An ecosystem-based fisheries assessment for some coral fishes in the coastal Seram Laut Island, Maluku

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Abstract. As the Seram Laut Island (SLI) community relies on coral fish resources, changes in coral fish populations will impact their income and nutritional needs. This research aimed to investigate the SLI ecosystem's status using risk score indicators and the management implications for the sustainability of the coral fish fishery ecosystem. This research used the tier 2 approach semiquantitative ecosystem-based fishery assessment (EBFA) method based on a risk score of 0 to 3, with four objectives: sustainability, habitat, biodiversity, and socio-economy. Several high-risk scores in the red zone were found in the fishing efforts indicator of *Lethrinus obsoletus*, *Siganus canaliculatus*, and *Cephalopolis miniata*, catch per unit effort (cpue) indicator of *S. canaliculatus*, maturity proportion, and fishing gear impact of *L. obsoletus* and *S. canaliculatus* and habitat quality indicator of *S. canaliculatus*. Coral fish's species risk index (SRI) ranged from 1.28 to 1.64 (yellow zone), with *L. obsoletus* having the highest SRI. The coastal of SLI's ecosystem risk index was in the limited range (yellow zone). For ecosystem sustainability, proper management should be developed with a focus on the indicators in the high-risk state (red zone) by spatial planning for coral and habitat conservation, as well as policies based on local wisdom.

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1 Introduction

Coral fish fisheries have significantly contributed to the primary source of income and nutrition for communities in Seram Laut Island (SLI), Maluku. Due to the firm reliance of the SLI community on coral fish resources, changes in coral fish populations will significantly impact their needs. Various factors, including overfishing, destructive fishing gear, and pollution, can affect the coral fish population. Various fish species depend on the coral reef ecosystem as their permanent habitat, nursery ground, and foraging habitat. Hence degradation of their habitat will reduce biodiversity and production [1]. Furthermore, bottom gillnets are a common type of fishing gear in Seram seas, and its fishing methods are linked to habitat destruction due to net snagging on corals, such as *Acropora* sp. [2].

Coral fish are highly vulnerable to population declines due to their high economic values, limited distribution, and reliance on habitat. Several studies have reported declines in coral fish populations due to coral reef degradation and over-exploitation, including in Papua New Guinea and Solomon waters [3-4]. Communities in SLI are highly dependent on coral fish production, so a decrease in its population can cause various problems, including economic decline, lack of nutritional food, and the collapse of the fisheries industry. Therefore, an ecosystem-based fisheries assessment (EBFA) is essential to develop proper management for ecosystem sustainability. This research integrated four objectives, including stock sustainability, habitat, biodiversity, and socioeconomic, in formulating ecosystem-based fisheries management in the coastal SLI.

Ecosystem-based management is essential for adequately managing some coral fish since habitat conditions, fisheries, and socioeconomic factors strongly influence their population. Some countries, including the United States, Australia, and Korea Waters, have performed ecosystem-based fisheries assessments to manage their fisheries [5-7]. Many fishers in SLI have captured the coral fish for over thirty years, but there is still a lack of data and studies on its fisheries. Due to the high dependence of the community on coral fish production, Ecosystem-based assessment for coral fish fisheries in the coastal SLI is essential to develop proper management.

Research that integrates aspects of fisheries with their habitats will provide a good understanding of appropriate management decisions [8]. It is challenging to undertake quantitative studies due to the paucity of time-series data on fisheries production, effort, and habitat conditions. For this reason, this research was conducted to develop a management model combining different fishery aspects using limited data. This work is crucial for monitoring fisheries resources in SLI and implementing management recommendations to prevent fish resource declines, which lead to financial losses, the loss of supplies of food source, and the loss of livelihoods for fishers. This research aimed to investigate the ecosystem's status using risk score indicators and the management implications for the sustainability of the coral fish fishery ecosystem in the SLI coast.

