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Research article

Multidimensional scaling for sustainability of small pelagic fisheries in Sunda Strait

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Abstract

The Sunda Strait is located at the confluence of two water masses (the Java Sea and the Indian Ocean) and contains abundant nutrients and phytoplankton, making it a potential fishing ground for pelagic fish. This research analyzed the sustainability of small pelagic fisheries in the Sunda Strait using a multidimensional approach. Rapfish (rapid appraisal technique to evaluate a fishery's sustainability status) analysis using multidimensional scaling was applied to analyze the sustainability status of each dimension. Leverage analysis was applied to identify the most influential attributes to the sustainability status of each dimension. The results produced average sustainability index values for four dimensions: ecological dimension (44.18) economic dimension (40.71) social dimension (48.34) and technological dimension (35.74). Stress values greater than 0.25 indicated there were unacceptable conditions for sustaining the small pelagic fisheries in the Sunda Strait. The research concluded that the status for small pelagic fisheries in Sunda Strait was less sustainable.

Introduction

The Sunda Strait is located between Java Island and Sumatera Island at the confluence of two water masses, the Java Sea and the Indian Ocean (Amri, 2008). This mixing of water masses results in abundant nutrients and phytoplankton (Amri et al., 2014) and represents a food source for pelagic fish (Kasim et al., 2014), suggesting its potential as a fishing ground with the target catch being pelagic fish (Irnawati et al., 2018).

In 2015 in Banten province, Indonesia, pelagic fish production was 28,451.7 tonnes, or approximately 67% of total fish production (Marine and Fisheries Agency of Banten Province, 2016a). The estimated sustainable yield of pelagic fish is approximately 50,000 tonnes (Marine and Fisheries Agency of Banten Province, 2016b). The Sunda Strait is a fishing area with potential for all-year activity, with highest annual productivity in the range 39,339–58,327 tonnes (Akmal et al., 2017; Nurkhairani et al., 2018). The utilization of pelagic fish resources in this area is dominated by small scale fisheries

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activity using a variety of fishing gear, with fresh fish as the end product. There are no industrial processing activities in this area because pelagic fish's current utilization is below the required yield.

The heterogeneous small scale of pelagic fisheries in the Sunda Strait needs integrated fisheries management to improve pelagic fish utilization. Charles (2001) explained that the assessment of integrated fisheries conditions covers at least four aspects: economic, social, ecological, and technological. However, there is a lack of methodology to assess the status of sustainable fisheries management that exploit multiple species, despite their socio-economic importance, and such a methodology should also take into account an ecosystem approach (Cissé et al., 2014). Pitcher and Preikshot (2001) explained that as a multidisciplinary human endeavor, the fisheries sector relates to not only ecological and or economic dimensions, but it also has social and technology inferences.

Information is needed regarding small pelagic fish sustainability in the Sunda Strait. The sustainability of small pelagic fish in the Sunda Strait is primarily determined by ecological, economic, social and technological aspects as indicated from the above citations. One method to assess fishery sustainability is Rapfish (rapid appraisal technique to evaluate fisheries' sustainability status). Rapfish is a technique that uses a simple, rapid and easily-scored attributes and multidisciplinary appraisal of the status of a fishery in terms of the relative levels of sustainability (Pitcher, 1999; Pitcher and Preikshot, 2001; Kavanagh and Pitcher, 2004). Importantly, Rapfish does not require extensive data as it relies upon the ordination of scored attributes grouped in ecological, economic, social and technological sustainability fields achieved by using multi-dimensional scaling including uncertainties (Adrianto et al., 2005; Murillas, et al., 2008; Cissé et al., 2014). Various works using the Rapfish technique have been published, including Preikshot et al. (1998), Pitcher and Preikshot (2001), Alder et al. (2002), Hartono et al. (2005), Tesfamichael and Pitcher (2006), Murillas et al. (2008), Lessa et al. (2009) and Andalecio (2010).

