EFFICIENCY AND PROFITABILITY ANALYSIS OF SEAWEED FARMING IN THE SOLOMON ISLANDS: A CASE STUDY FROM WAGINA, CHOISEUL PROVINCE.

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This paper should be cited as: Ngwaerobo, J. 2024. *Efficiency and profitability analysis of seaweed farming in the Solomon Islands: A case study from Wagina, Choiseul Province.* GRÓ Fisheries Training Programme under the auspices of UNESCO, Iceland. Final project. https://www.grocentre.is/static/gro/publication/1902/document/Ngwaerobo23prf.pdf

ABSTRACT

Seaweed *Kappaphycus alvarezii* has great potential to be a multimillion-dollar industry in Solomon Islands, however, production has not changed significantly over the last ten years. Wagina, one of the high-production islands, was chosen for this study to aid in the identification of the underlying problem. The objective of this study was to analyse the profitability and efficiency of various production scales and offer suggestions for improvement. Using Yamane formulas to calculate the appropriate sample size, 78 farmers were selected for the study and interviewed using a questionnaire. Stochastic Frontier Analysis (SFA) in the R software was used to evaluate the acquired data for Technical Efficiency (TE), while Net Present Value (NPV) and Internal Rate of Return (IRR) were used to examine the data for profitability. The results showed that the TEs for small-, medium-, and large-scale farms were 0.83, 0.87, and 0.44, respectively. The production of the farm was found to be greatly impacted by variables, including labour, age, experience, education, length of lines, construction, and farm size. On a medium scale, however, it was discovered that the factors of construction, number of plots, number of lines, and line length had a significant effect on production. For small-scale farms, no significant differences were identified for any of the variables. In terms of inefficiency, it was found that the number of lines, number of seeds per line, farm size, number of plots, age, and household might all lower efficiency for medium-sized farmers as well as for large farms. In terms of profitability, research conducted on small-, medium-, and large-scale farms revealed that each was profitable, albeit at a different scale based on the inputs and outputs of each scale. After a period of five years, the NPV for small-, medium-, and large-scale companies was USD 3,682.6, USD 8,004.5, and USD 52,337.7, respectively. Similarly, at the end of the five-year period, the IRR for small-, medium-, and large-scale farms was 26.8%, 33.5%, and 43.6%, respectively. According to the study's findings, small- and medium-sized farmers are making the best use of the resources at their disposal to produce at the greatest potential level. However, although there is space for development, the overall farm production process has certain inefficiencies. Production scale boosts profitability and efficiency. Although large-scale incomes can be rather substantial, many farmers cannot afford the necessary inputs. More comfortable possibilities for livelihood and growing output are provided by small and medium-sized farmers.

Keywords: Seaweed farming, technical efficiency, profitability, *Kappaphycus alvarezii,* Solomon Islands.

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1 INTRODUCTION

1.1 Status of the global seaweed fishery

Seaweed aquaculture is the fastest-growing aquaculture globally, second only to finfish aquaculture (FAO, 2022). Ninety-five percent of its cultivation occurs in Southeast Asia, East Africa, Latin America, and the Pacific Islands, with an estimated production of over 35 million metric tons (FAO, 2022) and a value of over USD 11 billion (FAO, 2020). Over the years, seaweed has gained prominence in various industries, including food and pharmaceuticals to cosmetics and biofuels, making it a sought-after product in the market, especially in Asia (FAO, 2022). There are more than eight different seaweed species farmed worldwide, the most common of which are shown in Figure 1 along with their respective production status. The common species cultured in the Asia-Pacific region are tropical seaweeds (*Kappaphycus alvarezii* and *Eucheuma* spp.) owing to their remarkable adaptability, short development period, and resource sustainability (Zhang et al., 2022), as well as conducive environment for farming.

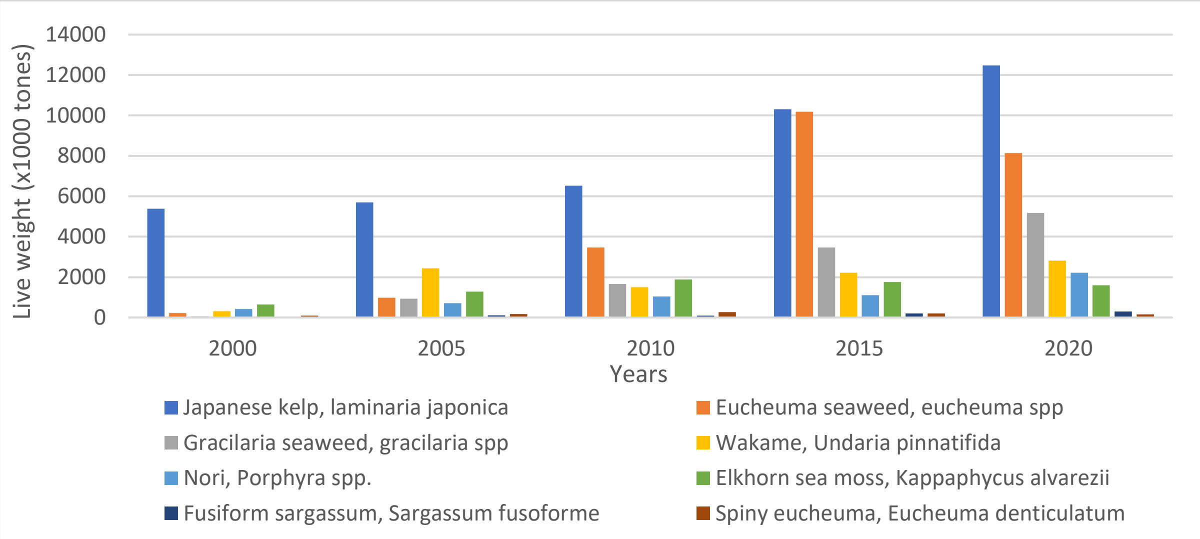

Figure 1. Commercial seaweed species farmed worldwide.

1.2. Tropical seaweed (*Kappaphycus alvarezii*)

K. alvarezii is a red algae indigenous to the Philippines and is the fifth most cultivated alga worldwide (Rudke, De Andrade, & Ferreira, 2020) (Figure 2). Most of its production occurs in the Philippines; however, in 2008, Indonesia took over and became the leading producer (Kambey et al., 2020; Porse & Rudolph, 2017; Zhang et al., 2022), with 11 million metric tons produced in 2015 and 2016, and similar production levels in 2017 and 2018 (FAO, 2020). Owing to its fast growth rate (up to 10.7% daily growth rate (DGR), high yield of 150–200 kg fresh biomass, in a 45-day cycle (Mantri et al., 2022), well-developed farming methods, and remarkable adaptability, it is easy to cultivate. Economically, *K. alvarezii* is an important raw material for carrageenan extraction and has been the major driver of the increase in farmed seaweed production (FAO, 2020). In the Asia-Pacific region, *K. alvarezii* is farmed in countries such as the Philippines, Malaysia, Indonesia (FAO, 2020), Solomon Islands, Fiji, Kiribati (Pickering, 2006), and recently in Papua New Guinea.

Figure 2. Tropical seaweed, *Kappaphycus alvarezii*.

1.3. Overview of the seaweed industry in Solomon Islands

1.3.1 Background of seaweed farming in Solomon Islands

The history of seaweed farming in the Solomon Islands traces its origins back to 1988, marking its initial introduction by the UK Overseas Development Agency (ODA) at VonaVona Lagoon and Rarumana in the Western Province of Solomon Islands (McHugh, 2006) (Figure 3). The project was designed for one year and a total of five metric tons were produced; however, it was affected by fish grazing. In 2000, the fisheries department, now known as the Ministry of Fisheries and Marine Resources (MFMR), used the reserved seaweed stock from VonaVona and conducted a trial run in Rarumana, where 600 kg were produced in 2002. This is when the European Union (EU), Secretariat of the Pacific Community (SPC) and the fisheries department came together and organised the first ever seaweed training for the farmers (McHugh, 2006). Since then, seaweed farming has gained momentum and has slowly spread to other provinces. The timeline of seaweed development in Solomon Islands is shown in Figure 4.

Figure 3. Vonavona Island where seaweed was first introduced.