2 Data and methods

2.1 Data collection

The data was collected by filling out questionnaires to 36 fishers on the coast of Seram laut Island (SLI) (Figure 1). Fishers used gillnet and handline, with the three key species including orange-striped emperor fish (*Lethrinus obsoletus*), white-spotted spine fish (*Siganus canaliculatus*), and coral grouper (*Cephalopolis miniata*). *L. obsoletus* and *S. canaliculatus* were the target species of the gillnet, whereas *C. miniata* was the target of the handline. The mesh size of the gillnet was 2.5 inches, and the hook size of the handline was 10-12.

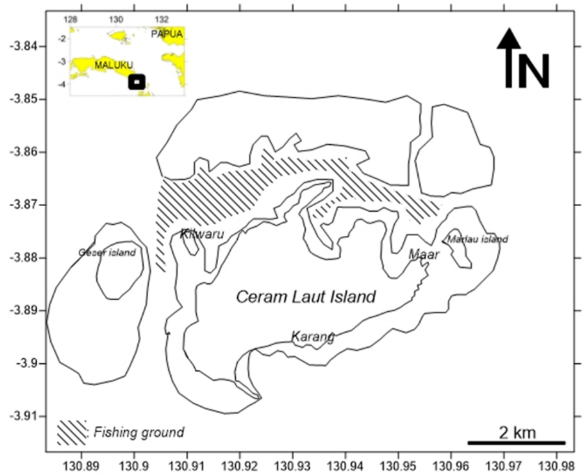

Fig. 1. The scope area for an ecosystem-based fisheries assessment for some coral fishes in the coastal of Seram Laut Island, Maluku.

2.2 Data analysis

The risk score ranges from 0 to 3, with details 0-0.99 being in the safety zone (green zone), 1-1.99 being the limited range (yellow zone), and 2-3 being the high-risk zone (red zone), applied in this study as part of a tier 2 approach semi-quantitative ecosystem-based fisheries assessment (EBFA) [7]. This study used four objectives with 12 indicators (Table 1). The four objectives include sustainability, biodiversity, habitat, and socio-economics.

The Objectives risk index was calculated based on the equation [7]:

$$\text{ORI} = \frac{\sum_{i=0}^{n} I_i W_i}{\sum_{i=1}^{n} W_i} \quad (1)$$

Where ORI is the objectives risk index, I_i is the score of indicator I, Wi is the weighting factor of indicator I, and n is the number of indicators.

The species risk index was estimated for *L. obsoletus*, *S. canaliculatus*, and *C. miniata*, following the equation [7]:

$$\text{SRI} = \lambda_s ORI_S + \lambda_B ORI_B + \lambda_H ORI_H + \lambda_E ORI_E \quad (2)$$

Where SRI is species risk index, λ_s, λ_B, λ_H and λ_E are the the weighting factor of sustainability, biodiversity, habitat quality and socio-economic and the ORI is objectives risk index.

The fisheries risk index (FRI) was determined for the gillnet and handline fisheries using each species' catch per unit effort. To measure the ecosystem risk index (ERI), the FRI was weighted with each fishery's total catch per unit effort (gillnet and long line). The fisheries risk index and ecosystem risk index are calculated based on the equation [7]:

$$FRI = \frac{\sum cpue(a)_i SRI_i}{cpue_i} \quad (3)$$

$$ERI = \frac{\sum cpue(b)_i FRI_i}{\sum Ci} \quad (4)$$

Where cpue (a) and cpue(b) are the catch per unit effort in each species and each fishery (gill net and hand line), respectively. FRI is the fisheries risk index, and ERI is the ecosystem risk index.

Table 3. Objectives, indicators and questionnaires of an ecosystem-based fisheries assessment for some coral fishes in the coastal Seram Laut Island, Maluku.