The current research aimed to analyze the sustainability of small pelagic fish in the Sunda Strait based on a multidimensional scaling approach using Rapfish. This research was expected to provide information about the sustainability of small pelagic fish in the Sunda Strait to optimize the management and the benefit of pelagic resource utilization.

Materials and Methods

Site and time of research

The study took place in the Sunda Strait coastal region in Banten province, Indonesia, from June to December 2019 in two regencies: Pandeglang and Serang. Banten province was selected because of the high proportion of fish landing occurring there. In each region, several data collection points were determined. In Pandeglang Regency, the coastal fishing port of Labuan, and the fish landing places of Sidamukti, Panimbang, Sumur, and Tanjung Lesung were selected. Data collection in Serang Regency was conducted at the fish landing places of Carita and Anyer. All data collection sites were the centers of high production volume of small pelagic fisheries in the Sunda Strait coastal area.

Data collection

Data collection consisted of 16 attributes that were grouped into four different evaluation fields (four for the ecological dimension, four for the economic dimension, four for the social dimension and four for the technological dimension), as presented in Table 1.

The selected attributes reflected the notion of small pelagic fisheries sustainability in the Sunda Strait. Most of the attributes and their corresponding scores were based on Pitcher (1999), Charles (2001), Fitrianti et al. (2014) and Abidin and Primyastanto (2017). The assessment of each attribute was conducted by scoring based on the indicators used. Evaluation of each attribute shows whether the fisheries are in good or bad condition related to their management and sustainability (Pitcher and Preikshot, 2001). The several attributes and their point rank scales, especially within an ecological dimension (the number of catches, size of the catch, change in fishing ground location, impact on the habitat), economic dimension (income-generation, feasibility level, alternative livelihood, fish selling price), social dimension (potential conflict, fisher experience, patron-client relation, institutional fisher), technological dimension (selectivity, by-catch, fish handling, fish processing) were determined based on an interactive discussion process with expert, stakeholders, and intensive literature studies. Each attribute's score was determined from direct measurement and analysis in the field, field surveys, in-depth interviews and scientific journals.

Table 1 Scoring criteria for sustainability of small pelagic fish in Sunda Strait for Rapfish analysis

Dimension	Attribute/ Description	Assessment criteria	Scoring
Ecology	Number of catches	Decreased	1
		Fluctuated	2
		Increased	3
	Size of catch	Getting smaller	1
		Fixed-size	2
		Getting bigger	3
	Change in fishing location	Getting further	1
		Quite far	2
		Relatively fixed	3
	Impact on habitat	Causes habitat destruction over large areas	1
		Causes damage to some habitats in a narrow area	2
		Safe to habitat	3
Economy	Income generation	Uncertain	1
		In accordance with regional minimum wage	2
		Exceeds regional minimum wage	3
	Feasibility level	Not feasible	1
		Good Enough	2
		Feasible	3
	Alternative livelihood	Nothing	1
		Few options to increase income of fisher	2
		Fair in increasing income of fisher	3
	Selling price	Not in accordance	1
		Less accordance	2
		Accordance	3
Social	Potential conflict	Frequent conflicts between fisher	1
		Some conflicts between fisher	2
		No conflict	3
	Fisher experience	< 3 years	1
		3–5 years	2
		> 5 years	3
	Owner system	Exist and fisher fully attached	1
		Exist and fisher not fully attached	2
		Exist and fisher not attached	3
	Institutional fisher	None	1
		Exist but not active	2
		Exist and quite active	3
Technology	Selectivity	Catch >3 species of fish with different sizes	1
		Catch ≤3 species of fish with different sizes	2
		Catch <3 species of fish with uniform size relatively	3
	By-catch	Bycatch of several species and not sold in markets	1
		Bycatch some species and some sold in markets	2
		Bycatch <3 species and sold in market	3
	Fish handling	Place in ice after catching	1
		Place in ice and salt after catching	2
		Direct processing in vessel	3
	Fish processing	Only dried	1
		Further processing	2
		Increase in added value	3

1 = bad; 2 = average; 3 = good.

