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ORIGINAL RESEARCH PAPER

Sustainability status of amphidromous nike fish, *postlarva Gobioidei*, in estuarine water

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ABSTRACT

BACKGROUND AND OBJECTIVES: Nike fish are a postlarvae group of gobies found in the Gobiidae and Eleotridae families. These fish are a seasonal delicacy in Gorontalo, with significant economic value and popularity among the community. Data from 2020 to 2021 showed a downward trend in Nike fish production in Gorontalo City despite ongoing efforts to promote it as a consumable fish. Therefore, this study assessed the sustainability status of Nike fish in the waters of Tomini Bay Gorontalo.

METHODS: This study was conducted across five Nike fishing locations in Tomini Bay, Gorontalo Province, namely the Bone-Bolango, Bilungala, Tombulilato, Taludaa, and Bilato estuaries, from April to September 2023. Data were collected through interviews with 109 Nike fishers and four experts from government agencies in Gorontalo Province. Meanwhile, other supporting data were obtained from various references that support the study objectives. The sustainability status analysis was conducted using rapid appraisal for fisheries, a software with an assessment method comprising five dimensions, ecological, economic, social, ethical, and technological, which are analyzed multi-dimensionally.

FINDINGS: The results showed that of the five dimensions analyzed, only one, the technological dimension, exhibited sustainability. Meanwhile, the other four dimensions, including ecology, economic, social, and ethical, showed a less sustainable status. Some attributes that significantly affected the sustainability of Nike fish resource use in the waters of Tomini Bay, Gorontalo, include fishing location, Nike diversity, by-products, profit distribution, contribution to regional revenue, dependence on subsidies, level of conflict, the role of fishermen in terms of sustainability, fish landing sites, handling on board, externalities (waste disposal), and the level of violations. The results of the multi-dimensional scaling analysis showed that the average index values of the ecological, economic, social, and ethical dimensions are 33.53, 40.33, 30.86, and 25.19, respectively, demonstrating a less sustainable status. Meanwhile, only one of the five dimensions studied has an index value of more than 50—the technological dimension. The multi-dimensional scaling index value of the technology dimension is 84.09, demonstrating its sustainable status. The stress value (0.14 to 0.15) and the coefficient of determination (0.91 to 0.94) in the multi-dimensional scaling calculation showed that the analysis carried out was appropriate.

CONCLUSION: The sustainability status of Nike fish in the waters of Tomini Bay, Gorontalo, is less sustainable and highly dependent on the environmental factors that support their life as amphidromous fish. The involvement of all stakeholder elements in implementing sustainable practices is also essential in terms of supporting sustainability. Therefore, this study provided important contributions that can be used by local governments and stakeholders to form appropriate management policies to ensure sustainability in the future. This study can provide information or insights for countries that have fishery potential similar to the waters of Tomini Bay, Gorontalo, to carry out better fisheries management.

NUMBER OF REFERENCES	NUMBER OF FIGURES	NUMBER OF TABLES
59	6	3

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INTRODUCTION

Nike fish are typically small, measuring 2 to 5 centimeters (cm) in size, and found seasonally in the waters of Tomini Bay, Gorontalo City, usually at the end of the lunar cycle until the new one begins (Sahami *et al.,* 2020). The seasonal appearance and unique flavor that characterize Nike fish are highly valued and hold economic importance. Nike fish possess critical historical and cultural significance. It is biologically defined as a group of amphidromous gobies in the postlarval phase. Sahami et al. (2019b) successfully initiated the discovery of the diversity of species that made up schools of Nike fish with the discovery of four species in the Gobiidae and Eleotridae families through a molecular analysis of cytochrome oxidase subunit I (COI) mitochondrial deoxyribonucleic acid (DNA). The Gobiidae and Eleotridae families dominate amphidromous species in tropical rivers (Keith and Lord, 2011). Gobies also dominate in terms of diversity and abundance of the species present in estuary habitats (Thuy *et al.,* 2022). During the amphidromous phase, goby fish grow and reproduce in freshwater habitats (Iida *et al.,* 2017), laying their eggs on the substrate at the bottom of the river (Yamasaki *et al.,* 2011). After hatching, the larvae drift to the sea, and the juveniles travel back to the river of their parental origin after spending a while in marine waters (Maie *et al.,* 2009). The presence of this fish is strongly affected by environmental factors that occur in the three distinct aquatic ecosystems, namely freshwater, estuarine, and marine waters. The amphidromous life cycle makes this fish population vulnerable to habitat modification and connectivity in marine and freshwater environments (Franklin *et al.,* 2019). Reduced riverine vegetation contributes to the abundance and distribution of gobies, as Keith et al. (2015) explained that the amount of plant cover on river banks is an important factor for goby fish habitats. The sustainability of the fish is also primarily determined by the success of the larval recruitment process from marine habitats to freshwaters (Simanjuntak *et al.,* 2021). Larval survival and distribution are strongly influenced by environmental factors such as water flow and coastal currents (Marina *et al.,* 2021), temperature and salinity (Roman *et al.,* 2019). Food availability in the habitat is also vital in the postlarval phase (Jackson and Lenz, 2016). Ecologically, Nike fish, as amphidromous fish, play an essential role in their habitat. They occupy various levels of food webs in rivers (Schoenfuss and Blob, 2007) and estuaries (Jenkins *et al.,* 2010), influencing the distribution of fauna in these waters (Hein and Crowl, 2010). The crucial role of these fish in their habitat makes their ecological value more significant than their economic value (Zhai *et al.,* 2023). Nike fish are widely distributed in the estuarine waters of Tomini Bay, namely Gorontalo City Bay (Sahami *et al.,* 2019a), Bone estuary (Olii *et al.,* 2017), Paguyaman (Sahami and Habibie, 2021), Taludaa, Bilungala, and Tombulilato estuaries. In these diverse waters, Nike fish continue to be actively harvested and consumed, reflecting the substantial efforts devoted to its usage. The data collected on Nike fish production in Gorontalo City between 2020 and 2021 showed a consistent decline in production. This decline in production supports the hypothesis of this study that all dimensions of sustainability (ecological, economic, social, technological, and ethical) concerning the use of Nike fish resources have a less-than-sustainable status. While various studies on the eco-biology and processing of Nike fish products have been conducted in recent years, none have addressed the sustainability status of the resource. To fill this gap, a multi-dimensional method was adopted to assess the sustainability status of these resources, using the rapid appraisal for fisheries (RAPFISH) method. Originally developed for fisheries, this method has also been used to assess other fields. Alder et al. (2002) used the RAPFISH method to evaluate the sustainability of marine protected area management. Meanwhile, Martias et al. (2023) used this same method to analyze the sustainability status of healthy settlement arrangements in the Penyengat Island coastal area, which has been designated as a cultural heritage site. Evaluating sustainable usage is the basis for ensuring the balanced exploitation of fishery resources (Bi *et al.,* 2023). The main aim of this study was to assess the sustainability status of Nike fish usage in the waters of Tomini Bay. This study was conducted across five Nike fishing locations in Tomini Bay, Gorontalo Province, Indonesia, in 2023.