Objectives	indicators	Questionnaires
Sustainability	1. Cpue	1.1. Trend of cpue
	2. Fishing efforts	2.1. Trend of fishing efforts
	3. Reproduction habitat	3.1. Coral health
	4. Captured size	4.1. Proportion of immature
Biodiversity	5. Bycatch	5.1. Proportion of bycatch
	6. Diversity	6.1. Fishing gear impact on biodiversity
		6.2. Composition change
Habitat	7. Fishing gear	7.1. Fishing gear impact on habitat
	8. Habitat condition	8.1. Habitat damage
	9. Pollution rate	9.1. Oil accident
		9.2. Plastic pollution
		9.3. Household pollution
Socio-economics	10. Income	10.1. Proportion of income and expenses
		10.2. Income trend
	11. Job satisfaction	11.1. Fisher's satisfaction
	12. IUU Fishing	12.1. IUU occurred

3 Results and discussion

The proportion of indicators in *L. obsoletus* included 8.3% in the green zone, 66.7% in the yellow zone, and 25% in the red zone. The proportion of indicators in *S. canaliculatus* included 16.67% in the green zone, 50% in the yellow zone, and 33.3% in the red zone. The proportion of indicators in *C. miniata* included 8.3% in the green zone, 83.3% in the yellow zone, and 8.3% in the red zone (Table 2). Several indicators on *S. canaliculatus* showed a declining catch rate, the rising fishing pressure, destructive fishing gear, and degraded habitat conditions. Habitat destruction will disrupt the life of various commercial fish species in coastal Seram Laut Island (SLI). Furthermore, the capture of *S. canaliculatus* and *L. obsoletus* often causes damage to coral reefs due to net snagging. Habitat degradation and high fishing pressure can be the main factors of declining catch rates. Seagrasses and coral reefs play a vital role as habitats for various fish species. Seagrass ecosystems are nursery grounds for juvenile *S. canaliculatus* and will migrate to coral reef ecosystems during the adult phase [9-10]. Habitat degradation in coral reef ecosystems will lead to an increase in juvenile natural mortality, which will decrease adult fish populations. In addition, habitat degradation will also reduce small fish populations, which are prey for many commercially important fish species [11]. Habitat conservation is essential to managing coral fisheries in the coastal SLI. High fishing pressure will also lead to overfishing, decreasing fish biomass and biodiversity [12] This condition will reduce the fish catch rate, leading to economic losses. Therefore, fishing quotas can be an alternative to maintaining the sustainability of commercial fisheries in the coastal SLI.

The maturity proportion indicator of *L. obsoletus* was found in the high-risk (red zone). Additionally, observational findings revealed that *L. obsoletus* captured by the gillnet in SLI are small immature fish. According to the evidence, *L. obsoletus* nursery ground is located in the fishing area of coastal SLI. When gonad maturity has been achieved, several *Lethrinidae* fish species migrate to offshore to spawn [13]. *Lethrinidae* larvae preferred the habitat associated with seagrass and coral reefs [14]. Fishing activities in the nursery region could hinder recruitment, endangering the sustainability of *L. obsoletus*. Protecting nursery habitats can be an alternative investment for the sustainability of fisheries in SLI waters.

Among all the objectives risk index (ORI), only the sustainability ORI of *L. obsoletus* was high risk (red zone), with an ORI of 2.06 (Figure 2), caused by rising fishing pressure and a small-size capture. Estimates of sustainability's objectives risk index in the high zone were also found in the round scad fishery caught by Purse Seine in Red Sea waters with a sustainability ORI of 2.03 [15]. The operation of non-selective and destructive fishing gear can cause the high ORI of various commercially important fish. Gillnet operations in SLI are carried out in shallow waters with several habitat variations with characteristics in seagrass ecosystems, coral reefs, and sandy substrates. Mature adult *S. canaliculatus* were still found in the fisher's catch. In contrast, adult *L. obsoletus* was not found in the gillnet fishing area, indicating that *S. canaliculatus* adults have more limited movements than *L. obsoletus*. A previous study has also found that emperor fish species *Lethrinus nebulosus* have long spawning migrations compared to other coral fish species [13]. *L. obsoletus* has a relatively long lifespan of about 13 years, with gonad maturity reached at 3-4 years [16]. Fishing operations in the nursery ground areas can inhibit migration and recruitment of emperor fish. Fishing quotas for *L. obsoletus* from gillnet gear can be an alternative to maintaining coral fish' sustainability in coastal SLI.

