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Effects of eco-friendly fishing gears on fishermen's welfare and sustainable fisheries: Lessons learned from Indonesia

Maharani Yulisti [a], Agus Syarip Hidayat [b], Carunia Mulya Firdausy [b,c,*], Ummi Mu'awanah [b], Nendah Kurniasari [a], Eka Nurjati [d]

[a] Research Center for Marine and Fisheries Socio-Economics, Ministry of Marine Affairs and Fisheries, Indonesia
[b] Research Center for Industrial Economy, Trade, and Services, National Research and Innovation Agency (BRIN), Indonesia
[c] Faculty of Economics and Business, University of Tarumanagara, Indonesia
[d] Research Center for Behavioral Economics and Circular, National Research and Innovation Agency (BRIN), Indonesia

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ABSTRACT

The eco-friendly fishing gears (EFFGs) have been widely suggested as fishing gears for sustainable blue economy development. This study aims to examine the effects of the utilization of the EFFGs of blue swimming crab (BSC) on fishermen's welfare and sustainable fisheries by taking Indonesia as a case study. The number of fishermen randomly sampled was 647. The method used to analyze the data was the Endogenous Switching Regression model. The results showed that factors that have significant positive effects on fishermen's decision to adopt the EFFGs are the membership of fishermen in fisheries groups, credit access to financial sources, decision synchronization, financial capability, and fishers' perception of environmental uncertainty. Meanwhile, the complexity of fishing gears and buyer pressure have significant negative effects on fishermen's decisions to adopt EFFGs. The results also confirmed that the welfare of BSC's fishermen is better off and received positive benefits for the preservation and regeneration of resources by using the EFFGs compared to the non-EFFGs. Therefore, the application of the EFFGs for BSC fisheries supports the sustainable blue economy development goals and needs to be recommended for other coastal areas in developing countries.

1. Introduction

The eco-friendly fishing gears (EFFGs) have been widely suggested as fishing gears for sustainable blue economy development (UNCTAD, 2016; UNEP, 2022; World Bank, 2016). This suggestion is part of the effort to support sustainable development themes addressed by the UN Brundtland Commission in 1987 and the 17 agenda document of Sustainable Development Goals (SDGs). The importance of the use of EFFGs for sustainability fisheries has also been confirmed by many empirical studies (see, for instance, Chaves-Rosales et al., 2008; Glass et al., 2007; Megwalu et al., 2018; Nwabeze and Erie, 2013; UNCTAD, 2016; Valdemarsen, 2003). The use of the EFFGs is argued to have many implications including social, cultural, and economic aspects such as changes in consumption behavior fishermen's financial resilience, social conflicts, food security, etc. (Béné et al., 2016; Serpetti et al., 2017).

The definition of the EFFGs here follows the FAO's guideline addressed in the Code of Conduct for Responsible Fisheries (CCRF). The guideline highlights that the implementation of sustainable fisheries has to pay attention to the sustainability of resources and the environment, social needs, and human economic needs (see, FAO, 1995 for further details of nine indicators to measure the friendliness of fishing gear). Conversely, the non-eco-friendly fishing gears (NEFFGs) are defined as fishing gears that have the potential to damage the environment and/or cause fish stock and resource depletion, have negative impacts on biodiversity, catch protected or endangered species, unaccepted by the community (e.g. conflict with local culture and with existing regulations). See, Hanafi et al. (2019a, 2019b) and Amarullah and Sumardi (2018).

The Government of Indonesia under the Ministry of Marine Affairs and Fisheries supported the above FAO's guideline by issuing two regulations, namely, the regulation of the Minister of Marine Affairs and Fisheries No. 17 of 2021 and the regulation of the Minister of Marine Affairs and Fisheries No. 18 of 2021. The first regulation related to the management of lobster (*Punulirus* spp.), crab (*Scylla* spp.), and crab

* Corresponding author at: Research Center for Industrial Economy, Trade, and Services, National Research and Innovation Agency (BRIN), Indonesia.
E-mail addresses: agus068@brin.go.id (A.S. Hidayat), cmfirdausy@gmail.com (C.M. Firdausy), umim003@brin.go.id (U. Mu'awanah), ekan005@brin.go.id (E. Nurjati).

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(*Portunus* spp.) in that it was clearly stated that fishermen are not allowed to catch egg-berried female crabs <60 g in weight and catching the size of crabs <10 cm (Ministry of Marine Affairs and Fisheries, 2021). While the second regulation regulates fish traps or fish pots (locally called *bubu*) and gillnets (locally called *jaring insang*) as the EFFG for catching crabs.

The reasons to justify fish traps and gillnets as EFFGs have been advanced in the literature (Thomas, 2019; Thomas et al., 2021; Rahman et al., 2019; Rouxel and Montevecchi, 2018; Cruz et al., 2018; Shabrina et al., 2020; Wang et al., 2022; Hanafi et al., 2019a, 2019b). Gillnet, for example, is categorized as EFFGs as this gear uses a curtain of netting that hangs in the water at various depths; the openings are sized according to the fish being caught. Thus, gillnet is considered resource-specific, eco-friendly, and responsible, without imparting any damage to the ecosystem (Thomas, 2019; Thomas et al., 2021).

However, dredge fishing gear is categorized as NEFFG for catching crabs (Boopendranath, 2009; Husni et al., 2021; Shabrina et al., 2020; Ummaiyah et al., 2017; Wijayanto and Yulianto, 2014). This is because dredging causes significant habitat damage. The mesh bags scoop up other types of marine life — everything from fish to sponges — which tend not to survive the experience (Boopendranath, 2009).

Other than dredges, the bottom trawl nets are categorized as the non-EFFGs (Pramitasari et al., 2016; Duadji and N., 2021; Chaliluddin et al., 2021; Hanafi et al., 2019a, 2019b; Arkonrat et al., 2013; Hamid and Wardiatno, 2015; Rahman et al., 2019). Due to these facts, Pramitasari et al. (2016), for instance, suggested the modified trawl net. This gear was found to be effective and did not result in a loss of catch with no significant differences in the catch composition between the conventional bottom trawl net and the modified trawl net. Therefore, this modified trawl net might offer a more feasible solution to fishermen (Hutapea et al., 2019; Jaya and Zulbainani, 2012; Yanti et al., 2019).

The implications of the use of the EFFGs have led to many policy suggestions. These suggestions include: strengthening fisheries law enforcement against prohibited types of fishing gear (Prince et al., 2020), improving the system of issuance/allocation of fishery permits, improving the management of fishery resources based on local wisdom and environmentally friendly (Armada et al., 2018), educated the fishermen to commit to using the EFFGs (Ernawati et al., 2017), intensive and consistent supervision from various interested stakeholders (Yanti et al., 2019), prohibiting the Mini plant to buy crab catches <10 cm in size (Gunasekera and Fairoz, 2016), and promoting alternative livelihoods in coastal communities other than fishermen, including developing aquaculture and marine culture and promoting ecotourism (Armada et al., 2018; Cruz et al., 2018).

However, implementing the policy suggestions is not simple and easy for many developing countries, including Indonesia. The reason is that the EFFGs utilization would lead to competing purposes between improving welfare vs. preserving environmental aspects and maintaining social stability. Due to its competitive nature, there will be trade-offs in achieving sustainable blue economy development (Asche et al., 2018; Béné et al., 2016; Hilborn et al., 2020; Kittinger et al., 2017; Zondervan and Zondervan, 2022; Utne, 2008). Therefore, restricting fishermen from catching crabs with various fishing gear regulations for dredges and bottom trawl nets to preserve environmental sustainability, on one hand, would lead to income reduction, and hence fishermen's welfare is worse off. On the other hand, encouraging fishermen to catch more crabs for economic gains without sufficient fishing gear regulation is dangerous for maintaining crab stocks.

While arguments pros and cons of the use of EFFGs are continuing (Asche et al., 2018; Hilborn et al., 2020; Zondervan and Zondervan, 2022), more evidence-based research to complement the pros argument of the EFFGs to support sustainable blue economy development is a must. One of the many pros arguments that have to be addressed concerns the effects of the EFFGs of blue swimming crabs-BSC (*Portunus pelagicus*) on fishermen's welfare and sustainable fisheries. This is considered an interesting research topic as the BSC is an export commodity that has high economic value on one hand and no regulations yet issued to the application of the non-EFFGs of BSC fishery specifically on the other hand. Also, the recent available empirical studies on crab fishery mainly focused on the impact of fishing on crab stock (Nabila et al., 2023) and the impact of fishermen conflict on the sustainability of crabs (Daris et al., 2022) to name just two studies.