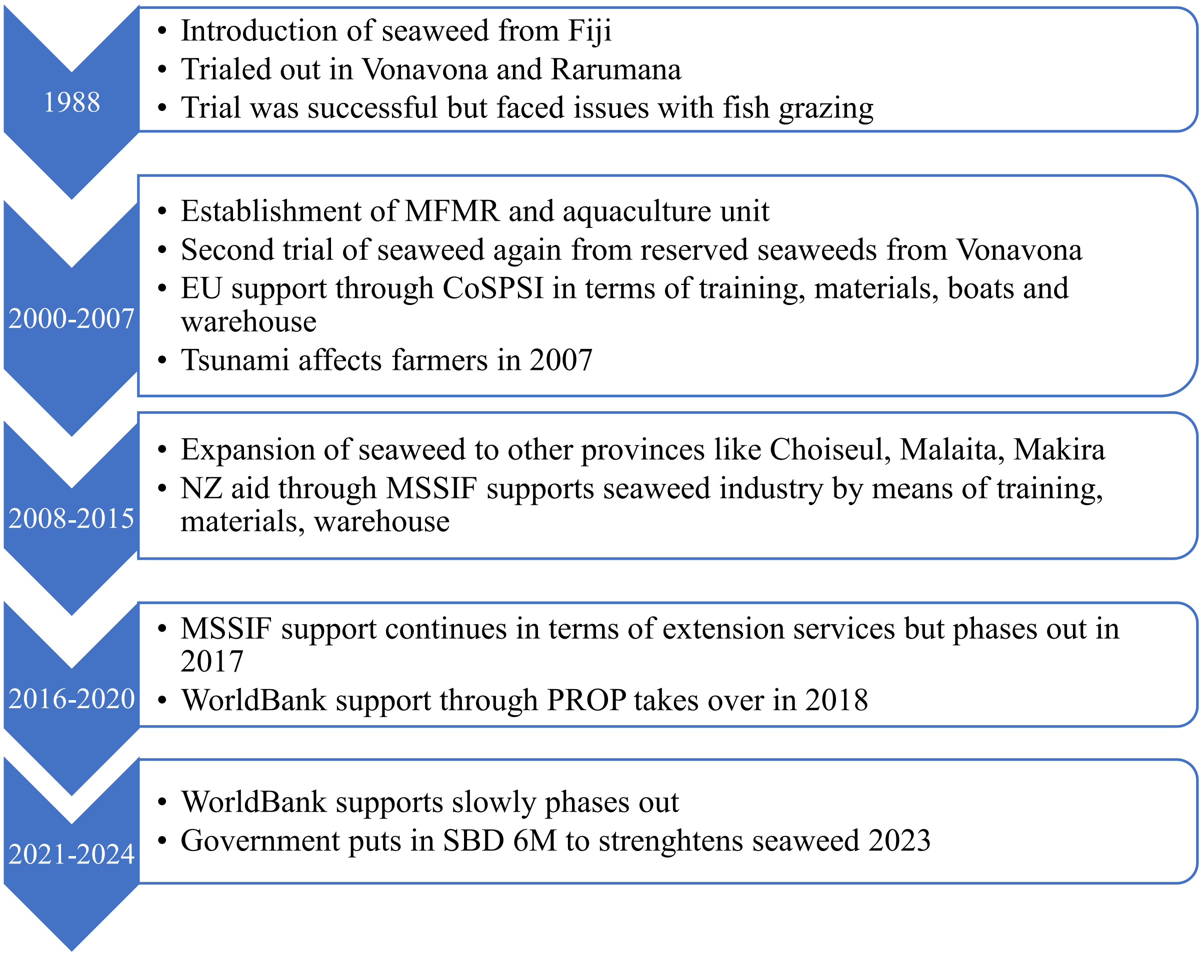

Figure 4. Timeline for seaweed development in Solomon Islands.

1.3.2 Seaweed production

There are approximately 22 seaweed sites in the Solomon Islands; however, currently, less than ten sites are active, with 584 active farmers, of which 320 farmers are from Wagina (MFMR, 2023). Over the past 20 years, the seaweed production trend has been characterised by distinct phases of growth, fluctuations, stabilisation, and occasional declines and rebounds (Figure 5). Beginning in 2002 with a modest annual production of 4 metric tons, the industry quickly gained momentum and experienced exponential growth until 2005, when production peaked at 321 metric tons. This initial phase reflected an increase in interest and interventions in seaweed farming. Subsequently, from 2006 to 2010, the industry entered a period of fluctuation, with production levels varying between 167 and 874 metric tons due to natural disasters and market dynamics. Despite these fluctuations, overall growth persisted and led to a more stable phase from 2011 to 2016, during which production consistently exceeded 1000 metric tons. This period indicated a maturing industry and the impact of interventions. However, from 2017 onwards, seaweed production experienced a notable decline, reaching its lowest point at 530 metric tons in 2017, followed by a rebound in 2020 to 1338 metric tons. The fluctuations during this period may have been driven by various factors, including market dynamics, sea cucumber open seasons, and the phasing out of interventions. Despite these challenges, production was maintained at 1250–1400 metric tons from 2021 to 2022.

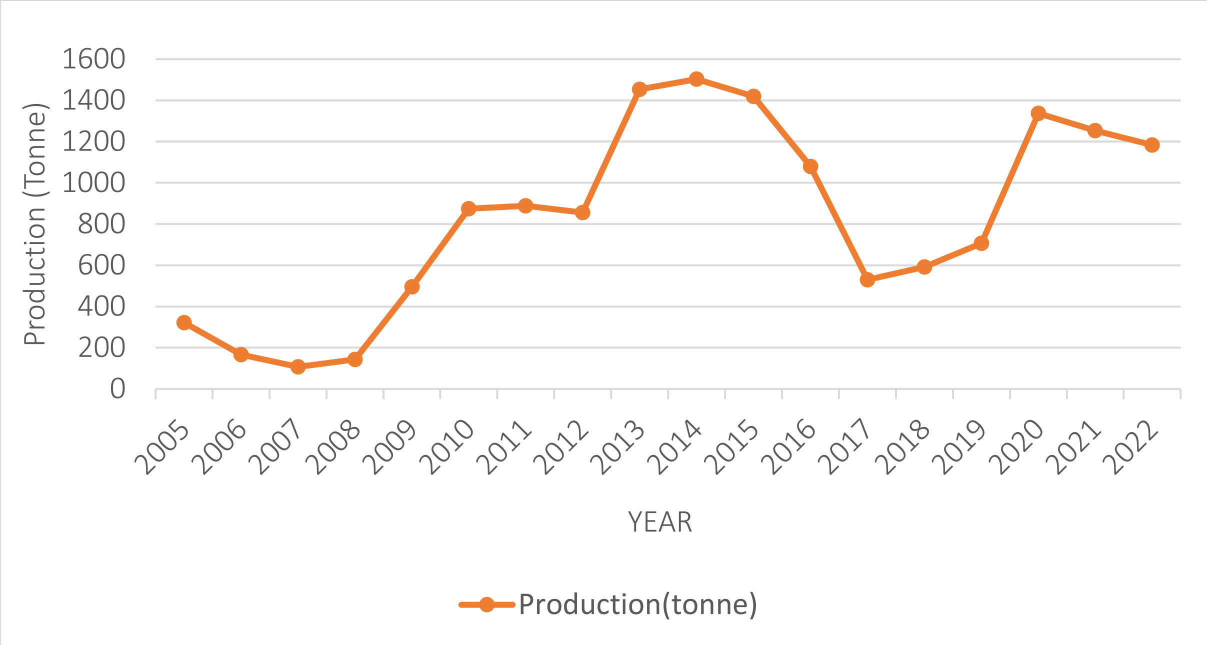

Figure 5. Annual seaweed production in Solomon Islands from 2005-2022.

1.3.3 Seaweed farming practices

Seaweed farming methods and techniques have evolved since their introduction, and advancements in farming systems, such as the integration of technology, may have played a crucial role. In Wagina, the seaweed farming system is intricately linked to the geographical features of the area, influencing the choice of farming methods. Given the prevalence of sandy flats and reef banks, the off-bottom method, specifically stick-to-stick cultivation, is predominantly employed (Figure 6). Seeds for cultivation are reserved or sourced from the farmers themselves during harvest, and mutual collaboration among farmers allows for seed supplementation if needed. The main plant lines vary in thickness, with 6 mm/ 5 mm and rarely 4 mm, while tie-tie or loops utilise 3 mm/ 2 mm, and anchor ropes employ 10 mm/ 12 mm.

The cultivation process involves hanging seeds (cuttings), weighing approximately 150–300 g, onto lines using loops or ties, with a spacing of 20–30 cm between each plant during planting (Figure 7). Harvesting occurs after 6–8 weeks, and the entire plant is manually collected and transported to the shore by boats for drying (Figure 7). However, studies have shown that harvesting at day 45 will yield good results in terms of quality and yield of carrageenan (Periyasamy, Subba Rao, & Anantharaman, 2019). Drying is primarily done by sunlight on a platform above the ground, with the process taking 5–7 days on sunny days or up to a month(s) on cloudy days or during the rainy season. Quality assurance is achieved through awareness, training, and experiential learning among farmers. Buyers assess the dryness of the product; anything still wet is considered of low quality and requires further drying. Threats to seaweed farming can range from rising temperatures, strong currents, fish grazing, and natural disasters.