Table 2. Risk score for all the indicators of EBFA on the orange-striped emperor (*Lethrinus obsoletus*), white-spotted spine foot (*Siganus canaliculatus*) and coral grouper (*Cephalopolis miniata*) in the coastal Seram Laut Island, Maluku.

Objectives	**Indicators**	**Weight**	***L. obsoletus***	***S. canaliculatus***	***C. miniata***
Sustainability	Catch per unit effort	3	1.81	2.17	1.97
	Fishing efforts	2	2.17	2.33	2.27
	Reproduction habitat	2	1.86	1.67	1.17
	Maturity proportion	2	2.55	0.77	1.60
Biodiversity	Bycatch	2	0.67	1.17	1.27
	Diversity	2	1.47	1.75	1.10
Habitat quality	Fishing gear impacts	3	2.11	2	1.18
	Habitat quality	2	1.56	2.17	1.97
	Pollution rate	2	1.19	1.06	1.43
Socio-economic	Income	3	1.56	1.83	1.97
	Job satisfaction	2	1.08	0.17	1.87
	IUU Fishing	2	1.36	0.83	0.53

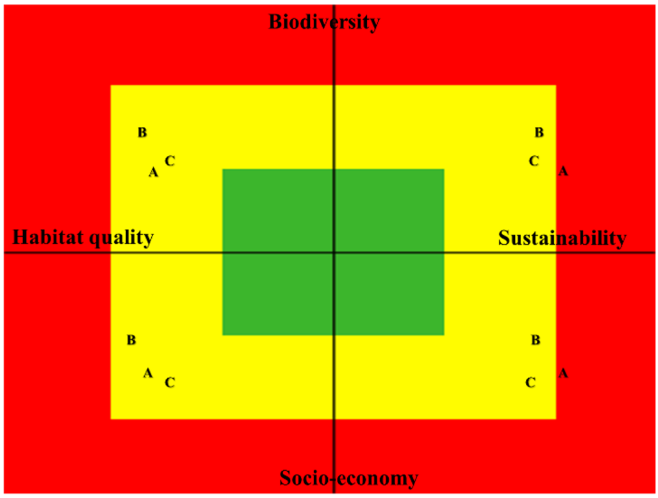

Fig. 2. Objective risk index for (A) orange-striped emperor (*Lethrinus obsoletus*), (B) white-spotted spinefoot (*Siganus canaliculatus*) and (C) coral grouper (*Cephalopolis miniata*) in the coastal Seram Laut Island, Maluku.

Species risk index (SRI) was 1.64 for *L. obsoletus*, 1.54 for *S. canaliculatus* and 1.55 for *C. miniata* (Table 3). The estimated species risk index has also been reported for several commercial species caught by trammel nets in Korean waters, ranging from 1.20 to 1.64 in 2000 [17]. *L. obsoletus* has the highest SRI due to the operation of gillnet gear, which tends to damage coral reefs, and none of the mature adult fish was found in the gillnet fishing area, while *C. miniata* has a lower SRI due to the hand line being operated in the deeper areas and having a less environmental impact than gillnets. This condition is also indicated by the gill nets' fishery risk index (FRI), which is higher than the hand line (Figure 3). Previous research has also found that hand line has less environmental impact than gill net [2]. Therefore, fishing with hand line is more recommended than gillnet for coastal SLI fisheries.

To decide what crucial management has to be done, examining each indication's risk score is essential. According to the findings of the EBFA study, the coast Seram Laut Island ecosystem risk index was in the limited range or yellow zone with a risk score of 1.60 (Figure 4). Management can focus on several indicators with risk scores in the red zone, including the declining catch rate of *S. canaliculatus*, the large number of small immature *L. obsoletus*, degradation of coral reef habitat due to the fishing operation and pollution. Some of these factors may raise the risk of the ecosystem risk index, push the risk into the danger zone and habitat losses, causing fish resource loss, which is vital to the SLI communities.