MATERIALS AND METHODS

This study was carried out across five specific estuaries of Nike fishing locations, namely Bone-Bolango (0°30’16.815” north: N, 123°3’44.3982” east: E), Bilungala (0°22’13.3782” N, 123°12’47.217” E), Tombulilato (0°18’34.6638” N, 123°21’35.3334”

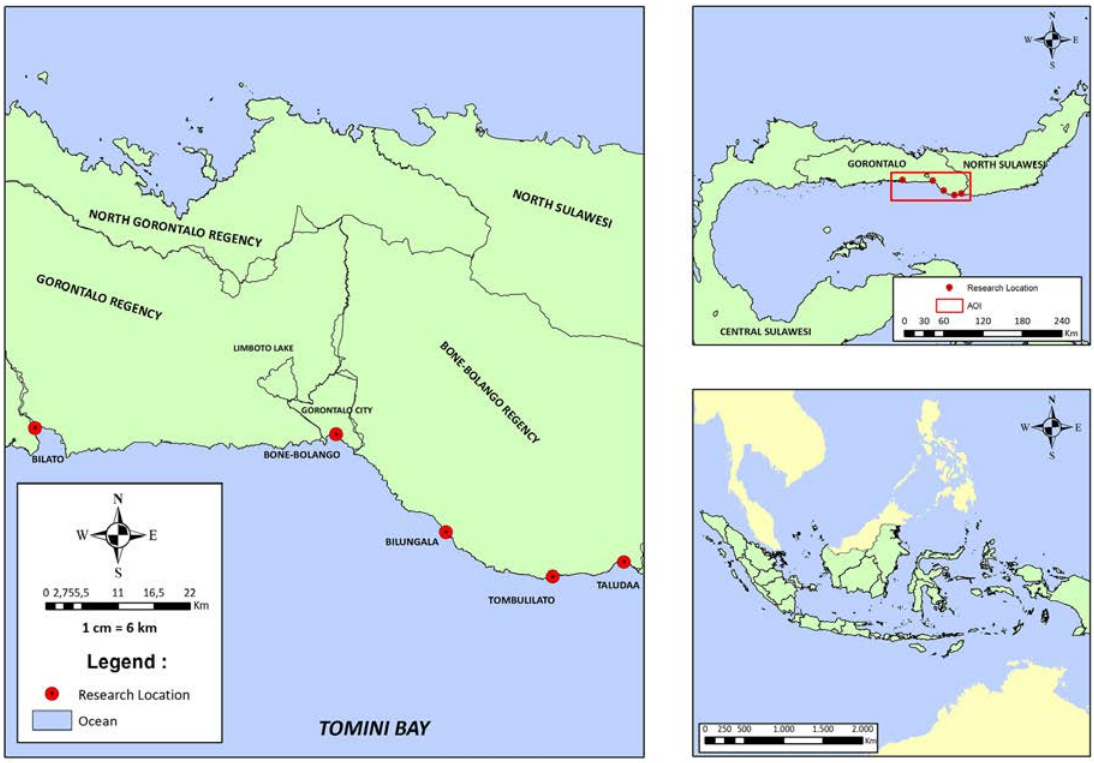

Fig. 1: Geographic location of the study area in the five specific Nike fishing locations: Bone-Bolango, Bilungala, Tombulilato, Taludaa, and Bilato estuaries, Indonesia

E), Taludaa (0°19'46.6818" N, 123°27'27.4104" E, and Bilato estuaries (0°30'49.1898" N, 122°38'57.6492" E), as shown in Fig. 1.

Data collection

This descriptive quantitative study used both primary and secondary data sources. Primary data were obtained by interviewing 109 Nike fishers in Gorontalo Province, as shown in Fig. 1, and consultations with four experts representing government agencies in the same region. Interviews with fishermen were carried out using closed questionnaires. The questionnaire for fisher respondents and experts refers to the attributes in each sustainability dimension modified from Pitcher (1999). Secondary data were obtained from various publications, reports, and other relevant documents that support the objectives of the study.

Data analysis

Data analysis was conducted according to the sustainability evaluation method using RAPFISH software. RAPFISH is an analytical method for evaluating the sustainability of fisheries, which is based on the ordination method focusing on the positioning of elements according to their measurable attributes. This method uses multi-dimensional scaling (MDS), a statistical method to simplify complex multi-dimensional data (Jimenez *et al.,* 2021). MDS in RAPFISH analysis was selected due to the fact that other multi-variate analysis methods, such as factor analysis and multi-attribute utility theory (MAUT), have proven incapable of producing stable results (Pitcher and Preikshot, 2001). In MDS, the object being observed is mapped into two or three-dimensional space so that the object or point is as close as possible to the origin. The configuration or ordination of an object or point in MDS is then approximated by regressing the *Euclidian* distance from point *i* to point *j* (d_{ij}) with the origin (δ_{ij}) using Eq. 1 (Borg *et al.,* 2018).

$$d_{ij} = \alpha + \beta\delta\beta_{ij} + \varepsilon \quad (1)$$

The technique used to regress Eq. 1 is the least squares method, which is based on the root of the Euclidian distance (squared distance), called ALSCAL. The ALSCAL algorithm is the most suitable method for RAPFISH and is easily available in almost all statistical software (Alder *et al.,* 2000). The ALSCAL algorithm is used in process regression to iterate until the intercept value in the equation reaches zero (a=0). Therefore, Eq. 1 changes to Eq. 2 (Borg *et al.,* 2018).

$$d_{12} = bD_{12} + e \quad (2)$$

When a stress value of (S) < 0.25 is reached, the repetition process is stopped, and the S value is achieved using Eq. 3 (Borg *et al.,* 2018).

$$s = \sqrt{\frac{1}{m}\sum_{k=1}^{m}\left[\frac{\sum_i\sum_j\left(d_{ijk}^2 - o_{ijk}^2\right)^2}{\sum_i\sum_j o_{ijk}^4}\right]} \quad (3)$$

In this study, the sustainability status of Nike fish in Gorontalo Province was evaluated across five main dimensions: ecological, economic, social, technological, and ethical. The framework used to determine these dimensions and their respective attributes was based on the concepts developed by Pitcher and Preikshot (Pitcher, 1999; Pitcher and Preikshot, 2001). The assessment of the sustainability of Nike fish comprised 44 attributes distributed across these dimensions. Specifically, there are eight attributes in the ecological dimension and nine each in the economic, social, technological, and ethical aspects, as shown in Table 1. To identify which attributes have the most significant impact on the sustainability within each dimension, leverage or sensitivity analysis was performed. This analysis is based on the priority order of changes in root mean square (RMS) ordination on the x-axis. When the RMS has a large enough value, this feature's function in determining sustainability becomes more prominent (more sensitive) (Widjaja *et al.,* 2024). Monte Carlo analysis was used to determine the effect of calculation errors and potential misjudgment of attributes by respondents. The smaller the difference between the sustainability index and the Monte Carlo simulation, the more accurate the results (Kavanagh and Pitcher, 2004).

