Estimation and causes of marine debris of gillnet fishing equipment components in the northern sea of Central Java, Indonesia

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Abstract. Abandoned, lost or otherwise discharded fishing gear (ALDFG) is a component of marine debris. Gillnet is a fishing gear potentially causing marine debris. This fishing gear is commonly used by small-scale fishermen on the north coastal of Central Java. This study aimed to estimate the average values as well as identify the factors of marine debris caused by gillnet components in the northern sea of Central Java. The research was conducted in Semarang City, Demak Regency, the fishing focal point of the north coast of Central Java. The study is based on a survey method and on descriptive analysys. Results showed that the average quantity of marine debris from gillnet components, for every fisherman, in 2022, in the northern sea of Central Java, especially in the appointed area, was 11.14±1.04 kg year^{-1}, the equivalent of 4.87±0.46 panels, at a confidence level of 95%. Some of the main factors that cause marine debris were determined and analyzed. The first one was the snagging of gillnets by seabed objects, due to limited technology, with an average value of fishermen's perception of 2.86. Second one was the conflict between fishermen during the operation of gillnet, with an average value of fishermen's perception of 2.76. The last factor was the heavy current resulting in shifting the position of the fishing gear, that was unnoticed by the fishermen, with an average value of fishermen's perception of 2.51.

Key Words: gillnet, marine debris, Central Java.

Introduction. Marine debris consists of any object that exists on the surface of the sea, in the sea and on the beaches, as an impact of human activities (Johan et al 2020). The amount of marine debris in coastal areas is generally caused by community activities, either intentionally or unintentionally, that are carried out continuously which have a negative impact on the coastal area environment (Jamback et al 2015). One source of marine debris based on anthropogenic activities is fishermen's activities in fishing (NOAA 2015). According to Triana et al (2018), all fishing gear that used by fishermen has an impact on the ecosystem of fish resources. The interaction between operational methods, fishing patterns and fishing gear, both with the environment as a natural factor and humans as anthropogenic factors might cause fishing gear to be abandoned, lost, discarded or released (Macfayden et al 2009).

The condition of the sea in the north coastal zone of Central Java, which has gentle contours and relatively calm waters, makes it an area of fishing centers, especially for small and medium scaled fisheries. Therefore, the northern coast of Central Java interacts a lot with fisheries' operational methods, fishing patterns, as well as fishing gears. Two of the fishing centers on the north coastal of Central Java are Semarang City and Demak Regency, while one of the most used fishing gears isthe gillnet. Fishing operations using gillnet has a large potential to generate ghost gear, which is one of marine debris (Macfadyen et al 2009; Gilman et al 2016; Link et al 2019). Huntington (2016) stated that gillnet is a fishing gear that has a high loss rate, especially in fishing areas that use a variety of fishing gear. In particular, passive fishing gear such as traps and gillnets will potentially become ghost gearlost (Dagtekin et al 2017). Baziuk (2017) also stated that gillnets are one of the highest contributor ghost gears in the world, followed by traps and fish aggregating devices (FAD). Susanto et al (2022) states that 71% of fishermen experience 3-4 times gillnets loss every month. The purpose of the study was to estimate the average value of marine debris of components of gillnet and identify the factors causing marine debris in the northern sea of Central Java.

Material and Method

Description of the study sites. The study was carried out from October 2022 to February 2023. The locations of the reasearch were conducted in the fishing grounds based in Semarang City (Mangunharjo, Tanjungmas) and Demak Regency (Bedono, Betahwalang, Morodemak, Sayung, Tambakbulusan, Wedung) (Figure 1).

