Sustainability analysis of coastal and marine management in East Nusa Tenggara Province, Indonesia

Sari Hauliah Ahmad Koda[1,5*], *Kastana* Sapanli[2], *Ario* Damar[3,4], *Agus* Sadelie[4], and *Tridoyo* Kusumastanto[2,4]

[1]Doctoral Program in Tropical Ocean Economics Graduate School, 16680 IPB University, Indonesia
[2]Department of Resource and Environmental Economics, Faculty of Economic and Management, 16680 IPB University, Indonesia
[3]Department of Aquatic Resources Management, Faculty of Fisheries and Marine Sciences, 16680 IPB University, Indonesia
[4]Center for Coastal and Marine Resources Studies, 16153 IPB University, Indonesia
[5]Faculty of Fisheries, Muhammadiyah University, 85228 Kupang, East Nusa Tenggara, Indonesia

Abstract. The analysis of the sustainability status of coastal and marine management in East Nusa Tenggara Province was conducted using the Rap-Coastal method, a development of the Rapfish technique commonly applied in assessing the sustainability of capture fisheries. This approach involves four main dimensions: ecological, economic, social, and governance policy. Data for these four dimensions were obtained through interviews and field observations in the study area, then analyzed using the Rap-Coastal software to determine the sustainability index for each dimension. The analysis results show that the overall sustainability status of coastal and marine management in East Nusa Tenggara Province is 66.92, indicating that management practices across the four dimensions fall into the moderately sustainable category. Based on the Leverage analysis of the ecological dimension, the most sensitive attributes affecting coastal and marine sustainability in NTT are fish stock levels (RMS 7.52). For the economic dimension the most sensitive is unemployment rate (RMS 33.62). In the social dimension, the three most sensitive attributes is community dependence on coastal and marine resources (RMS 7.58). Meanwhile, the Leverage analysis for the governance policy dimension shows that the attribute of institutional presence and involvement (RMS 7.88) is the most sensitive.

1 Introduction

East Nusa Tenggara (NTT) Province is one of Indonesia's strategic archipelagic regions endowed with abundant marine resources, ranging from coral reefs, mangroves, and seagrass beds to a wide variety of economically valuable fish species. This vast ecological potential

* Corresponding author: shauliah@yahoo.co.id; hauliah13sari@apps.ipb.ac.id

positions NTT as a crucial area for supporting food security, blue economy development, and marine biodiversity conservation at both national and global levels. In recent years, marine ecological management in NTT has been strengthened through the establishment of marine protected area networks, ecosystem rehabilitation programs such as mangrove and coral reef restoration, and the enhancement of sustainable fisheries governance. These efforts have involved not only central and regional governments but also civil society organizations, academics, and local fishing communities. Developed coastal regions should be encouraged to enhance industrial transfer and innovation diffusion toward less developed regions [1]. From a social perspective, coastal communities in NTT exhibit a high level of dependence on the sea as their primary source of livelihood. Maritime traditions and local wisdom, passed down through generations, play an important role in maintaining a harmonious relationship between humans and the marine environment. However, this strong dependence often faces challenges such as limited access to education, technology, and community adaptive capacity in responding to environmental changes. Therefore, strategies to strengthen social capacity are essential to enable coastal communities to actively participate in sustainable marine management [2]. From an economic standpoint, the marine and fisheries sector represents one of the key pillars. This research is needed to contribute to the management of coastal and marine resources in East Nusa Tenggara Province. This research aims to study the sustainability status of coastal and marine management in East Nusa Tenggara Province based on the ecological, economic, social, and governance policy dimensions.

2 Research method

Primary data was collected through direct interviews using a purposive sampling technique. This method was chosen to gain in-depth insights from respondents with pertinent expertise. The study comprised 20 participants from various backgrounds: 10 government representatives related to seven marine economic sectors fisheries, marine tourism, marine mining, marine industries, sea transportation, marine construction, and marine services along with four academics/experts and six representatives from the community (including NGOs and the private sector).