Therefore, this study aims to examine two research objectives. First, to examine the determinant factors of fishermen in deciding to adopt EFFGs. Second, to estimate the effects of EFFG utilization on the welfare of BSC fishermen and BSC sustainability resources. The findings of the study do not only have urgency and novelty to fill the research gap and provide knowledge contribution concerning the EFFGs for BSC fishery development but also convince BSC fishermen and other stakeholders that the use of the EFFGs does not reduce their welfare and against the global commitment of sustainable blue economy development in particular and sustainable development goals (SDGs) in general.

2. Methodology

2.1. Survey locations and sampling method

The study was carried out in the Cirebon regency of the province of West Java and Demak regency of the province of Central Java (Fig. 1). These two regencies are the two main representative locations of BSC fishermen in Indonesia (Badiuzzaman et al., 2014; Simbolon et al., 2020). In these two regencies, we found both BSC fishermen who operated the EFFGs (i.e. fish traps/pots and gillnets), and the NEFFGs (i.e. dredges and bottom trawl nets).

After determining the survey locations, we conducted both qualitative and quantitative surveys of BSC fishermen between April–June 2022. The qualitative survey was conducted by undertaking site observation and in-depth interviews with both the EFFGs and NEFFGs' fishermen, BSC collectors, crab peelers, and the BSC mini plants, as well as Focus Group discussion (FGD) with the fishermen group, fishery extension workers, and the Fishery officials in the two survey locations. The purposes of the qualitative survey were: (1) to have views from the interviewees and group discussion participants on issues related to the BSC fishing activities, marketing, and their knowledge and perception of conservation, environment, and sustainability; and (2) to clarify any data and information collected from questionnaire instrument that was found unclear and needs further explanations.

Further, the quantitative survey was undertaken by distributing the questionnaires to sample respondents both EFFGs and NEFFGs. However, before distributing the questionnaires to the sample respondents, a consultation with the statistical officials of the Central Board of Statistics and the Fishery officials in each survey location was organized. The purpose of this consultation was to get data on the number of BSC fishermen population in each of the survey locations. The Central Board of Statistics in two survey locations recorded that the BSC fishermen population in Cirebon regency was about 2340 fishermen, consisting of 2154 and 186 fishermen who use EFFGs and NEFFGs. In Demak regency, there were about 1684 fishermen, consisting of 1606 and 78 fishermen who use EFFGs and NEFFGs, respectively.

Given the number of the population in each survey location, a simple random sampling technique was applied to determine the EFFGs and the NEFFGs fishermen as sample respondents. The reason for applying a simple random sampling procedure was to make generalizations about a specific population and leave out any bias (Sekaran and Bougie, 2016). The total number of BSC fishermen randomly selected as sample respondents was 647 in both regencies. The sample respondents selected in Cirebon were 347 (or 15 % of the total fishermen population). While the sample respondents selected in Demak were 300 (or 18 % of the total fishermen population). Note that the number of samples in both locations complies with the sampling rules, and is even larger than the minimum required sample for statistical analysis (Azen and Walker, 2011).

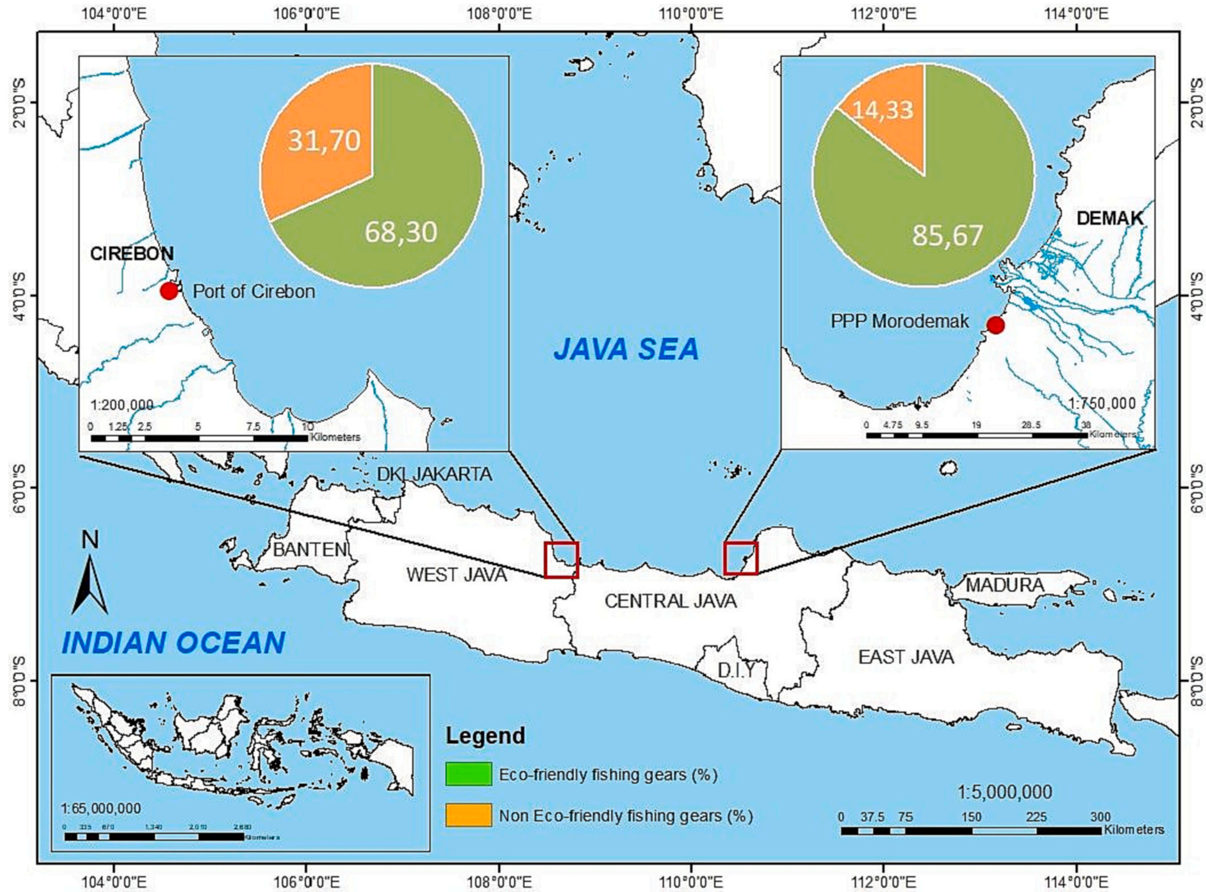

Fig. 1. Map of the research area and its proportion of fishermen adopted fishing gear at each location.
Source: map of Indonesia, PT. Multi Bali Abadi, 2023.

Of the total 647 sample respondents of BSC fishermen, 494 respondents were BSC fishermen who adopted the EFFGs, while the rest of the 153 sample respondents were BSC fishermen who use the NEFFGs as shown in Table 1.

To distribute and collect the questionnaires, fishery extension workers in each survey location were involved. Before the questionnaire was given to them, training on related materials questioned in the questionnaires was organized for them. This was aimed to minimize any issues or problems associated with questions asked, and language barriers to understanding materials questioned in the questionnaire. Detailed questions asked in the questionnaire focused on managing the BSC fishing activities, harvesting, marketing, external factors, and their knowledge and perception of conservation, environment, and sustainability. Also, sample respondents were asked to provide information on household characteristics, social capital, and fishing performance (e.g. yields and net profit).

Table 1
Number of sample respondents who adopted EFFG and NEFFG based on the survey.

Fishing gears	Cirebon regency		Demak regency		Total	
	N	%	n	%	n	%
Eco-friendly fishing gears (EFFG)	237	68.3	257	85.7	494	76.4
Non-Eco-friendly fishing gear (NEFFG)	110	31.7	43	14.3	153	23.6
Total n	347	53.6	300	46.4	647	100

Notes: n = number of sample respondents.
Source: calculated from questionnaires.

After completing the data collection, the next step was to analyze the data by using the Endogenous Switching Regression model. The detailed stages of the analysis were as follows.