An in-depth interview was conducted with 20 respondents chosen using the purposive sampling method. Respondents were chosen from 1) fishing communities and elite figures of the local fisheries society (9 respondents); 2) government and fisheries authorities: at the fishing port, fish landing center (4 respondents); and 3) fisheries entrepreneurs (7 respondents).

Data analysis

Rapfish was applied to analyze the sustainability status of small pelagic fish in the Sunda Strait using multidimensional scaling (MDS), which is an ordination method. In order to have fixed reference points, Rapfish includes a good or perfect small pelagic fishery (defined as 100% sustainability score), consisting of the best possible score for all attributes in the respective dimensions, and an inadequate or worst small pelagic fishery (defined as 0% sustainability score), which has the worst score. It includes two half-way scores: each the mirror image of the other to scale the vertical dimension and a set of pre-defined anchor points to avoid vertical flipping of the MDS ordinates (Kavanagh and Pitcher, 2004).

The scores in each dimension were analyzed based on MDS (Kavanagh and Pitcher, 2004). The MDS output was rotated so that the good to bad reference vector was horizontal and scaled between zero and 100%. Ordination errors were indicated by a stress value greater than 0; a stress value greater than 0.25 was considered undesirable (Clarke and Warwick, 1997). A stress value indicated the relative position of fisheries management, whether a good fit or bad fit. In Rapfish, stress values less than 0.25 (S = 0.25) indicate good model conditions (Fitrianti et al., 2014; Muslim et al., 2019). The validity of Rapfish was statistically evaluated based on the measurement of stress values and the R square (squared correlation) value of each dimension. The requirement for the stress value statistically was a value less than 25, while the R square should be close to 100% (Nababan et al., 2007).

Sustainability status was determined by assessing the fisheries sustainability index (0–100). The sustainability index value refers to the value categories 0–25 (not sustainable), 26–50 (less sustainable), 51–75 (sufficiently sustainable) and 76–100 (sustainable) based on research results (Hermawan, 2006; Budianto, 2012; Fitrianti et al., 2014; Abidin and Primyastanto, 2017; Muslim et al., 2019).

Leverage analysis was carried out to determine which of the attributes were sensitive and affected each dimension's sustainability. Determination of sensitive attributes could be seen from the attributes (one or two attributes) with the highest values (Abidin and Primyastanto, 2017).

Results

Sustainability status of small pelagic fish

The radar chart (kite diagram) and two-dimensional plots from the MDS ordinations for all dimension aspects are shown in Figs. 1 and 2. Kruskal's stress value was higher than 0.25, and the R-square value was 0.895 on average (Table 2).

The results indicated the value of sustainability in the ecological, economic, social and technological dimensions of small pelagic fisheries, with scores of 44.18; 40.71; 48.34; 35, 74. respectively. Based on these scores, the small pelagic fisheries in the Sunda Strait are categorized as less sustainable (Table 2). In general, the social dimension rank was the most sustainable, while the technological dimension was the least sustainable.

The stress values for all dimensions were in the range 0.29–0.30 (Table 2), which indicated the management of small pelagic fisheries in the Sunda Strait was in a harmful condition. The stakeholders must improve their management practices to increase the sustainability aspect of small pelagic fish in the Sunda Strait.

Leverage value

The leverage of individual attributes on Rapfish ordinations determines how much each attribute in each dimensional aspect influences the overall ordination. The leverage analysis results indicated that several attributes influenced the sustainability status of each dimension. Within the ecological dimension, the main attribute that had the most influence on the sustainability score of small pelagic fisheries in the Sunda Strait was the catch size (Fig. 3).

