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Status of Sustainable Livelihoods of Seaweed Cultivaters on Nain Island, North Sulawesi Province, Indonesia

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Abstract— *Seaweed farming is an important source of livelihood for many people but is vulnerable to global and local pressures. Resilient cultivators are able to maintain, and even grow, their livelihoods, despite these pressures. Increasing the resilience of seaweed farmers contributes to the prevention and alleviation of poverty. The aim of this research is to determine the status of sustainability of seaweed cultivation livelihoods in Nain Island, North Sulawesi Province, Indonesia. Based on the results of the Rapfish analysis, a sustainability index was obtained for the economic and institutional dimensions with unsustainable status, for the socio-cultural dimension less sustainable, and the technological dimension with moderately sustainable status. Sensitive attributes that influence 9 of the 16 attributes. For the economic dimension, sensitive factors are market chain, marketing and acceptance. In the socio-cultural dimension, sensitive attributes are family participation and other businesses. In the technological dimension, the attributes that influence or need to be intervened in the sustainability status of seaweed cultivation businesses are the availability of industry and the availability of clotheslines. And in the institutional dimension, the influential attributes are the extension center and the origin of capital. The results of the sustainability index analysis for each dimension of seaweed cultivation activities on Nain Island are included in the less sustainable category at this time. The results of research regarding the ecological conditions in seaweed cultivation on Nain Island are in accordance with the existing theory that the suitable season for cultivation is the dry season. Then, regarding the availability of the seeds themselves, they are always available with medium quality seeds, because the seeds are used repeatedly. The average depth of water for farmers' cultivation is 6.27, based on theory, this depth is suitable for seaweed cultivation activities.*

Keywords— seaweed, cultivators, livelihoods, strategy, sustainability status

I. INTODUCTION

Seaweed stands as a significant economic commodity in global trade. It possesses substantial economic value, is easily cultivated, and involves low production costs, making it accessible to various societal levels. However, seaweed production in North Sulawesi has experienced a sharp decline since the late 2000s, primarily due to the decreased output in North Minahasa, particularly on Nain Island, a key production center. Peak production on Nain Island occurred between 1996 and 2000, reaching 350-400 tons per month, before plummeting by the end of 2000 and hitting zero by early 2003 (Gerung et al., 2008). This decline persisted until 2007 without recovery (Ngangi, 2012), posing significant challenges for cultivators on Nain Island.

According to data from the North Sulawesi Provincial Fisheries Office, seaweed production in the region has fluctuated dramatically over the past three years. In 2017, production dropped by 52.2% compared to the previous year, followed by increases of 59.8% in 2018 and 9.4% in 2019. In 2020, however, production again decreased by 51.3%. These fluctuations underscore the need for a comprehensive study to assess the sustainability status of seaweed cultivators' livelihoods, particularly on Nain Island, North Minahasa Regency, Indonesia.

Seaweed cultivation often faces production volatility due to limiting factors such as shorter planting seasons, which impact yields, space-use conflicts, insufficient oversight and community involvement, loss of cultivation areas, and post-harvest handling challenges, alongside socio-economic and institutional aspects.

The cultivation of seaweed is undeniably vulnerable to various limiting factors that threaten the sustainability of livelihoods in Nain Village. The primary focus of sustainable livelihood approaches is to enhance livelihoods by integrating all development components to alleviate poverty (Wright et al., 2016). Adopting a sustainable livelihood approach provides a means to improve the identification, assessment, implementation, and evaluation of development programs, thereby more effectively addressing the priorities of the poor both directly and at policy levels (Karl et al., 2002).

The findings of this study on the sustainability status of seaweed cultivation livelihoods can serve as a reference for strategies to develop seaweed farming by increasing production capacity, disease control, value chain enhancement, marketing channels, regulations, and institutional frameworks. The aim of this research is to determine the sustainability status of seaweed cultivation livelihoods in Nain Village, North Sulawesi Province, Indonesia.