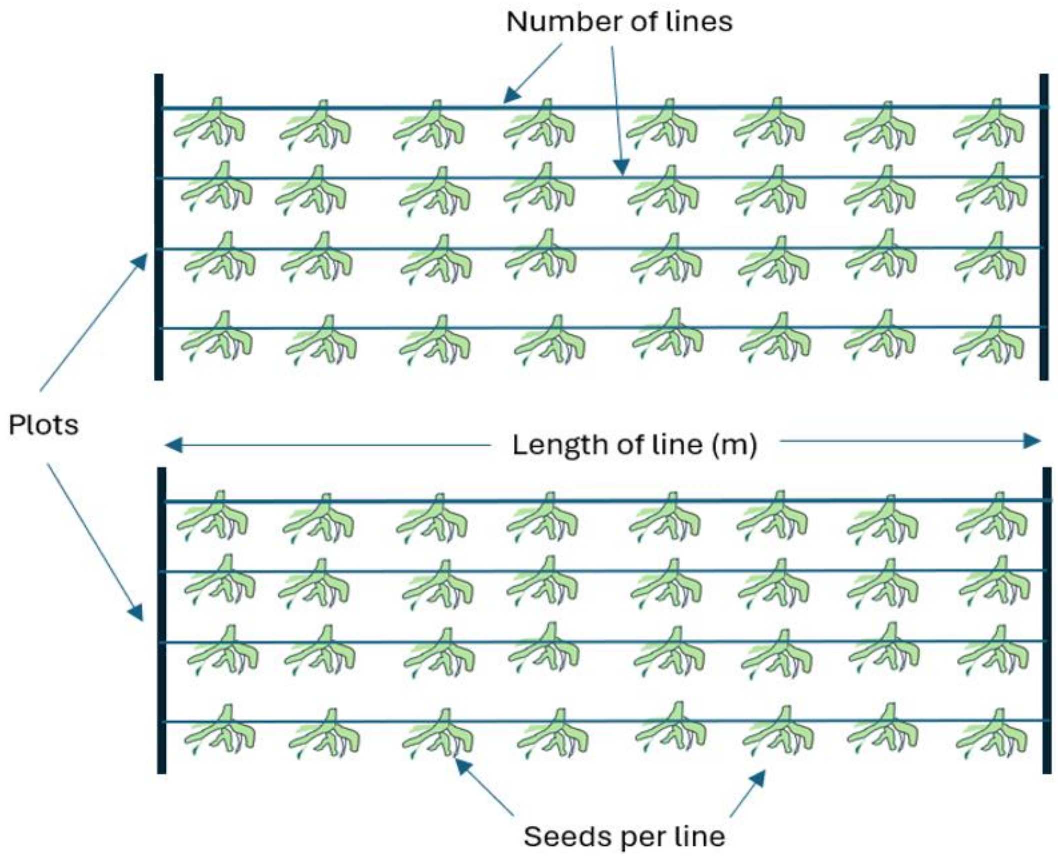

Figure 6. An illustration of how seeds are attached using the seaweed off bottom method.

Figure 7. Preparing seeds for planting (left) and harvesting (right).

Buyers provide bags, which are sometimes supplemented by farmers, and the harvested seaweed can be stored at home until it is time to sell. An average fully loaded seaweed bag can weigh approximately 50 kg. The market involves middlemen or buyer agents purchasing from farmers in the farming area, storing the seaweed in a warehouse, and then transporting it by ship to Honiara (the capital of Solomon Islands). Buyers retrieve the bags from the wharf and transport them to the warehouse for processing, repacking, and eventual export.

1.3.4 Farm-gate price

Farm-gate prices of seaweed fluctuated from 2005 to 2023 (MFMR, 2023) (Table 1). Beginning at USD 0.06/ kg in 2005, there was a general upward trend until 2012, with prices increasing steadily to USD 0.53/ kg. From 2013 to 2016, the prices stabilised and remained relatively consistent between USD 0.53/ kg and USD 0.35/ kg. In 2017, there was a slight increase to USD 0.40/ kg, followed by a period of stability from 2018 to 2019, maintaining the same price. A significant jump occurred in 2020, with prices rising notably to USD 0.47/ kg, and this upward trend continued into subsequent years, reaching a peak of USD 0.70/ kg in 2023. Overall, the trend shows fluctuations, periods of stability, and significant increases in the farm-gate price of seaweed over the observed period.

Table 1. Farm gate price from 2005 – 2023 in the Solomon Islands

Year	Farm-gate price (SBD)	Farm-gate price (USD)
2005	$ 0.50	$0.06
2006	$1.00	$0.12
2007	$1.50	$0.18
2008	$1.70	$0.20
2009	$2.50	$0.29
2010	$3.70	$0.43
2011	$4.00	$0.47
2012	$4.50	$0.53
2013	$4.50	$0.53
2014	$2.60	$0.30
2015	$2.70	$0.32
2016	$3.00	$0.35
2017	$3.40	$0.40
2018	$3.40	$0.40
2019	$3.40	$0.40
2020	$4.00	$0.47
2021	$4.30	$0.50
2022	$5.00	$0.59
2023	$6.00	$0.70

1.3.5. Economic potential

While seaweed export only represented 0.3% of total exports by weight from the country the economic benefit is significant. The fishery holds significant potential to be a multi-million-dollar industry, contributing to the country's foreign exchange earnings through exports. For instance, in 2022, the total revenue was SBD 3.5 million (USD 950,000) (MFMR, 2023). The peak revenue collected in 2014 was over SBD 10 million (USD 1.3 million) (Figure 8).

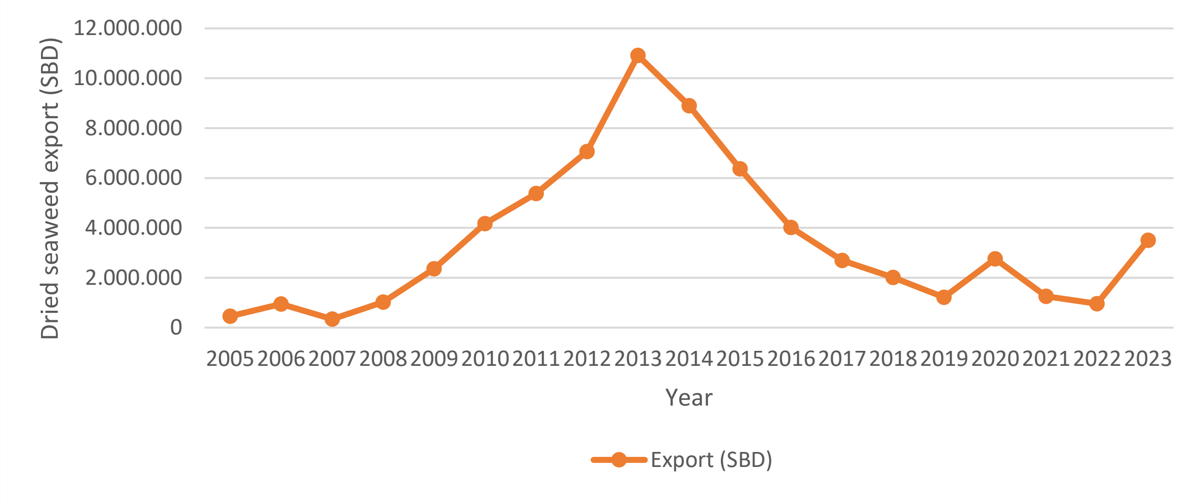

Figure 8. Seaweed export earnings for Solomon Islands from 2005 to 2023.

In the context of the market, the geographical location of the Solomon Islands is strategically advantageous because of its proximity to the Asian market. This geographical advantage has led to the direct export of seaweed to China and Vietnam, which serve as the principal countries of destination and major buyers. From a cost perspective, seaweed cultivation exhibits cost-effectiveness relative to certain aquaculture and traditional agricultural practices. This economic efficiency is attributed to the minimal capital required for both the initiation and management of seaweed cultivation, rendering it a financially prudent alternative. Furthermore, the prolonged shelf life of seaweed, which extends up to three months when adequately dried and stored under appropriate conditions, contributes to its economic viability. This characteristic permits both producers and buyers to store their respective products for extended durations, particularly in instances of extreme weather, thereby enhancing the overall economic feasibility of seaweed farming in the region.

1.3.6 Socioeconomic importance

The seaweed industry has a significant impact on community livelihoods, leading to the participation of most coastal communities in this fishery. According to Kronen (2010), a socio-economic survey conducted in Wagina revealed that seaweed farming has become a pivotal source of income diversification, significantly benefiting households. With 92.5% of seaweed-earning households having more than two income sources, compared to 50% in non-seaweed households, it is evident that seaweed farming enhances income diversity. On average, seaweed farming households earn approximately USD 1,200 more annually than their non-seaweed counterparts. The positive impact extends beyond financial aspects, as seaweed farming has led to a reduction in fin fishing activities, increased regular income, improved access to equipment, and enhanced purchasing power in the community.