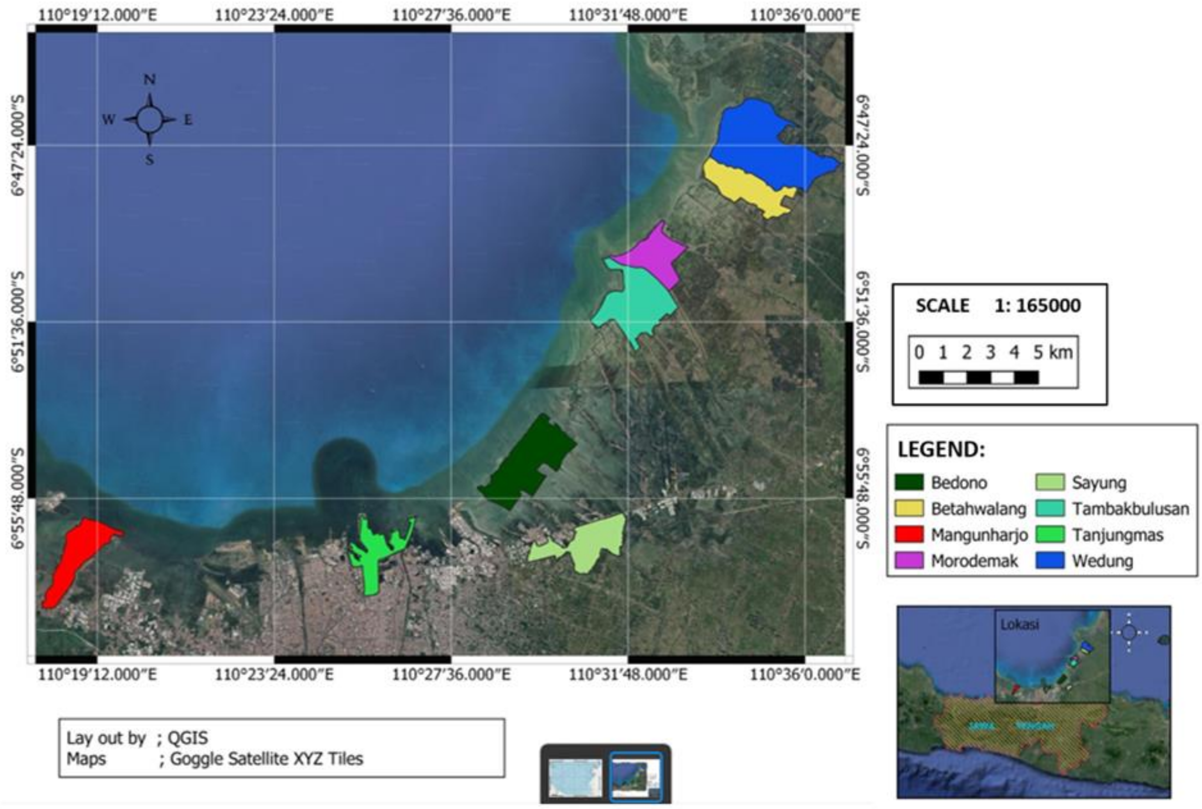

Figure 1. The location of the study at Semarang City and Demak Regency.

Data collection method. Interviews were conducted with 100 artisanal gillnet fishermen who have lost their fishing gear in the last one year. In determining the number of samples, the study used the formula of Lemeshow (1997), because the population is unknown.

$$n = \frac{Z_{1-\alpha/2}^{2} p(1-p)}{d^{2}}$$

Where:
n - number of samples minimum;
$Z_{1-\alpha/2}$ - z value on the degree of confidence 1-α/2 (95%, Z=1.96) ;
p - maximum estimate 0.5;
d - sampling error = 10%.

Lemeshow (1997) stated that choosing 0.5 for p in the formula for sample size will always provide enough observations. Based on this formula, the sample taken is obtained the number 96.04 for the minimum sample, but researchers rounded up to 100 respondents to minimize internal errors filling out the questionnaire. The precision or sampling error used is 10% (Lemeshow 1997).

$$n = \frac{z^2 p(1-p)}{d^2}$$

Where:
n - number of samples;
z - standard value - 1.96;
p - maximum estimate 0.5;
d - alpha 0.1.

