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Climate change adaptation in seaweed aquaculture: A survey of farmer knowledge and practices

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Abstract: This study aimed to assess the knowledge level of seaweed farmers regarding climate change and adaptation practices against climate change impacts in Takalar District, South Sulawesi. Data were collected using the quantitative survey method, comprising observations, interviews, and questionnaires with 178 respondents. Approximately 37.64% of the farmers had a rudimentary understanding of climate change, but their insight was limited. However, over 70% perceived its risks and effects, and 64.05% had heard of seasonal changes. For adaptation, 80.34% engaged in early harvesting upon the appearance of disease symptoms, while 77.53% performed crop monitoring twice a day. More than 60% adapted planting schedules and spacing in relation to climate. More than 50% adopted superior seeds and different cultivation methods. These outcomes highlight the ways in which seaweed farmers are already responding to climate challenges and serve as important information for designing stronger forms of adaptation. Such adaptive behaviors can help mitigate possible losses and build resilience in the seaweed farming community. The findings should also help inform climate adaptation efforts in similar coastal communities around the world and contribute to broader discussions about how to sustain agricultural practices in a changing climate.

Keywords: *Adaptation behavior, Climate change impacts, Climate change, Knowledge, Risks, Seaweed farming.*

1. Introduction

Global climate change has emerged as a crucial issue affecting various sectors, including fisheries and marine. Seaweed farming is among the aquaculture subsectors with a significant economic impact and food security in coastal areas [1-3]. Seaweed, a leading commodity, has grown to be a source of income for many coastal households, particularly in nations like Malaysia, the Philippines, and Indonesia [4, 5]. Seaweed products are used in a number of sectors, including food, cosmetics, and pharmaceuticals, contributing to local and national economies [6-8].

Based on BMKG observations, the average air temperature in Indonesia during the period 1991-2020 was 26.7°C; in 2023, the average air temperature reached 27.2°C, indicating an average air temperature anomaly of 0.5°C in 2023. The year 2022 recorded an average rainfall in Indonesia of 2,898 millimeters (mm) year. However, the frequency of rain varies in each region with a reasonably high intensity, and the south Sulawesi region is one of them. Predictions of future temperature increases, changes in high or low rainfall patterns, and wind speeds in Indonesia based on various climate models will vary by region [9]. The fact that climate change will keep changing to evolve in the future emphasizes the importance of understanding how seaweed farmers are perceived and adjusting to the effects of the changing climate.

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Indonesia has more than 70% of its sea area and has allocated 12 hectares for seaweed cultivation hektar [10]. Besides being easy to cultivate, the capital required is also relatively small [7]. An insignificant increase in production was recorded in 2021 at 9.09 million tonnes and in 2022 at 9.6 million tonnes, or a rise of 5.61% % [11]. Still, due to the temperature increase, seaweed quality has decreased, with smaller sizes and lower carrageenan content [12]. In addition, the low quality of cultivated seaweed cultivars is increasingly vulnerable to pest and disease attacks, biotic and abiotic environmental pressures, and climate change [13]. Seaweed farmers rely heavily on cultivation calendars based on weather and seasonal calculations [14]. However, this method is now less effective due to increasingly erratic weather conditions caused by climate change. Extreme heat and heavy rainfall affect seedlings' growth and seaweed farms' development, resulting in a year-on-year decline in production [15].

Climate change has a substantial impact challenge for seaweed farmers, as changes in rainfall patterns and prolonged droughts can interfere with seaweed's life cycle and output [16, 17]. These changes not only impact crop yields but also affect the economic welfare of farming households that depend on seaweed businesses [7, 18, 19]. Therefore, the knowledge of seaweed farmers is crucial in determining how to react to and overcome climate change challenges [20, 21]. This knowledge can be influenced by various factors such as experience and access to information, and technology [22]. Meanwhile, adaptation behaviors undertaken by seaweed farmers include multiple actions aimed at adjusting farming methods, increasing resilience, and lessening susceptibility to climate change's detrimental effects [23].

An in-depth understanding of adaptation behavior is essential [24] to help seaweed farmers improve their welfare and inform policymakers in designing effective programs and policies to support the development of seaweed aquaculture, especially in South Sulawesi. The 1609 seaweed farmers living in coastal areas, particularly in the two research villages of Laikang and Ujung Baji in Takalar Regency, are extremely susceptible to climate change effects, contributing to the loss of natural resources and livelihoods. Prolonged droughts and irregular rainfall patterns are common problems farmers face and are considered the most detrimental risks in terms of monetary losses [25, 26].

Previous research has found various adaptation measures used by farming communities in response to climate variability, as per the findings of Tripathi and Mishra [27] and Belay, et al. [28] stating that adaptation measures to combat climate change include agroforestry, irrigation investment, intercropping, planting short-term crop varieties, changing cropping patterns, and adjusting planting and harvesting schedules. farmers can also conserve soil and water by biological means, including the assimilation of residues. Adaptation measures can also be carried out by managing farm management, income diversification, rituals, innovative mechanisms, and better extension services [29-32]. The findings of Islam, et al. [33] state that farmers' understanding of climate change does not necessarily affect adaptation practices, but the understanding shapes their attitudes regarding the causes of climate change. However, empirically there is little information specific to seaweed farmers and in-depth research on seaweed farmers' level of knowledge and adaptation behaviors to climate change is limited and requires further exploration.

It is estimated that climate change is impacting the maritime industry [34]. Consequently, it is essential to comprehend how various segments of communities that rely on natural resources, like seaweed farmers, react to and adapt to these changes. This study aims to assess seaweed farmers' knowledge and adaptation behaviors in response to climate change. Using survey data from seaweed farmers on climate change impacts, such as prolonged droughts and changes in rainfall patterns, to analyze their adaptation strategies to address livelihood vulnerabilities.