Moreover, there is a shift toward store-bought processed foods, such as canned tuna and pork luncheon, driven by increased income from seaweed farming (Kronen, 2010). Gender participation in seaweed farming is notable, with men contributing 68% of the total annual working time, particularly in replanting, maintenance, and harvesting. The positive correlation between the number of women in a seaweed-producing household and higher income underscores the role of gender in seaweed farming. Above all, perceived changes that seaweed brings about are an increase in income, a better life, and improved food security (Kronen, 2010).

1.3.7 Policies supporting aquaculture and the seaweed industry.

Solomon Islands has established a comprehensive policy framework, overseen by the MFMR, to govern aquaculture and seaweed farming activities. These policies aim to ensure environmental sustainability, food security and livelihood, accelerate trade and market, and support sustainable economic growth (Table 2), both nationally and to meet the United Nations sustainable development goals 1, 2, 3, and importantly, SDG14, life under water target 14.7, which states to increase the economic benefits to small island developing States and least developed countries from the sustainable use of marine resources, including through sustainable management of fisheries, aquaculture, and tourism.

The development of the aquaculture industry in the Solomon Islands is supported by several overarching policies (MFMR, 2020; 2018 and 2015) (Table 2), one of which identified seaweed as one of the top three fisheries commodities for aquaculture development alongside tilapia and sea cucumber and ranked it as the number one commodity for both artisanal and commercial development in terms of high feasibility and potential benefits. However, while the seaweed industry has commercialised, it lacks a dedicated policy, and ongoing efforts are underway to develop a seaweed action plan to guide its development.

Table 2. National policies that support aquaculture development.

Policy	Policy statement
Solomon Islands Government Policy Document	Distribute the benefits of Solomon Islands fisheries and aquaculture endowments through innovation and technology, accelerated trade, and marketing.
National Development Strategy 2016 - 2035	Promote sustained and inclusive economic growth. Thereby, recognize the importance of aquaculture for value adding and export earning to achieve sustainable growth.
Fisheries Management Act 2015	Provides the legal basis for MFMR's mandate. For example, a valid and applicable license is required when engaging in commercial aquaculture.
Corporate Plan 2020-2023	Ensures the development of the aquaculture sector to contribute fully to food and nutritional security and economic and social benefits for the people.
Solomon Islands National Fisheries Policy 2019 - 2029	Develop and establish a sustainable and well-managed aquaculture sector that supports rural livelihoods, food security, economic returns, and stock enhancement.
Solomon Islands National Aquaculture Development Plan 2019 - 2023	Identifies seaweed as the top priority for Solomon Islands in artisanal and commercial aquaculture.

1.3.8 Policy interventions

Policy interventions have been instrumental in the development of aquaculture (Henriksson et al., 2021), aiming to enhance productivity, promote sustainability, and improve the livelihoods of seaweed farmers. The growth of seaweed production in the Solomon Islands over the years can be attributed to several interventions.

The European Union project under the Commercialization of Seaweed Programme in Solomon Islands (CoSPSI) was the first to support seaweed farming from 2002 to 2006, with only four locations engaged in seaweed farming: Rarumana, Wagina, Shortlands, and Manaoba. The farmers were supported with training, seaweed materials, outboard motors, PF-Net (broadband email), and warehouses, which increased the production from four metric tons in 2002 to over 300 metric tons in 2005 (McHugh, 2006). A total of SBD 17 million (USD 2.2 million) was granted for the project, SBD 1.5 million (USD 195, 000) for feasibility studies in 2002, and an additional SBD 15 million (USD 1.9 million) for a three-year seaweed commercialisation project, commencing in July 2005 (McHugh, 2006).

The next intervention occurred in 2010, following the decline in seaweed production due to the impact of the 2007 tsunami. The intervention was by the New Zealand government through the Mekem Strong Solomon Islands Fisheries (MSSIF) program. The program allocated a budget of SBD 3.74 million over three years in 2010–2013 for equipment and training at new and existing farm sites, farming supplies, and consultation time (Wallis, Glass, & Smith, 2014). Furthermore, the program facilitated connections with buyers to ensure market access for seaweed products. This intervention resulted in a peak in production from 2013 to 2015.

The Pacific Regional Oceanscape Programme (PROP) and regional partners, such as the Secretariat of the Pacific Community (SPC), have also played a key role in strengthening existing programs. These programs and partnerships have strengthened technical assistance, infrastructure development, and training, thereby contributing to the development and sustainability of the seaweed fishery.

In terms of sustainability, the trend clearly shows that seaweed production is directly proportional to interventions, and there was a clear indication of production decrease when those interventions were phased out, even though other factors, such as price fluctuations, beche-de-mer open seasons, and weather, also contributed.

1.3.9 Challenges of the seaweed fishery in Solomon Islands

Seaweed production in the Solomon Islands has encountered numerous challenges over the years. These challenges encompass both natural and human-induced factors. Natural risks include geological instabilities, such as earthquakes and tsunami activities, climatic conditions, such as rising seawater temperatures and heavy seas, and potential impacts of climate change (Kronen, 2010). Additionally, herbivorous fish grazing, sedimentation from logging and coastal development, fluctuations in fuel prices, the opening season for sea cucumber harvesting, and market price volatility for seaweed contribute to the complexity of sustaining seaweed production. Kronen (2010) also highlights that the low financial power as well as maintenance and operational cost present major bottlenecks for further expansion and maintenance of seaweed operations.

1.4. Research problem and aim of the study.

Despite the initial success and widespread adoption of seaweed farming, a concerning trend has surfaced in recent years, particularly since 2013. Over the past decade, Solomon Islands has witnessed significant shifts in production. The industry experienced a notable peak in 2014 when production reached a substantial 1,503 metric tons, signifying a robust and flourishing period for seaweed farming. However, the subsequent years have seen fluctuations with uncertainty in the trajectory of this industry.

The uncertainty in seaweed production was acknowledged by the MFMR (2023). These fluctuations have been documented and serve as a crucial reference point for understanding the challenges faced by the industry. The report emphasises the need for a comprehensive analysis to identify the root causes of these fluctuations and establish a framework for sustainable growth.

Given the economic and environmental significance of seaweed farming in the Solomon Islands, addressing production uncertainties is important. Seaweed not only contributes to the livelihoods of local communities but also plays a role in global markets, with applications ranging from food to pharmaceuticals. The stagnation and fluctuations observed in Solomon Islands' seaweed production pose potential threats to both local economies and the broader seaweed industry. To sustain and elevate the success of seaweed farming in the Solomon Islands, there is a pressing need to focus on understanding the underlying causes of production fluctuations. According to Kronen (2010), while seaweed farming has brought about numerous benefits, addressing external factors affecting production is crucial for ensuring sustainable growth in Wagina. This research can encompass a multidimensional approach, exploring factors such as the efficiency and profitability of the farming system, farming practices, and policy implications. By conducting a comprehensive investigation, the ministry can formulate targeted strategies to address the challenges and pave the way for a more stable and thriving seaweed industry in the Solomon Islands.

The primary aim of this study is to conduct a comprehensive evaluation of the efficiency and profitability dynamics within the existing seaweed cultivation practices. The overarching goal is to provide insights and recommendations aimed at strengthening and fostering the growth of the seaweed industry, thereby supporting its long-term viability and economic significance. The central research question driving this study concerned comparing small-, medium-, and large-scale seaweed production. This research question was further narrowed down into several sub-questions, including exploring potential differences in resource efficiency and profitability among these production categories, examining the efficacy of current strategies employed in seaweed farming, and assessing the perceived necessity for enhancing management within the seaweed industry. To guide the course of this study, specific research objectives were outlined. These objectives encompass the following:

- an evaluation of the efficiency and profitability of seaweed industry operations,
- as an analysis of factors needed to enhance the entire production system and
- formulating recommendations for government support to strengthen the overall sustainability and effectiveness of the industry.

2 METHODOLOGY

2.1 Study site

2.1.1. Wagina community

The Wagina community was chosen as the case study for this investigation (Figure 9). Wagina is an island that lies within the Choiseul Province. In 2019, the number of residents was 1720 (SINSO, 2019); however, today the number of inhabitants has slightly increased. The island is inhabited by a group of Kiribatians who migrated to the Solomon Islands in the 1950s after originally hailing from Kiribati. Seaweed, fishing, and mat weaving provide the majority of their revenue (Kronen, 2010).

Figure 9. Wagina community, the seaweed proposed study site.

2.1.2. Selection criteria

The location for the case study was chosen in collaboration with the Aquaculture Division of the MFMR and based on the following criteria:

1. Wagina has a leading seaweed farming community with a high production volume since seaweed was introduced.
1. It has a substantial number of active farmers which is important to ensure that the study has a good representative sample for analysis and
2. A list of farmers was compiled and is available at the MFMR. As of 2023, the active farmers were 320, constituting approximately 54% of the population of seaweed farmers in the Solomon Islands (MFMR, 2023).