The sampling technique used proportional random sampling by dividing the samples taken based on the proportion of each regency as many as 50 respondents. The technique of determining sample members is by taking representatives from each group in the population whose number is adjusted to the number of subject members in each of these groups. The total population of gillnet fishermen in Semarang City is 322 fishermen and in Demak Regency there are 1,184 fishermen.

Table 1

Sample size at each study site

No	*Location*	*Number of fishermen*	*Sample calculation for each research location*	*Sample*
1	Tanjungmas	179	(179/322) x 50	28
2	Mangunharjo	143	(143/322) x 50	22
3	Tambakbulusan	160	(160/1184) x 50	7
4	Sayung	273	(273/1184) x 50	11
5	Betahwalang and Morodemak	539	(539/1184) x 50	23
6	Wedung	212	(212/1184) x 50	9
	Total	1,506		100

The questionnaire apllication strategy for some fishermen used a respondent-driven sampling (RDS) method. This method is a combination of snowball sampling method with randomization to meet the standard probability sampling method. That makes it possible to draw statistically valid samples from previously unreached groups (Pudjihastuti 2014).

Data analysis. Analysis of the causes of marine debris of gillnet fishing equipment components in the northern sea of central java was carried out using qualitative and quantitative approaches. The collected data was processed thematically using Microsoft Excel. The calculation of the estimated weight of the net is empirical, according to the formula of Prado & Dremiere (2017).

Knotted netting. Knotted netting was calculated using the following formula (Prado 2017):

$$W = H\, xL\, X\, \frac{RTex}{1000} x\, k = H\, x\, L\, x\, \frac{1000}{lm}\, x\, k$$

Where:
W - nets weight;
H - number of legs (bars) of net points in the vertical direction, or twice the number of net points in the vertical direction;
R tex - the size of twine in the netting;
lm - net thread size per unit of weight in m kg^{-1};
L - stretched length of the net in meters;
k - knotted correction factor.
The correction factor value can use the correction factor table (k) of the net knotted.

Rope weight. The rope weight follow this equation (Pratiwi et al 2019):

$$W = v \; x \; \rho$$

Where:
W - weight of rope in air (kg);
v - rope volume (m^3);
ρ - density of material (kg m^{-3}), (for PE - polyethylene it is of 950 kg m^{-3}).

Rope volume. The rope volume formula was calculated using the following formula (SNI 8328:2016):

$$V = A \; x \; L \; x \; k$$
$$A = \pi \; x \; r^2$$

Where:
A - cross-sectional area (m^2);
L - rope length (m);
k - volume coefficient for polyethylene (0.62 – 0.65);
π - pi (3.14);
r - radius (0.5 times diameter).

Sinker weight. The sinker weight was calculated using the following formula:
Sinker weight (SW) = number of sinkers x weight of each sinker

Float weight. The float weight was calculated using the following formula:
Float weight (FW) = number of floats x weight of each float

Total weight of fishing gear. The total weight of fishing gear was calculated using the following formula (Fridman 1998.):

TW = W (nets)+ W(rope) + SW+ FW

Where:
TW- total weight of fishing gear;
W (nets) - nets weight;
W (rope) - weight of rope in air;
SW – sinker weight;
FW - float weight.

Interval estimation analysis. Interval estimation was used in data analysis to determine the estimated value of the average value of gillnet fishing gear components which become marine debris. The interval estimation analysis formula followed this equation (Britania 2020):

$$P \left[\bar{x} - z\alpha_{/2} . {}^{S}\!/_{\sqrt{n}} \leq \mu \leq \bar{x} + z\alpha_{/2} . {}^{S}\!/_{\sqrt{n}} \right] = 1 - \alpha$$

Where:
P – probability;
$\bar{x}$ – mean of the sample distribution mean;
$z\alpha_{/2}$- value from the cumulative normal distribution table;
S - standard deviation of the sample distribution mean;
α – significance level (5%) error.