2.2. Modelling utilization of eco-friendly fishing gears

The utilization of eco-friendly fishing gears and its implications in terms of the outcomes were modelled in the setting of a two-stage framework. The outcomes of interest were (a) crab production, (b) net profit from the capture of BSC for the welfare of BSC fishermen, (c) egg berried female captured crabs, and (d) size of crab captured by the BSC fishermen for sustainability measures in both sites. All outcomes were measured on a year basis due to different seasons of fishing in a year.

In the first stage, we used a selection model for EFFG utilization where a representative risk adverse fishermen household chooses to employ EFFG if it generates net benefits. Let M^* be the latent variable that captures the expected benefits from the utilization choice with respect to not employing.

$$M_i^* = Z'\alpha + \varepsilon_{1i} \; with \begin{cases} M_i = 1 \text{ if } M_i^* > 0 \\ M_i = 0 \text{ otherwise} \end{cases} \tag{1}$$

That is, fisherman household i will choose to employ ($M_i = 1$), through the utilization of eco-friendly fishing gears in response to sustainability as well as productivity, if $M^* > 0$, and 0 otherwise. The vector Z represents variables that affect the expected benefits of utilization. These factors can be classified in different groups. First, we consider the individual characteristics of the fishermen (e.g. formal education, experience on fishing activities). For instance, fishermen characterized by more educated might be more aware of sustainability and therefore relatively more likely to employ the EFFGs. Then, socio-economic factors (e.g. financial capacity, access to capital fund) as well as fishermen perception on environmental uncertainty can also play a role in determining the probability of EFFGs utilization. For instance, fishermen portrayed by more thought of uncertain climate nowadays might be more aware of eco-friendly fishing practices and hence relatively more likely to employ EFFGs.

Access of credit to formal banking is an important variable because the fisherman thought of employing EFFG needs additional costs. Households that have limited access to credit can have less capital available to be invested in the implementation of EFFG. Fishermen attitudes imply to their acts towards egg-berried female crabs if it is caught, and fisherman's knowledge on the allowable size of crab caught. Those indicators are important as fisherman's attitude on choosing fishing gears. Financial capability defines fisherman's financial ability on employing more eco-friendly fishing gears and their steps on allocating fishing profits, as well as their ability to have fishing gear in a short time. Fisherman's capability is important variables because their allocation may imply their profits on fishing practices.

Furthermore, knowledge of EFFG is also important for fisherman to select their gear. Should they not understand and usual of EFFG, they might be less aware of utilizing EFFG. Fishermen must have information about EFFG before they can consider utilizing them. Decision synchronization are characterized by fisherman perception whether there are plans between fisherman and customers on fish caught promotion due to EFFG utilization, estimate demand for EFFG products, and solution seeks for EFFG challenges. It is expected that the more decision synchronization between fisherman and his customer, the more EFFG might be employed. Buyer concern refers to customer pressures on increasing the utilization of eco-friendly fishing gears and more attentive and consideration on marine environment. It is important in the model because this may determine on choosing fishing gears (See, Appendix 2 for details variables and its definition).

In the second stage, the effects of EFFG utilization on outcomes of interest are estimated. The production of crabs and the net profit of this production were estimated because it can be measured as the welfare of the fishermen. Egg-berried females captured and the number of crabs per kilogram caught were estimated to measure the sustainability of crab fishing practice.

The model approach for examining the effects of EFFG utilization on fisherman welfare and sustainability would be to include a dummy variable equal to 1 in a production function if the fisherman household adopted EFFG and estimate this using the ordinary least squares (OLS) regression. This approach, however, might yield biased estimates because it assumes that the utilization of the EFFGs is exogenously determined while it is potentially endogenous. The decision to employ EFFG is voluntary and may be based on individual self-selection. Fishermen who employ EFFG may have systematically different characteristics from those who do not and may have decided to employ based on expected benefits. Unobservable characteristics of fishermen and their fishing practice may affect both the utilization decision and fishing performance, resulting in inconsistent estimates. For example, if only the most experienced or educated fishermen choose to employ EFFG, and we fail to control for skills, the estimated parameters will be biased. For the model to be identified, it is important to use as exclusion restrictions, thus as selection instruments, not only those automatically generated by the nonlinearity of the selection model of utilization (1) but also other variables that directly affect the selection variable but not the outcome variable.

We accounted for the endogeneity of the implementation decision by estimating an Endogenous Switching Regression (ESR) model with full information maximum likelihood. For the model to be determined, it is crucial to use a selection instrument(s) as exclusion restrictions. These instrument variables are generated from the non-linearity of the selection model of the implementation, which directly affects the decision to employ but not the outcome variable of non-adopters (Pizer, 2016). In this case study, we used instrument variables of fishermen's perception of environmental uncertainty (e.g. uncertainty of climate, weather and current). We established the acceptability of these instruments by performing a simple falsification test (Table 5). If a variable is a valid selection instrument, it will affect the utilization decision significantly but it will not affect the outcomes among fisherman households that did not utilize the EFFGs. First step of the falsification test is estimating the decision to utilize the EFFGs using a probit model of all independent variables, and the variable selected as an IV (environmental uncertainty) should be significant; Second step is estimating outcomes of interest (production, net profit, crab size and egg-berried female capture) using simple OLS of all variables on NEFFG group, and the outcomes variables selected should not be significant.

To determine selection biases, we adopt an ESR model of fishing performance and sustainability, where fishermen face two regimes:

$$\text{Regime 1 (EFFG fishermen)}: \quad y_{1i} = \beta_1 x_{1i} + \varepsilon_{1i} \ \text{ if } M_i = 1 \tag{2a}$$

$$\text{Regime 2 (NEFFG fishermen)}: \quad y_{2i} = \beta_2 x_{2i} + \varepsilon_{2i} \quad \textit{if } M_i = 0 \tag{2b}$$

where y_i is the outcome of interest (crab production, net profit, egg-berried female captured, and size of crab caught in a year) in Regimes 1 and 2, and x_i represents a vector of fisherman characteristics, and the head and fisherman household's characteristics, technology characteristics, and the factors that influence the utilization decision included in Z.

Finally, the error terms in Eqs. (1), (2a), and (2b) are assumed to have a normal distribution, with zero mean and covariance matrix, i.e. $(\varepsilon_1, \varepsilon_2) \sim N(0, \sum)$ with :

$$\sum = \begin{bmatrix} \sigma_\varepsilon^2 & \sigma_{\varepsilon1} & \sigma_{\varepsilon2} \\ \sigma_{\varepsilon1} & \sigma_1^2 & . \\ \sigma_{\varepsilon2} & . & \sigma_2^2 \end{bmatrix}$$

where σ_ε^2 is the variance of the error term in Eq. (1), which can be assumed to be equal to 1 since the coefficients are estimated only up to a scale factor (Maddala, 1986, p. 223). σ_1^2 and σ_2^2 are the variances of the error terms in Eqs. (2a) and (2b), and $\sigma_{\varepsilon1}$ and $\sigma_{\varepsilon2}$ represent the covariance of ε_i, ε_{1i}, and ε_{2i}. Since y_{1i} and y_{2i} are not analyzed simultaneously, the covariance between ε_{1i} and ε_{2i} is not specified (reported as dots in the covariance matrix) (see, Maddala, 1986, p. 224). The error term of the selection Eq. (1) ε_{1i} is linked to the error terms of Eqs. (2a) and (2b) (ε_{1i} and ε_{2i}). Hence, a significant implication of the error structure is that the expected values of ε_{1i} and ε_{2i} are conditional on the sample selection being non-zero:

$$E(\varepsilon_{1i}|M_i = 1) = \sigma_{\varepsilon1}\frac{\phi(Z_i\ \alpha)}{\Phi(Z_i\ \alpha)} \equiv \sigma_{\varepsilon1}\lambda_1 \tag{3a}$$

$$E(\varepsilon_{2i}|M_i = 0) = \sigma_{\varepsilon2}\frac{\phi(Z_i, \alpha)}{1 - \Phi(Z_i\alpha)} \equiv \sigma_{\varepsilon2}\lambda_2 \tag{3b}$$

where ϕ is the probability function of a standard normal density, Φ is a cumulative function of standard normal density, $\lambda_{1i} = \frac{\phi(Z_i,\alpha)}{\Phi(Z_i\alpha)}$ and $\lambda_{2i} = \frac{\phi(Z_i,\alpha)}{1-\Phi(Z_i\alpha)}$. λ_1 and λ_2 are the inverse mills ratio calculated from the selection equation and will be included in Eqs. (2a) and (2b) to correct for selection bias in a two-step estimation procedure. If the estimated covariances $\widehat{\sigma}_{\varepsilon1}$ and $\widehat{\sigma}_{\varepsilon2}$ are statistically significant, then the implementation decision and fishery performance are correlated. There is evidence of endogenous switching, and the null hypothesis for the absence of sample selectivity bias is rejected. This model is defined as an endogenous switching regression (Maddala and Nelson, 1974).