The analysis used to assess the sustainability status of coastal and marine management in East Nusa Tenggara Province applies a multidimensional scaling (MDS) approach known as Rap-Coastal, which is a modification of the Rapfish method used data that were used in this study were collected by conducting to evaluate the sustainability of capture fisheries. In this study, the determination of coastal and marine management attributes includes four dimensions: ecological, social, economic, and governance policy. The assessment process involves several stages as follows:

a) Identification of key indicators for sustainable coastal and marine management across the four dimensions ecological, social, economic, and policy-governance. Each indicator in every dimension is determined based on relevant literature reviews and reference criteria.
b) Scoring each indicator on an ordinal scale according to sustainability criteria for each factor, combined with scientific judgment from experts reflecting the actual conditions of the study area for the ecological, social, and economic dimensions. For certain social indicators and all governance indicators, data were obtained from questionnaires filled out by selected respondents.
c) Formulating sustainability index values for coastal and marine management in East Nusa Tenggara Province, ranging from 0 to 100%, as presented in Table 1 below [3].

Table 1. Categories of sustainability status based on the RAP-coastal analysis index values

Index Value	Category
$0 \leq x \leq 25$	Unsustainable
$25 \leq x \leq 50$	Less Sustainable
$50 \leq x \leq 75$	Moderately Sustainable
$75 \leq x \leq 100$	Sustainable

d) Conducting a Leverage Analysis to identify the factors that have the greatest influence on the sustainability of coastal and marine management. These factors have values ranging from 2 to 8. Indicators with values below 2 are considered to have little or no influence, while values above 8 indicate dominant or sensitive factors that contribute significantly to the sustainability index of marine management.
e) Subsequently, a Monte Carlo Analysis is performed to test the confidence level of the overall index value as well as that of each dimension. This analysis helps account for potential errors in the assessment process, variations in scoring among researchers, and the stability of the MDS analysis.

3 Results and discussion

3.1 Sustainability analysis of coastal and marine management in NTT Province

The analysis results indicate that the sustainability status of coastal and marine management in East Nusa Tenggara Province is 66.92. This value suggests that the management of coastal and marine areas measured across four main dimensions (ecological, economic, social, and policy and governance) falls into the moderately sustainable category. The validity of this sustainability assessment is demonstrated by the statistical parameters stress value and R-square (R^2), which reflect the accuracy and reliability of the Rap-Coastal model used. The sustainability status is represented by the sustainability index value for each dimension, as presented in Table 2 below.

Table 2. Sustainability index values and parameters of coastal and marine management in East Nusa Tenggara Province

Sustainability Dimension	Sustainability Index	Sustainability Status	Stress (%)	R-square (%)
Ecological	63.93	Moderately Sustainable	15.73	93.65
Economic	70.85	Moderately Sustainable	16.91	87.61
Social	60.71	Moderately Sustainable	16.12	93.47
Policy and Governance	72.19	Moderately Sustainable	14.22	94.52
Average	**66.92**	**Moderately Sustainable**		

(Source: Data analysis 2025)

A stress value is considered acceptable when it is less than 25%, and an R-square (R^2) value greater than 80% indicates a good model fit [4]. This demonstrates the appropriateness of the attributes across the four dimensions used in the sustainability status analysis of coastal and marine management in East Nusa Tenggara Province. The results of the analysis show the sustainability levels of the indicators assessed in the ecological, economic, social, and

policy and governance dimensions. The sustainability index values for these four dimensions are visualized in a kite (radar) diagram (Figure 1), which illustrates both the positive and negative contributions of each attribute within its respective dimension. This visualization shows that the average index value falls within the moderately sustainable category. To maintain and further enhance the sustainability status in the future, efforts are needed to strengthen and preserve the sensitive attributes that have a significant influence on the index values across the ecological, economic, social, and policy-governance dimensions.