Standard deviation. Standard deviation was calculated using the following formula (Britania 2020):

$$S = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}}$$

Where:
S – standard deviation:
x_i – data value to i;
$\bar{x}$ – mean of the sample distribution mean;
n – total number of data items.

The data tendency test. The tendency test was carried out to determine the tendency of a research data based on criteria through a predetermined rating scale, namely the Likert scale 1-4. There are three steps of the tendency test (Djemari 2008). First, the average and standard deviation of each variable and sub-variable are calculated.

$$Mi = \frac{high\ score + low\ score}{2}$$

$$Sd_i = \frac{high\ score - low\ score}{6}$$

Where:
Mi – ideal mean;
Sd_i – ideal standard deviation.

Second, from the ideal mean and ideal standard deviation, it can be determined three categories (Table 2).

Table 2

Propensity criteria

Propensity criteria	*Interval Scores*	*Categories*
$\bar{x} \geq (Mi + 1.Sd_i)$	$\bar{x} \geq 3$	Scores tend to be very high
$(Mi + 1.Sd_i) > \bar{x} \geq Mi$	$3 > \bar{x} \geq 2.5$	Scores tend to be high
$Mi > \bar{x} > (Mi - 1.Sd_i)$	$2.5 > \bar{x} \geq 2$	Scores tend to be low
$\bar{x} < (Mi - 1.Sd_i)$	$\bar{x} < 2$	Scores tend to be very low

Where:
Mi – ideal mean;
Sd_i – ideal standard deviation
$\bar{x}$ - the average score of gillnet fishermen opinion about marine debris components of gillnet fishing gear.

Third, this analysis was used to determine the opinion of gillnet fishermen about marine debris of gillnet fishing gear components. Perception was determined through classifying the average score results of the questionnaire answers per indicator.

Results. The net material of gillnet in the northern sea of Central Java generallyconsists of synthetic or plastic materials. Synthetic fibers (polymers) made from plastic base material that can last up to 600 years until completely decomposed (Macfadyen et al 2009). Widely used net material is polyamide (PA) or can generally be called nylon. Polyamide is included in synthetic fibers. The general properties of synthetic fibers are resistant to weathering and decay, also resistant to friction and pull (Kemhay & Syamsuddin 2021). The nature of these materials which are difficult to digest in nature makes them be the largest contributor waste which results in damage to the natural balance (Najmi et al 2022). PA materials used by gillnet fishermen for gillnet on the north coastal of Central Java were generally PA monofilament, PA multifilament and PA mono multifilament. The brand of nets generally used by fishermen on the north coastal of Central Java were Arida and Momoi.

Estimation of marine debris of gillnet fishing gear components. The result of observations of gillnet fishing equipment in the fishing centered area of Semarang City and Demak Regency showed that the gillnet fishermen used polyamide (PA) monofilament and PA monomultifilament nets. There were various dimensions of gillnet. The length for one net panel was ranging from 32 to 52 m and the height of the nets was 14 mesh to 100 mesh. The diameter of yarn used was 0.2–0.3 mm with 2-4 inches of mesh size, while the head rope and the float rope were made of polyethylene (PE) and were having 3 mm and 6 mm of diameter and 32-52 m of length, with 1 m length addition at each end. The float rope and the sinker rope were made of polyethylene (PE) with 2 mm of diameter. Meanwhile, the PA monofilament had 2 mm of diameter and 37.5–70.50 m of length with 1 m additional length at each end. As much as 15-57 pieces of SH-3 floats were used, with a 14-gr buoyancy. The ballasts used 125-361 pieces of tin material weighing 4 gr each.

Figure 2. Measurement of gillnet construction at Semarang City (original photos).