2. Literature Review

Studies on seaweed farmers' knowledge and behavior in adapting to climate change are briefly described in this section. Climate change is the term for long-term changes in global weather and temperature patterns caused by natural or human-induced factors, which have different impacts on different regions and communities and require different adaptation measures [35-37]. Adaptation means adjustments in human environmental systems to respond to climate conditions in order to minimize the risk of climate change impacts or to take advantage of opportunities [25, 38, 39]. Factors that lead to varied adaptation responses in different regions due to climate change include social, economic, and ecological conditions, as well as available infrastructure [40-43]. To implement suitable adaptation measures to lessen vulnerability and boost the resilience of the overall agroecological system, farmers must first comprehend the effects of climate change [44, 45]. Adaptation strategies and behaviors are key components in the adaptation process [46-48]. Misunderstanding can lead to inappropriate adjustment measures [49]. Farmers are more inclined to support laws and actions intended to mitigate the possible effects of climate change if they are aware of these effects [50-52].

Many studies point to the importance of understanding how farmers perceive climate variability and the factors that shape their perceptions to promote adaptive behavior [14, 53, 54]. Adaptability is influenced by various factors, including knowledge of climate change, information, and access to appropriate technologies, organizations, and policies [23, 55-59].

Several countries have researched knowledge and behavior on climate change and adaptation processes, including Ghana [60] Ethiopia [61] Kenya [62] Mexico: [63] Africa [64, 65] Thailand [66] Vietnam [28] Malaysia [67] and only a few studies focus on coastal areas, especially seaweed farmers.

This research provides important indicators for adaptation policies. However, they may be ineffective or difficult to apply to other vulnerable communities, due to differences in hazard impacts, household socio-economic conditions, and varying levels of response [68, 69]. This is especially crucial for the most vulnerable people and resource-constrained coastal communities. There is research on the role of seaweed farming in climate change mitigation and the socioeconomic aspects of seaweed farming in Ross, et al. [70]; Ndobe, et al. [71]; Phang, et al. [72]; Teniwut and Teniwut [73] and Zamroni [74]. Empirically, however, there is limited in-depth research on how vulnerable seaweed farmers are to livelihoods and hazards from climate change impacts, and how knowledge relates to adaptive behavior.

3. Methods

3.1. Study Area

The study was carried out in Takalar District's Mangarabombang and Sandrobone subdistricts. Every subdistrict chose a single village, which is shown in Figure 1. The selection of areas was done purposively with the consideration that Takalar District is the largest seaweed-producing center in South Sulawesi. Laikang and Ujung Baji villages were selected because they have the highest seaweed production and the largest number of seaweed farms compared to other villages in Takalar District. The map of the research area can be seen in Figure 1.

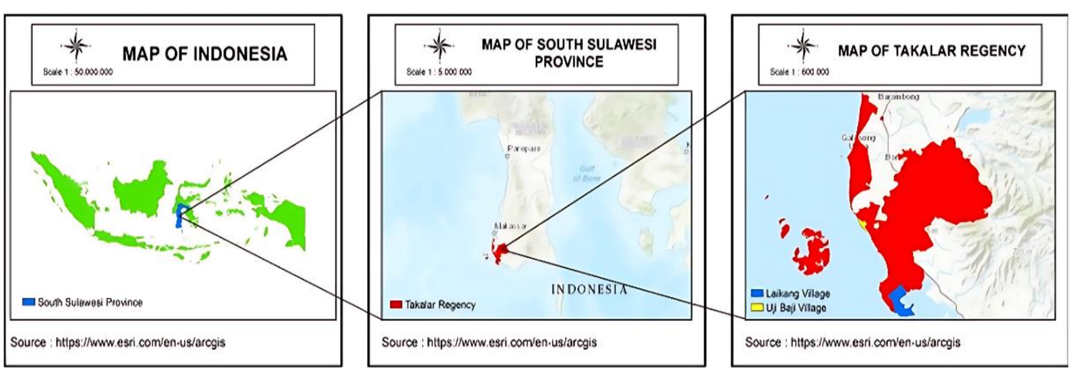


Figure 1.
Map of the study area.

3.2. Sampling

The data used in this study came from a cross-sectional survey of seaweed farmers in two locations: Laikang Village and Ujung Baji Village. The total population of seaweed farmers in Laikang Village was 964 people, and in Ujung Baji Village, it was 645 people; because the number was too large, a sample was drawn using the Slovin formula $n = \frac{N}{N.d^2+1}$, resulting in a sample size of 178 farmers. Data were obtained through actual observations, interviews, and questionnaires by seaweed farmers who became respondents. In addition to collecting data on various socio-economic attributes, the survey also included information on climate change knowledge and adaptation behaviors of seaweed cultivators in the face of climate change. Interviewed respondents were questioned regarding their understanding of climate change definition, seasonal shifts, impacts, risks, and climate change information.

3.3. Data Analysis

The goal of descriptive analysis is to offer an overall picture of the characteristics of rainfall and dry season patterns for five years, from 2019 to 2023, in two research locations: Laikang Village (Cikoang Station) and Ujung Baji Village (BPPK Galesong Station).

Analysis of knowledge and adaptation behavior of seaweed farmers used a quantitative descriptive approach. Descriptively, through interpretation and understanding, then presented in the form of narrative text. To produce quantitative data, the Likert scale is used for measurement in quantitative analysis to determine the length of the interval on the measuring device. To create instrument items in the form of statements or questions, the measured variable is first divided into several indicators. Every item on the instrument has a response on a Likert scale, with positive and negative gradations. Variable identification and indicators can be seen in Tables 1 and 2.

Correlation analysis was used to determine the relationship between two variables, namely climate change knowledge and adaptation behavior of seaweed farmers. After categorizing all data, each score on the independent and dependent variables was matched to construct a cross-tabulation contingency table. Data analysis was conducted using SPSS version 23 software.

Table 1.
Indicators of seaweed farmers' knowledge level on climate change.