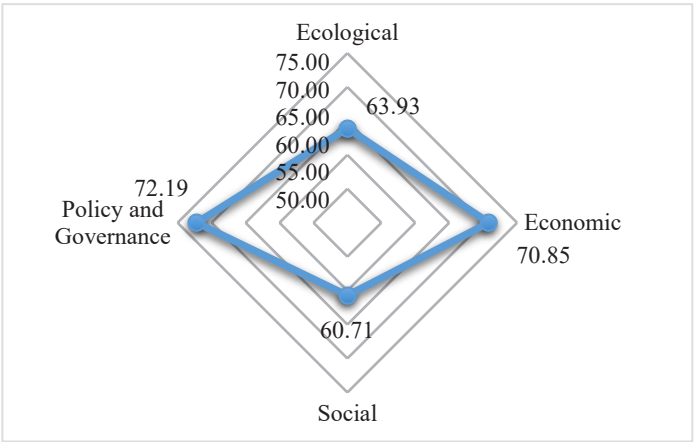

Fig. 1. Four-Dimensional kite diagram of sustainability

3.2 Ecological dimension sustainability status

The MDS analysis using the Rap-Coastal method shows that the sustainability index value for the ecological dimension of coastal and marine management in East Nusa Tenggara Province, based on five attributes, is 63.93. This value indicates a moderately sustainable status. Figure 2 presents the results of the sustainability index analysis.

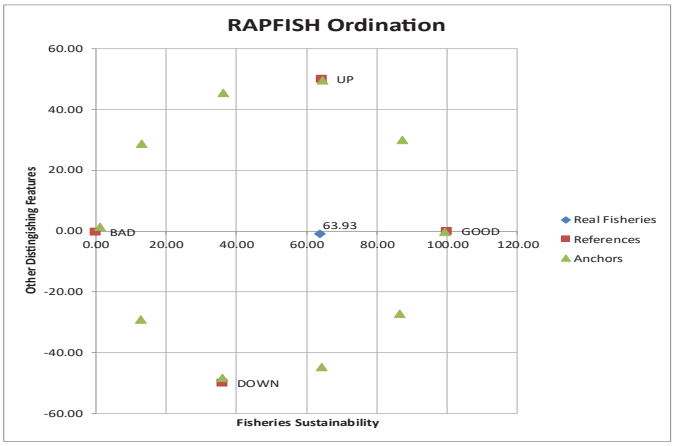

Fig. 2. Rap-Coastal ordination of ecological dimensions (Data analysis 2025)

Based on the Leverage analysis for the ecological dimension, the three most sensitive attributes influencing the sustainability of coastal and marine management in NTT are fish stock (RMS 7.52), coastal erosion (RMS 6.51), and ecosystem rehabilitation (RMS 6.43). Among these, fish stock (RMS 7.52) emerges as the most sensitive attribute within the

ecological dimension. The high Leverage score reflects the critical role of fish stock availability in maintaining both the sustainability of coastal ecosystems and the livelihoods of fishing communities. A decline in fish stocks due to overfishing or habitat degradation directly affects local food security and the regional economy. Therefore, implementing quota-based fishing management, protection of spawning grounds, and strict monitoring of fishing activities should be prioritized to ensure ecological balance and long-term sustainability. As illustrated in Figure 3, data on fish production in East Nusa Tenggara over the past five years show a declining trend from 2020 to 2023, although in 2024 production began to rise again, reaching 91,276,185 units.