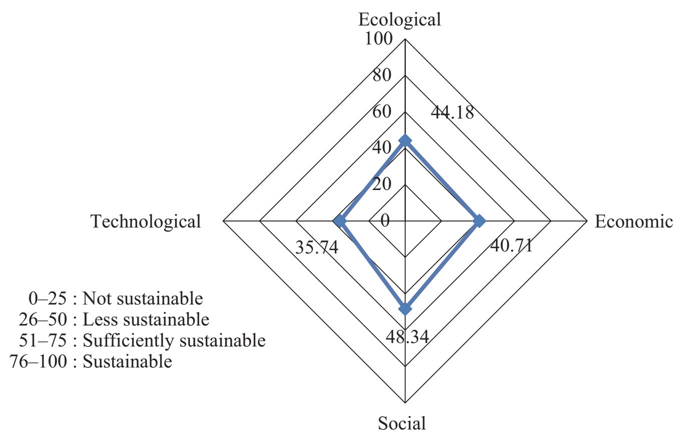

Fig. 1 Kite diagram from multidimensional scaling ordinations for all dimension aspects based on Rapfish analysis of small pelagic fisheries in Sunda Strait

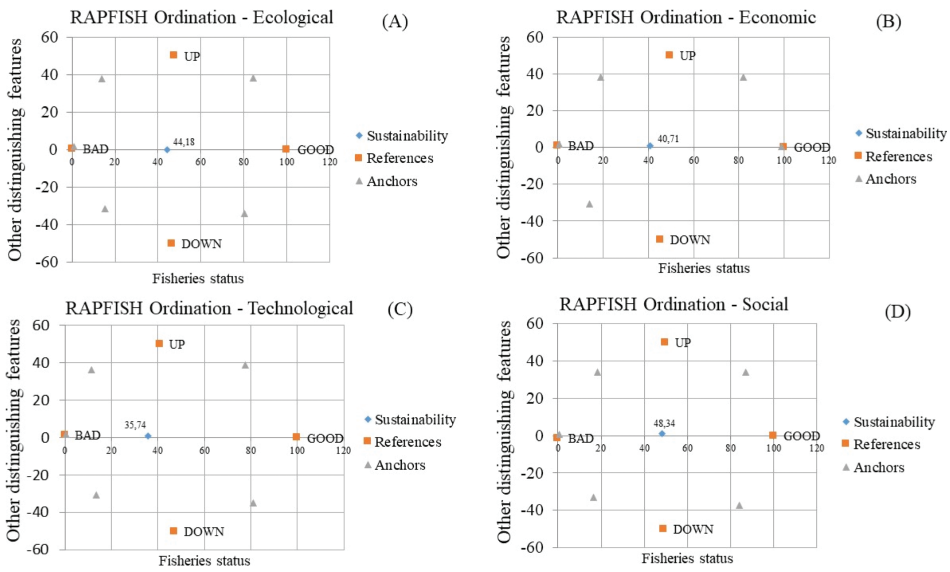

Fig. 2 Two-dimensional plots of multidimensional scaling ordination of small pelagic fisheries in Sunda Strait

Table 2 Assessment values of multi-dimension sustainability of small pelagic fisheries in Sunda Strait

Dimension	Sustainability index	Stress	R^2	Sustainable status	Rank
Ecological	44.18	0.30	0.89	Less sustainable	2
Economic	40.71	0.29	0.89	Less sustainable	3
Social	48.34	0.29	0.89	Less sustainable	1
Technological	35.74	0.30	0.91	Less sustainable	4

R^2 = squared correlation

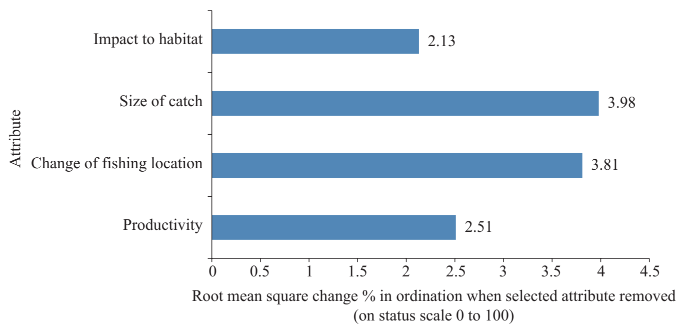

Fig. 3 Leverage analysis of ecological dimension for small pelagic fisheries in Sunda Strait