Indicators	Operational Definition	Measurement
Climate change definition	Knowledge of the origins, impacts, and solutions associated with long-term variations in global temperature and weather patterns caused by human activities, natural causes, or the effects of greenhouse gas emissions.	Likert scale
Seasonal shifts	Changes in the timing or duration of seasons that come earlier, later, or last longer or shorter than expected based on historical climate patterns, both wet and dry seasons in one year.	Likert scale
Climate change impacts	The impacts of long-term changes in global climate conditions, such as long droughts and shifting rainfall patterns, have the potential to affect the level of productivity, quality, and sustainability of seaweed farming activities.	Likert scale
Risk of climate change	Potential losses or negative impacts arising from climate change on the environment and human life.	Likert scale
Climate change information	Intensity in obtaining information and the sources of information received	Likert scale

Source: Reyes-García, et al. [75] and Reyes-García, et al. [76].

Table 2.
Indicators of seaweed farmers' adaptation behavior to climate change.

Indicators	Operational Definition	Measurement
Determining the planting schedule	The process of planning seaweed planting time based on the dry season and the rainy season	Likert scale
Using superior varieties	It was planting seaweed cultivars with superior traits, such as resistance to pests and diseases, high productivity, good quality, and the capacity to adjust to changing environmental circumstances as a result of climate change.	Likert scale
Location diversification	Strategies used in seaweed cultivation in different locations to reduce the risk of loss.	Likert scale
Spacing according to environmental conditions	Determine the distance between plants based on site conditions to ensure optimal seaweed growth.	Likert scale
Relocating the location	The process of moving the place or area where seaweed is cultivated from one location to another to adjust to environmental changes and reduce the risk of loss	Likert scale
Control 2 times a day	Routine monitoring to ensure seaweed plants are growing well and there are no signs of problems such as pests and diseases.	Likert scale
Harvest when there are symptoms of disease	Actions were taken to harvest seaweed early to prevent more significant losses.	Likert scale

Source: De Jong Cleyndert, et al. [18].

3.4. Model empires

Data analysis was used to see the relationship between the variables of knowledge and adaptation behaviour using the correlation coefficient with the following equation:

$$r = \frac{n \sum xy - \sum x . \sum y}{\sqrt{n \sum x^2 - (\sum x)^2} . \sqrt{n \sum y^2 - (\sum y)^2}}$$

Description:
r = Correlation coefficient
x = Score obtained from all items
y = Total score obtained from all items
$\sum x$ = x distribution
$\sum y$ = y distribution
$\sum x^2$ = x distribution score
$\sum y^2$ = y distribution score

4. Results

4.1. Demographics

Seaweed growers from Laikang Village, Mangarabombang sub-district, Ujung Baji Village, Sanrobone sub-district, and Takalar district were included in the respondents' demographic profile. To understand farmer characteristics and their relationship to climate change adaptation awareness and behavior, a demographic analysis was conducted assessing three main factors: age, education level, and seaweed farming experience.

4.1.1. Age

Age is one indicator that affects a person's success and decision-making ability. Knowledge often increases with age, and people at a productive age usually work more efficiently and optimally than people at a non- productive age [77].

Table 3.
Demographic distribution of seaweed farmers by age group.

Age	Frequency	Percentage (%)
Productive	161	90.45
Non-productive	17	9.55
Total:	178	100

A total of 90.45% of respondents were at productive age (15-64 years old), and 9.55% were at non-productive age (>64 years old). The productive age has a greater physical capacity to perform work efficiently, and older age tends to have better knowledge and experience about environmental conditions [78].

4.1.2. Level of Education

Education level refers to the last formal level completed, such as elementary school, junior high school, high school, and college. Education impacts a person's mindset [79].

Table 4.
Distribution of formal education levels pursued by seaweed farmers.

Level of education	Frequency	Percentage (%)
No School	10	5.62
Primary school	100	56.18
Junior secondary school	45	25.28
High secondary school	22	12.36
Diploma II	1	0.56
Total	178	100

The education level of 56.18% of respondents only completed primary school. They only have enough basic knowledge to understand simple seaweed farming practices. Despite having practical experience, Their capacity is limited by their low level of education to adopt new technologies and information to improve aquaculture business productivity. Higher levels of education, such as senior high school (12.36%) and diploma II (0.56%), frequently possess an innovative perspective, quick to understand new information, able to find solutions, adaptive to change, and effective in dealing with problems and evaluating actions. Education generally influences the mindset of farmers in accepting and implementing innovative ideas [77, 80].

4.1.3. Seaweed Farming Experience

Cultivation experience is the duration of time spent by seaweed farmers running their businesses. Experienced farmers usually understand and know the business better than beginners. The duration of experience is divided into three categories: beginner, intermediate, and experienced.

Table 5.
Frequency distribution of farmers' experience in seaweed farming

Experience (Years)	Frequency	Percentage (%)
Beginners 1-4	32	17.98
Intermediate 5-10	56	31.46
Experienced >11	90	50.56
Total:	178	100

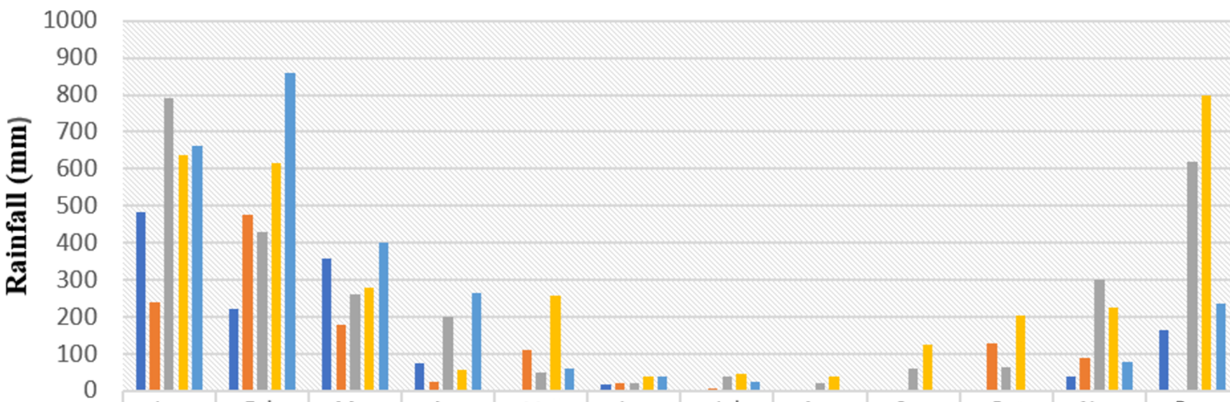
Generally, 50.56% of farmers possessed more than 11 years of experience in seaweed farming (Table 5). This indicates that the farmers' experience has grown, so they have an excellent opportunity to improve the management of seaweed farming in the future. Years of experience in seaweed farming allows them to understand the best planting, maintenance, and harvesting techniques.