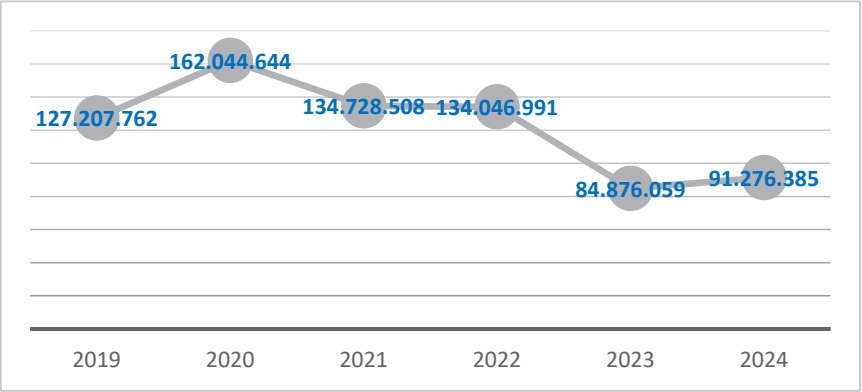

Fig. 3. Fish production data chart of East Nusa Tenggara Province for the last six years (Marine and Fisheries Department of NTT Province 2025)

The coastal erosion (RMS 6.51) indicator demonstrates a high level of sensitivity, as shoreline degradation can reduce the quality of coastal ecosystems, threaten coastal settlements, and destroy marine habitats A study using the Digital Shoreline Analysis System (DSAS) to examine shoreline variations in Kelapa Lima District, Kupang, found consistent rates of erosion from 2015 to 2020 [5]. The data revealed that the average rate of change due to abrasion reached −10.52 m/year, although some areas experienced accretion. Furthermore, other research findings indicate that these changes manifest as both abrasion and accretion of varying magnitudes. From 2014 to 2018 and 2018 to 2023, significant shifts occurred, with maximum erosion reaching -37.98 m in Kupang City and peak deposition measuring 187.09 m [6]. During 2014–2018, the areas affected by abrasion in Kelapa Lima, Kota Lama, and Alak were 4.01 hectares, 0.63 hectares, and 1.24 hectares, respectively. Mitigation efforts against erosion such as planting coastal vegetation, constructing environmentally friendly coastal protection structures, and controlling human activities in erosion-prone zones are strategic actions that need to be strengthened to prevent further coastal degradation. The ecosystem rehabilitation (RMS 6.43) indicator, although slightly less sensitive, remains a crucial factor for maintaining ecological sustainability. Proper rehabilitation measures such as coral reef restoration, mangrove forest rehabilitation, and seagrass bed restoration can enhance ecosystem functions in preserving biodiversity, improving fisheries productivity, and protecting coastal areas from natural disasters. Without continuous and sustainable rehabilitation interventions, ecosystem degradation will intensify and weaken the environmental carrying capacity for coastal communities [7, 8]. Data show that the mangrove forest area in East Nusa Tenggara Province increased from 17,571.32 hectares in 2014 to 21,951 hectares in 2024. The comparison of mangrove forest areas between 2014 and 2024 is illustrated in Figure 4 below.

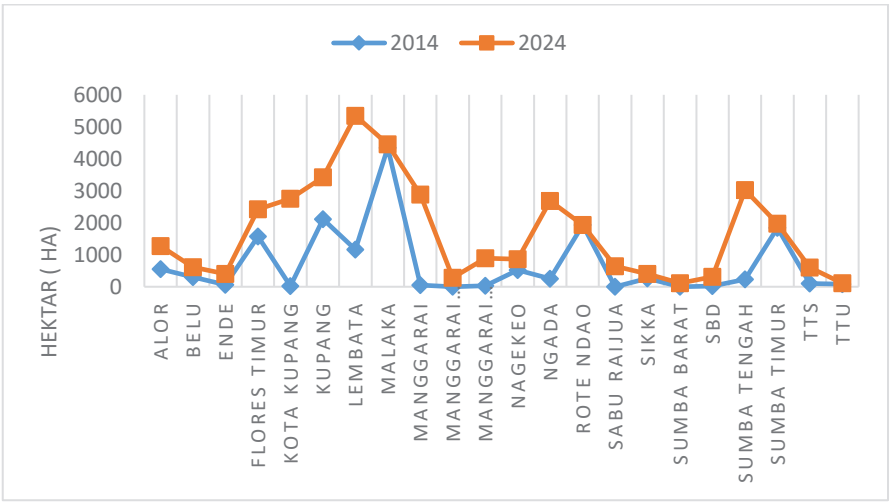

Fig. 4. Comparison of mangrove forest area in NTT Province in 2014 and 2024 (Marine and Fisheries Department of NTT Province; Natural Resources Conservation Center (BBKSDA) of NTT Province 2025)