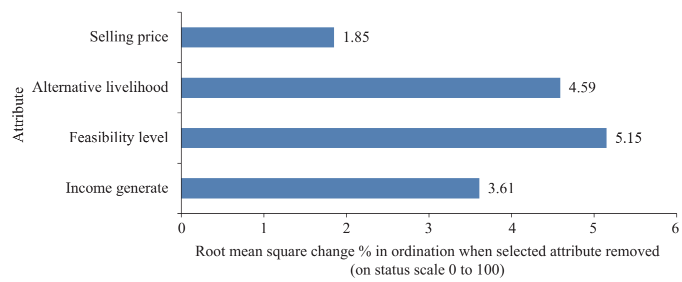

Fig. 4 Leverage analysis of economic dimension for small pelagic fisheries in Sunda Strait

The economic dimension attributes that mostly influence the sustainability score of small pelagic fisheries in the Sunda Strait are feasibility level (Fig. 4). The institutional fisher is the most influential attribute within small pelagic fisheries (Fig. 5). Within the technological dimension, by-catch is the most influential attribute for the sustainability of small pelagic fisheries in the Sunda Strait (Fig. 6).

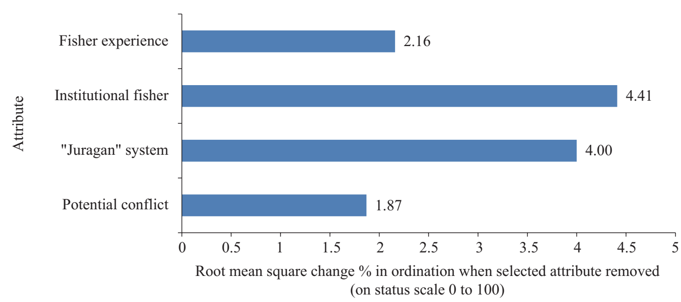

Fig. 5 Leverage analysis of social dimension for small pelagic fisheries in Sunda Strait

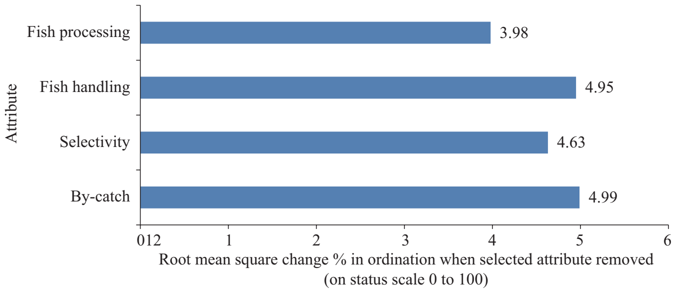

Fig. 6 Leverage analysis of technological dimension for small pelagic fisheries in Sunda Strait

Discussion

The results of the two-dimensional plots from the MDS ordinations for all dimensions showed that the fisheries were less sustainable, as presented in Fig. 2 where the vertical distribution of small pelagic fisheries on the Y-axis represents variations in scores; the differences are not related to sustainability (Pitcher and Preikshot, 2001). The rank ecological dimension was the most sustainable and the technological dimension was the least sustainable.

For ecological issues, the number of catches was positively correlated to the distance to the fishing location as the fishing vessels moved to more distant fishing grounds to increase the catch. This distance had increased to 11 km according to Sumirat (2011), due to the degradation of the water quality in the Sunda Strait. In addition, Boer and Aziz (2007) found that the decrease in fish stock and fishing productivity in the Sunda Strait indicated that the fishing status for this area was overexploited.

Gillnet and boat seine were used generally on daily trips. However, when insufficient fish were netted, to cover the operational costs, the trip duration was increased to 2–3 days. Maouel et al. (2014) noted that the economic indicators related to fisheries conditions were changing based on fishing time or fishing duration. A long trip was becoming increasingly necessary to cover operational fishing costs.