II. RESEARCH METHODS

This research will be conducted from March 2023 to November 2023. The research location is Nain Island, North Sulawesi Province, Indonesia. The population in this study were seaweed cultivators spread across 2 villages, namely Nain Main Village and Nain Satu Village. The sample of respondents was selected using the purposive sampling method. The number of samples that were respondents in this research were 75 seaweed cultivating households.

Method of collecting data

The types of data used in this research are primary data and secondary data. According to Sekaran and Bougie (2016) primary data is information obtained directly by researchers related to the specific research objectives. Secondary data is information collected from existing sources (Sugiyono 2013).

The type of primary data used to evaluate the sustainability status of seaweed cultivators' livelihoods on Nain Island includes 4 dimensions, namely economic, socio-cultural, technological and institutional dimensions (Table 1).

Table 1. Types of Research Data

a. Dimensions Economy - Income - Marketing - Chain market	b. Dimensions Technology - Provider Information - Industry processing - Availability clothesline - Availability boat
c. Dimensions Social Culture - Education - Amount dependents - Participation family - System social management	d. Dimensions Institutional - Alternative business Other - Origin Capital - Institution group farmer - Institution finance - Hall counseling.

Source: Adapted by Yusuf (2012); Permana Ari (2019)

Meanwhile, the type of secondary data used is literature related to evaluating the livelihoods of seaweed cultivators. This secondary data is used to support primary data, such as sharpening problem analysis, identifying possible shortcomings in research results, determining the meaning and relationships between variables, carrying out synthesis and obtaining new perspectives.

Primary data collection was carried out with the help of the instrument "the fisheries livelihoods resilience communities check (FLIRES check)". FLIRES check is an instrument in the form of a questionnaire offered by Stanford et al. (2017) to measure the sustainability status of seaweed cultivation livelihoods, then adapted to measure the sustainability status of seaweed cultivation livelihoods. This instrument is useful for identifying the strengths and weaknesses of the livelihoods of seaweed farming households (Stanford et al. 2017). In the field interview, each respondent was asked about each attribute contained in the FLIRES check. Each response is assessed by the interviewer using a Likert scale on a value range from 1 to 4 (from bad to good). Apart from that, this primary data was also obtained through observations at the research location by observing behavior and events related to seaweed cultivation livelihoods.

III. DATA ANALYSIS

The research data will be analyzed with multi-dimensional scaling (MDS) and leverage, using Rapfish software (Pitcher and Preikshot 2001; Pitcher et al. 2013). Rapfish software can be used for free (www.Rapfish.org/software) or downloaded and then applied via R programming (www.r-project.org). Techniques in Rapfish are commonly used to describe the general sustainability status of fisheries (Pitcher and Preikshot 2001; Kavanagh and Pitcher, 2004). However, in the FLIRES check it is understood as the level of sustainability of seaweed cultivation livelihoods (Stanford et al. 2017).

MDS analysis is used to determine an index that describes the sustainable livelihood status of each seaweed farming household. The assumption is that a high index value indicates that the seaweed farming household has a profitable livelihood portfolio (high level of sustainability). The index is then visualized in the form of scatter plots for each field in each seaweed cultivating household which is represented by plot points spread across the MDS. In reading these scatter plots, the x-axis displays the position of each seaweed cultivating household on a scale of 0 (bad) to 100 (good) then the y-axis displays the differences between seaweed cultivating households but with the same status in that field. but with different combinations of scores on each attribute.

The further to the right the position of the seaweed cultivating household, the better the index value and status obtained. The sustainability status of livelihoods is determined using a predetermined scale, namely the highest scale of 100 (good) divided into 4 categories (not sustainable, less sustainable, quite sustainable and very sustainable) (Table 2).