Based on the results of the research at the fishing centers of Semarang and Demak, in general at such fishing grounds the gillnet is used at 1-10 m sea depth. Gillnet fishing gear belong to fishermen in Semarang City and Demak Regency mostly operated through lines 1b and 2. Based on Regulation of the Minister of Maritime Affairs and Fisheries of the Republic Indonesia number 18 year 2021 fishing line 1a measured 2 miles from the shoreline, fishing line 1b covers waters outside fishing line 1a up to 4 miles, while fishing line 2 covers waters outside fishing line 1 up to 12 nautical miles. There were small gillnets that operates through that operate from 2 miles of shoreline up to 4 miles, at 1-10 m sea depth. The operation of gill nets was carried out by permanently installing them (fixed gill nets), by drifting (drifting gill nets) on the surface, in the middle, or at the bottom of the waters to block the swimming direction of schooling of pelagic, demersal, or crustacean fishing target, either to make it entangled or spun on the body of the nets. As much as 30-40 pieces of gillnet were used by fishermen of Semarang and Demak Regency to catch crabs (*Portunus* sp.). Meanwhile, to catch demersal fish they used 20-25 pieces of bottom gillnet.

Fishing ground for gillnet operation in the northern coastal sea of Central Java were spread along the waters of Kendal, Semarang, Demak and Jepara. The targeted catch using bottom gillnet were crabs (*Portunus* sp.), white snappers (*Lates* sp.) and tigawaja (*Pennahia* sp.). The targeted catch of Morodemak fishermen (Demak Regency) was mackerel *(Rastrelliger* sp.*)* while the main catch of three-layer gillnet (trammel net) in Bedono Demak was shrimp. Related to the fishing activities, fishermen in the city of Semarang and Demak usually practiced the one day-fishing. The results of interviews and sample measurements of gillnet that become marine debris are presented in Table 3.

Table 3
Total weight estimation of gillnet fishing equipment components becoming marine debris over a year, in Semarang City and Demak Regency

Region (Fishing base)	*Local name*	*Estimated weight (kg panel^{-1})*	*Number of respondents (n)*	*Number of gillnet components subjected to marine debris (panels)*	*Total weight of the gillnet components subjected to marine debris (kg)*
Tanggulsari Mangunharjo	Gillnet Milenium	8.60	2	6	14.82
Semarang City	Jaring Kejer	1.19	20	97	104.80
Tambaklorok Tanjung Mas	Gillnet Milenium	16.01	7	7	84.62
Semarang City	Jaring Kejer	1.96	21	81	171.99
Sayung Demak Regency	Gillnet tiga lapis	2.34	11	92	228.87
Karangtengah Demak Regency	Gillnet Tigawaja	2.62	7	42	103.38
Betahwalang Demak Regency	Jaring Kejer	1.93	10	44	137.82
Morodemak Demak Regency	Gillnet Kembung	3.41	13	66	163.71
Wedung Demak Regency	Jaring Kejer	1.96	9	46	103.50
Total		40.2	100	481	1113.50

The estimated weight value calculated in Table 4 was obtained by using the formula of the total weight of fishing gear, consisting of the net weight, rope weight and weight of sinker and float. Calculation of weight estimation was based on the measurement of the gillnet composing each panel. Based on the identification results presented in Table 2, the estimated point value and standard deviation of gillnets subjected to marine debris, per capita, within one year can be calculated:

$$\hat{\mu} = \frac{1}{n}\sum_{i=1}^{n} x_i = \frac{1113.50}{100} = 11.14 \text{ (kg)}$$

The value of the standard deviation (S)

$$S = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}} = 5.32 \text{ (kg)}$$

And the confidence interval:

$$\left[\bar{x} - z\alpha_{/2} . {}^{S}/_{\sqrt{n}} \le \mu \le \bar{x} + z\alpha_{/2} . {}^{S}/_{\sqrt{n}}\right] = 10.1 \le \mu \le 12.18 \text{ (kg)}$$