3.3 Economic dimension sustainability status

The *Multidimensional Scaling* (MDS) analysis using *Rap-Coastal* revealed that the sustainability index for the economic dimension of coastal and marine resource management in East Nusa Tenggara Province (NTT) reached 70.85, indicating a fairly sustainable condition. The results of the sustainability index analysis are shown in Figure 5 below.

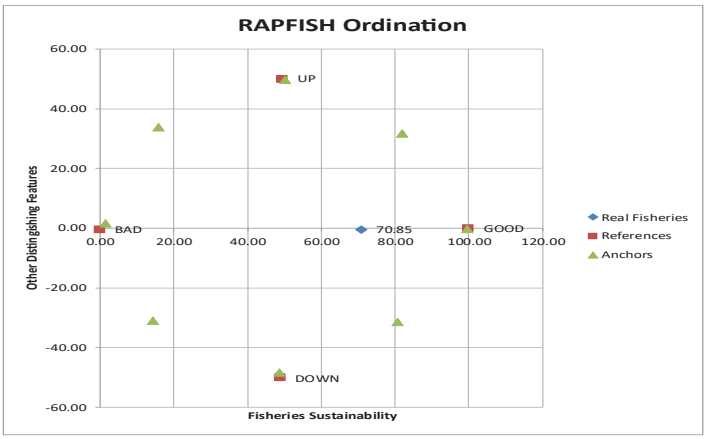

Fig. 5. Rap-Coastal ordination of economic dimension (Data analysis 2025)

Based on the *Leverage Analysis*, two attributes were identified as the most sensitive to the sustainability of coastal and marine management in NTT, namely unemployment rate (RMS 33.62) and contribution of the marine sector (RMS 33.52). The unemployment rate (RMS 33.62) emerged as the most influential attribute in the economic dimension. The high sensitivity of this indicator reflects that the success of coastal and marine resource management is closely related to the availability of employment opportunities for local communities. Data show that the Open Unemployment Rate (OUR) in East Nusa Tenggara Province has been decreasing consistently over the years (Figure 6). In 2020, the OUR was

recorded at 4.28%, and it continued to decline to 3.02% in 2024. This percentage remains lower than the national OUR average of 4.76% as of February 2025. Overall, the data indicate a consistent downward trend in the unemployment rate in NTT since 2020, suggesting an improvement in employment conditions. This trend demonstrates that the development of coastal and marine economic sectors contributes positively to enhancing local livelihoods an economic resilience.

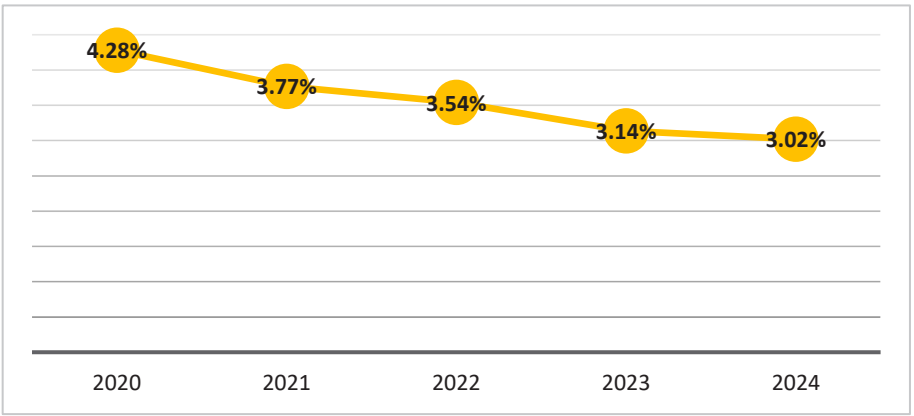

Fig. 6. Chart of Open Unemployment Rate (OUR) percentage in NTT Province over the last five years (2020–2024) (BPS 2025)

Furthermore, the contribution of the marine sector (RMS 33.52) also has a significant influence on the sustainability of the economic dimension. This attribute reflects the extent to which the marine sector contributes meaningfully to the regional economy. The percentage contribution of the marine-based economic sector was 19.34% in 2019, fluctuated over the following years, and increased again in 2023 to 19.44%.