2.2. Data collection procedure

2.2.1. Selection of farmers

Yamane's formula, which assumes a 95% confidence level (P=0.5), was used to determine the sample size (Yamane, 1967). However, 10% of the sample was utilised for precision due to time and financial constraints (e). Thus, a total of 78 farmers out of 320 active farmers were surveyed (see formula). The Excel RAND () function was utilised to select farmers by entering their names and randomly selecting the farmers to be interviewed.

Yamane´s formula

$$n = \frac{N}{1+(N(e)2)}$$

where n is the sample size, N is the population size, and e is the level of precision.

2.2.2. Development of questionnaire and survey

A survey was administered using a questionnaire. The FAO handbook for socioeconomic sample survey – principles and practice (Pinello, Gee, & Dimech, 2017), a questionnaire used for seaweed socioeconomic survey in Solomon Islands (Kronen et al., 2010), and a questionnaire used in a report by a previous GRO-FTP fellow (Thidza, 2021) were used as guides for developing the questionnaire. The questionnaire was designed to target seaweed demographic details, socioeconomic, and economic (efficiency and profitability) data (see Data Collection). One of the aquaculture employees of MFMR made data collection possible by flying to Wagina on March 12, 2024. The survey was conducted between March 12 and 19, 2024.

2.2.3. Collection of data

All the farmers were scattered throughout the small islands where their seaweed farms were located. Each day for three days, the officer travelled by a mechanised boat and interviewed 25 to 30 farmers. The questionnaires were later scanned and analysed.

2.3. Data analysis

The data collected were analysed for demographic, socioeconomic, statistical description, and economic (efficiency and profitability) characteristics. Furthermore, analysis was conducted for different scales of production (Table 3), except that no efficiency analysis was performed for large-scale production because of low sample representation. Different economic models were used for the analyses of efficiency and profitability.

Table 3. Categories of farms based on their annual production: small-scale, medium-scale, and large-scale farms

Criteria	Small	Medium	Large
Monthly production quantities	<=1000kg)	1001-5000kg	>5000kg

2.3.1 Efficiency analysis

Various models have been used to evaluate efficiency (Coelli et al., 2005; Şen et al., 2022; Xie et al., 2021). However, for this research, a stochastic frontier model (Coelli et al., 2005) was employed, and the frontier package in R was used to assess the efficiency of different production scales. This method is particularly important when evaluating the efficiency of performance, and it has led to the development of various methods to measure efficiency and productivity. Efficiency was measured by analysing seaweed production (dried weight) in relation to input variables (Coelli et al., 2005). First, the data were cleaned and organised into an Excel spreadsheet in a format that was readable by the model. This included the dependent variables (production and income) and independent variables (Table 4).

Table 4. Variables with their explanations.

Variables	Explanation	Unit
Fuel	Fuel used for transportation	Gallon
Labour	Family help converted into labour	Cost
Const	Construction costs associated with drying tables	Cost
Experience	Farmers experience	Number of years
Fsize	Farm size	m^2
NPlots	Number of plots	Quantity
Nlines	Number of lines (ropes)	Quantity
Sline	Seeds per line (rope)	Seedlings
Llines	Length of line (rope)	m^2
Training	Training attended	Trainings related to seaweed
Household	Number of people per household	Number of people
Edu	Education status of farmers	Level of education reached
Age	Age of farmers	Years

Stochastic frontier analysis (SFA) was conducted using the following model equation:

$$Yi = f(Xi;\ \beta) - Ui + Vi)$$

Where, $\mathbf{Y_i}$ is the observed output for observation i, $\mathbf{X_i}$ represents the vector of observable inputs, **β** is the vector of parameters to be estimated, **f (·)** is the deterministic part of the model representing the production frontier, $\mathbf{U_i}$ is a positive random error term representing technical inefficiency, **Vi** is a non-negative random error term representing random shocks or noise.

2.3.2 Profitability analysis

The Net Present Value (NPV) and Internal Rate of Return (IRR) are key performance indicators for evaluating profitability (Qi, Wang, & Xu, 2023). NPV is the present value of future cash flows discounted at a fixed rate, usually the cost of capital (Gaspars-Wieloch, 2019). A positive NPV signifies that an investment is financially viable if the returns exceed the costs (Mielcarz & Paszczyk, 2010). Concurrently, the IRR represents the project's intrinsic rate of return and defines the discount rate at which the NPV equals zero. It clarifies whether an investment exceeds or falls short of the expected return by comparing the IRR to the cost of capital. Using these tools, investment prospects may be thoroughly assessed, allowing well-informed decisions to be made about the allocation of resources and the optimisation of shareholder value. The two formulae below were used to calculate PV and NPV. Microsoft Excel was used for the calculations, including the IRR.

$$\mathrm{PV} = \frac{\mathrm{FV}}{(1 + r)^t}$$

where **PV** is the present value, **FV** is the future value or cash flow, **r** is the discount rate (representing the interest rate or rate of return expected), and **t** represents the period in the future (years).

$$\mathrm{NPV} = \sum_{t=0}^{n} \frac{\mathrm{Net\ Benefit}_t}{(1+r)^t}$$

where **n** is the total number of periods and **r** is the discount rate, which reflects the time value of money.

3 RESULTS

The results present a comprehensive analysis of various dimensions of seaweed farming in Wagina. A detailed examination and interpretation of the data presented in Tables 5–9 uncovered insights into the composition of the seaweed demographic, socioeconomic profiles, statistical descriptions of production, scale of operations, economic efficiency, and profitability. These analyses offer valuable insights into the dynamics of seaweed production, which are vital for understanding the efficiency, profitability, and challenges crucial for boosting the seaweed industry in the Solomon Islands.

3.1 Demographic information of the seaweed farmers

Table 5 presents an analysis of the demographic and experiential features of farmers. In terms of age distribution, 48.7% of the sample's farmers were 30 years of age or younger, and 19.2% were aged 31–40 years. These individuals were followed by farmers who were 41–50 (16.7%), 51–60 (10.3%), and over 60 years (5.1%). Regarding household size, the majority of farmers (50%) had five or fewer members, 46.2% had six to ten members, and households with more than 10 members (3.8%) comprised the lowest category. The gender distribution of the sample revealed that male farmers comprised 79.5%, while female farmers comprised 20.5% of the total. In terms of education, most had completed junior secondary school (F1-3) (48.7%), while others had completed primary school (42.3%), senior secondary school (F4-7) (6.4%), or university education (2.6%). A wide range of farming experience existed in the industry, with the majority falling into the 8–15-year age group (35.9%), followed by 4–7 years (28.2%), >15 years (24.4%), and 1–3 years (11.5%). Lastly, regarding the number of seaweed training sessions attended, the majority of farmers (91%) said they had not received any training, compared with 6.4% who had attended one session and 2.6% who had attended two sessions of training.

3.2. Socioeconomic information of the seaweed farmers

This study investigated several factors concerning farmers' productivity and farm attributes (see Table 6). Approximately 78.2% of farmers owned farm areas ranging from 1001 to 5000 m^2, while 16.7% and 5.1% had areas smaller than 1000 m^2 and larger than 5000 m^2, respectively. In terms of the number of plots, most farmers (39.7%) reported having two plots, followed by 33.3% with three plots, 9.0% with one plot, and 9.0% with more than four plots. The predominant range for the number of lines used was 101-200 lines (30.8%), followed by 301-400 lines (20.5%), <=100 lines (3.8%), >500 lines (14.1%), and 201-300 lines (26.9%). Concerning line length, most farmers reported lines between 21 and 30 meters (66.7%), while 26.9% reported lines <=20 meters, and 6.4% reported lines longer than 30 meters. Lastly, regarding the frequency of harvests per month, the majority of farmers indicated harvesting twice a month (43.6%), followed by once a month (9.0%), four times a month (20.5%), and 15.4% harvested more than five times.

Table 5. General characteristics of seaweed farmers

Group	Frequency	Percentage (%)
Age of farmers		
<=30	38	48.7
31 – 40	15	19.2
41 – 50	13	16.7
51 – 60	8	10.3
>60	4	5.1
Total	78	100%
Household size		
<=5	39	50
6-10	36	46.2
>10	3	3.8
Total	78	100%
Gender		
Male	62	79.5%
Female	16	20.5%
Total	78	100%
Education		
No education	0	0.0
Primary	33	42.3
Junior secondary (F1-3)	38	48.7
Senior Secondary (F4-7)	5	6.4
University	2	2.6
Total	78	100%
Experience		
1-3 years (beginner)	9	11.5
4-7 years (Intermediate)	22	28.2
8-15 years (advance)	28	35.9
>15 years (Expert)	19	24.4
Total	78	100%
Training attended		
0 training	71	91.0
1 training	5	6.4
2 training	2	2.6
Total	78	100%

Table 6. Socioeconomic characteristics of the farming system.