The conservation of habitat requires proper spatial planning as an investment in the long-term viability of fisheries. Implementing the Seram Laut Island fisheries policy required local community supervision and supporting local wisdom. In addition to habitat conservation, the government needs to provide adequate fish landing facilities so fishers can land and report their catches. Afterward, management based on catch quotas can be implemented for high-risk species. Total Allowable catch can be a management option to help fish stocks recover [18-20]. Specific IUU fishing issues connected to fish bombs need to be addressed strongly. Strict legislation and a close partnership between the local community and political institutions are necessary to strengthen local wisdom [21]. Ecosystem-based management is the key to achieving satisfaction from various parties, both related to the sustainability of fish resources, habitat and the economic sustainability of the community on Seram Laut Island.

Fishing communities have implemented local wisdom-based management for fisheries sustainability in several waters in Indonesia [22]. A local wisdom-based system known as "sasi" can be applied to fisheries in SLI. The management system includes the closure in some areas and spawning periods for several high-risk species. The government can strengthen these management tools by supporting research on spawning areas and seasons, fishing quotas, and optimal catch sizes. Implementing such management is expected to provide fisheries sustainability so that the community's food source and economic needs can continue to be met. To execute management that all stakeholders can agree upon, socialization of the significance of ecosystem sustainability and collaboration between the government, local communities, fishing industry, and researchers are required.

Table 3. Objectives risk index (ORI), Species risk index (SRI), Fisheries risk index (FRI) and Ecosystem risk index (ERI) for some coral fishes in the coastal Seram Laut Island, Maluku.

Fishery	Species	Objectives	ORI	SRI	FRI	ERI
Gillnet	*L. obsoletus*	Sustainability	2.06	1.64	1.62	1.60
		Biodiversity	1.07			
		Habitat	1.69			
		Socio-economy	1.37			
	S. canaliculatus	Sustainability	1.78	1.54		
		Biodiversity	1.46			
		Habitat	1.78			
		Socio-economy	1.07			
Hand Line	*C. miniata*	Sustainability	1.77	1.55	1.55	
		Biodiversity	1.18			
		Habitat	1.48			
		Socio-economy	1.53			

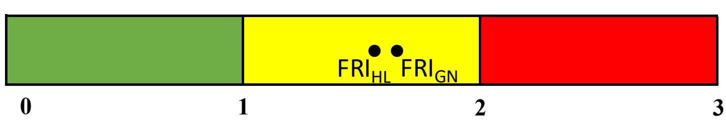

Fig. 3. Fisheries risk index of gill net fisheries (FRI_{GN}) and hand line fisheries (FRI_{HL}) for some coral fishes in the coastal Seram Laut Island, Maluku.

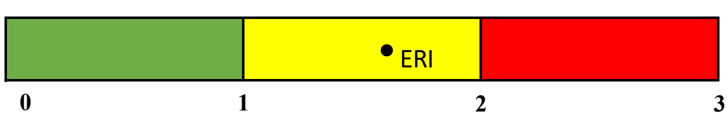

Fig. 4. Ecosystem risk index (ERI) of the coastal Seram Laut Island, Maluku.

4 Conclusion

Some high-risk scores in the red zone were found in the cpue indicator of *S. canaliculatus*, fishing efforts indicator of *L. obsoletus*, *S. canaliculatus*, and C. *miniata*, maturity proportion indicator of *L. obsoletus*, fishing gear impacts indicator of *L. obsoletus* and *S. canaliculatus* and habitat quality indicator of *S. canaliculatus*. Management can focus on reducing the risk of some of those indicators with ecosystem-based management, including the spatial planning for coral reef and habitat conservation, as well as policies based on local wisdom for the sustainability of habitat, fish resources, and the community's economy in Seram Laut Island.

Acknowledgements

The authors thank the Global Environment Facility (GEF-6) and the Ministry of Marine Affairs and Fisheries Republic of Indonesia for supporting this research financially.

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