3.4 Social dimension sustainability status

The MDS analysis using Rap-Coastal shows that the sustainability index value for the social dimension of coastal and marine management in East Nusa Tenggara Province, derived from five attributes, is 60.71. This value indicates a moderately sustainable condition. The results of the sustainability index analysis are shown in Figure 7 below.

Based on the Leverage analysis for the social dimension, the three most sensitive attributes affecting the sustainability of coastal and marine management in East Nusa Tenggara are: community dependence on coastal and marine resources (RMS 7.58), community participation in management (RMS 6.50), and local wisdom (RMS 6.43). First, community dependence on coastal and marine resources (RMS 7.58) is identified as the most sensitive attribute. This indicates that most coastal communities rely heavily on marine resources to meet their livelihoods. High dependence can increase the risk of overexploitation if not balanced with sustainable management systems. Therefore, livelihood diversification and capacity building for communities to develop environmentally friendly alternative enterprises are crucial. Second, community participation in management (RMS 6.50) also plays a vital role in the sustainability of the social dimension. The high sensitivity of this indicator emphasizes that active community involvement in decision-making, monitoring, and policy implementation processes is a key factor in successful coastal management. Enhancing community participation can be achieved through public consultations, fishermen's groups, and transparent and inclusive local institutions. Third, local wisdom (RMS 6.43) is an essential factor supporting sustainable coastal management. Traditional

practices passed down through generations—such as seasonal fishing bans or customary rituals for marine conservation—have proven effective in maintaining ecosystem balance. Integrating local wisdom with modern management policies will strengthen governance legitimacy and improve community compliance with applicable regulations.

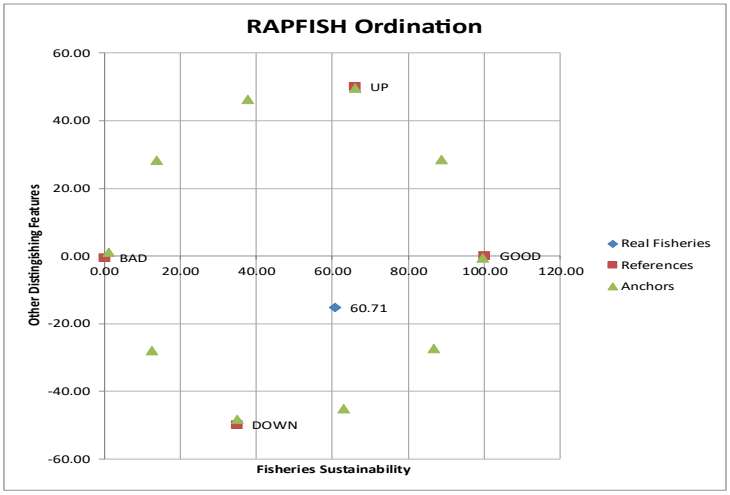

Fig. 7. Rap-Coastal ordination of social dimension (Data analysis 2025)

3.5 Governance policy dimension sustainability status

The MDS analysis using Rap-Coastal shows that the sustainability index value for the governance policy dimension of coastal and marine management in East Nusa Tenggara Province, based on seven attributes, is 72.19. This score indicates a moderately sustainable condition. The results of the sustainability index analysis are shown in Figure 8 below.