The ESR framework can be used to estimate the average treatment effect of the treated (ATT) and untreated (ATU) by comparing the expected values of the outcomes of adopters and non-adopters in actual and counterfactual scenarios. The model can be used to compare the expected outcomes of the fisherman households that adopted EFFG (4a) concerning the fisherman households that did not employ (4b), and to investigate the expected outcomes in the counterfactual hypothetical cases (4c) that the utilized farm households did not adopt EFFG, and (4d) that the non-utilized farm household adopt it. Following Di Falco et al. (2011), the ATT and ATU are calculated as follows:

Households who adopted EFFG (observed in the sample):

$$E(y_{1i}|M = 1; x) = \beta_1 x_{1i} + \sigma_{\varepsilon 1}\lambda_{1i} \tag{4a}$$

Households who did not employ the EFFGs (observed in the sample):

$$E(y_{2i}|M = 0; x) = \beta_2 x_{2i} + \sigma_{\varepsilon 2}\lambda_{2i} \tag{4b}$$

Households who adopted the EFFGs had they decided not to adopt (counterfactual):

$$E(y_{2i}|M = 1; x) = \beta_2 x_{1i} + \sigma_{\varepsilon 2}\lambda_{1i} \tag{4c}$$

Households who did not adopt EFFG had they decided to employ (counterfactual):

$$E(y_{1i}|M = 0; x) = \beta_1 x_{2i} + \sigma_{\varepsilon 2}\lambda_{2i} \tag{4d}$$

In addition, we calculate the effect of the treatment "to employ" on the treatment effect on the treated (ATT) as the difference between Eqs. (4a) and (4c):

$$\begin{aligned} \mathrm{TT} &= E(y_{1i}|M = 1; x) - (y_{2i}|M = 1; x) \\ &= x_{1i}(\beta_1 - \beta_2) + \lambda_{1i}(\sigma_{\varepsilon 1} - \sigma_{\varepsilon 2}) \end{aligned} \tag{5}$$

which represents the impacts of EFFG utilization on outcomes of the fisherman households that actually employ the EFFGs. Similarly, we calculate the effect of impacts of the treatment on the untreated (TU) for the fisherman households that actually did not employ the EFFGs as the difference between (4d) and (4b).

$$\begin{aligned} \mathrm{TU} &= E(y_{1i}|M = 0; x) - E(y_{2i}|M = 0; x) \\ & x_{2i}(\beta_1 - \beta_2) + \lambda_{2i}(\sigma_{\varepsilon 1} - \sigma_{\varepsilon 2}) \end{aligned} \tag{6}$$

Eqs. (4a) and (4b) are the actual estimations observed in the sample, whereas Eqs. (4c) and (4d) represent the counterfactual estimations of outcomes. The second term (λ) is the selection term that captures all potential effects of the differences in unobserved variables.

3. Results and discussion

3.1. Characteristics of BSC fishermen

By analysing descriptively the data collected from questionnaires, there are several similarities and differences between BSC fishermen characteristics with the EFFGs and the NEFFGs. The similarities were found in terms of age, formal education, the number of family members, the number of trainings, the years of experience, attitudes, and knowledge about eco-friendly gears. While differences were found in the following characteristics (Table 2). Fishermen's involvement in fishing groups, for example, showed that the number of EFFG fishermen joining the fishermen group is higher than that of non-EFFG fishermen. In the financial capability, while the EFFG fishermen have better financial capability and their proportion of taking credit from banks was also higher than those of NEFFG fishermen. This is because they need additional funds to buy new equipment and upgrade fishing equipment according to environmentally friendly standards.

Further, the fishermen's attitudes towards preservation and regeneration differ significantly, in which EFFG fishermen have a better attitude than NEFFG fishermen. The fishermen's attitudes include attitudes towards unused fishing gear, by-catches, catching and re-releasing crabs laying eggs, and dumping garbage into the sea. In addition, the fishermen's views on the complexity of the fishing gear of BSC have significant differences. The EFFG fishermen felt that their fishing gear was very complex in the creating process and required more operation experience and the friendliness of the fishing gear to the environment/ecosystem. Also, EFFG fishermen argue that they face higher environmental uncertainty and buyer pressure than NEFFG fishermen (Table 2). Fishermen interviewed stated that the reason is mainly because the income of BSC fishermen is susceptible to changing weather conditions and global markets. During the low season, BSC fishermen in Cirebon regency are unable to go fishing because of strong winds and high waves, so that their income decreased significantly. This condition consequently pushed them to look for other economic opportunities or re-shifting from the use of the EFFGs (fish traps/pots and/or gillnets) to the non-EFFGs (dredges and/or bottom trawl nets).

In terms of business characteristics, BSC fishermen have significant differences between EFFG fishermen and NEFFG fishermen, as shown in Table 3. In total, by combining samples from both areas (Cirebon and Demak Regencies), the production and profit of the EFFG BSC fishermen were significantly higher than those of the NEFFG BSC fishermen. In terms of the number of catches, the EFFG BSC fishermen caught more egg-berried females compared to the NEFFG BSC fishermen. This seems as if EFFG fishermen are not environmentally friendly. However, based on the interview results with the EFFG BSC fishermen, the reality is different. They stated that any egg-berried female crabs caught by them

Table 2
Characteristics of respondents.

Characteristics	Units	EFFG	NEFFG	Diff.	Sig
		n = 494	n = 153	n = 647	
Age of fishermen	Years	43.45	43.25	0.20	*
Formal education	Years	6.25	6.09	0.16	
Family size	People	4	4	0.00	
Member of fishermen group	%	69	53	0.16	***
Training on fisheries	Vol. per year	0.26	0.18	0.08	
Experience on fishing	Years	23.74	23.74	0.00	
Access to formal credit	%	18.22	10.39	7.83	**
By-catch	%	50.20	66.23	16.03	***
Fishermen attitudes	%	18.02	14.94	3.08	**
Financial capability	%	77.33	66.01	11.32	***
Decision synchronization	%	21.66	4.54	17.12	***
Knowledge on eco-friendly gears	%	39.88	46.75	6.87	
Buyer concern	%	60.12	64.28	4.16	
Environment uncertainty	%	58.50	33.12	25.38	***

Notes: n = number of sample respondents; Diff = difference; Sig = Significance; EFFGs = Eco-friendly fishing gears; NEFFGs = Non-eco-friendly fishing gears.
* Significant at 10 %.
** Significant at 5 %.
*** Significant at 1 %.
Source: calculated from the questionnaire data.

Table 3
Characteristics of BSC fishing businesses between EFFG and NEFFG fishermen.

Businesses characteristics	Total		
	EFFG	NEFFG	DIFF.
	n = 494	n = 153	
Crab production (kg/year)	4031.5	3428.7	602.8**
Net profit (IDR million/year)	157	85.4	71.3**
Size of crab (Ind./kg)	8.01	11.71	−3.67***
Egg-berried female captured (%)	17.21	16.34	0.87*

Notes: n = number of sample respondents.
US $ 1 = IDR 15,021.30 (September 2022).
EFFG = Eco-friendly fishing gears; NEFFG = Non-eco-friendly fishing gears; Ind = individual; Diff = difference.
* Significant at 10 %.
** Significant at 5 %.
*** Significant at 1 %.
Source: calculated from the questionnaire data.

were released back into their habitat shortly after they inspected their catch. This is also confirmed by the survey results (see Table 3), where it can be seen that the attitude of the EFFG BSC fishermen towards preservation and regeneration is much better than that of the NEFFG BSC fishermen.