Group	Frequency	Percentage %
Farm size		
<=1000 m2	13	16.7
1001-5000 m2	61	78.2
>5001 m2	4	5.1
Total	78	100 %
Number of plots		
1	7	9.0
2	31	39.7
3	26	33.3
4	7	9.0
>5	7	9.0
Total	78	100 %
Number of lines		
<=100	3	3.8
101- 200	24	30.8
201- 300	21	26.9
301 – 400	16	20.5
401 – 500	3	3.8
>500	11	14.1
Total	78	100 %
Length of lines		
<=20 m	21	26.9
21-30 m	52	66.7
>30 m	5	6.4
Total	78	100 %
Harvest per month		
1	7	9.0
2	34	43.6
3	9	11.5
4	16	20.5
>=5	12	15.4
Total	78	100 %

3.3. Statistical description of the production systems

A descriptive analysis of seaweed farming provides valuable insights into the industry, supported by the data (Table 5). Production levels show significant variability across farms, with a mean of 1602 ± 1327.13 kg and ranging from 320 to 12000 kg. This variability underscores the influence of factors, such as farming techniques, inputs, infrastructure, and environmental conditions. The mean farmed area of 1545m² and an average of 2.86 plots per farm ranging from 1 to 15 highlighting the diversity in farm sizes available to farmers, with some having access to vast areas while others have limited space. The mean number of lines per farm was approximately 342 ± 304.79, indicating varied infrastructure investments and government support in terms of ropes. Similarly, the average line length was 25.59 m, with some farms using lines as short as 15 m and others as long as 54 m, reflecting differences between new and experienced farmers. Additionally, the mean number of seeds planted per line was 81.44, with variability from 46 to 102 seeds per line, indicating the availability of ropes and scale of operation. Moreover, the mean age of farmers was 35.69 ± 12.71 years, indicating diverse experience levels. Additionally, the average household consisted of 5.71 individuals, ranging from 2 to 12 members per household. Furthermore, the mean years of experience in seaweed farming was approximately 10.83 ± 6.17 years, showcasing a blend of experience and fresh entrants engaging in the industry.

Additionally, Table 6 presents expenditure and production figures in USD on a monthly and annual basis for each scale category. Small-scale farmers, represented by 22 individuals, contributed 28.2% of the sample, with monthly expenditures averaging USD 232.7 and monthly production valued at USD 504.1. Medium-scale farmers, constituting the largest proportion at 70.5%, comprised 55 farmers, and demonstrated higher expenditure and production figures, averaging USD 642.0 and USD 964.1 monthly, respectively. Large-scale farming was represented by a single farmer, making up 1.3% of the sample, with significantly higher expenditure and production figures, totalling USD 2,080.0 and USD 7,024.2 monthly, respectively.

Table 7.Descriptive statistics of seaweed farming systems.

Variables	*Mean*	*SD*	*Min*	*Max*
Production	1602.0 kg	1327.1	320	12000
Farmed area	1545.0 m^2	1110.4	500	7000
Plots	2.9	1.8	1	15
No. of Lines	342.0	304.8	80	2500
Length of lines	25.6 m	5.8	15	54
Seeds per line	81.4	13.5	46	102
Harvest per line	73.9	15.4	25	100
Harvest per month	3.1	1.9	1	10
Age	36.0 years	12.7	14	69
Household	5.7	2.2	2	12
Experience	10.8 years	6.2	1	24

Table 8.Frequency, expenditure, and production of the three seaweed production categories.

Group (scale)	**No. of farmers**	**Percentage**	**Expenditure (USD)**		**Production (USD)**	
			Monthly	Annually	Monthly	Annually
Small	22	28.2	$232.7	$2,972.6	$504.1	$6053.0
Medium	55	70.5	$642.0	$7,703.9	$964.1	$11,569.1
Large	1	1.3	$2,080.0	$24,960.2	$7,024.2	$84,290.4
Total	78	100%				

3.4. Economic Analysis of the different production scale

The study categorised farmers into small-, medium-, and large-scale production categories (Table 8). Among the surveyed farmers, 28.2% were classified as small-scale producers, 70.5% as medium-scale producers, and only 1.3% as large-scale producers. For small-scale production, the average monthly total income was USD 504.1, with total input costs of USD 232.7. Medium-scale producers reported an average monthly total income of USD 964.1 and total input costs of USD 642.0. Large-scale producers had substantially higher figures, with an average monthly total income of USD 7,024.2 and total input costs of USD 2,080.0. On an annual basis, small-scale producers reported an average total income of USD 6,053.0 and total input costs of USD 2,972.6. Medium-scale producers had an average annual total income of USD 11,569.1 and total input costs of USD 7,703.9. Large-scale producers reported significantly higher annual figures, with an average total income of USD 84,290.4 and total input costs of USD 24,960.2.

3.4.1. Technical efficiency analysis

The analysis of seaweed farming data reveals key findings about the factors influencing seaweed yield (Table 9). Notably, the intercept has a significant impact, with an estimated value of approximately 6.96. However, specific input variables, such as fuel, labour, and infrastructure (Const), do not significantly affect yield, as evidenced by their coefficients (0.03, 0.08, and 0.21, respectively). In contrast, Z_(Intercept) stands out as statistically significant (coefficient of approximately 1.44), underlining its notable influence on seaweed yield. Although experience shows a positive coefficient, indicating a potential impact, it is not statistically significant (coefficient of approximately 0.0134). Variables, such as farm size and the number of plots, exhibit minimal effects, whereas others, such as the number of lines, seeds per line, training, household, education, and age, have nonsignificant coefficients, suggesting a limited influence on seaweed yield.

Based on their p-values, which all exceeded the accepted standards for significance ($p > 0.05$), none of the variables in the small-scale analysis demonstrated statistically significant effects. It is important to note that the estimates for some variables are directional. Variables such as the number of plots, seeds per line, training, household, education, and age showed positive estimates, suggesting that there may be a tendency for the result to increase when these factors increase. However, this link was not statistically significant in our analysis. In contrast, variables, such as farm size, number of lines, experience, and length of lines, exhibited negative estimations, indicating that increases in these parameters can result in declines in the outcome.

Table 9. Technical efficiency for overall, small and medium scale.

Production scale	Positive variables	Negative variables	Technical Efficiency (TE)
Overall farm	Construction, education, age, experience, fuel, farm size, length of lines, & labour	Number of lines, seeds per line, training, number of plots, household	0.44019
Small Scale	Construction., number of plots, seeds per line, training, household, education & age	Fuel, labour, experience., Farm size, number of lines & length of lines	0.83417
Medium scale	Construction, number of plots, number of lines, length of lines, and experience.	Household, training, seeds per line and farm size	0.86521

Key:
Blue coloured variables are significant.
Black coloured variables are not significant.

Additional Information: * = Significant on 90%, ** = Significant on 95%, *** = Significant on 99%

Table 10. Level of efficiency and percentage of farmers.

Level of efficiency	Distribution of farmers			Percentage (%)		
	Small scale	Medium scale	Entire farmers	Small scale	Medium scale	Entire farm
<0.5	1	0	64	4.5	0.0	82.1
0.5 – 0.6	2	0	5	9.1	0.0	6.4
0.6-0.7	2	4	6	9.1	7.3	7.7
0.7 – 0.8	2	10	0	9.1	18.2	0.0
0.8 – 0.9	3	19	0	13.6	34.5	0.0
0.9 - 1	12	22	3	54.5	40.0	3.8
Total	22	55	78	100%	100%	100%