Table 2. Index Value for Determining the Sustainability Status of Seaweed Cultivation Livelihoods

No.	Range-Score	Livelihood Status
1.	0.00 – 25.00	No sustainable
2.	25.10 – 50.00	Not enough sustainable
3.	50.10 – 75.00	Sustainable
4.	75.10 – 100.00	Very sustainable

Source: Kavanagh and Pitcher (2004)

Leverage analysis is used to determine sensitive attributes that can become leverage in increasing the index value of the field that has been measured (Kavanagh and Pitcher, 2004). These sensitive attributes are factors that influence the sustainability of seaweed cultivation livelihoods. Sensitive attributes are determined by selecting attributes that have a root mean square (RMS) change value close to half or more of the value scale on the x-axis. Then the index that MDS has produced from all the fields that have been obtained by each seaweed cultivating household is displayed in one plot in the form of a radar diagram.

In the Rapfish technique, several statistical parameters are also analyzed, namely: stress value, coefficient of determination (R2), and Monte Carlo (MC). The stress value is useful for determining the goodness of fit (accuracy) of the analysis results using MDS. Kavanagh and Pitcher (2004) recommend that an acceptable stress value is less than 0.25. The coefficient of determination (R^2) is useful for determining whether or not it is necessary to increase the number of attributes in order to reflect the dimensions being studied closer to the actual situation. An R^2 value close to 1 means that the number of attributes used to assess a dimension is quite accurate. Monte Carlo is an analysis used to estimate the influence of error (random error) in the statistical analysis process. The results of the Monte

Carlo analysis were compared with the results of the MDS analysis to determine the differences between the two. The small difference between MDS and Monte Carlo (<1) indicates that random errors in the analysis process are relatively small.

IV. RESULTS AND DISCUSSION

General Condition of Research Location

Nain Island is in Wori District, North Minahasa Regency, North Sulawesi Province, Indonesia. Initially, Nain Island consisted of two villages, namely Nain Village and Tatampi Village. In 2012, the expansion occurred, Nain Village became Nain Main and Nain 1 Villages. Nain Main Village is a Bajo Tribe community, while Nain One Village is a Siau-Tagulandang Tribe community, and Tatampi Village has Tarente Hamlet. The majority of people from these 3 villages work as seaweed cultivators. This research took 2 villages with the largest majority of people, namely Nain Village and Nain Village 1. These two villages are located side by side. This is different from Tampi Village, where you have to take a boat or walk about 30-45 minutes from Nain Main Village to get there. Nain Main Village with a majority Muslim population and Nain 1 Village with a majority Christian population have a high level of tolerance where both villages really appreciate their religious and cultural events. On major Muslim holidays, the people of Nain 1 Village will come and visit and hold gatherings, likewise with the people of Nain 1 Village, when celebrating major Christian events, the people of Nain Main Village will visit and want to celebrate.

The population of Nain Village is 2,054 people, consisting of 1,062 men and 992 women, with 642 family heads. The majority of Nain Village residents work as fishermen, which in this case also doubles as seaweed cultivators. The number of fishermen is 588 people or 86.75% and only 13.25% have a profession that is not a fisherman.

Seaweed cultivation in Nain Village began in 1989 and has developed into a major livelihood since 1995 (Mondoringin, 2005). Seaweed cultivation in Nain Village uses the surface long rope method, this method is known as longline because it uses a long-stretched rope. This method is also one of the surface methods that is most popular with cultivators because besides being easier, the tools and materials used are more durable, relatively cheap and easy to obtain.

Length of Seaweed Cultivating Business

In the following table it can be seen that the percentage of years of business for seaweed cultivators in Nain Main and Nain 1 Villages is between 10 and 40 years.

Table 3. Old Profile of Seaweed Cultivating Business

No.	Length of business (years)	Amount	Percentage
1.	10-20	18	24.00
2.	21-30	37	49.33
3.	31-40	20	26.67
	Total	75	100.00

Source: Primary Data Processing (2023)

Based on the table on the distribution of length of business by cultivators, it was found that the majority had been in seaweed cultivation for between 21-30 years with a percentage of 50%. This means that most of the cultivators in Nain Main and Nain 1 Villages have been involved in cultivation for a long time. Judging from the age distribution of the most cultivators at 42% with an age range of 41-50 years. This means that the average cultivator has become a cultivator from the age of 20. Some cultivators have started learning to cultivate seaweed since their school days. This table also proves that dependence on this cultivation business is very high judging from how long they last in this business.