4.2. Climate Change in the Study Area

Farmers generally think that climate change is to blame for the extended droughts and altered rainfall patterns that have occurred in recent years. Scientific data for the last five years at two stations in the research area, BPPK Galesong station and Cikoang station in Takalar Regency (Figures 1 and 2) support seaweed farmers' knowledge of prolonged droughts and changes in rainfall patterns.

The average monthly rainfall data for 2019-2023 at GPPK Galesong station shows that the highest rainfall variability changes yearly, as well as the dry season, where the long dry season occurs in 2019 and 2023 from June to October. The average monthly rainfall data at Cikoang station shows that in 2021 and 2022, it rained almost all year round, and the peak of the long dry season also occurred in 2019 from June to October. Rainfall of less than 50 mm for the first 10 days (dasarian) and the next 20 days mark the beginning of the dry season. An area has entered the dry season if, within 10 days, there is less than 50 mm of rainfall, and when summed with the following 20 days, the total rainfall in 30 days is less than 150 mm. Under these conditions, the dry season will begin in the first 10 days when the rainfall is less than 50 mm. The active east winds (Australian Monsoon) from the Australian continent also signal the start of the dry season in Indonesia, while the west winds (Asian Monsoon) that bring water vapor signal the beginning of the wet season [9].

The research locations' climate change is comparable to China's, where the dry season lasts from June to August, especially in the seaweed growing centers' eastern and southern regions. However, rainfall in China is still significant during the summer, so the drought risk is less significant than in tropical countries. The wet season in China occurs during spring, March to May, and early summer. During this period, heavy rains can affect water quality and seaweed growth [81].



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2019	482	221	359	76	5	18	0	0	0	0	39	165
2020	240	475	179	25	110	20	8	0	5	130	88	0
2021	790	430	262	200	50	20	40	20	60	65	300	620
2022	638	615	280	58	258	40	47	40	125	204	225	800
2023	662	858	400	265	60	40	25	0	0	0	80	238

Month

Figure 2.
Average monthly rainfall in the study area from 2019-2023 at BPPK Galesong station, Takalar Regency.

Excessively high temperatures can slow seaweed growth or even cause damage, while a lack of rainfall can increase water salinity and affect the health of seaweed plants. As a result, farmers must adjust cultivation techniques or choose a more appropriate harvest time to minimize losses. Seaweed farmers often face challenges during the long dry season, such as high water salinity and temperature,

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which can slow growth and increase the risk of losses. In contrast, abundant water availability and cooler temperatures can favor seaweed growth during the peak rainy season in December and January. However, too much rain can also bring other risks, such as physical damage to plants from waves or strong currents. Research has shown that while the rainy season can provide certain benefits, such as increased growth, extreme weather conditions can damage aquaculture infrastructure and reduce yields. Therefore, farmers must monitor weather conditions and strengthen their farming structures during the rainy season. A good understanding of these seasonal patterns is crucial for farmers to plan their activities, choose optimal planting and harvesting times, and take the necessary adaptation measures to face climate challenges [82].

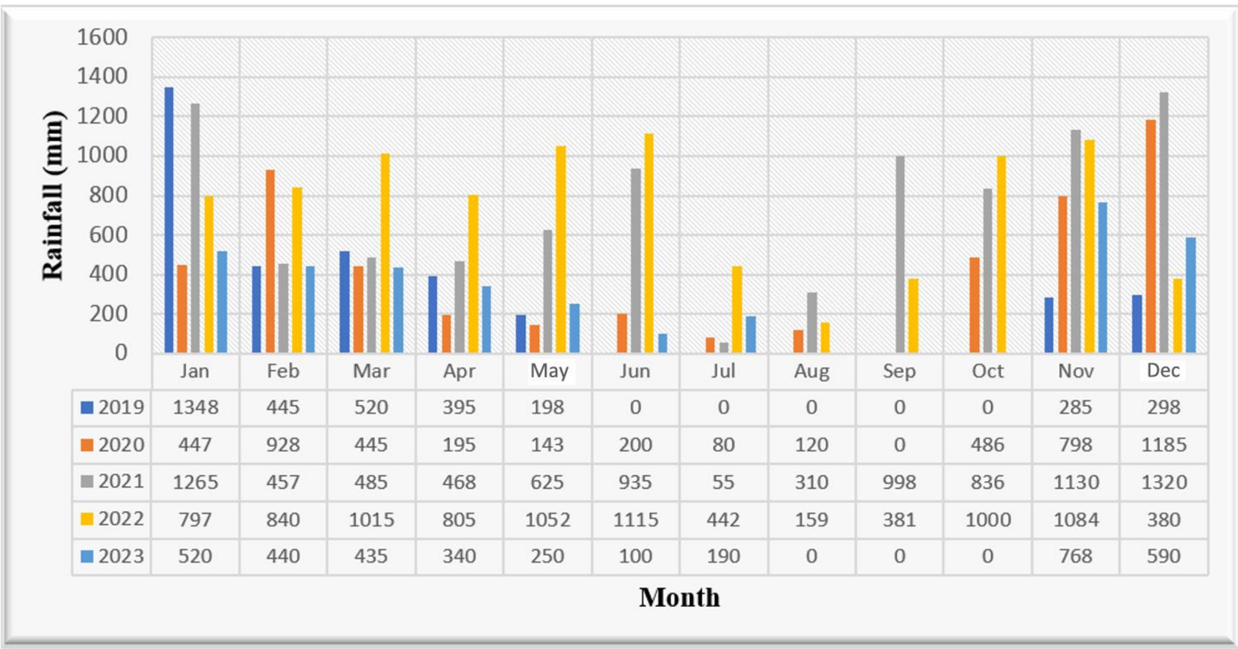

Figure 3.
Average monthly rainfall in the study area from 2019-2023 at Cikoang Station, Takalar Regency.