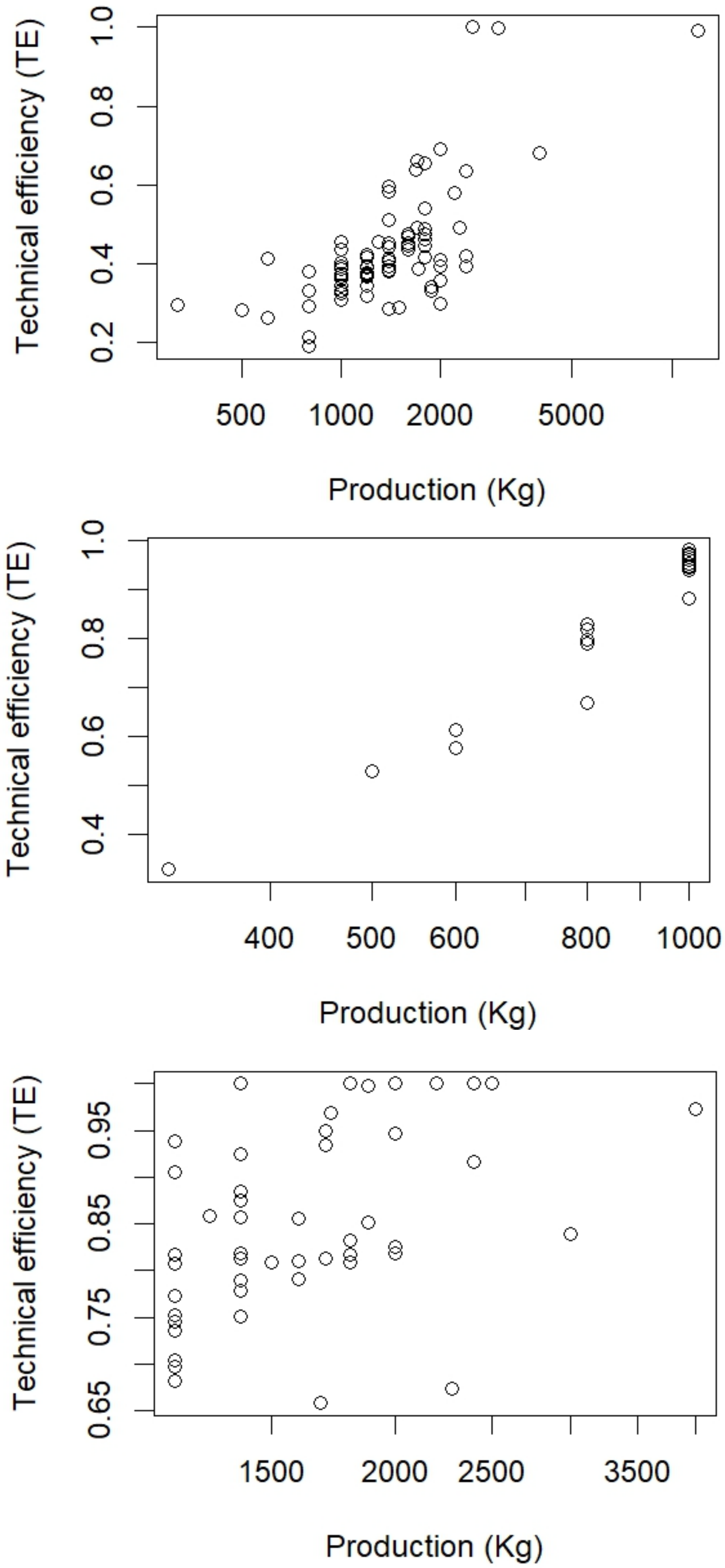

Figure 10. Efficiency level for the farmers. Top (overall seaweed farmers), middle (small scale farmers) and bottom (medium scale farmers).

Several variables within the medium-sized seaweed farmers displayed significant effects on productivity (p-values < 0.05). The study shows that increasing training and farm size were associated with lower productivity outcomes, whereas positive estimates for variables such as fuel, experience, number of plots, number of lines, length of lines, and education indicated that increases in these factors would lead to increased production. These relationships were statistically significant. However, despite their statistical significance, infrastructure (Const) did not exhibit significant effects on production, as their p-values exceeded the cutoff threshold. Furthermore, the medium-scale seaweed farmers' technical efficiency (TE) value of 0.87 suggests that, on average, they are operating at approximately 86.52% of their maximum potential efficiency, indicating room for improvement in their operations.

Farmers' efficiency levels varied, indicating different performance levels (Table 10). A total of 6.4% of farmers are classified as having an efficiency between 0.5 and 0.6. Similarly, 7.7% of farms reach 0.6–0.7 efficiency levels. Notably, not a single farmer in the dataset achieved efficiency levels ranging from 0.7 to 1.0. Nonetheless, 3.8% of all farmers reached efficiency levels of 0.9 to 1.0. Remarkably, Figure 8 shows that two out of the three farmers with the highest efficiency were from the medium scale farmer group.

3.4.2. Profitability analysis

The study examined financial indicators, total investments, and benefits for small, medium, and overall production categories over a five-year period (Figure 11). Small-scale farmers made an investment of USD 1,943.4, with varying annual rewards ranging from USD 1,943.4 in the first year to USD 4,050.9 in the fifth year. Over the five years, the NPV was USD 20,539.3, with an IRR of 26.8%. The annual returns for medium-sized farmers, with a total investment of USD 1,930.8, varied from USD 11,719.4 in the first year to USD 8,004.5 in the fifth year. The NPV over a five-year period was USD 46,937.6, with an IRR of 33.5%. For overall farms, farmers were required to invest USD 2,259.94 in total, with yearly rewards ranging from USD 10,348.7 in the first year to USD 7,401.6 in the fifth year. The five-year NPV was USD 44, 067.6, with an IRR of 25.0%.

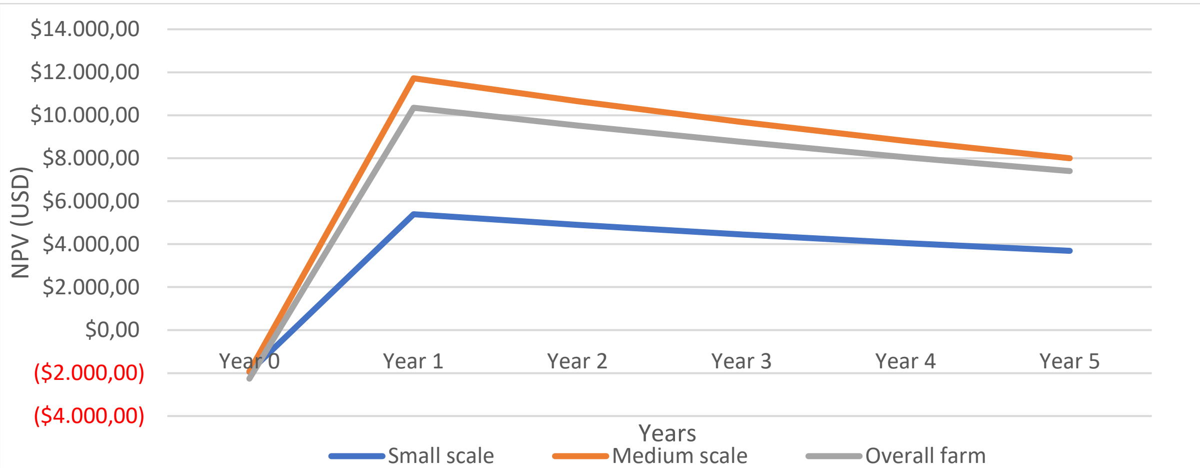

Figure 11. Present value over a five-year period for the overall, small and medium farmers.

4 DISCUSSION

4.1. Demographic analysis of the seaweed farmers

Seaweed farming involves a diverse range of age groups, each contributing to the success and sustainability of this valuable seaweed industry. The survey showed that 48.7% of the farmers were younger than 30 years. Since the majority of them are young and some dropped out of school, diving into seaweed is their sole means of providing for their families. In India, the majority of seaweed farmers fall into this category because they are open to adopting alternative livelihoods and actively contribute to seaweed farming (Mantri et al., 2022). In the present study, the second most dominant age group was those aged between 30 and 40 years, reflecting maturity and as their commitment increases, they tend to find solace as this category is most comfortable for the farmers, the inputs are conducive for managing. Similar findings were noted by Mantri et al. (2022) among seaweed growers in India, the majority of whom were aged between 30 and 50 years. People in this age group are productive and play a crucial role in sustaining seaweed cultivation as an alternate source of income. This can be reflected in their household size, which consists of a higher number of household members. While fewer people over 50 engage in seaweed farming, those who do so because of their experience and knowledge support the stability of the sector.

Recognising the role of households in aquaculture is of great importance. In Malaysia, 950 fishing families are involved in aquaculture, including seaweed aquaculture (Hussin et al., 2015). In Indonesia, approximately 267,000 households benefit from seaweed farming (Rimmer et al., 2021). In Wagina, more than 300 households benefit from seaweed farming. In the present study, 50% of the farmers' household sizes were less than five and were dominated by young and elderly couples living alone. A study by Saili et al. (2019) showed that the common household size in Malaysia is 6–8 members. In places where seaweed is cultured in the Solomon Islands, households play a significant role in livelihoods and income and community resilience. The labour component is replaced and undertaken by households. This explains why Wagina does not have hired labour for seaweed harvesting.

Seaweed farming involves a diverse group of individuals, including both men and women. Although specific gender percentages may vary across regions, the present study shows that men still dominate seaweed farming in Wagina, comprising 79.5%, while women accounted for 25%. Similar results were observed by Kronen et al. (2010) in a study done on gender and seaweed farming in Wagina, however, for this study more men were involved, and the number of women was lower. This speaks well of the role that men are the dominant leader in the household in the Kiribatians culture. Even though men head seaweed farming, it is considered a household business, and women are highly involved in replanting and maintenance (40%) and harvesting (34%) (Kronen et al., 2010).