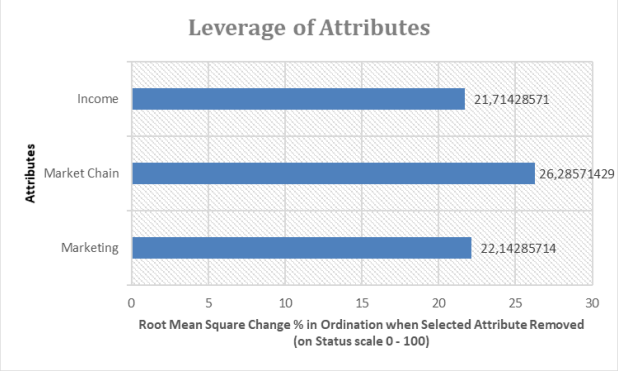
Sustainability Status of Seaweed Cultivation Business

The sustainability of the seaweed cultivation business is considered by 4 dimensions, namely economic, socio-cultural, institutional and technological. In each dimension there are several attributes that are measured qualitatively and quantitatively, then given weights using Multidimensional Scaling (MDS) analysis. The attributes used are modifications from Yusuf (2012); and Permana Ari (2019). The scoring for each attribute in each dimension is based on the real conditions of seaweed cultivation activities on Nain Island, North Sulawesi Province, Indonesia.

Economic Dimension

The Rapfish analysis (MDS) of three economic dimension attributes yielded a

sustainability index value of 21.27, indicating a non-sustainable status. According to Nababan et al. (2007), the sustainability status category with an index value of 0–24.99 is classified as non-sustainable. The attributes identified as influencing the economic dimension include: (1) income, (2) marketing, and (3) market chains. The non-sustainable status of the economic dimension sustainability index is affected by these attributes, each contributing differently to the overall index value. The leverage analysis results revealed that the most influential attribute is the market chain.



Source: Primary Data Processing (2023)

Fig. 1. Role each attribute dimensions economy in continuity business cultivation grass sea

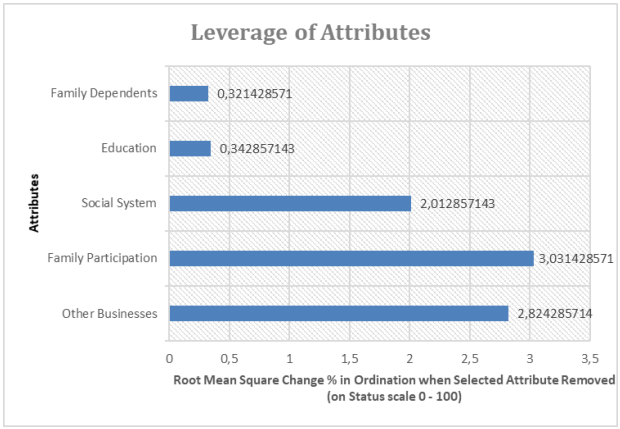
Figure 1 illustrates the market chain, which significantly influences the economic dimension of the sustainability of seaweed farming on Nain Island. The market chain involves both long and short marketing channels, which are affected by various factors, such as the distance between producers and consumers, the level of product damage, production scale, and the financial condition of the enterprise (Hanafiah & Saefuddin, 1986). As a perishable commodity, seaweed requires an effective and efficient marketing channel. These channels typically include distribution flows from farmers to intermediary traders, wholesalers, and eventually export to large-scale industries in Makassar and Surabaya, Indonesia. Theoretically, marketing is defined as a social process or organizational function aimed at distributing products to meet consumer needs (Hasan, 2013). Based on interviews, it was found that the marketing channels utilized by seaweed farmers remain suboptimal, preventing farmers from directly exporting their harvests.