The goodness of Fit in terms of the MDS calculations was indicated by the magnitude of the stress (S) value (Pitcher and Preikshot, 2001). The validity of the model was determined by the magnitude of the coefficient of determination (R^2) (Samimi *et al.,* 2023). A well-fitted model is indicated by an S value of less than 0.25 (< 0.25) and an R^2 of approximately 1. The assessment score for each aspect ranges from 0 (representing the worst or bad scale) to 100 (representing the best or good scale). An index value of more than 50 (> 50) indicates that the aspect being assessed is properly maintained. Conversely, when the index value is < 50, the aspect is unsustainable (Kavanagh and Pitcher, 2004). The categorization of this index is also in accordance with the sustainability index categories, according to Sutaman et al. (2017) and Widjaja et al. (2024). The sustainability index categories according to several references are shown in Table 2.

RESULTS AND DISCUSSION

The sustainability status of Nike fish in several locations within Tomini Bay, including the Gorontalo City Bay, Bone Bolango, Taludaa, Tombulilato, and Bilato estuaries, was analyzed using RAPFISH and ordination analysis supported by the results of Monte Carlo analysis. The results of the ordination and Monte Carlo analyses showed that of the five dimensions assessed, four of them, namely ecological, economic, social, and ethical, had scores less than 50. This implied that these dimensions are in the less sustainable category. The technology dimension had a score greater than 50 and was within the sustainable category. This result is not in line with the initial research expectations, which estimated that all dimensions were less sustainable. The results of the MDS analysis and the sustainability status of Nike fish usage are shown in Table 3.

The results of the RAPFISH analysis are accurate, as proven by the S value and the R^2 shown in Table 3. A decreased S value showed a high degree of accuracy, which reflected a good fit, while the opposite was true in the case of an increased S value (Martias *et al.,* 2023). The results of a good RAPFISH analysis tend to be characterized by an S value of < 0.25 and an R^2 that is approximately 1 (Patawari *et al.,* 2023). The results of the analysis for each sustainability dimension are reported as follows.

Table 1: RAPFISH dimensions and attributes in Nike fish sustainability assessment

Dimension	Attributes
Ecological	Use rate of fish resources
	Total catch
	By-catch
	Nike diversity
	Location of fishing grounds
	Conservation area
	Closed season
	Environmental quality
Economic	Economic value
	Marketing distribution
	Source of livelihood
	Subsidy dependency
	Contribution to regional revenue
	Profit distribution
	Labor absorption
	Business prospects
	Income relative to provincial minimum wage
Social	Education level
	Environmental knowledge
	Level of conflict
	Development of fishermen
	Community role in sustainability
	Fishermen role in sustainability
	Participation of family members
	Level of business socialization
	Fishermen role in planning
Technological	Tool selectivity
	Shipboard handling
	Ship size
	Tool use
	Negative effect on habitat
	Safety for fishermen
	Threat to protected fish
	Fish landing sites
	Post-harvest handling
Ethical	Rules and regulations
	Level of violation
	Mitigation of ecosystem damage
	Habitat damage mitigation
	Waste discharges (externalities)
	Customary rules and local wisdom
	Fishermen role in policy
	Access to resources
	Alternative employment

Table 2: Index values and sustainability categories

Sustainability categories	Index value		
	Kavanagh and Pitcher, 2004	Sutaman *et al.*, 2017	Widjaja *et al.*, 2024
Bad: unsustainable	0-24.99	0-25	0-25
Less: less sustainable	25-49.99	26-50	25.01-50
Sufficient: quite sustainable	50-74.99	51-75	50.01-75
Good: very sustainable	75-100	76-100	75.01-100

Table 3: Results of RAPFISH analysis on the sustainability status of Nike fish use

Dimension	Average MDS score across five study sites	S	R^2	Sustainability Index Category	Average Monte Carlo Values across five study sites	Difference between MDS and Monte Carlo
Ecological	33.53	0.14	0.94	Less: less sustainable	34.78	1.25
Economic	40.33	0.15	0.93	Less: less sustainable	40.78	0.45
Social	30.86	0.14	0.94	Less: less sustainable	31.19	0.33
Technological	84.09	0.14	0.94	Good: very sustainable	81.65	2.44
Ethical	25.19	0.14	0.91	Less: less sustainable	26.04	0.85

Ecological dimension

In the ecological dimension, eight attributes were assessed, including the use level of fish resources, the size of the catch, fish species diversity, by-catch, the locations of fishing and conservation areas, closed season, and environmental quality. The ordination analysis showed a sustainability index of 33.53 for Nike fish use in the less sustainable category. To evaluate the potential impact of errors related to scoring and the ordination process on determining the sustainability status, the results of the Monte Carlo analysis were examined. Monte Carlo analysis is a simulation method used to evaluate the effect of random errors on all dimensions (Saputro *et al.,* 2023). Preserving the sustainability of the ecological dimension in capture fisheries is a critical concern. It is essential to prevent the over-exploitation of fish resources in a given water body, ensuring they remain within their availability and carrying capacity (Fu *et al.,* 2018). The main concern in the concept of ecologically sustainable fisheries development focuses on the maintenance of stock or biomass sustainability, as well as increasing the capacity of the ecosystems without exceeding their carrying capacity (Zhang *et al.,* 2022). Detailed results from the ordination and Monte Carlo analyses and the leverage analysis are shown in Fig. 2.

The highest attribute values identified in the leverage analysis showed the attributes that require special attention in supporting the sustainability of Nike fish use. The three attributes that need to be considered in supporting the sustainable use of Nike fish in the ecological dimension are shown in Fig. 2a-b. These include the location of the fishing area, species diversity, and by-catch. The location of Nike fishing in Tomini Bay, Gorontalo Province, remains the same (fixed) due to its unique amphidromous nature. Their eggs are carried by the river currents and hatch in estuary areas, leading to a stable fishing location. This finding is similar to Castellanos-Galindo (2011), who states that relatively permanent fishing locations were also found in the Pacific Ocean, North Colombia. Fishing locations are an important issue in fisheries, especially artisanal fisheries. Fishermen in artisanal fisheries tend to use simple and cheap fishing gear, and most fishing locations are close to the beach/shallow areas (Batista *et al.,* 2014). These findings indicate the need to protect fishing locations by conserving the habitat and areas of amphidromous fish (Franklin *et al.,* 2019). Species diversity is also a highly sensitive attribute, and the results obtained showed that the types of fish caught at the five fishing locations varied from 11 to 12 species (Sahami *et al.,* 2022). Maintaining this diversity is critical to prevent the extinction of Nike fish. Species extinction can be one of the main factors resulting in a biodiversity crisis (Modesto *et al.,* 2018). Resource conservation is an effort that can be made to help ecological systems support a higher diversity of species (Silva *et al.,* 2015). Fishing intensity and quantity caught by fishermen each season are quite high, posing a potential threat to the sustainability of Nike fish (Pasisingi and Olii, 2023). The Indonesian community has long engaged in consumptive and ornamental uses of the fish. The conservation aspect needs to be considered for its sustainability (Niesenbaum, 2019). Based on interview results and direct observations during fishing activities, the by-catch in terms of Nike fishing is very small (<10 percent: %). This small by-catch should be preserved to avoid disrupting the food chain of the aquatic community. Global regulations, such as the Food and Agriculture Organization (FAO) Code of Conduct on Responsible Fisheries, require fishermen to reduce the amount of by-catch to lessen