3.2. Determinant factors of eco-friendly fishing gear utilization

The results of statistical analysis on factors determining the decisions to utilize of the EFFGs showed that fishermen who involve in fisheries groups, credit access to financial sources, decision synchronization, financial capability, and fishers' perception of environmental uncertainty have a significant positive correlation with fishermen' decision to adopt the EFFGs. Meanwhile, several characteristics or variables that have a significant negative correlation with fishermen' decisions to use EFFGs on BSC fisheries are the complexity of fishing gears and buyer pressure (Table 4 and Appendix 1).

The involvement of fishermen in groups is one of the factors influencing fishermen's decision to utilize the EFFGs. Fishermen's interaction with peers in the group encourages them to learn and change their perceptions, opinions, and behaviors to fit with the group's norms (Brehm and Kassin, 1993; Myers, 2013). The unique thing is that almost all BSC fishermen group is established based on the similarity of the fishing gear used. Most of the EFFG fishermen form groups formally and are recognized by the government. The group establishment is essential for the fishermen as it relates to how government disburses programs and assistance in fishing gear and business skills development.

Table 4
Determinants of fishermen decision on the utilization of EFFGs.

Variables	ESR	Probit model	Marginal effects
Age	0.003	0.003	0.001
	(0.009)	(0.010)	(0.002)
Formal education	−0.042	−0.043	−0.011
	(0.027)	(0.027)	(0.007)
Number of family size	−0.051	−0.052	−0.013
	(0.046)	(0.044)	(0.011)
Experience on fishing	−0.006	−0.006	−0.001
	(0.010)	(0.011)	(0.003)
Training on fishing	0.027	0.024	0.006
	(0.105)	(0.115)	(0.029)
Fishermen group	0.944***	0.936***	0.236***
	(0.149)	(0.148)	(0.035)
Credit to formal banking	0.351*	0.359*	0.091*
	(0.201)	(0.185)	(0.047)
Fishermen attitude	−0.170**	−0.158	−0.040
	(0.185)	(0.175)	(0.044)
Decision synchronization	1.074***	1.078***	0.272***
	(0.216)	(0.244)	(0.058)
By-catch	−0.460***	−0.461***	−0.116***
	(0.128)	(0.128)	(0.031)
Financial capability	0.518***	0.523***	0.132***
	(0.146)	(0.136)	(0.033)
Knowledge on EFFG	−0.057	−0.070	−0.018
	(0.156)	(0.163)	(0.041)
Buyer pressure	0.216	0.223	0.056
	(0.154)	(0.163)	(0.041)
Environmental uncertainty	0.992***	0.971***	0.245***
	(0.164)	(0.176)	(0.041)
Constant	−0.250	−0.228	
	(0.406)	(0.401)	
Wald Chi^2	176.08***	97.27***	
Pseudo R^2		0.1820	
Log Likelihood	−6177.2921	−289.48297	
Observations	647	647	647

Notes: Standard errors are in parenthesis.
ESR = Endogenous Switching Regression; EFFGs = Eco-friendly fishing gears.
* Significant at 10 %.
** Significant at 5 %.
*** Significant at 1 %.
Source: calculated from the survey data.

Based on the in depth-interview with some fishermen groups, this phenomenon occurred because of several reasons: first, the group establishment is essential for the fishermen as it relates to how government disburses programs and assistance. According to the government regulation No.50 of 2015, fishermen groups established on the basis of common interests, potential fish resources, environmental conditions, administrative location, or fishing means; second, the sense of friendship and brotherhood within the group is strongly embedded in helping each other; third, they have a common interest in dealing with potential social issues among fishermen that arise due to various things such as catching territory conflict, fishing gear destruction by other fishermen groups, etc.

On the other hand, most of the non-EFFG fishermen run their businesses individually without joining a group and are pretty rare in receiving government assistance. This happened because by the regulation of the Minister of Marine Affairs and Fisheries, non-EFFG fishing activities is prohibited. Hence, establishing a non-EFFG fishermen group is against the law.

There is a phenomenon that some fishermen are not consistently utilizing the EFFGs and decide to switch to the NEFFGs even though they are actively involved in the group. According to Leavitt (1978), such a phenomenon could occur because the way an individual sees things comes from his group and societal membership. As community members, the EFFG fishermen cannot avoid their interactions with the NEFFG fishermen and might compare each other's benefits derived from the fishing gear used. This condition is perceived as social pressure. This suggests indirectly that deciding the type of fishing gear to be used depends on how the EFFGs and the NEFFGs group exert much social pressure. Hence, group coaching is pivotal to be carried out intensively and consistently.

Another influential variable is the ease of access to credit. The easier the access to the bank credit, the higher the fishermen's probability of adopting the EFFGs. Fishermen need a substantial amount of money because the investment and operational costs of adopting the EFFGs are relatively higher than those of the NEFFGs.

To illustrate, the cost of making the EFFGs for a fish trap/pot (*bubu*) was IDR 60,000/unit. One fishing vessel employed 1500–2000 units of the fish trap/pot. Hence, the total costs for fish traps/pots were IDR 90–120 million (equals to US$ 5992–US$ 7989). Meanwhile, the average price of the EFFG for a gillnet was IDR 600 thousand/unit (equals to US$ 40/unit), and a gillnet vessel employed five units for five fishermen. Even though gillnet fishing gears were fairly cheap, they required recurring net repairing costs every 2–3 times of fishing trips at the amount of IDR 50 thousand/gillnet. Also, gillnet fishermen have to spend higher costs because the gillnet vessels need to explore the broader fishing ground with a more prolonged operation (up to 5–7 days/trip). Note that, 1 USD is equal to IDR 15,021.30 at the time of survey.

In contrast, the operational costs of the NEFFGs (dredge gear and bottom trawl nets) were relatively cheaper than the EFFGs (fish traps/pots and gillnets). The price of a dredge gear was only IDR 900 thousand (equals US$ 60). In addition, dredge fishing gear did require minor repair costs, and a fishing vessel employed three units of dredge gear. Both dredges and bottom trawl nets only needed a one-day fishing trip and the fishing ground is relatively within a short distance.

In terms of funding sources, fishermen generally had informal funding sources from collecting traders or fish processors (mini plants). In return, the fishermen must sell their catches to the ones providing the capital. BSC fishermen who sold their BSCs to mini plants usually have a tied agreement or patron-client relations. In the transaction process, mini plants sort out certain specifications of BSC purchased from fishermen to meet the requirements set by the manufacturing firm. Those mini plants generally had networked with export-oriented manufacturing firms. The Mini plants also routinely communicated with the fishermen on market preferences.

Another factor affecting the decision to use the EEFGs is environmental uncertainty. The income of BSC fishermen is susceptible to changing weather conditions and global markets. During the low season, BSC fishermen in Cirebon Regency are unable to go fishing because of strong winds and high waves, so their income decreased significantly. This condition consequently pushed them to look for other economic opportunities or re-shifting from the use of the EFFGs (fish traps/pots and/or gillnets) to the non-EFFGs (dredges and/or bottom trawl nets). If not, they have to borrow money from the money lenders or the mini plants that have a patron-client relationship to fulfill their costs of living. Global markets also affect the price of BSC. When the export demand for BSC is low, the income of BSC fishermen falls drastically.

3.3. Effects of the EFFGs on fishermen's welfare and sustainability

As detailed in the method of data analysis, the approach to investigate the effects of using the EFFGs on the outcomes consists of estimating an OLS model of four outcomes that includes a dummy variable equal to 1 (if the fisherman household adopted EFFG), and 0 otherwise (Appendix 3). The results from the OLS estimation lead us to conclude that there is no difference in results compared to ESR. This approach, however, assumes that utilization of EFFG is exogenously determined while it is a potentially endogenous variable. The estimation via OLS would yield biased and inconsistent estimates. In addition, OLS estimates do not explicitly account for potential structural differences between the outcome functions of fisherman households that adopted the EFFGs and the outcome functions of fishermen households that did not utilize the EFFGs. The details of OLS estimation results are provided in Appendix 3.

To estimate the effects of the EFFGs utilization on BSC fishermen's performance, welfare, and sustainability, as addressed in the method section we specified four functions for the utilization, and non-adopter regimes on BSC production, net profit, egg-berried female capture (EBFC), and size of BSC captured yearly. In the ESR framework, the regime equations are estimated jointly with a criterion function that explains which regime an observation would fall in. Proper identification requires that the criterion function contain all variables from the regime equations plus at least one instrument (Lokshin and Sajaia, 2004). We used fishermen's environmental uncertainty perception as the instrument correlated with individual utilization behavior. Fishermen's perception of the uncertainty of their environment on fishing practices may evoke their awareness of utilizing the EFFGs to preserve the environment and maintain their fishing practices. Fishermen's perception of environmental uncertainty is not correlated with outcomes.