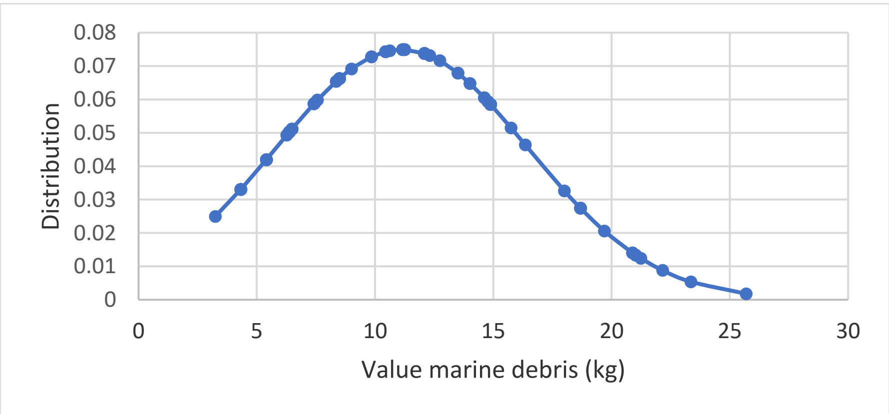

Figure 2. Bell curve chart marine debris value of gillnet gear component.

The calculation of the estimated number of nets, expressed as gillnet panels experiencing marine debris, by fisherman, within one year, in the northern sea of Central Java, can be performed as follows:

$$\hat{\mu} = \frac{1}{n}\sum_{i=1}^{n} x_i = \frac{481}{100} = 4.81 \text{ (panels)}$$

With the standard deviation (S)

$$S = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}} = 2{,}33 \text{ (panels)}$$

And the confidence interval

$$\left[\bar{x} - z\alpha_{/2}.{}^{S}/_{\sqrt{n}} \leq \mu \leq \bar{x} + z\alpha_{/2}.{}^{S}/_{\sqrt{n}}\right] = 4{,}41 \leq \mu \leq 5{,}33$$

Based on a confidence interval with a confidence level of 95%, the parameter μ (mean) is located between the upper limit and the lower limit, so it can be concluded that in 2022, each fisherman from the northern sea of Central Java (the studied area) generated 11.14±1.04 kg or 4.81±0.46 panels of gillnet debris. Dagtekin et al (2017) determined that in the Turkish Black Sea the average estimated value of gillnet loss per vessel was 1.54±0.47 panels. On the other hand, Susanto et al (2022) stated that in one season the net fishermen in Banten Bay experience a loss of fishing gear between 5-10 panels.

The Data tendency test. Gillnet marine debris were caused by several factors. Respondent cause perception indicators are shown in Table 4.

Table 4

Variable tendency level of abandoned, lost and discarded fishing gear

Variable		*Indicator*	*Score*	*Rank*
Abandoned fishing gear	a)	Bad weather prevented the collection of fishing gear	2.4	4
	b)	Ships had problems in the middle of the sea so it was difficult to bring gillnet fishing gear to land	2.08	6
	c)	High cost of fuel usage in the search for lost fishing gear	2.03	7
Lost fishing gear	a)	Heavy currents resulted in the shifting of position of the fishing gear that is unnoticed by the fishermen	2.51	3
	b)	Gillnet fishing gear caught by the propeller of a passing ship	2.31	5
	c)	Gillnet fishing gear snagged by seabed objects due to limited technology	2.86	1
	d)	Conflicts between fishermen during gillnet fishing gear operations	2.76	2
Discarded fishing gear	a)	The fisherman had no place to store the already unused catch device—finally the device was dumped to the sea/shore	1.51	8
	b)	the unavailability of facility for the offshore removal resulted in the capture tool gillnet discarded at sea/ seaside	1.47	9

In most cases, gillnet fishing gears were snagged by seabed objects due to technological limitations. At (a 2.86 average value of fishermen perception), this cause falls into a quite high category. The second cause was the conflict between fishermen during the operation of gillnet, with a 2.76 average value of fishermen's perception. The third cause was determined by heavy currents resulting in displacement of fishing gear position that is unrecognised by the owner, having a 2.51 average value of fishermen's perception. These three factors tend to be dominant, while the other factors are below the value of 2.50.