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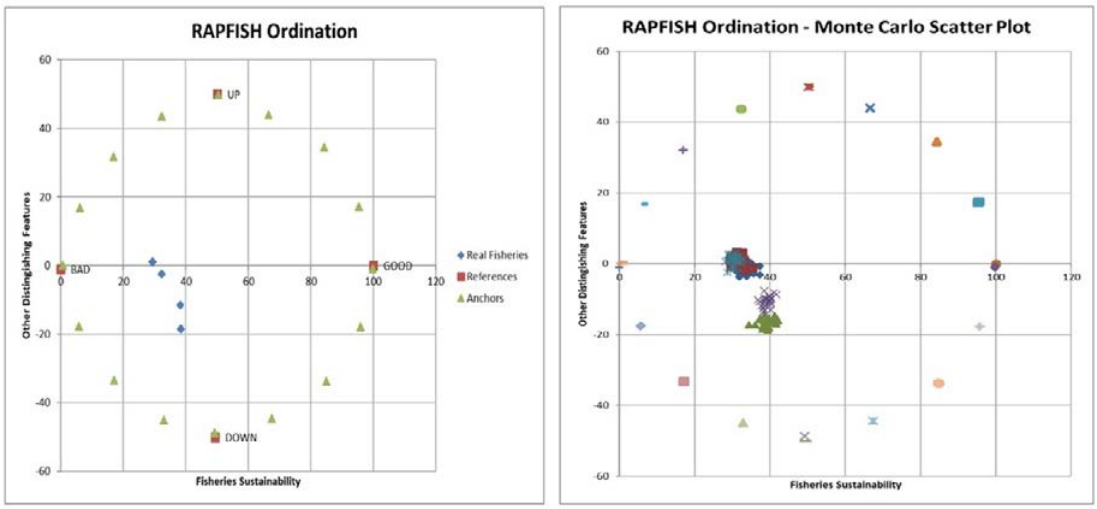

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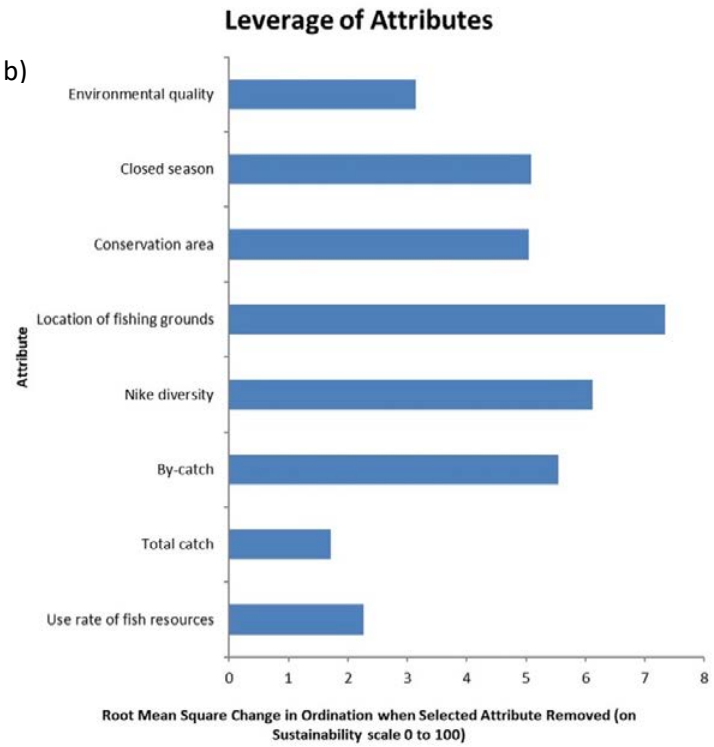

Fig. 2: (a): Results of ordination and Monte Carlo analysis; (b): leverage of attributes on the ecological dimension

the environmental impact of their fishing methods. These regulations ensure that all countries adhere to the fundamental principles of sustainable fisheries management.

Economic dimension

This study evaluates the economic dimension using a range of attributes, including attributes used to analyze the economic dimension in the existing

study, such as 1) the economic value (profit), 2) marketing distribution, 3) source of livelihood, 4) subsidy dependency, 5) contribution to regional revenue, 6) profit distribution, 7) employment, 8) business prospects, and 9) income relative to the provincial minimum wage. The ordination and Monte Carlo analyses showed that the sustainability index value for the economic dimension of Nike fishing in Tomini Bay, Gorontalo Province, was 40.33, as shown in Table 3. Based on the classification of the sustainability status, this figure falls within the less sustainable category. The results of the leverage analysis identified three attributes that significantly impact the economic dimension sustainability index, as shown in Fig. 3a-b.