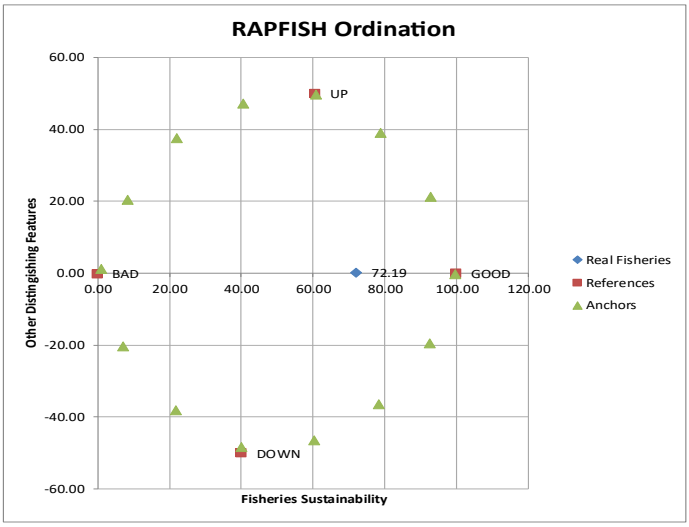

Fig. 8. Rap-Coastal ordinance of governance policy dimension (Data analysis 2025)

Based on the leverage analysis of the governance policy dimension, the three most sensitive attributes influencing the sustainability of coastal and marine management in East Nusa Tenggara are the existence and involvement of institutions (RMS 7.88), law

enforcement and implementation (RMS 5.38), and planning and coordination in management (RMS 5.28). First, the existence and involvement of institutions (RMS 7.88) is identified as the most sensitive attribute. This highlights the crucial role of government agencies, traditional institutions, and civil society organizations in supporting sustainable coastal area management. Without effective inter-institutional coordination, existing policies may not be properly implemented. Therefore, strengthening institutional capacity and enhancing stakeholder synergy are essential to ensure effective governance. Enhanced synergy across various levels of government has proven effective in optimizing the management of coastal and marine areas. Through collaborative governance, coordination between institutions and communities can be strengthened, trust among stakeholders can be fostered to encourage broader participation, and the capacity of both state and non-state actors for shared decision-making can be more effectively developed [9].

Second, law enforcement and implementation (RMS 5.38) indicates that sustainability is strongly influenced by the consistency of regulatory enforcement. Well-designed regulations will have little impact if their implementation is weak. Thus, strengthening legal enforcement, including improving the capacity of supervisory officers and imposing strict sanctions, is necessary to prevent illegal activities such as destructive fishing, coastal encroachment, and marine pollution. Third, planning and coordination in management (RMS 5.28) also play an important role in maintaining governance sustainability. Sound planning and cross-sectoral coordination ensure that coastal management programs align with community needs, ecological conditions, and regional development goals. Without adequate coordination, there is a risk of program overlap, policy inefficiency, and limited community participation in supporting implemented policies.

3.6 Monte Carlo analysis

Monte Carlo analysis is used to detect sources of error or uncertainty arising from data variability. Errors in the RAPFISH (or Rap-Coastal) analysis may occur due to several factors, including: (1) errors in attribute scoring caused by limited information, misunderstanding of attributes, or incorrect scoring methods; (2) variations in scoring due to differences in opinions or judgments among researchers; (3) instability in the repeated MDS analytical process (unstable anchor positions); (4) data entry errors or missing data; and (5) high “stress” values in the analysis results. Error detection is performed by comparing the MDS index values with those obtained from the Monte Carlo simulation. Table 3 presents the comparison between the sustainability index values derived from the MDS analysis and those obtained through Monte Carlo simulation.

Table 3. Differences in index values between MDS and Monte Carlo analysis

Dimension	MDS Value (%)	Monte Carlo (%)	Difference (%)
Ecology	63.93	62.56	1.37
Economy	70.85	66.10	4.75
Social	60.71	59.54	1.17
Governance Policy	72.19	69.75	2.44

(Source: Data analysis 2025)

Based on the results of the Monte Carlo analysis, the differences between the MDS and Monte Carlo ordination results for each dimension are relatively small, i.e., less than 5%. This indicates that the sustainability analysis results across the four dimensions ecological, economic, social, and governance policy have a low scoring error rate, small score variability, and a stable analytical process, while also avoiding errors due to missing data. Therefore, it can be concluded that the results of the sustainability status analysis of coastal and marine management in East Nusa Tenggara Province have a high level of reliability and confidence.