4.3. Knowledge

Climate change knowledge for seaweed farmers involves understanding how climate change affects water conditions for seaweed farming so that they can decide on adaptation measures to maintain sustainable production. The percentage of seaweed farmers' knowledge level is presented in Figure 4.

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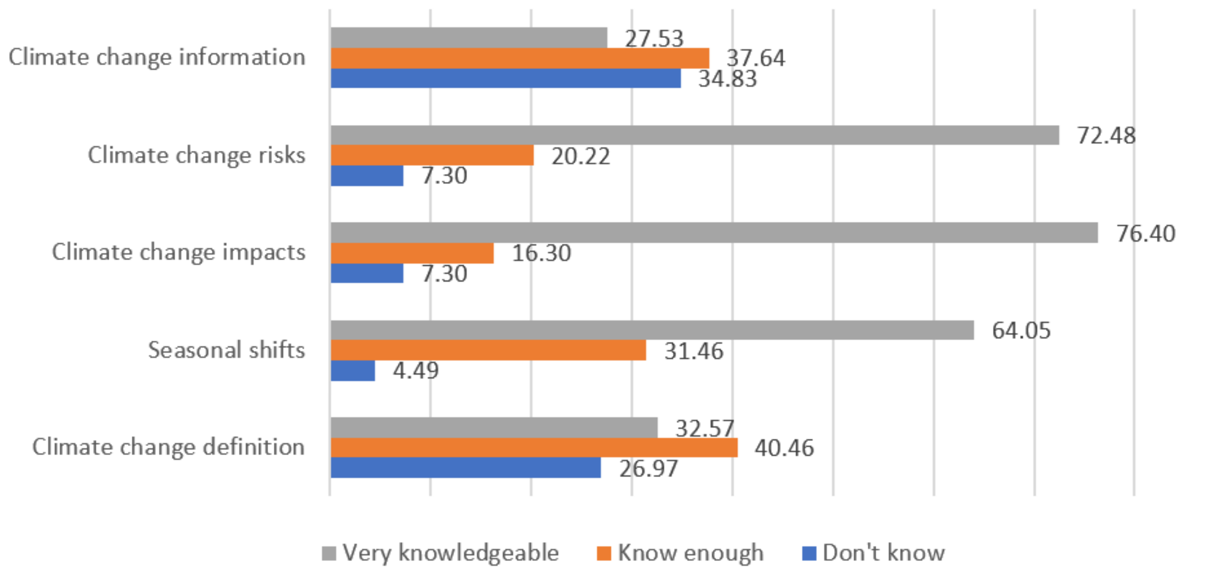

Figure 4.
Percentage of seaweed farmers' knowledge level on climate change.

5.1. Climate Change Definition

Understanding the meaning of climate change is crucial for seaweed growers to make informed decisions about mitigation and adaptation measures. Figure 4 shows that 40.46% of seaweed farmers know about climate change. However, they still do not fully understand some aspects of climate change. Farmers stated that weather patterns change due to human activities such as deforestation and factory construction in various regions. The most common indicators used by farmers in identifying climate change are increased temperatures and changes in the rainy and dry seasons. This awareness encourages them to be more responsive and adaptive to changing environmental conditions timing. This response positively impacts the sustainability of seaweed farming, where they apply more adaptable tactics to deal with the problems caused by climate change. In light of the study's findings [83] stated that climate change knowledge significantly increases adaptation behavior among farmers.

5.2. Seasonal Shifts

Climate change impacts seasonal shifts; 64.05% of farmers are aware of seasonal shifts because of climate change within the past five years. This shows that there is an awareness of changes to their farming business. Generally, farmers often interpret climate change as the transitional season, the transition between the rainy and dry seasons that is irregular and more difficult to predict. The transitional season is characterized by sudden changes in weather, including heavy rains, wind, or temperature swings. These changes directly impact climate change, as farmers experience difficulties determining planting, maintenance, and harvesting times. The belief of the phenomenon of seasonal shifts among farmers is that the season usually changes every 6 months, but in recent years, the dry season can be longer, and the rainy season can be shorter and vice versa. This has implications for the sustainability of seaweed businesses, as they must find new ways to adapt to the increasingly unpredictable weather that disrupts the cropping cycle.

5.3. Climate Change Impacts

Climate change significantly impacts seaweed farming, affecting the environmental circumstances necessary for the best growth. 76.40% of seaweed farmers recognized that climate change significantly impacts farming, which depends on stable marine environmental conditions. Seaweed farmers observed that climate warming has caused extended droughts and altered rainfall patterns, which have increased both seawater and air temperatures, whereas, during the dry season, the air temperature and seawater temperature are scorching, in addition to an increase in salinity. Scorching seawater temperatures cause seaweed to fall off or be damaged easily, so respondents often experience losses. Most seaweeds grow well in the optimal temperature range of 25 -300C, especially for tropical seaweeds such as Eucheuma sp. and Gracilaria sp., which respondents generally cultivate. According to the researchers [84, 85] the extended dry season leads to a rise in seawater temperatures to 33-350C, resulting in seaweed bleaching, also known as ice-ice (white spot). In addition, during prolonged droughts, high salinity causes stunted seaweed growth. Faster evaporation of seawater during droughts can increase water salinity, causing stunted seaweed growth compared to that growing at optimal salinity. The decrease in growth rate is related to osmotic pressure that disrupts physiological and metabolic processes and inhibits photosynthesis, resulting in stunted growth [86, 87].