These attributes include profit distribution,

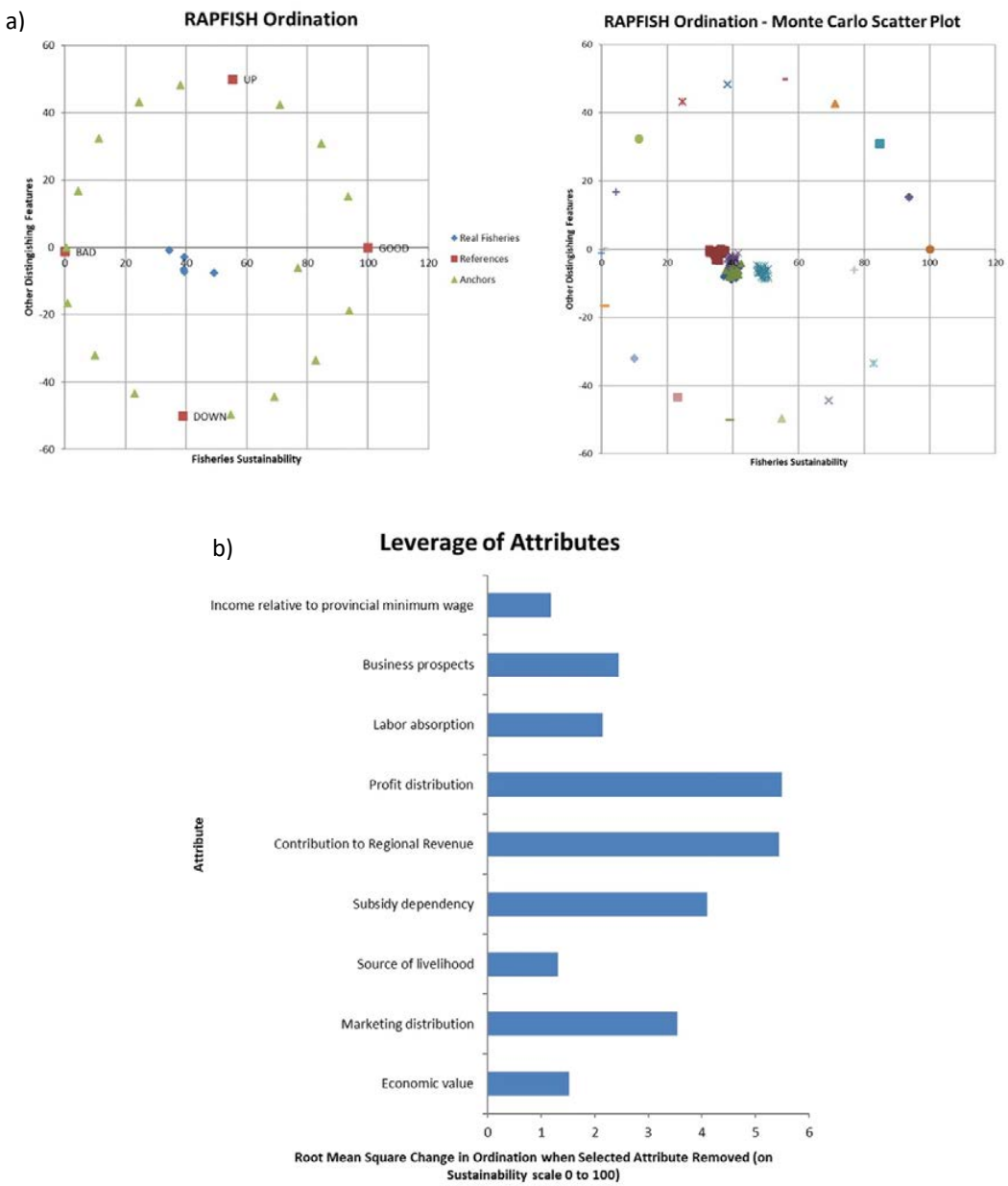

Fig. 3: (a) Results of ordination and Monte Carlo analysis; (b): leverage of attributes on the economic dimension.

contribution to regional revenue, and subsidy dependence. Profit distribution is one of the attributes that have the highest sensitivity in the economic dimension. Interviews with Nike fishermen showed that Nike fishing activities are generally conducted in groups, where capital owners achieve greater profit distribution. As part of this practice, the profits obtained are distributed among group members after deducting business capital, maintenance costs, and expenses incurred from repairing damaged fishing gear. The profit distribution in this study is similar to Hendrik *et al.* (2020), which mentions the wage and profit sharing system at the Belawan Ocean Fishing Port, North Sumatra Province, where the owner or investor has a 60% share and working fishermen have a 40% share of the profits from the catch. This profit-sharing system does not follow Indonesian Fishing Regulation No. 16/1964 due to the lower wages provided to working fishermen. According to Benner and Wrubel (1989), the pattern of cooperation between fishermen who own capital and fishermen who work in the local areas is complicated and will be difficult to change. The profit-sharing system implemented tends to benefit fishermen who own capital. This system has an impact on the low investment development of fishermen and the weak economic, social, and political position of fishermen, which ultimately has an impact on their economic welfare (Fauzi and Anna, 2005). The unequal distribution of profits can lead to the overexploitation of resources (Tietenberg and Lewis, 2012) and has the potential to give rise to other problems such as poverty and crime. To achieve economic sustainability, efforts to improve profit distribution should refer to Indonesian Fishing Regulation No. 16/1964. The next attribute that affects the sustainable use of Nike fish in the economic dimension is the contribution to regional revenue. Information obtained from stakeholder interviews showed that the contribution of regional revenue use activities in Gorontalo Province is minimal. This is because most catches are not sold through fish auction sites but directly to collectors, except for fishermen in Gorontalo City. The most substantial sources of regional revenue come from local levies obtained through tax levies on auction sites and markets (Syamsuddin, 2021). The irregular and seasonal occurrence of Nike fish is a major reason for the absence of revenue collection from this source. Dependence on subsidies is another contributing factor, especially the fuel oil subsidy provided by the government to support the fisheries sector. This subsidy has been prohibited since 2020, as stated in the Sustainable Development Goals (SDGs) item 14. Dependence on subsidies can have both positive and negative effects. On the positive side, it can stimulate the development of fisheries, increasing national income, while the negative aspects are related to destructive practices, such as illegal, unreported, unregulated fishing (IUUF).

Social dimension

The ordination and Monte Carlo analyses (Fig. 4a) showed that the sustainability index value for the social dimension of Nike fishing in Tomini Bay, Gorontalo Province, is 30.86. This places it within the less sustainable category. The social dimension of the sustainability status of Nike fishing includes the analyses of nine attributes to determine the main sensitivities. The leverage analysis identified two attributes as the most sensitive in influencing the sustainability of the social dimension. These include the level of conflict and the fishermen role in sustainability, as shown in Fig. 4b. The level of conflict is the most influential attribute that affects the sustainability of Nike fish use in Gorontalo Province. Conflict between fishermen tends to occur due to scarce resources, structural imbalances within the group, misinformation, competitive desires, and poor peer relationships (Devlin *et al.,* 2022). Based on interviews held with Nike fishermen in Gorontalo Province, no conflict has been reported, thereby indicating a positive practice that needs to be maintained. This harmony is attributed to their adherence to local wisdom, a fundamental part of the Gorontalo community culture. Local wisdom, including concepts like *huyula*, *heeluma*, and *hiimbunga* (local name), instills a habit of tolerance and family-oriented conflict resolution (Yunus, 2014). The next attribute that affects sustainability in the social dimension is the fishermen role in sustainability. The results of the interviews showed that Nike fishers tend to pay less attention to the long-term sustainability of this species, often engaging in large-scale catches when fish is abundant. This continuous fishing practice during each season tends to threaten the future sustainability of Nike fish. The decline in Nike fish production from 2020 (average 7.95 tons/month) to 2021 (2.04 tons/month) indicates a