As shown in Table 5, the fishermen's perception of environmental uncertainty can be considered as valid selection instruments. This variable is a jointly statistically significant driver of the decision to adopt the EFFGs as the p-value in the Probit regression model 1 was 0.000 but had no significant impacts on the equations of outcomes of interest for those that did not adopt EFFGs (Model 2 related to the fishermen's perception on environment uncertainty on BSC production) in which the p-value was 0.207.

The statistical results of the ESR estimates for BSC production, net profit, egg-berried female captured, and size of crab caught are exhibited in Table 6. The Wald χ^2 test statistics show that the independent variables are jointly statistically significant ($p < 0.000$). The values for sigma are statistically significant in the outcome equations. This implies that selection bias is present, which justifies using ESR. The lower part of Table 6 presents the estimated covariance terms together with the results from the Wald test of joint independence for all equations (Fuglie and Bosch, 1995; Lokshin and Sajaia, 2004). The coefficients of the correlation terms ρj do not significantly differ from zero. These statistical results suggest that the hypothesis for the absence of sample selectivity bias cannot be rejected. However, differences in the coefficients of all functions between the EFFGs and the NEFFGs fishermen illustrate the presence of heterogeneity in the sample (σj), which would cause bias if not controlled.

The Endogenous switching regression results in Table 6 also show that the variables affecting BSC production are unique. The fishermen's attitude is the only positive and significant variable affecting BSC production on both sides using the EFFG and the non-EFFGs. This suggests that the strength of the mindset built by fishermen in adopting the EFFGs can affect the ways of catching BSC. This attitude would be able to offset losses for the loss of by-products with a negative coefficient, which is naturally experienced when fishermen shift from the non-EFFG to the EFFG. By-product means more catches from other fishes. A negative and significant variable of experience indicates a need to increase BSC production by adopting the EFFGs. Fishermen who have been using the non-EFFGs for a long time would need adjustments to increase the EFFGs-based catches.

Moreover, buyer concern on increasing the use of eco-friendly fishing gear, preserving fishing areas, and considering the marine environment had different impacts significantly on the size of crabs captured by both fishermen groups. Buyer concern significantly affects the size of crabs captured positively by eco-friendly fishing gear fishermen, while it affects the size of crabs captured negatively by non-eco-friendly fishing gear. The negative impact of buyer concern on the size of crabs captured on non-eco-friendly fishing gear fishermen might be because their buyers did not have any requirements on crabs captured and sold to them; hence, the numbers of crabs captured and sold to their buyers were higher than eco-friendly fishing gear fishermen.

3.3.1. The effect of eco-friendly fishing gear on the fishermen's welfare

Table 7 presents the estimates of the expected fishermen's

Table 5
Falsification test on the validity of sample selection.

Independent variables	Dependent variables				
	Model 1 ($n = 494$) EFFG (1/0)	Model 2: NEFFG ($n = 153$)			
		BSC production. (kgs 000/year)	Net profit. (IDR million/year)	EBFC (per cent/year)	Size of crab (individual/kg)
Fishermen's perception of environmental uncertainty	0.9536***	−0.5*	34**	−0.03	−1.37
Wald test	χ^2 = 93.28***	0.95***	2.37***	4.57***	6.71***
Pseudo-R^2/R-squared	0.1846	0.0819	0.1817	0.2992	0.3856

Notes: Model 1 is estimated using a probit method; Model 2 is estimated using OLS; Standard errors are in parentheses; EFFG = Eco friendly fishing gears; NEFFG = Non-eco-friendly fishing gears; EBFC = egg-berried female capture.
* Significant at 10 %.
** Significant at 5 %.
*** Significant at 1 %.
Source: calculated from the survey data.

Table 6
Endogenous switching regression results for fishermen's productivity, welfare, and sustainability.

Variables	BSC production		Net profit		EBFC		Size of crab captured	
	EFFG	NEFFG	EFFG	NEFFG	EFFG	NEFFG	EFFG	NEFFG
Age	8.82	4.54	382,246	2,289,119	0.003	−0.002	−0.016	0.004
	(17.27)	(20.99)	(14,785,87)	(1,543,020)	(0.002)	(0.004)	(0.022)	(0.051)
Education	33.34	−62.35	9,013,419**	3,844,296	−0.012*	−0.039***	−0.055	0.347**
	(45.83)	(70.31)	(3,931,160)	(5,274,083)	(0.006)	(0.012)	(0.059)	(0.173)
Family size	37.83	−79.15	−8,977,590	−10,889,202	−0.002	−0.023	−0.187*	0.230
	(75.940)	(142.98)	(65,02,964)	(10,494,559)	(0.010)	(0.024)	(0.099)	(0.351)
Experience in fishing	−53.15***	−9.03	−2,298,896	−1,214,360	−0.006**	0.001	0.015	−0.033
	(18.07)	(22.51)	(1,547,455)	(1,697,072)	(0.002)	(0.004)	(0.023)	(0.055)
Fishermen group	279.09	−267.52	79,744,065***	−14,497,323	0.058	0.196***	2.000***	−1.404
	(258.12)	(425.22)	(23,006,103)	(35,940,209)	(0.038)	(0.071)	(0.315)	(1.046)
By-catch	−917.86***	287.11	−26,006,303	38,282,027	0.181***	0.069	0.535*	−0.642
	(227.39)	(369.71)	(19,939,436)	(31,147,029)	(0.032)	(0.062)	(0.291)	(0.837)
Financial capability	103.80	−521.46	68,884,294***	92,733,987***	0.101***	0.324***	0.790**	3.144***
	(268.13)	(451.66)	(23,328,045)	(35,646,640)	(0.037)	(0.075)	(0.338)	(1.154)
Credit to formal banking	286.19	296.96	32,391,917	−55,009,123	0.004	−0.067	0.289	−0.123
	(307.39)	(543.20)	(26,485,925)	(40,585,896)	(0.042)	(0.091)	(0.396)	(1.312)
Knowledge on eco-friendly gears	212.03	468.51	29,815,149	−99,112,351***	0.305***	0.002	−1.988***	−0.789
	(279.49)	(397.17)	(24,161,933)	(297,12,910)	(0.038)	(0.067)	(0.351)	(1.008)
Buyer pressure	−1323.16**	179.79	−116,460,713***	−6,375,928	0.001	0.030	1.483***	−7.322***
	(272.48)	(426.45)	(23,330,912)	(32,884,106)	(0.036)	(0.071)	(0.347)	(1.070)
Fishermen attitude	2335.22***	−78.65	135,086,100***	89,137,390**	−0.073*	−0.071	−0.033	−3.870***
	(296.05)	(483.31)	(25,335,267)	(35,388,794)	(0.040)	(0.082)	(0.384)	(1.183)
Decision synchronization	75.18	−946.76	−33,679,985	−136,066,018*	−0.032	0.021	1.043***	−1.606
	(291.51)	(863.76)	(25,917,474)	(74,676,330)	(0.042)	(0.144)	(0.372)	(2.038)
Constant	5066.85***	4709.75***	116,244,395*	−32,971,905	−0.047	0.262	5.848***	15.390***
	(732.88)	(1077.05)	(63,538,566)	(87,460,946)	(0.100)	(0.182)	(0.925)	(2.640)
Sigma	7.745***	7.539***	19.102***	18.732***	−1.176***	−1.164***	1.148***	1.521***
	(0.03)	(0.08)	(0.032)	(0.082)	(0.033)	(0.063)	(0.039)	(0.074)
Rho	−0.124	0.314	−0.077	−0.243	0.116	0.164	1.323***	0.259
	(0.125)	(0.254)	(0.170)	(0.391)	(0.204)	(0.240)	(0.146)	(0.261)
Observations	647	647	647	647	647	647	647	647

Notes: Standard errors are in parentheses; EBFC = egg berried female captured; MoSG = member of society group.
* Significant at 10 %.
** Significant at 5 %.
*** Significant at 1 %.
Source: calculated from the survey data.

Table 7
Average expected outcomes per year fishing; actual and counterfactual effects.