Another impact farmers feel is the changes in rainfall patterns that have occurred in recent years, relying on observation and natural signs, namely, if salinity decreases, the seaweed physically looks pale or shows signs of swelling and flabbiness. The pale color is considered a decrease in quality and affects the selling price. Eucheuma sp. seaweed requires a relatively narrow range of salinity to grow optimally, between 28-35 ppt [88]. According to the research Erbabley and Kelabora [84] decreasing salinity affects seaweed's osmoregulation process. When water salinity decreases, the seaweed absorbs more water, resulting in the seaweed becoming brittle and slowly starting to fall off. Farmers also observed that strong currents due to changes in rainfall patterns caused physical damage by breaking or tearing the tallus and seaweed quickly escaping the bonds carried by the currents. According to Rohman, et al. [89] the ideal current for seaweed growth ranges from 0.2 to 0.4; the current has too large a negative impact on seaweed. During the rainy season, reduced light intensity causes the growth of the tallus not to develop, so the resulting production is small. According to research Wong [90] a decrease in light intensity can reduce the rate of photosynthesis, and there is a decrease in biomass and discoloration, which indicates inhibited thallus growth. The lack of sunlight makes seaweed more susceptible to diseases like ice-ice disease, sea moss, and Mollusca (small clams) attached to seaweed.

5.4. Climate Change Risks

Climate change brings a range of risks that impact the environment and people. 72.48% of seaweed farmers know the risks they face due to climate change. They often experience crop failure and losses due to pest and disease attacks triggered by climate change. Pests and diseases, such as moss, snails, fungi, and ice-ice disease, actively attack seaweed during the long dry season. The findings of studies conducted by Ward, et al. [91] said that high temperatures are one of the factors that cause ice-ice illness to develop. Farmers also face the risk of crop failure in the wet season caused by physical damage to the seaweed, such as broken plants drifting away by currents and waves. In addition, the risk farmers face is that every year in the rainy season, high rainfall intensity causes flooding because the area has a poor drainage system and cannot handle the volume of water, so they are worried about experiencing negative impacts in the future. Likewise, coastal abrasion occurs annually with a loss of 3 to 4 meters of shoreline. However, it is not comprehensive in the study area because most of the area has a more complex rock substrate. As stated in Tanner [92] beaches dominated by rigid rock substrates have more stable shorelines and are less affected by storms and high waves.

5.5. Climate change information

Seaweed farmers are extremely reliant on environmental circumstances such as seawater temperature, salinity, and weather, all affected by climate change. Therefore, they need to obtain appropriate and up-to-date climate change information to make the necessary adaptations. 34.83% of seaweed farmers were informed about climate change. They obtained their information through counseling and the Internet. They stated that many online educational platforms and video tutorials helped them learn about new practices in seaweed farming, techniques for adapting to climate change, and technological innovations that can increase productivity. However, despite the availability and usefulness of this information, they have not adopted these new practices and technologies due to various limitations**.** 37.64% of farmers moderately agreed that they obtain information by searching for it online or on social media. However, the information received is still not detailed and comprehensive enough to be effectively applied in seaweed farming activities. They strongly expect an increase in education and socialization related to climate change. Both through training programs, counseling, and technological support, so that they are better prepared to face the various challenges arising from climate change.

5.6. Adaptation behavior

Adaptation behavior refers to how seaweed farmers adapt to the changing climate and this is critical to ensuring the viability of seaweed farming. Figure 5 presents the percentage of adaptation behaviors undertaken by farmers.

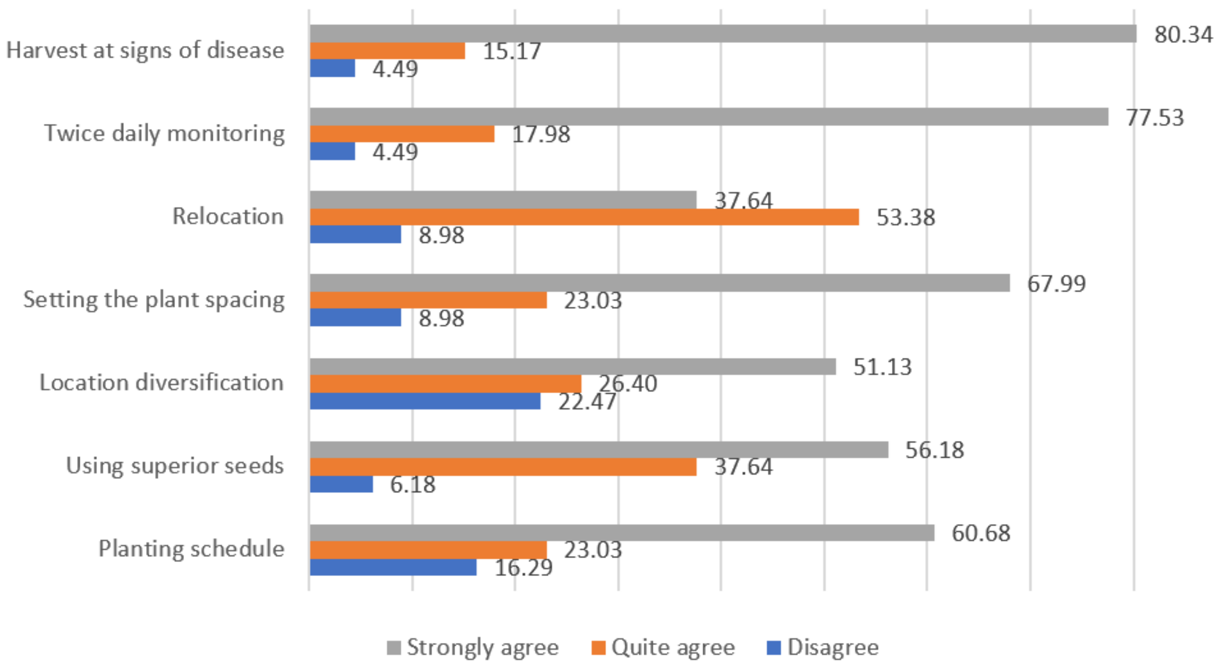

Figure 5.
Percentage of seaweed farmers' adaptation behavior to climate change.