Discussion. Fishermen often experience damage and loss of some fishing gear panels. In most cases, they were used and got snagged the seabed objects, in particular those like traditional FADs (Fish Aggregating Devices). Bamboo residuals were sometimes left behind, in the sea. Snagging occurs due to the limited technology. Traditional fishermen usually rely on their experience in conducting fishing operations unequipped with any fishing aids such as global positioning system (GPS) and fish finder tools, without knowing the exact condition of the fishing ground. The use of technology on ships, such as GPS, cell phones and fish finders, will reduce fishing operational errors that cause fishing gear components to be lost due to coral snagging or other seabed objects (Antonelis 2013). Snagging of net components on seabed objects results in damaged and disconnected nets and generally only partial net loss (Macfadyen et al 2009). When caught, fishermen try to pull until the rope in the net breaks by itself or if it is not possible to be pulled, the fisherman will break or cut the net (Komarudin 2020). The ocean current is one of the causes of the loss of gillnet in the northern sea of Central Java. The ocean current is a mass movement of sea water that moves from one place to another (Azis 2006). Ocean currents can occur due to pressure differences between one place and another (Azis 2006). According to Link et al (2019), heavy currents can cause high ghost gear potential in the sea. The current can move the position of fishing gear from one place to another unknown by the fishermen. Based on interviews with fishermen, in general, the current causes a break in the connection part of the rope and then part of the fishing gear is carried away by the current, eventually becoming marine debris.

In addition, currents also have a relationship with the snagging factor. The currents carry some parts or even the whole gillnets throughout the waters, which eventually get stuck on some seabed objects and other fishing gear operated on the same fishing line. The seabed objects can be in the form of traditional fishermen FADs, as well as debris such as broken boats, logs, and others. The most snagged gillnet gear is the bottom gillnet. Generally, only parts of the gear that are lost. The limitation of technology available result in a lack of information on the conditions of the sea bottom. Therefore, when the net is caught by a seabed object, fishermen can only try to pull it until the connection on the net breaks by itself. The problems that arose apart from the above factors were due to fishing gear conflicts that often occur in the northern coastal of Central Java. Such conflicts can be caused by the use of varied fishing gear at sea, as well as the same fishing grounds. Dagtekin et al (2017) stated that the main causes of gillnet loss in the eastern Black Sea region of Turkey were: conflict (50%), bad weather (39.47%) and only 10.53% of net losses were caused by other reasons. According to Ricardson et al (2021), conflict with other fishing gear is the third reason for the loss of fishing gear after bad weather factors and errors in fishing operational methods. In Semarang City and Demak Regency, disputes often occured during the operation of fishing gear, such as between sodo (push net) and arad (mini trawl) fishermen. Gillnets were operated passively. They were being immersed at the sea bottom or on surface, often then accidentally carried away by sodo and arad fishing gear which actively sweep out the sea bottom. This caused in gillnet damage, cut out, or lost.

Conclusions. The results showed that the average value of marine debris of gillnet components for each fisherman in 2022, in North Coastal of Central Java, especially in the studied area, was 11.13±1.06 kg, the equivalent to 4.81±0.46 panels per year, at a confidence level of 95%. Factors that caused marine debris were gillnet snagging on the seabed due to technological limitations, heavy currents resulting in the shifting position of fishing gear (unnoticed by the owner) and conflicts that happened between fishermen during the operation of gillnet fishing gear. To overcome such issues, marine debris management strategies need to be done, by optimizing the synergy between the government, environmental organizations, and fishermen through marine debris management programs. Besides, increasing the access to information technologies such as GPS and fish finder, would significantly facilitate gillnet fishing gear operations.

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