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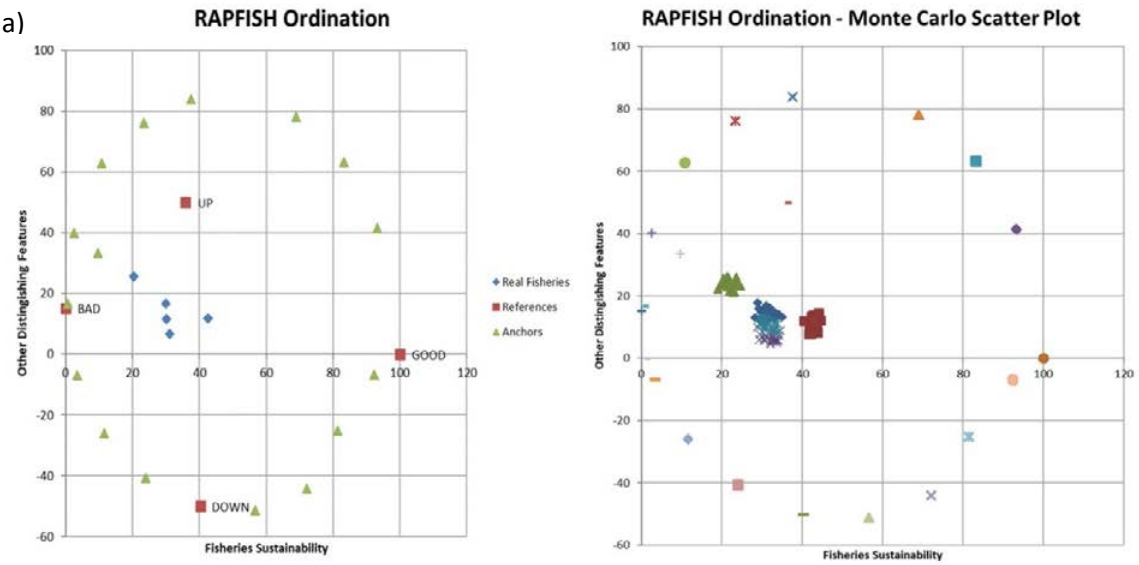

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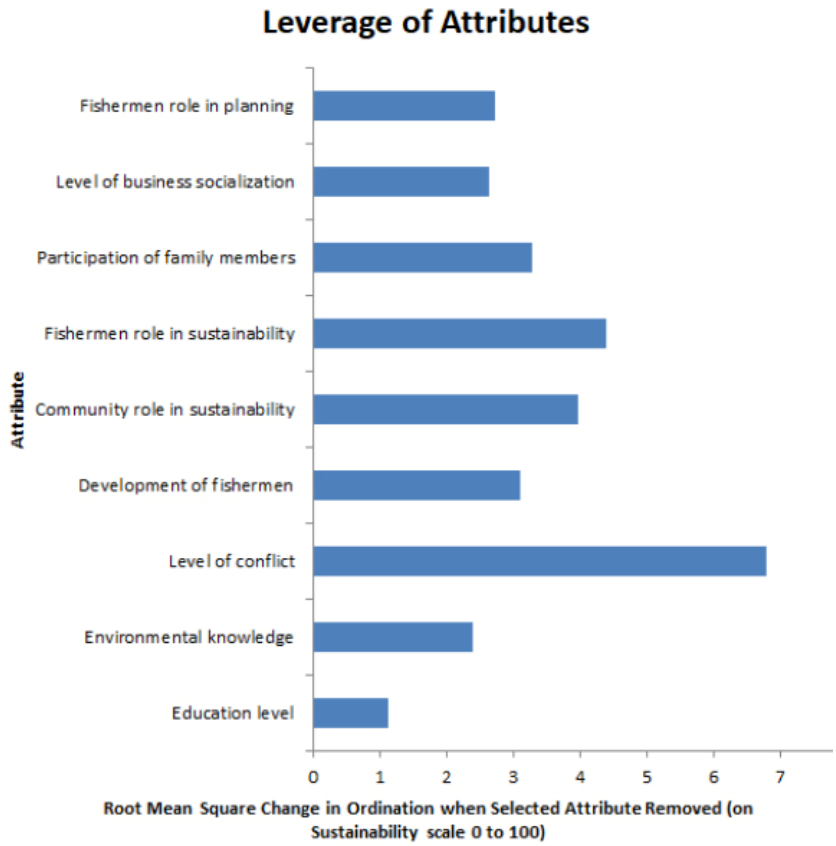


Fig. 4: (a) Results of ordination and Monte Carlo analysis; (b): leverage of attributes on the social dimension.

threat to the sustainability of these fish resources. The role of fishermen in conservation efforts plays an important strategy in resource sustainability (Neubauer *et al.,* 2013). It is essential to conduct awareness campaigns through socialization and establish community watchdog groups to preserve Nike fish resources. Fisher and fishing communities must learn fishing practices that support resource sustainability (Nunoo *et al.,* 2015). Involving local community knowledge can also increase the success of resource management and conservation (Adiga *et al.,* 2015). Local community knowledge can also contribute to determining fisheries management monitoring measures (Dias *et al.,* 2020).