Means of outcome variable	Fishermen household—type and treatment effects	Decision stage		Average treatment effects
		To adopt	Not to adopt	
Blue swimming crab prod. (kg/year)	Fishermen that adopt (ATT)	4031	3888**	144*
	Fishermen that did not adopt (ATU)	4075	3428	647***
Net profit. (IDR million/year)	Fishermen that adopt (ATT)	157	25.3	131***
	Fishermen that did not adopt (ATU)	149	85.4	63.1***

Notes:
US$ 1 = IDR 15,021.30 (Sept 2022).
ATT = Average Treatment to the Treated.
ATU = Average Treatment to the Untreated.
* Significant at 10 %.
** Significant at 5 %.
*** Significant at 1 %.
Source: calculated from the survey data.

performance under actual and counterfactual conditions from the ESR model. The results show that the EFFGs utilization positively affect BSC production and net profit of BSC fishing practices. BSC yield is, on average, 144 kgs lower than it would have been had by the EFFG fishermen who do not adopt the EFFGs. The results illustrate that while the EFFGs and the NEFFGs fishermen achieve a high BSC production yield in kg/year of measurement, it is higher for the EFFGs fishermen. In addition, the NEFFGs fishermen who had changed their fishing gears to the EFFGs, the yields would have been 647 kg/year higher than its actual impacts on their yields. Similar to BSC yield, fishermen's net profit is, on average, IDR 131 million (equals US$ 8721) lower than it would have been had by the EFFG fishermen who do not adopt EFFG. Meanwhile, for the NEFFGs fishermen who shifted their fishing gears to the EFFGs, their profits would have IDR 63.1 million (equals US$ 4200) higher than its actual impacts.

The Average Treatment Effect of crab production of the EFFGs fishermen is greater than that of the NEFFGs fishermen. This occurred because of two main factors. First, the NEFFGs such as dredge and bottom trawl nets can catch both large and small crabs as well as other by-catches. Hence, in terms of volume, the NEEFG fishermen can catch more catches. Second, most of the NEFFGs have less concern on the issues of preservation and regeneration. Therefore, they tend to take all the catches including the small crabs and egg-berried females which should be returned to the sea.

On the other hand, the EFFG fishermen have a better attitude towards preservation, regeneration, and environmental sustainability, so they only take large crabs. For the small crabs <10 cm and the crabs with laying eggs are released back into the sea. In addition to the environmental consideration, the EFFG fishermen have also practiced such action because of economic considerations. The market price for large crabs caught by the EFFGs is much higher. Furthermore, such kind of practice has to some extent also been influenced by the buyer pressure for a more environmentally friendly fishing process.

An encouraging finding shows that the average expected outcomes calculation in Table 8 is that fishermen who consistently adopt the EFFGs can generate higher profits. The fishermen in Demak and Cirebon

Table 8
Average expected outcomes per year fishing; actual and counterfactual effects.

Means of the outcome variable	Fishermen household—type and treatment effects	Decision stage		Average treatment effects
		To adopt	Not to adopt	
Egg-berried female captured (ratio)	Fishermen that adopt (ATT)	0.17	0.28*	−0.11***
	Fishermen that did not adopt (ATU)	0.16	0.1634	−0.0034**
Size of crab (crab/kilogram)	Fishermen that adopt (ATT)	8	14	−6***
	Fishermen that did not adopt (ATU)	4	12	−8***

Notes:
ATT = Average Treatment to the Treated.
ATU = Average Treatment to the Untreated.
* Significant at 10 %.
** Significant at 5 %.
*** Significant at 1 %.
Source: calculated from the survey data.

Regency view this high profit as a market incentive for those adopting the EFFGs. This market incentive is in the form of a higher price margin paid by buyers at the Mini plant level and processing companies for the price of large-sized crab.

Further, Table 8 shows that the crabs caught using the EFFG are larger than those of the non-EFFG catch. This is indicated by the number of crabs per kg obtained by fishermen with the EFFG, which is 8 crabs/kg compared to 14 crabs/kg crabs caught using the non-EFFGs. In addition to the market incentive mechanism factor, the ability of the EFFGs fishermen to increase profits also occurs due to their internal factor transformation. Let's look at the results of Endogenous switching regression on the profit equation. The EFFG fishermen's attitude variable consistently plays an essential role in increasing the profit. This variable and three other variables (education, group support, and organization support) positively impact profits. These findings indicate that a change in mindset accompanied by capacity building, peer cooperation, and a fair market incentive mechanism are essential in improving crab fishermen's welfare.

3.3.2. *The effect of eco-friendly fishing gear on sustainable fisheries*

The EFFGs utilization has positively contributed to maintaining environmental preservation. Table 8 shows that using the EFFGs has reduced the percentage of catching crabs laying eggs between 2.83 % and 9.24 %. In addition, the EFFGs utilization has also been proven to maintain fishery resources' sustainability. Table 8 shows that crabs caught by the EFFGs are larger than those caught by the non-EFFGs.

Furthermore, Table 8 also shows that if the EFFGs fishermen changed their fishing gear to the NEFFGs, the number of crabs per kilogram caught would increase. The selectivity of the NEFFGs is very low. Dredge fishing gears would be raking all organisms on the seabed and pulling them out to the vessels. Hence, all the fish and crabs would be yielded, and it is impossible to release the small crabs or egg-berried female crabs due to damaged conditions. On the contrary, it is possible to sort and release small crabs or egg-berried female crabs from the EFFGs because the operation of those fishing gears would not damage the crabs.

In addition, the fishing area of the EFFG was farther than dredge fishing gears (NEFFG). The analysis shows that the average distance of the fishing area of fish traps (EFFG) was 13.7 miles from the shoreline, while the dredge fishing area (NEFFG) was 3.9 miles from the shoreline. Crabs spawn in the coastal waters, and when the eggs are matured enough in the abdomen of female bodies, those egg-berried female crabs migrate to the high seas with higher salinity levels (King, 2007). Therefore, dredge fishermen would catch more female crabs with eggs than fish trap fishermen. Despite the high crab yields in dredge fishing gear, clams were the main catches of dredge fishermen; hence, the fishing area was close to the shoreline (coastal waters).

Catching egg-berried female crabs would disrupt the sustainability of crab stocks. The growth rate of crabs lower than its exploitation led to the overexploited crab status in some Indonesian waters. For example, the exploitation rate in Jepara water was recorded at 78 % (Setiyowati and Sulistyawati, 2019), in Central Buton water was 61 % for male crabs and 71 % for females (Hamid and Wardiatno, 2015), as well as in Southeast Sulawesi water was recorded at 66.8 %. In Central Buton waters, the exploitation rate of female crabs (71 %) is higher than that of male crabs (61 %) (Sara and Astuti, 2019). This condition needs to be responded to by strict law enforcement of the Management of Lobster (*Panulirus* spp.), Crab (*Scylla* spp.), and Crab (*Portunus* spp.) in the Territory of the Republic of Indonesia enacted by the Minister of Marine Affairs and Fisheries Regulation No. 17 of 2021.

Finally, the positive effects of the EFFGs on sustainability were also shown in the egg-berried female crab caught. If the EFFGs fishermen changed their fishing gears to the NEFFGs, the egg-berried female crabs were significantly higher than its actual observations. A similar condition implies to the NEFFGs if the NEFFGs fishermen changed to the EFFGs in that the yields of egg-berried female crabs would be lower than in real observations. Thus, the EFFGs have a positive effect on the BSC sustainability resources, and vice versa.

4. Conclusions

The objectives of this paper were to analyze the driving forces behind blue swimming crab (BSC) fishermen's decision to utilize eco-friendly fishing gear and to investigate the effects of this decision on the welfare of BSC fishermen and its sustainability.

The analysis of the determinants of utilization highlighted very interesting results. Fishermen who are involved in fisheries groups, credit access to financial sources, decision synchronization, financial capability, and fishermen's perception of environmental uncertainty have positive effects on the probability of EFFG use. Fisheries groups may lead fishermen to change their perceptions, opinions, and behaviors of destructive fishing gears through interactions, discussions, and debates among them. Both access to formal credit and financial capability are crucial in determining a fisherman's decision on fishing gear because they need significant capital to purchase eco-friendly fishing gear. Decision synchronization is critical in determining the decision on eco-friendly fishing gear since a joint decision between a fisherman and its buyer may hinder disagreements regarding the fish captured. A fisherman's perception of environmental uncertainty is also necessary for the decision because it relates to the fishing strategy and adaptation of the fisherman.