4 Conclusion

Based on the results and discussion, it can be concluded that coastal and marine management in East Nusa Tenggara Province is currently in a moderately sustainable condition, with an average sustainability index value of 66.92. Furthermore, leverage analysis identifies the most sensitive attributes across four key dimensions that significantly influence this sustainability. In the ecological dimension, fish stock resources (RMS 7.52) were found to be the most sensitive attribute, while the economic dimension is primarily driven by the unemployment rate (RMS 33.62). Socially, the social dimension is most affected by the level of community dependence on coastal and marine resources (RMS 7.58). Finally, within the governance policy dimension, the existence and active involvement of relevant institutions (RMS 7.88) emerge as the most critical factors for future management strategies.

The author expresses sincere gratitude and appreciation to Beasiswa Pendidikan Indonesia (BPI) for the support provided. Special acknowledgments are also extended to the Center for Higher Education Funding and Assessment under the Ministry of Higher Education, Science, and Technology of the Republic of Indonesia, as well as the Endowment Fund for Education Agency of the Ministry of Finance of the Republic of Indonesia for their invaluable contribution to the completion of this work.

Reference

1. Y. Wang, Y. Meng, H. Zhang, W. Wang, Assessing the resilience of marine ecological-economic systems: A multi-level approach for sustainable coastal governance. Chinese Journal of Population, Resources and Environment. **23**, (2025). https://doi.org/10.1016/j.cjpre.2025.10.012
2. A.N. Renur, A. Fauzi, D. Solihin, T. Kusumastanto, Analisis tata kelola laut di Provinsi Maluku, In Proceeding of the Seminar Nasional Riset dan Kebijakan Sosial Ekonomi Kelautan dan Perikanan, Jakarta, Indonesia, September 22, (2020).
3. A. Fauzi, S. Anna. Pemodelan sumberdaya perikanan dan kelautan (Gramedia Pustaka Utama, Jakarta, 2005)
4. P. Kavanagh, T.J. Pitcher, Implementing Microsoft Excel Software for rapfish: A technique for the rapid appraisal of fisheries status. Fisheries Centre Research Reports. **12**, 2 (2004).
5. Y. Luwarti, LK. Alexander, T. Ismawan, Analisis laju perubahan garis pantai di Kecamatan Kelapa Lima Kota Kupang. Jurnal Ilmiah Bahari Papadak, Edisi Oktober 2023. **4**, 2 (2023). https://dx.doi.org/10.14288/1.0074801
6. N.N. Nawa, J.T. Amandus, L.A. Antonius, F. Yunus, Examination of variations in abrasion and shoreline accretion dynamics in Kupang City utilizing remote sensing technology. Jurnal Ekologi, Masyarakat dan Sains. **6**, 1 (2025). https://doi.org/10.55448/mr454h18
7. D.V. Pattimahu, Kebijakan pengelolaan hutan mangrove berkelanjutan di Kabupaten Seram Bagian Barat Maluku, Ph.D. Thesis, Institut Pertanian Bogor, Indonesia, 2010.
8. Muhsimin, Strategi pengelolaan ekosistem mangrove berkelanjutan di Wilayah Pesisir Desa Akuni Kec. Tinanggea, Kab. Konawe Selatan, Master Thesis, Institut Pertanian Bogor, Indonesia, 2018.
9. M.V.S. Asio, C. Cvitanovic, J.Lau, A. Diedrich, Collaborative governance in marine and coastal management: A systematic review. Ocean and Coastal Management. **272**, (2026). https://doi.org/10.1016/j.ocecoaman.2025.108020