Income is defined as the amount of money earned from sales during a specific period after deducting the cost of goods sold (COGS), expenses, and other costs. In this study, income refers to the net income of seaweed farmers, as determined through direct interviews with the farmers. The average net income received by farmers from their most recent harvest amounted to IDR 9,975,550, which is significantly higher than the average Minimum Wage of North Minahasa Regency for Year 3, amounting to IDR 3,485,000.

The sustainability index of the economic dimension can be enhanced to achieve greater sustainability if the supporting attributes are managed optimally. This can be achieved by strengthening the role of attributes that contribute positively and minimizing the influence of attributes that negatively impact the sustainability index value within the economic dimension.

Socio-cultural Dimension

Based on the Rapfish analysis, the sustainability index for the socio-cultural dimension was 40.96, which is categorized as less sustainable. Several attributes are identified as influencing the sustainability level of the socio-cultural dimension, namely: (1) education level, (2) number of dependents, (3) family participation, (4) social system, and (5) alternative livelihoods. Further leveraging analysis highlighted three key attributes with significant influence: (1) family participation, (2) alternative livelihoods, and (3) social system.



Source: Primary Data Processing (2023)

Fig. 2. Role each attribute dimensions social culture in sustainability business cultivation grass sea

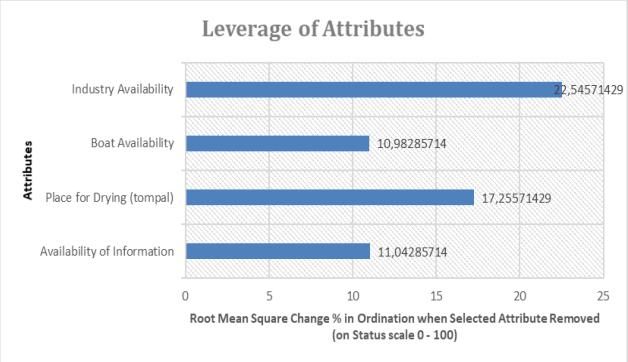
Based on the analysis of the figure above, the first and most influential attribute is the level of family participation in seaweed farming activities. This is evident from field observations where male family members, such as fathers and sons, are typically responsible for tasks at sea, including site preparation, maintenance, and harvesting. Meanwhile, female family members, such as mothers and daughters, are more involved in socio-economic activities on land, such as rope-making, seedling attachment, and seaweed drying. Consequently, nearly all farming households actively involve their family members in the farming process. Moreover, these activities are often conducted collaboratively in groups through a community-based mutual cooperation system to enhance efficiency and foster collective efforts. This finding aligns with the study by Yusuf (2012), which identified family participation as the most influential attribute in the success of seaweed farming.

The second significant attribute is the limited alternative employment opportunities for the residents of Nain Island. The available job options to meet household needs are minimal unless residents seek employment outside the region. As a result, the community exhibits a high dependency on seaweed farming activities. At present, seaweed farming is regarded as the most promising economic activity for improving the well-being of coastal communities, given its relatively low capital requirements and the simple technology involved in managing this enterprise.

The third attribute is the existence of a supportive social system. In this context, farmers not only involve their family members but also leverage group-based systems in managing seaweed farming operations. This collaborative approach facilitates the completion of tasks through mutual cooperation, thereby enhancing efficiency and fostering solidarity among community members.

Technological Dimension

The sustainability status of the technological dimension, as measured through four key attributes, yielded an index value of 55.11, indicating a moderately sustainable status (Figure 6). The attributes contributing to this dimension include: (1) availability of information, (2) availability of processing industries, (3) availability of drying facilities, and (4) availability of boats. A leverage analysis was conducted to identify sensitive attributes that significantly influence the sustainability index value of the technological dimension. The analysis revealed that the two most sensitive attributes are (1) availability of processing industries and (2) availability of drying facilities.



Source: Primary Data Processing (2023)

Fig. 3. Role each attribute dimensions technology in continuity business cultivation grass sea

Field observations indicate that the availability of seaweed processing industries remains inadequate, with neither industrial-scale nor home-based processing systems yet established. Consequently, harvested seaweed is typically processed only to the drying stage before being exported to other regions for further post-harvest processing. This attribute requires focused attention to improve the sustainability index within the technological dimension.