Meanwhile, several characteristics or variables that have a significant negative correlation with fishermen's decision to use EFFGs on BSC fisheries are the complexity of fishing gears and buyer pressure. This is because the more difficult to build and operate fishing gear, the less fishermen would use the gear. Buyer pressure is also important in the decision because the more pressure the buyer conveys, the less fisherman would choose this buyer and its fishing gear recommendation.

Furthermore, the study found that many factors affect fishermen of BSC in deciding the utilization of the EFFGs and the NEFFGs. This study suggested that EFFG utilization positively affects BSC production and net profit of BSC fishing practices. Further, the crabs caught using the EFFG are larger than those of the non-EFFG catch. The positive effects of the EFFGs on sustainability were also shown in terms of the egg-berried female crab caught. If the EFFGs fishermen changed their fishing gears to the NEFFGs, the egg-berried female crabs were significantly higher than its actual observations. Therefore, the EFFGs have a positive effect on the BSC sustainability resources.

Therefore, it is time for Indonesia and other developing countries to design policies for effective strategies to implement the EFFGs to cope with the effects of destructive fishing gear on fishermen's welfare and BSC fishery resource sustainability. The facilitation of credit access to the EFFG technology can be part of the policies to speed the process of the EFFG's utilization to realize the global call for sustainability in marine resource development in particular and the sustainable development goals (SDGs) in general. In addition, the dissemination of the positive impacts of employing eco-friendly fishing gears is of utmost importance in the implementation of eco-friendly fishing gear, which could result in more welfare of the crab fishermen and more sustainability of crab resources irrespective of their unobservable characteristics. Future research is needed to better understand the impacts of the adoption of several fishing gears on fishermen's welfare and resource sustainability. Also, more research effort should be allocated to different fish commodities with the most valuable ones.

CRediT authorship contribution statement

Maharani Yulisti: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Writing – original draft, Writing – review & editing. **Agus Syarip Hidayat:** Conceptualization, Data curation, Formal analysis, Methodology, Writing – original draft, Writing – review & editing. **Carunia Mulya Firdausy:** Conceptualization, Data curation, Formal analysis, Methodology, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **Ummi Mu'awanah:** Conceptualization, Data curation, Formal analysis, Methodology, Writing – original draft. **Nendah Kurniasari:** Conceptualization, Data curation, Methodology, Writing – original draft. **Eka Nurjati:** Data curation, Formal analysis, Methodology, Project administration, Writing – original draft.

Declaration of competing interest

We would like to declare that

- All authors have contributed equally in the manuscript;
- This manuscript has not been submitted to, nor is under review at, another journal or other publishing venue;
- The authors have no competing as well as no conflict of interests with the authors of this manuscript and with any organisations.

Data availability

Data will be made available on request.

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Appendix A

Appendix 1
The complexity variables of crab fishing gears.

Variables	Average value			
	EFFG		NEFFG	
	Fish trap (crab pot)	Bottom Gillnet	Dredges	Small bottom trawl
	$N = 295$	$N = 199$	$N = 88$	$N = 65$
The variables of fishing gears complexity				
1. Easy to build the gears	3	2	3	2
2. Easy to operate	2	3	2	2
3. Need more experience	2	3	2	2
The variables of environment uncertainty				
1. Uncertainty of environment condition (current, climate, weather)	3	2	2	3
2. To predict the needs of buyers	3	2	2	3
3. To predict competitor behavior on using EFFG	3	2	2	3
4. EFFGs are fast growing	3	2	3	3
The variables of buyer pressure				
1. Buyer request to increase the use of EFFG	2	3	3	3
2. Buyer request to preserve fishing area	2	3	3	3
3. Buyers/processing plants consider the environment seriously	2	3	3	3

Notes: 1 = agree more, 2 = agree, 3 = disagree, 4 = disagree more.
EFFGs = Eco-friendly fishing gears; NEFFG = Non-eco-friendly fishing gears.
Source: calculated from the survey data.

Appendix 2
Variables and its definition.

Variables	Definition
Age of fishermen	Age of fishermen at the time they filled the questionnaire (year)
Formal education	Length of time attending formal education (year)
Household size	Number of nuclear family members who are dependent on the fisherman (persons)
Experience on fishing	Length of experience as a fisherman (year)
Training on fisheries	Frequency of training attended annually (number)
Member of Fishermen group	Membership in a fishermen group (yes = 1, no = 0)
Credit to formal banking	Currently getting a loan from the bank (yes = 1, no = 0)
Fishermen attitude	Having awareness towards preservation and regeneration of crabs (yes = 1, no = 0)
Decision synchronization	The decision of using EFFG is coordinated with buyers (yes = 1, no = 0)
By-catch	Fishermen bring home by-catch (yes = 1, no = 0)

(*continued on next page*)

Appendix 2 (*continued*)

Variables	Definition
Financial capability	Ability to buy new equipment and upgrade fishing equipment (yes = 1, no = 0)
Knowledge eco-friendly gears	Having a good understanding of EFFG (yes = 1, no = 0)
Buyer concern	The buyers of crabs express their concern of using EFFG (yes = 1, no = 0)
Environment uncertainty	Fishermen's perception on uncertainty of environment condition (current, climate, weather), the need of buyers, and competitor behavior on using EFFG (yes = 1, no = 0)

Appendix 3
OLS regression of outcomes.

Variable	Crab yields		Net profit		EBFC		Size of crab caught	
	EFFG	NEFFG	EFFG	NEFFG	EFFG	NEFFG	EFFG	NEFFG
Age of fishermen	9.2009	−1.5609	3.50E+05	1.90E+06	0.0033	−0.0031	−0.0139	−0.002
Formal education	28.3259	−38.0168	8.8e+06*	3.50E+06	−0.0101	−0.0365**	−0.0161	0.3951*
HH size	23.6273	−20.1619	−9.30E+06	−1.00E+07	0.0014	−0.0178	−0.1463	0.3645
Experience	−53.1695**	−2.2909	−2.30E+06	−8.00E+05	−0.0065**	0.0016	0.0168	−0.0265
Training	−52.08	−7.7e+02*	4.10E+06	−6.3e+07*	−0.0506*	−0.0939	−0.2832	−1.0275
Member of fishermen group	440.1332	−5.20E+02	8.3e+07***	2.60E+07	0.0503	0.1856*	1.1861***	−2.1623*
Credit to formal banking	282.2195	462.954	3.50E+07	−2.10E+07	0.0018	−0.0402	−0.0536	0.0814
Fishers attitude	2.2e+03***	−1.90E+02	1.4e+08***	7.00E+07	−0.0666	−0.0884	−0.0405	−3.9218**
Decision synchronization	163.4125	−9.00E+02	−2.90E+07	−7.00E+07	−0.0402	0.0398	0.1557	−1.5898
By-catch	−9.4e+02***	337.2907	−2.90E+07	1.80E+07	0.1827***	0.0707	1.1132***	−0.6768
Financial capability	121.811	−7.10E+02	7.3e+07**	1.1e+08***	0.0845*	0.3113***	0.2598	2.5783*
Knowledge eco-friendly gears	396.0746	633.5422	2.70E+07	−8.7e+07**	0.2820***	0.0227	−1.9553***	−0.4701
Buyer concern	−1.2e+03***	193.8775	−1.2e+08***	4.70E+06	−0.0194	0.0326	1.4734***	−7.3897***
Environment uncertainty	511.706	−5.30E+02	−2.10E+04	3.20E+07	−0.0793	−0.0342	−0.6378	−1.4087
Constanta	4.5e+03***	4.3e+03***	1.10E+08	−2.80E+07	0.0271	0.2119	7.5929***	14.8210***
Samples (n)	494	153	494	153	494	153	494	153
R^2	0.281	0.1166	0.1976	0.2199	0.3448	0.3128	0.1854	0.3925
R^2-adjusted	0.26	0.027	0.1742	0.1408	0.3256	0.2431	0.1616	0.3309
F-stat	13.37	1.30***	8.43	2.78***	18.00	4.49***	7.79	6.37***

Notes: Standard errors are in parenthesis. EFFG: Eco friendly fishing gears; NEFFG: Non-eco-friendly fishing gears.
* Significant at 10 %.
** Significant at 5 %.
*** Significant at 1 %.
Source: calculated from the survey data.

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