagic' species in demersal fisheries [4].

Fish behavior is generally influenced by food availability [24], reproductive cycles [25], and shelter [26]. The number of species at higher trophic levels may be affected by the modifications made to fishing gear, which may also have an impact on benthic macroinvertebrate ecosystems [27][28][29][30] found that excessive sedimentation created anoxic conditions with a high concentration of nutrients in the sediment of a tropical estuary lagoon with a high density of artisanal fishing gear.

The relationship between the right fishing gear and the type of substrate is related to the type of seabed, which is the habitat and roaming area of the demersal fish. Different seabed characteristics require different treatment methods. Water areas that have coral reef ecosystems are sensitive areas so that in carrying out fishing efforts it is necessary to pay attention to the applicable rules related to the working principles of the fishing gear used.

This study successfully produced fish-catch volumes based on region and sediment type, habitat estimation based on bathymetry and sediment type, and determination of fishing gear based on bathymetry and habitat. The largest catch of demersal fish is landed in the city of Bengkulu, followed by Mukomuko, North Bengkulu, Kaur, and Seluma, and the least in South Bengkulu. The most abundant species in each district were Pampus argentus, Scomberoides lysan, Lutjanidae sp., Epinephelus sp., Ariidae sp., and Trachinotus carolinus. The sediment type was classified into five classes: sandy mud, muddy sand, gravel-mud sand, gravel-sand, and sand.

Each district has a different type of substrate, and the species of demersal fish caught is also different, even though the fishing gear used tends to be almost the same. The seven districts use ocean-drift gillnets, set gilnets, bottom longlines, and hand lines, but there is a large variation in the species caught. Based on the type of substrate, depth, and type of fish obtained, Mukomuko, North Bengkulu, Bengkulu, Central Bengkulu, Bengkulu City, Seluma, South Bengkulu, and Kaur districts were recommended to use handlines, fish traps, cash nets, encircling gillnets, and fixed gillnet stakes at depths of 0-10 m. At depths of 10-50 m, set nets, encircling gillnets, and bottom longlines can be used. At depths of 50-100 m, bottom longlines and seine nets can be used, as well as at depths of 100m-500m. However, for depths >500 m, ocean-drift gillnets are generally used. The recommendation of a suitable fishing gear is determined based on the 5 (five) highest productivity or most efficient fishing gear and is also adjusted to national standards.

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