The availability of drying facilities for seaweed cultivation in Nain Island recorded an RMS value of 16.65, with most farmers having their own drying facilities. The drying facilities used consist of two types: raised drying platforms (locally known as para-para) and nets spread over sand. While seaweed dried on raised platforms is of higher quality and cleanliness compared to net drying, the adoption of raised platforms remains limited. This is due to the fact that traders offer the same price for seaweed dried using either method, coupled with farmers' immediate need for cash to meet daily living expenses.

The availability of information is considered a non-sensitive attribute in the technological dimension, largely due to the limited access to relevant information. For instance, seaweed price

fluctuations are predominantly determined by traders. As highlighted in the study by Mariati (2007), farmers' awareness of the importance of information is a critical factor influencing their demand for agricultural information.

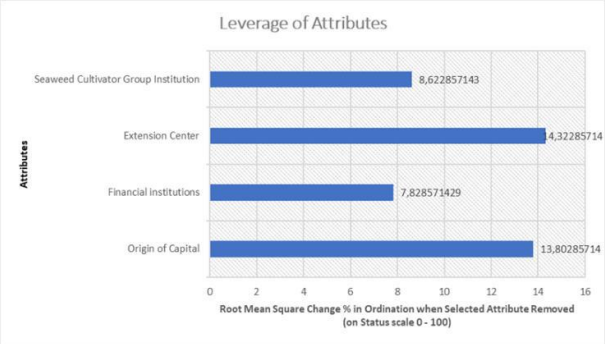
Similarly, the availability of boats is also categorized as a non-sensitive attribute, with an RMS value of 11.06. Boats play a crucial role as a means of transportation to seaweed cultivation sites. However, field observations reveal that most farmers rely on borrowed boats, typically shared within farmer groups. This reflects farmers' limited access to adequate production facilities.

To enhance the sustainability index, effective management of these attributes is essential. This can be achieved by strengthening the role of attributes that positively contribute to the sustainability index while mitigating the negative impact of less supportive attributes. Such an approach is expected to elevate the sustainability status of the technological dimension from moderately sustainable to highly sustainable (Yusuf, 2012).

Dimensions Institutional

Institutional support is crucial in enhancing both the income and production of seaweed farmers. According to Valderrama, Cai, Hishamunda, & Ridler (2013), seaweed farming not only holds high income potential but also requires institutional support for effective management. The Rapfish analysis of the institutional dimension with four attributes yielded a sustainability index score of 13.21, indicating a non-sustainable status. The attributes influencing the sustainability of the institutional dimension include: 1) source of capital, 2) farmer groups, 3) financial institutions, 4) extension services. Leverage analysis identified two influential attributes: 1) extension services and 2) source of capital.

Extension services in seaweed farming, based on field observations, are largely unrecognized by farmers in their farming activities. Consequently, farmers lack up-to-date information and knowledge in managing their businesses, relying solely on their personal experiences. Based on work experience, 21 respondents had 1-6 years of experience, indicating they are relatively new to the business and still require guidance from more experienced individuals. To improve the sustainability of seaweed farming, the government needs to pay more attention to extension services as a means of educating farmers to enhance their businesses.



Source: Primary Data Processing (2023)

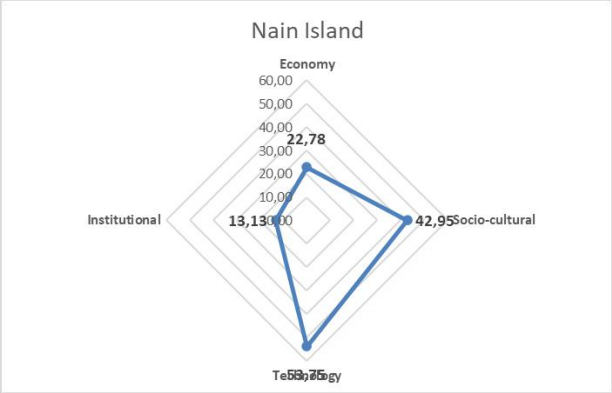
Fig. 4. Role each attribute dimensions institutional in continuity business cultivation grass sea

The second attribute is the source of capital; most seaweed farmers use their own capital to start their businesses, due to the relatively low initial capital required. However, this does not preclude other farmers from obtaining capital loans. Some farmers borrow from traders under the agreement that the seaweed harvest must be sold to the trader who provided the loan.