5. Determining Planting Time

One of the strategies seaweed farmers use to adapt to climate change is to determine planting times. This is done because of the erratic seasonal changes that are difficult to predict now. 67.68% of farmers schedule planting and plan carefully to optimize seaweed growth and avoid losses due to extreme weather conditions. They stated that climate change makes crop yields more uncertain. Therefore, farmers need to determine planting schedules by taking into account when the arid seasons and pluvial seasons occur to lower the chance of crop failure. The research results [93] that it is essential to make appropriate adjustments to the cultivation season in order to avoid periods of extreme weather and ensure optimal seaweed growth. During the dry season, planting starts when seawater conditions are still relatively stable and salinity is not too high while planting in the rainy season starts in the period when rainfall is not too high to reduce the impact of the decrease in salinity. 23.03% agreed with the planting schedule but did not know precisely when to start planting, so they planted when most other

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farmers had already started planting. Only 16.29 percent of farmers did not follow a fixed schedule; they planted immediately after harvesting. They choose to face the risk and continue planting. One strategy seaweed farmers employ to adapt to climate change is adjusting their planting schedules. This approach is necessary due to the increasingly unpredictable and erratic seasonal changes. However, if they do not have debts, at times they opt not to plant to minimize the chances of failure.

5.1. Using Superior Seeds

One way to adapt to climate change is to use better seeds that are more resilient to constantly shifting climatic conditions. 56.18% of farmers use varieties suitable for environmental conditions, generally in Laikang Village, cultivating Eucheuma Sp. grass *(E. cottonii and E. spinosum*). Meanwhile, in Ujung Baji Village, they generally cultivate *Galsilaria Sp.* Both areas have different water conditions. 37.64% of farmers stated that they use the same seeds as other farmers and that these varieties have been cultivated for generations. Only 6.18% of farmers stated that they just continued the existing practice without evaluating the quality of the seedlings. They do not know whether the seedlings are superior or not. This is generally the case for farmers who have only cultivated seaweed for 1-3 years.

5.2. Location Diversification

One crucial adaptation tactic in the face of climate change issues is site diversification, helping farmers to be more flexible and resilient. 51% of farmers diversify their locations with three or more locations to reduce the risk of loss. 26.40% do not regularly diversify and only do so when they have sufficient resources. Diversification is done to find out which locations have good seaweed growth. Only 22.47% of farmers did not diversify because they only had one location. Farmers planted seaweed in several locations at the beginning of the dry season or when entering the rainy season. They only lowered 15-20 rope stretches as an experiment and monitored these locations to determine the places with the best seaweed growth. This diversification of locations is done to reduce the risk of loss each place has a unique set of environmental factors, other places might not be as affected if one is plagued by pests and diseases or if the water quality shifts in a way that could damage seaweed plants. Diversity in cultivation locations can help mitigate climate change and buffer against negative impacts from unforeseen environmental factors [94].

5.3. Setting the Plant Spacing

A total of 67.99% of farmers adjust the spacing of the planting ropes to 25-30 cm when the water conditions are stable, but if the currents and waves are strong, the spacing is stretched to 40-50 cm to reduce the possibility of friction and damage to algae plants. In addition, farmers reduce the number of rope stretches during high rainfall in the rainy season to reduce the risk of more significant losses. Large waves and fierce winds frequently accompany the rainy season. According to research by Millar, et al. [95] strong currents and waves can damage plants and affect growth, while weak currents and waves tend to favor growth by increasing water circulation and nutrient delivery. In addition, farmers lower the plants more profoundly into the water during solid currents and waves by adding buoys (plastic bottles filled with water) so that the ropes descend deeper, where the waves and currents are weaker. Generally, seaweed is submerged about 1 - 2 meters deeper than the water's surface during solid currents and waves to protect the plants from the physical forces of waves and currents that can damage plant structures and disrupt growth. After the waves weaken, farmers raise the seaweed plants by reducing the number of float bottles. This is done so that the plants again get enough sunlight for photosynthesis. Likewise, farmers adjust the planting position during the rainy season by raising or lowering the plants based on high or low rainfall intensity. Farmers lower the seaweed planting position to about 50 cm from the water surface during this season. When associated with water conditions with high rainfall, this measure aims to avoid low salinity at the water surface. Although short-lived, freshwater can affect seaweed's osmoregulation process [91, 96]. Only 8.98% of farmers do not do plant spacing because the location is far away and requires much labor, making it difficult to make precise and consistent arrangements.

5.4. Relocation

Farmers move their farming sites to deeper waters when environmental conditions change, causing seaweed plants to become infested with pests and diseases. Generally, farmers move the location during the dry season, where the water temperature is hotter, especially in shallow waters. According to research by Makame, et al. [97] seaweed cultivation in deep waters (0.5 meters deep at receding tide and 3-5 meters deep at rising tide) is considered an effective solution to deal with and adapt to increasing temperatures and the threat of disease. Only 37.64% of farmers routinely relocate because they have adequate resources. 53.38% of farmers do not intensively relocate, even though they have multiple sites, because relocating their farms is costly, especially for labor and transportation. 8.98% do not move their farms because they only have one location.

5.5. Twice daily monitoring

Regular control is a form of active response that helps seaweed farmers adapt and remain productive amid uncertain sea conditions due to climate change. As many as 77.53% of farmers control their seaweed plants twice daily to monitor for potentially harmful pests and diseases. They conduct monitoring in the morning and evening or when the sea water has receded. Farmers stated that pest infestations are difficult to detect early and can develop quickly. Therefore, frequent control is necessary. Regular monitoring can quickly identify early signs of pest infestation before it spreads and extensively damages the crop, thus preventing significant losses and ensuring the crop remains healthy. A total of 17.98 percent do not routinely carry out twice-daily controls due to time constraints, especially for those with other sources of income outside of seaweed farming. Meanwhile, only 4.49% of farmers who did not carry out twice-daily control stated that it was impossible to carry out twice-daily control due to the location's distance.