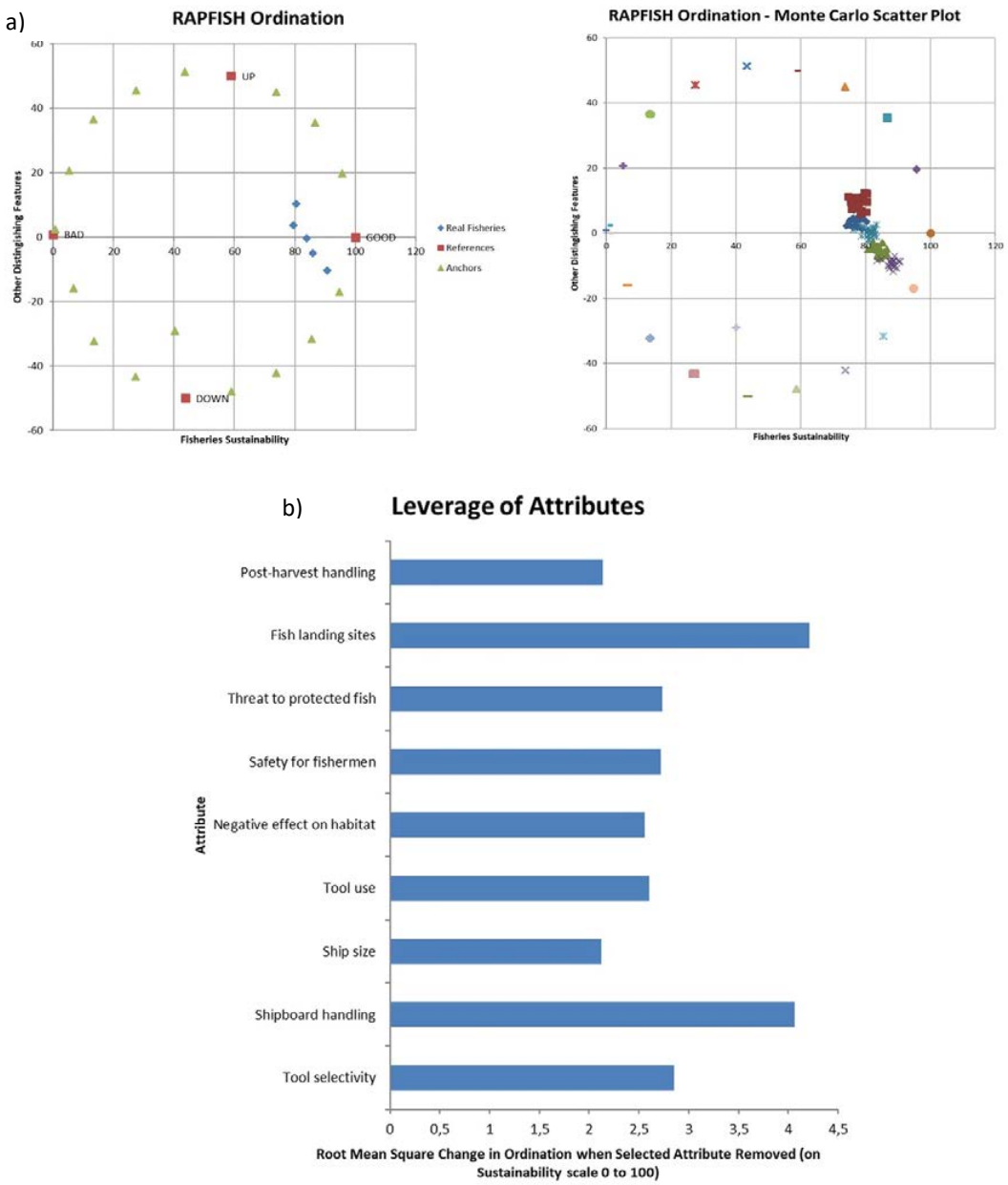


Fig. 5: (a) Results of ordination and Monte Carlo analysis; (b): leverage of attributes on the technology dimension.

Technology dimension

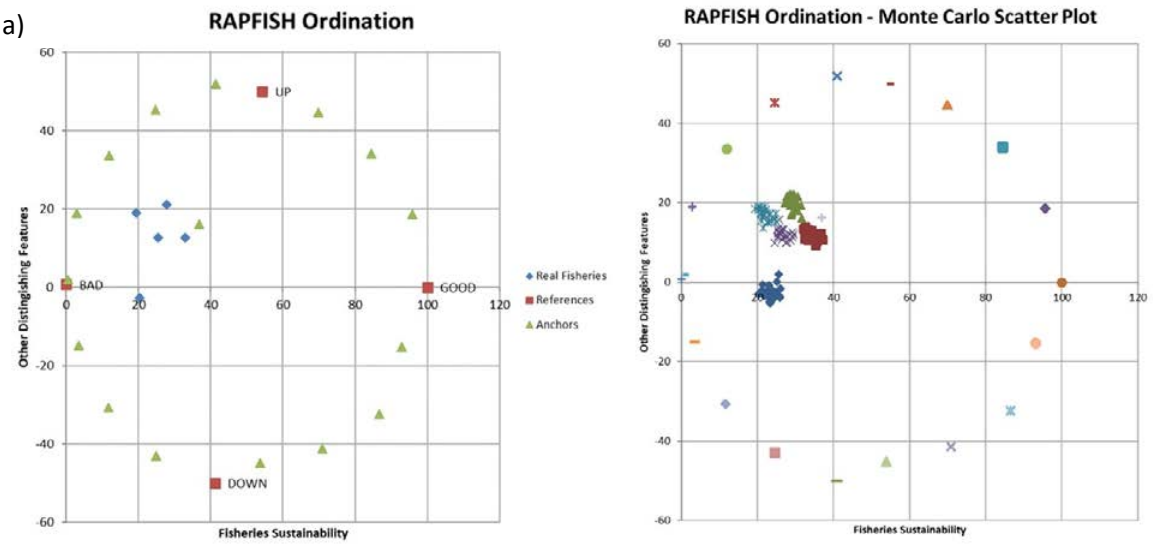
The technological dimension is a significant factor in assessing the sustainability of Nike fishing. The ordination and Monte Carlo analyses results showed a sustainability value of 84.09, and when viewed through the technological dimension, the Nike fish in the waters of Tomini Bay were within the sustainable category. Technology is the only dimension that has a sustainable status in this study. The distribution of ordination values at each Nike fishing location further supported the sustainability status of the technological dimension, as shown in Fig. 5a. Nine attributes were used to analyze the sustainability of the technological dimension, namely fishing gear selectivity, onboard handling, vessel size, use of auxiliary tools, negative effect on habitat, fisher safety, threatening protected fish, fish landing site, and post-harvest handling, as shown in Fig. 5b. The results of the leverage analysis showed that two attributes, fish landing sites and onboard handling, have a significant impact on the sustainability index of the technology dimension. The interviews with Nike fishing fishermen showed mixed results for each Nike fishing location. At the Taludaa Estuarine fishing site, it was found that landing sites for Nike fish were properly distributed with adequate facilities. For the Tombulilato, Bilato, and Bone-Bolango estuaries, fish landing sites were concentrated in one location. For the Bilungala estuary, the Nike fish landing site was reported to be inadequate. To ensure the sustainable use of this species, special attention and various policies need to be implemented to address this attribute. The existence of a port greatly influences the success of the fishing industry as a landing place for fish catches (Huntington *et al.,* 2015). The proper management of fish landing ports is essential to support the quality and sustainability of fisheries businesses (Lubis and Pane, 2017).

Ethical dimension

The sustainability index for the ethical dimension of Nike fishing was determined to be 25.19 across the five fishing sites, as shown in Fig. 6a. This score showed that the ethical dimension was considered less sustainable when compared to the others under investigation. The study identified nine specific attributes that impact the sustainability of the ethical dimension, as shown in Fig. 6b. The results of the leverage analysis showed that two critical attributes significantly impact the sustainability index, namely externalities (waste disposal) and the level of violations. In terms of externalities, interviews held with certain practitioners showed that waste resulting from Nike fishing activities is typically minimal or occasionally absent. This was due to traditional boats and simple fishing gear, which support this attribute by reducing waste disposal. Fishermen stated that they generally avoid discarding hazardous materials or waste into the sea. Regarding the level of violations, the interview results showed that minimal violations were committed in the five study sites. The use of traditional boats and simple fishing gear contributed to the minimal level of violation. The seasonal pattern of Nike fish occurrence (Olii *et al.,* 2017) is believed to contribute to the minimal level of violations committed by fishermen.

The study results have shown that, in general, the sustainability of Nike fish in all fishing locations within Tomini Bay, Gorontalo, is threatened. To ensure the future sustainability of this species, it is essential to address the main attributes in each dimension. An important element is the establishment of sustainable livelihoods, which includes the capacity to withstand and recover from pressures and shocks while safeguarding and improving the necessary assets for natural resource use (Mensah and Enu-Kwesi, 2019). Riverine amphidromous gobies on tropical islands exhibit continuous high reproduction in response to environmental uncertainties. Their larvae encounter diverse environmental challenges, including temperature fluctuations and food availability, as they drift from downstream areas to the sea (Teichert *et al.,* 2016). Reproductive activity is mainly influenced by the temperature of the water in upstream areas and is also affected by factors like female body condition and competition in downstream areas (Keith *et al.,* 2015). The sustainability of Nike fish in the future is dependent on the availability of the river, which serves as a critical environment for their growth, reproduction, and the transition of eggs into the sea and juveniles back to the river. Effective management of the adult phase, including the avoidance of overfishing gobies and the release of those carrying eggs when caught, is also important (Sahami and Habibie, 2020). Environmental conditions, as proven by the negative growth pattern of Nike fish and its length–weight relationship (LWR) analysis, play a significant role in the production

a)



b)