The technological dimension's selectivity issue was closely related to the economic dimension due to low-selective fishing gear that caught low economic-value fish that were usually non-target species with a low selling price despite high production, due to their low demand, the low quality of fish and their small size (Genisa, 1999). Furthermore, such fishing activities using non-selective fishing gear placed high ecological pressure on fish stock sustainability.

The results of the leverage analysis showed that business feasibility was the most critical factor in the economic sustainability of small pelagic fisheries, followed by alternative livelihood. Income from small pelagic fisheries activities had a significant correlation to business feasibility. However, the increase in fish prices from selective fishing gear generated a high income for those catching small pelagic fish in the Sunda Strait (Nababan et al., 2007), which affected the business feasibility of small pelagic fisheries.

Therefore, developing alternative livelihoods for those working in the small pelagic fisheries in the Sunda Strait is very important to support their fishing income, since that income from fishing activities was below the provincial minimum wage of IDR 1.6 million (bps.go.id as at 2020). Furthermore, even outside the fishing sector, well-designed alternative livelihood schemes would require improvement in the practical skills of those working n the fisheries industry. However, suitable alternative livelihoods are expected to decline fishery over-dependency and over-capacity of the fishery resources, fishing effort and would enhance stock recovery and ultimately ensure successful fisheries management of small pelagic fisheries (Stolberg et al., 2006; Asiedu and Nunoo, 2013).

The most crucial part of the social dimension was the presence of fisher institutions which were expected to be a driving force in improving the human resources quality of fisher. However, in small pelagic fisheries of the Sunda Strait, there remained a clash with the community owner system and the fisher's institution cannot run optimally due to individuals be dependent on obtaining capital from the owner (known as "Juragan"), so that the role of community institutions is neglected. Hidayat (2013) stated that improving the standard of living and welfare of individuals working in the fisheries sector also required effort to increase access to information on various financial, credit, capital and technological sources.

One social aspect that could become an obstacle was related to the courtier system prevailing in the community. This is common in almost all traditional fishing businesses due to human resources weaknesses especially in obtaining finance. In the small pelagic fisheries along the Sunda Strait coast, this is known as the "Langgan" system, whereby capital providers are referred to as bosses, who provide fishing capital loans for fisher to purchase logistical provisions. In the standard form, the fisher must sell their catches to the bosses at a preset price, which is undoubtedly detrimental to the fisher. Lubis et al. (2014) stated that fisher's losses were caused by the courtier system even when the fisher's catches are in good condition. The courtier could be removed by strengthening the fishing community's existing institutions to improve their human resources and freedom in trying to improve their welfare. Hidayat (2013) stated that in enhancing the fishing community's institutional capacity, at least four things were required: the development of human resources, business opportunities, improved resource management and environmental improvements and that these needed to be carried out in an integrated and synergistic manner.

The issues that need to be considered in the sustainability of small pelagic fisheries are related to the technological dimension. Technological aspects of the Sunda Strait small pelagic fisheries can cause stress on ecological aspects in terms of sustainability. The selectivity of purse seine fishing gear needs to be a concern considering that purse seine is the fishing gear with the most significant productivity. Octoriani et al. (2015) stated that purse seine in the Sunda Strait has much bycatch, so it can be said to be less selective. The bycatch consisted of demersal fish, namely *Upeneus* sp. and *Nemipterus* sp. because the nets reach the depth inhabited by these species. Catching activities (technology) is one of the factors that affect fish abundance in an area (Masrikat, 2012), so that appropriate management effort is needed for technological sustainability to reduce pressure on the ecological dimension. This would be expected to increase sustainable catch production in long term.

Therefore, a balance in all dimensions is needed to sustainably manage small pelagic fisheries. Failures in fisheries management occur when management only focuses on one particular dimension. With multi-aspect management, it is expected that fisheries problems can be completely from all aspects. Adam and Surya (2013) stated that success in the management of fisheries resources must be seen from interrelatedness of the economic, environmental and social aspects.

Conflict of Interest

The authors declare that there are no conflicts of interest.

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