The third attribute is farmer groups. Fundamentally, farmer groups serve to mobilize human resources among farmers. Farmer group development plays a role in enhancing the knowledge, attitudes, and skills of farmers (Thomas, 2008). The main issue is the lack of farmer group presence, which would support the development policy framework. Farmer groups assist members by facilitating needs ranging from purchasing production inputs to post-harvest handling and marketing (Hariadi, 2011). Financial institutions also support farmers who are part of these farmer groups.

Value Index Continuity from Four Dimensions

The Multi-Dimensional Scaling (MDS) analysis yielded the sustainability status and index for seaweed cultivation activities. The sustainability status reflects the sustainability condition of seaweed cultivation activities along the coast of Nain Island based on the four examined dimensions. The obtained indices are presented in Figure 5.



Source: Primary Data Processing (2023)

Fig. 5. Kite diagram index value continuity from four dimensions activity cultivation grass sea in region Nain Island

The analysis using the Rapfish method indicates that the sustainability index for the economic dimension is 21.03, indicating an unsustainable status. The index for the socio-cultural dimension is 40.96, which denotes a less sustainable status, while the technological dimension has an index of 55.11, signifying a moderately sustainable status. Meanwhile, the institutional dimension has an index of 13.21, indicating an unsustainable status. These indices reflect the sustainability of each attribute based on current management practices.

According to Azis (2011), optimizing seaweed resource management in the coastal region of Bantaeng Regency revealed that the technological and institutional dimensions are less sustainable, whereas the ecological, economic, and socio-cultural dimensions are moderately sustainable. In this study, the institutional dimension is also found to be unsustainable. To enhance the sustainability status in the future, improvements need to be made to the attributes within each dimension.

The sustainability index analysis results for each dimension of seaweed cultivation activities in Nain Island, North Minahasa Regency, fall into the less sustainable category at present. Efforts can be made to enhance the sustainability status by addressing sensitive attributes in each dimension. The sustainability status of seaweed cultivation activities in Nain Island, North Minahasa Regency, can be observed from the index values of each dimension as presented in the following table:

Table 4. Index value and sustainability status of seaweed cultivation businesses in North Minahasa Regency

No.	Dimension	Index Value
1.	Economy	22.78
2.	Socio-cultural	42.95
3.	Technology	53.75
4.	Institutional	13.13
	Average	33.15
	Status	Less Sustainable

Source: Primary Data Processing (2023)

The leveraging analysis approach applied to the economic, socio-cultural, technological, and institutional dimensions enables the identification of sensitive attributes that can serve as references to enhance the sustainability status of seaweed farming on Nain Island. This approach focuses on maintaining and optimizing attributes with positive impacts while mitigating those with negative influences on sustainability.

The results of the Rapfish analysis indicate that all evaluated attributes related to the sustainability status of seaweed farming exhibit a relatively high level of accuracy. This is evidenced by stress values ranging from 13–18% and determination coefficient (R^2) values between 0.91–0.95 (Table 5). According to the literature, the analysis is considered valid if the stress value is less than 0.25 (25%) and the R^2 value approaches 1.0 (Fisheries, 1999 as cited in Aziz, 2011).

Table 5. Results analysis rapfish for mark Stress and Efficient (R^2)

Parameter	Dimensions Continuity			
	Economy	Socio-cultural	Technology	Institutional
Stress	0.17	0.18	0.16	0.13
R^2	0.97	0.95	0.91	0.95

Source: Primary Data Processing (2023)

Dimensions Ecology

The selection of cultivation sites is a fundamental step in determining the success of seaweed farming (Indriani and Sumiarsih, 2003). The selection process should be based on the ecological suitability of the area. Ecological factors influencing seaweed farming include physical, chemical, and biological environmental conditions (Doty, 1988 in Yusuf, 2004). The sustainability indicators of the ecological dimension analyzed in this study are presented in Table 6.