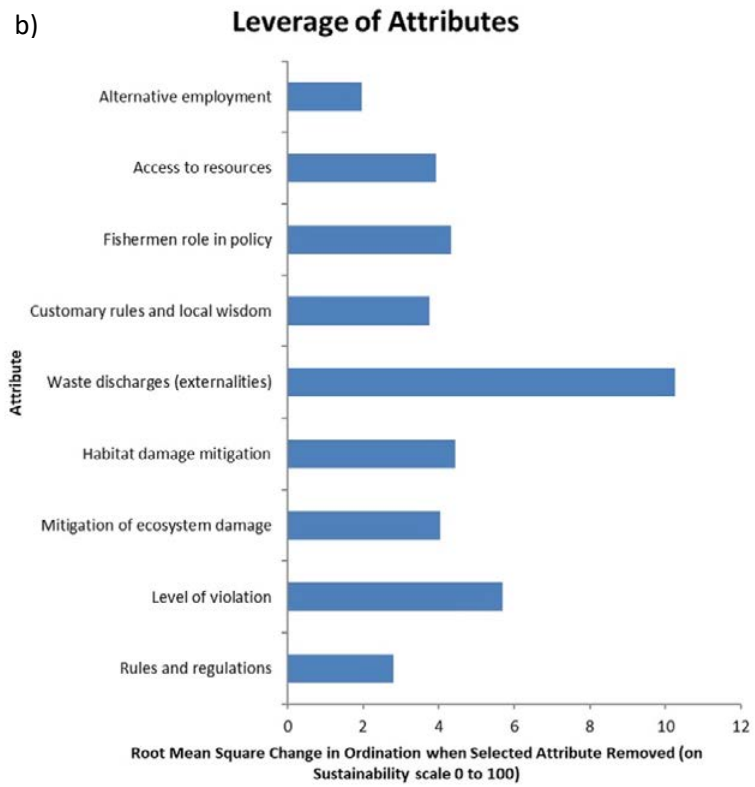


Fig. 6: (a) Results of ordination and Monte Carlo analysis; (b): leverage of attributes on the ethical dimension.

process (Sahami *et al.,* 2023). The sustainability of Nike tends to depend on future actions. To achieve this, it is imperative to combine high fishing efforts with effective habitat management, ensuring long-term sustainability (Sahami and Habibie, 2020). The connection between environmental and livelihood sustainability is extremely important. In essence, the entire framework for sustainable livelihoods is dependent on the concept of ensuring that it is maintained (Mensah and Enu-Kwesi, 2019). Ecosystem management-based methods and models have been proposed in the quest for sustainable fisheries. These methods regulate the management of fisheries resources and contribute to the sustainable development of the economy and society (Bi *et al.,* 2023). The sustainability of seafood production does not depend solely on the abundance of fish stocks. It mainly focuses on the ability of fisheries management systems to adapt fishing pressure to appropriate levels (Hilborn *et al.,* 2015). Two main recommendations that can be given to local governments are: 1) Create regulations regarding the management of Nike fish resources, and 2) increase the knowledge of fishermen and local communities regarding the eco-biology of Nike fish.

CONCLUSION

In conclusion, the novelty of this study was the use of five dimensions, namely ecological, economic, social, technological, and ethical dimensions, to evaluate and assess the sustainability status of amphidromous Nike fish resources in the waters of Tomini Bay, Gorontalo, which includes the Bone-Bolango, Bilungala, Tombulilato, Taludaa, and Bilato estuaries. The sustainability status was assessed using RAPFISH with the MDS approach. A total of forty-four factors that influence sustainability across five dimensions were considered in this study. The MDS analysis found that of the five dimensions examined, only one dimension, the technological dimension, showed sustainable status (>50), with an average index value of 84.09. In contrast, the other four dimensions, namely the ecological, economic, social, and ethical dimensions, showed less sustainable status (<50), with average index values of 33.53, 40.33, 30.86, and 25.19. The S value and the R^2 in the MDS calculation ranged from 0.14 to 0.15 and 0.91 to 0.94, indicating that the analysis is appropriate. The sustainability status of each dimension was found to have the same trend in all research locations. It was reported that the sustainability of using Nike fish resources in Tomini Bay, Gorontalo, was threatened. From the results of the leverage analysis, it was found that twelve leverage attributes were identified as having had a significant effect on the sustainability of Nike fish resources in the waters of Tomini Bay, Gorontalo. The government and stakeholders prioritized the leverage attributes to formulate appropriate management policies to ensure the future sustainability of Nike fish in the waters of Tomini Bay. As the dimension with the lowest average index value, the primary focus must be on the ethical dimension in order to increase the sustainability of the use of Nike fish resources, emphasizing 1) externalities (waste disposal) and 2) the level of violations. The next dimension that needs to be prioritized is the social dimension, with particular emphasis related to 1) the level of conflict and 2) the role of fishermen in sustainability. Leverage attributes such as 1) the location of fishing grounds, 2) Nike diversity, and 3) by-catch need to be prioritized concerning the ecological dimension. Minimal externalities (waste disposal), low level of violations, minimal conflict, and minimal by-catch from research findings do not guarantee sustainability in the ethical and social dimensions, as proven by the low value of the sustainability index in the ethical and social dimensions. Further, in the economic dimension, factors such as 1) profit distribution, 2) contribution to regional revenue, and 3) dependence on subsidies were identified as important to achieve sustainable implementation. For the technological dimension as the only dimension that indicates sustainable status, factors such as 1) fish landing sites and 2) handling on board need to be improved. This study provides a valuable contribution to the government as a reference for policymaking in developing strategies for the sustainable use of these species in the waters of Tomini Bay, Gorontalo. Even though this study focuses on the waters of Tomini Bay, Gorontalo, the results can provide information or insight for countries with similar fisheries potential to carry out better management.

AUTHOR CONTRIBUTIONS

F.M. Sahami, the corresponding author, was responsible for all study activities, from conception and design, drafting, and critical revision of the manuscript. S.N. Hamzah contributed to conception

and design, analyzing and interpreting the data, and preparing the manuscript. A.H. Tome collected the data and critical revision of the manuscript. S.A. Habibie collected and acquisition of data, statistical analysis, and drafting the manuscript. M.R.U. Puluhulawa analyzed and interpreted data.

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CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy have been completely witnessed by the authors.

ABBREVIATIONS

%	Percent
<	Less than
>	More than
ALSCAL	The root of the Euclidian distance
cm	Centimeter
COI	Cytochrome oxidase subunit I
d_{ij}	Euclidian distance from point i to point j
DNA	deoxyribonucleic acid
E	East
et al.	Et alia
FAO	Food and Agriculture Organization
Fig.	Figure
IUUF	Illegal, unreported, unregulated fishing
LWR	Length-weight relationship
MAUT	Multi-attribute utility theory
MDS	Multi-dimensional scaling
N	North
R^2	Coefficient of determination
RAPFISH	Rapid appraisal for fisheries
RMS	Root mean square
S	Stress
SDGs	Sustainable development goals
x-axis	Horizontal number line

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