5.6. Harvest at signs of disease

Cultivators harvest early when there are symptoms of ice-ice disease is one way to reduce potential losses. 80.34% of farmers stated that to avoid more significant losses, they must harvest immediately if symptoms of the ice-ice disease appear on some plants and replace them with healthy plants. The ice-ice disease spreads quickly, with plants turning white, wilting, and eventually dying. However, they only remove the infected parts if only 1 or 2 plants are affected. A total of 15.17% stated that they sometimes harvest late due to unfavorable weather, such as big waves that make it difficult to take immediate harvesting action. Only 4.49% said they did not harvest immediately because the location was far and difficult to reach, especially during bad weather conditions.

5.7. Correlation Analysis Results

Table 6 shows the correlation of knowledge level on climate change and adaptation behavior with a 0.730 correlation coefficient, which means there is a strong, significant correlation. The higher the farmers' knowledge about climate change, the more significant the change in adaptation behavior carried out by farmers. According to the research conducted by Asrat and Simane [98]farmers are aware of the effects of climate change. However, this understanding does not always translate into concrete actions to reduce its impact. They face limitations regarding resources and support needed to implement broader and sustainable changes in their cultivation practices. This means that changing climate conditions are demonstrably forcing seaweed farmers to adjust their strategies to substantially survive or maintain their productivity. An adaptation response is not just a tiny response but a clear and significant change in behavior. Adaptation is necessary to lessen the negative effects of climate change on ecosystems and people [99].

Table 6.
Correlation between knowledge level and seaweed farmers' adaptation behavior to climate change

		Climate change knowledge	Adaptation behavior
Climate change knowledge	Pearson Correlation	1	0.730**
	Sig. (2-tailed)	178	0.000
	N		178
Adaptation behavior	Pearson Correlation	0.730**	1
	Sig. (2-tailed)	0.000	
	N	178	N

Note: ** Correlation is significant at the 0.01 level (2-tailed).

6. Discussions

A wide range of literature has examined how people's understanding of climate change affects their daily lives. This includes whether understanding and awareness cause environmental changes like carbon emissions, lifestyle changes, or environmental policy changes [100-102]. However, the majority of existing research relies on snapshots of knowledge and adaptation behavior observed at a particular moment in time, which makes it challenging to examine the dynamics of change within a population and frequently lacks the detail necessary to investigate how climate change affects people's or communities' long-term decision-making.

This study extends the literature by using a cross-sectional dataset of 178 seaweed farmers in two villages in Takalar District over five years to assess a) how climate change is occurring in the study sites? b) What is seaweed farmers' knowledge of climate change, and c) the relationship between climate change knowledge and adaptation behavior? Overall, only 40.46 percent of seaweed farmers are aware of climate change. This suggests that, by definition, farmers are aware of climate change but still require additional education. They have recognized signs of change, such as erratic rainfall patterns or prolonged dry seasons. However, their understanding is still limited to direct experience without the support of adequate scientific information. This is a positive sign for policymakers to support *them*, as more detailed and scientifically-based information on climate change, long-term weather predictions, and effective adaptation strategies can significantly assist with expert assistance or access to relevant knowledge resources and enhance their capacity to adapt to climate change. The adaptation behavior of farmers with the highest percentage, 80.34%, was harvested when there were symptoms of disease attack. In addition, 77.53% of farmers conducted routine control twice a day, as well as determining planting schedules and adjusting plant spacing according to environmental conditions on average >60%, diversifying locations and using superior seeds on average >50% (comparable to the study's findings [103].

This study's findings show evidence that in the last 5 years, seaweed farmers have experienced seasonal shifts and changes. The dry season has become longer, and there have been changes in rainfall patterns. Seaweed farmers often attribute the long dry season to increased seawater temperature and salinity, which can inhibit seaweed growth, especially species such as *Eucheuma* cottonii, which are susceptible to water temperature and salinity changes. Likewise, erratic rainfall patterns, including unseasonal rains, lead to pest and disease risk issues and increased tides that can raise the possibility of crop failure (similar research results of Erbabley and Kelabora [84] and Rohman, et al. [89].

Generally, seaweed farmers are aware but not in-depth about climate change. They have to deal with weather uncertainties that have been part of their lives for a long time. The critical question is how farmers can be assisted in adapting to increasingly uncertain weather conditions in the future, especially by understanding the complex correlation between their knowledge of climate change and the adaptive behaviors required. Although our results clearly show that climate change knowledge significantly affects adaptation behavior, De Jong Cleyndert, et al. [18] recommend cultivating seaweed in deeper waters and using new technologies to cope with rising temperatures. We recommend that the government facilitate farmers with information and training focused on climate risk management and adaptation strategies to improve farmers' understanding and preparedness for climate change and increase monitoring and research efforts about mitigating the consequences of climate change on marine environments to understand better the changes occurring and how to adjust farming practices.

The tiny sample size is one of our study's weaknesses (n = 178) and the fact that the study only included data and knowledge from five years of seaweed farmers. The small data size also did not allow us to classify the data based on seaweed farmer typologies (e.g., ocean-grown versus pond-grown). We also had limitations in accessing information on climate data as the BMKG's detection tools relating to changes in temperature, light intensity, wind speed, and wave height were not yet available. As a result, seaweed farmers have difficulty obtaining adequate weather forecasts or early warning systems, which are not well documented. These limitations suggest the need for further research that is more inclusive, participatory, and comprehensive to understand the difficulties that seaweed farmers encounter as a result of climate change.

7. Conclusions

Farmers who perceive the problems posed by climate change are likely to modify their adaptation options and apply more appropriate adaptation tactics. A significant, very strong exist correlation between climate change knowledge and adaptation behavior, meaning that climate change is not only perceived but also drives action among seaweed farmers to secure their livelihoods. The higher their knowledge of climate change, the more likely farmers are to adopt adaptation steps to mitigate risk and increase productivity. Given the risks that seaweed farmers face due to climate change, the government can provide extension programs, availability of details regarding climate change, and the development of adaptive technologies. Policy support in the form of technical assistance plays an important role in strengthening the adaptive capacity of farmers to the impacts of climate change in order to maintain the sustainability of seaweed farming businesses.

Transparency:

The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

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