Table 6. Suitability between fact field and theory

No.	Management Attributes	Bad	Good	Scale	Field Facts	Mark
1 .	Planting Season	0	1	Rainy season=(0), dry season=(1)	1	1
2 .	Seed Availability	0	2	not available=(0), rarely available=(1), always available=(2)	2	2
3 .	Seed Quality	0	2	poor=(0), average=(1), good=(2)	1	1
4 .	Depth	0	2	not suitable(<1m->6m)=(0), suitable (1 m- 4 m)=(1), very suitable(4 m-6 m)=(2)	5.93	2

Source: Primary Data Processing (2023)

Based on Table 6, the first indicator is the planting season. Interviews with seaweed farmers revealed that the dry season is the most suitable period for seaweed farming. Yusuf's study (2012) assigned a score of 0 for the rainy season, indicating unsuitability, and a score of 1 for the dry season, indicating suitability for cultivation. This is attributed to the high risk of crop failure during the rainy season due to strong winds and waves that damage the seedlings. Additionally, research by M. Amin et al. (2005) demonstrated that heavy rainfall could stimulate the growth of algae, which hinders seaweed development and triggers diseases such as ice-ice. However, prolonged dry seasons may also pose a risk by promoting diseases like white spot (Pong-Masak et al., 2009; Parenrengi et al., 2011). Thus, while the dry season is more conducive to seaweed farming, it is not without risks.

The second indicator is the availability of high-quality seedlings. Superior seedlings are essential to ensure optimal growth and resilience against unfavorable environmental conditions, such as strong waves. According to Anggadiredja (2006), the success of seaweed cultivation is significantly influenced by seed quality. Field observations indicated that seed availability is generally adequate, although high-quality seedlings are not always accessible. Consequently, farmers often rely on seedlings of moderate quality.

Water depth is another critical factor influencing the sustainability of seaweed farming. Water depth affects temperature stratification, light penetration, and nutrient distribution, all of which impact seaweed growth (Doty, 1987 in Tamrin, 2011). Yusuf's study (2012) developed a water depth suitability scale, where a depth of 1–4 meters was considered suitable (score 1) and 4–6 meters was considered highly suitable (score 2). The average water depth observed at the study site was 5.93 meters, which meets the criteria for seaweed farming. Furthermore, water depth is strongly influenced by tidal conditions, with depth ranges at the cultivation site varying between 1 and 10 meters (Yusuf, 2012).

Considering the sustainability indicators presented in Table 6 and comparing theoretical frameworks with field data, a consistency between the two was observed in the context of seaweed farming. These findings suggest that the study site meets the ecological criteria necessary for successful cultivation.

V. CONCLUSION

1. Based on the results of the Rapfish analysis, the sustainability index for the economic and institutional dimensions was found to be unsustainable, while the socio-cultural and technological dimensions were found to be less sustainable. Sensitive attributes affecting

sustainability consist of 9 out of 16 attributes. For the economic dimension, the sensitive factors include market chain, marketing, and reception. For the socio-cultural dimension, the sensitive attributes are family and other business participation. For the technological dimension, the attributes requiring intervention to improve sustainability status in seaweed farming are the availability of industry and drying lines. In the institutional dimension, the influential attributes are counseling centers and sources of capital. The sustainability index analysis for each dimension of seaweed farming activities on Nain Island, North Sulawesi, Indonesia falls under the category of less sustainable at this time.

2. The research results regarding ecological conditions in seaweed farming businesses on Nain Island align with existing theory that the optimal season for cultivation is the dry season. The availability of seeds is consistent, although the quality is medium because the seeds are reused multiple times. The average water depth for farmers is 6.27 meters, which is in accordance with the theory and suitable for seaweed cultivation activities.

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