A study distributed to all farmers in the area revealed that a very low percentage of the farmers had completed senior[1] secondary school and university. Most of the farmers (48.3%) had reached Junior[2] secondary (grades 7-9), 42.3% had finished primary[3] education and 6.4% had reached senior education level. In Malaysia, most farmers have reached primary education

[1] Also known as high school
[2] .Also known as middle school
[3] .Also known as elementary school

levels (Saili et al., 2019). In Wagina, the primary and junior levels were dominated by the age group above 30 years, and the younger generation below 30 years reached the senior education level. According to the farmers, the reason for this trend was simply because in the 1990s and early 2000s, there were fewer schools around Wagina and competition was tough to secure spaces at schools for junior and senior levels, resulting in most children only reaching primary or junior education levels. Another reason, as stated by Kronen et al. (2010), is that families may also decide that children should participate in seaweed farming, which means that they leave school at an early stage and no longer have access to secondary or tertiary education.

Seaweed training is essential for establishing and improving the industry. Some training programs have focused on farming techniques to enhance production, while others have focused on ecological awareness and addressing challenges, ensuring quality production, and helping communities adapt seaweed farming as a sustainable alternative livelihood (Bindu & Levine, 2011). In the present study, it was identified that most of the farmers surveyed (91.0%) reportedly had not received any training related to seaweed farming. Farming techniques were learned from other farmers and the propensity to experience over years engaged in the industry. Only 6.4 % reportedly attended one training, and 2.6% had two trainings. Some of the trainings offered included seaweed farming and management, as well as value-adding. Despite a very low percentage of farmers having undergone training, most of the farmers surveyed were advanced seaweed farmers with 8–15 years of experience, followed by the intermediate group with 4–7 years of experience. This indicates that seaweed farming skills can easily be learned from experience, and in Wagina, skills are predominantly comprised of farmers with extensive experience in seaweed farming.

4.2. Socioeconomic analysis of the farming system

The data presented provide insights into the distribution of lines, their lengths, and the harvest per month, which identifies several patterns and implications.

First, regarding the distribution of lines, it is evident that most observations fall within the 101–200 and 201–300 ranges, constituting 30.8% and 26.9%, respectively. This suggests that the dataset predominantly consists of moderate-sized samples, with smaller proportions representing shorter and longer line counts. The lower frequency of lines exceeding 400 and those under 100 may indicate either a specific selection process or limitations in data collection. Second, considering the length of lines, the majority (66.7%) fell within the 21–30 m range. This indicates a commonality in line lengths, possibly reflecting standardised practices, farm size, or equipment limitations. The relatively small proportion of farmers with lines exceeding 30 m (6.4%) may reflect experience and management advantages, such as a higher number of drying tables, proper storage facilities, owning more than one boat for transportation, and farm size.

Finally, examining the harvest per month, the data showed a varied distribution. The most frequent observation was two harvests per month, constituting 43.6% of the total, followed by four harvests at 20.5%. This indicates a diverse operational schedule, potentially influenced by factors such as seasonal variations, market demands, household size, and labour or resource availability. Other determining attributes include seaweed biomass, carrageenan yield, and gel strength (Villanueva et al., 2011). It was found that 15.4% of farmers harvested five or more plots each month. This is for farmers who use a six-week planting cycle and might also be related to intensive seaweed practices or good support for harvesting and drying. According to

(Tiroba, 2007) to get the most harvest possible, a six-week cycle is crucial. Your weekly rotating crop comes from planting each block once a week.

Overall, these results provide valuable information on the operational dynamics of Wagina seaweed farming. The prevalence of moderately sized lines, common line lengths, and diverse harvest frequencies indicates a nuanced approach to seaweed farming, which may be influenced by a combination of logistical, environmental, and economic factors. Further analysis and contextual information are necessary to fully interpret the observed patterns and their implications for seaweed management and sustainability.

4.3. Economic Analysis of the different production scale

Regarding the production scale that dominates the seaweed industry in Wagina (Table 8), 70.5% of farmers produce between 1000 and 5000 kg of dried seaweed per month, 28.2% produce less than 1000 kg, and 1.3% produce more than 5000 kg per month.
According to Wagina, the most manageable category for most farmers is medium size, which is also correlated with the input factors that farmers are able to manage. For instance, in this category, the average number of lines that can be managed is 379 with a length of 26 m. This category also includes the amount of space used for farming, the quantity of drying tables, storage, and transportation. The same applies for the categories of small and large producers, with the exception that the input variables are lower for small and higher for the large category, respectively (Table 8).

In contrast, as the size increases, so do costs and profits (Table 8). This is because higher input costs, along with better management techniques, translate into higher profits from farming. The difference in the gap between large, medium, and small-scale farms is due to the higher investment associated with large-scale farming, for instance, infrastructure, equipment, and materials used.

4.4. Economic efficiency analysis

4.4.1. Efficiency analysis of the overall farm

TE is a measure of how effectively resources or inputs are utilised in the production process. The TE of the entire seaweed production in Wagina was low at TE= 0.48, which means that seaweed production is operating at 48% of its maximum potential efficiency. This is slightly lower than the TE of 69% found for farmers in Semporna and Sabah in Indonesia (Saili et al., 2019). This lower efficiency could be one potential reason why production has remained stagnant between 1000 and 1600 metric tons for the past decade and has never reached the target production scale of 5000 metric tons per year, as proposed by the government. For the present study, there were indications that the stochastic model identified that variables, such as construction, experience, farm size, length of lines, education, and age, had a positive impact on production; however, the difference observed was not significant. This finding is in line with studies done by (Saili et al., 2019; Nursan et al., 2022; Riatiga et al., 2017), however, their study shows that experience, age, farm size, and labour have some positive impact efficiency of seaweed farming but not variables. The positive coefficient suggests that an increase in the natural logarithm of the variables is associated with an increase in the TE of seaweed production but for the present case study it was not significant. However, investments in constant capital could moderately improve production efficiency because investing in infrastructure, such as drying tables, allows for more seaweed to be dried, which allows farmers to produce more seaweed. In terms of education and experience, the positive coefficient indicates that higher levels of education together with experience can impact the efficiency of seaweed production. This could be due to the fact that education and experience often equip individuals with better problem-solving skills and innovative approaches that can enhance productivity. By contrast, the positive age coefficient indicates that older people are generally more productive when producing seaweed. This may be explained by the knowledge and expertise that come with age.

In contrast, certain variables, such as the number of plots, number of lines and seeds per line, and training and household, were negatively correlated with production, which may relate to the management of the entire seaweed farm. Having many plots, increasing the number of lines, and planting more seaweed in a dense area could affect growth and increase diseases, resulting in a low harvest. The survey results indicate that some farmers have limited farming space, and the only way to increase production is to increase the number of seeds per line, which can be risky. Seaweed cultivation is influenced by various factors, including water quality, temperature, and nutrient levels. Hence, adjustments should be made based on local conditions and best practices to maximise production efficiency.

Although the overall TE was low, it suggests that there is room for improvement in the seaweed production process. Farmers could potentially increase their production by optimising resource allocation, improving cultivation techniques, or addressing inefficiencies. According to the stochastic frontier model (Coelli et al., 2005), additional random noise or disturbances could also influence TE. These factors include natural disasters, disease outbreaks, and fish grazing. The model explains 48% (TE = 0.48) of the variation in seaweed production efficiency. Although this is a moderate level of explanation, it suggests that there are other factors not included in the model that could account for the remaining 60% of the variation. The efficiency data (Table 10) show that the majority of farmers (82.1%) have a TE of less than 0.5. This aligns with the TE of 0.48 from the model, reinforcing the conclusion that there is potential for improvement in seaweed production efficiency. The data also suggest that interventions aimed at improving efficiency could have a substantial impact, given that only 3.8% of farmers are operating at a TE of 0.9 to 1.0.

4.4.2. Efficiency analysis of small-scale farmers

For small-scale farmers, none of the variables showed statistically significant effects on efficiency, as all estimates for the variables had p-values above 0.05. However, according to the survey, the TE for small farmers was relatively high, indicating that small-scale seaweed farmers are operating at a level of efficiency that allows them to achieve a significant portion of their maximum potential output. In other words, they are making effective use of their resources and production factors to produce seaweed. Moreover, with regard to the efficiency level, it was shown that 68.1% of the farmers were operating at an efficiency level between 0.8 and 1. The difference in total efficiency between the entire farm (0.48) and small-scale farmers (0.83) may stem from various factors, such as inputs and operational costs involved in this fishery.

4.4.3. Efficiency analysis of medium scale farmers

The transition from small-scale to medium-scale farming seems to enhance technical efficiency, with medium-scale farmers operating at a slightly higher efficiency level (TE =

0.87). This finding is similar to a study done by (Nursan et al., 2022) which looked at the production efficiency of seaweed cultivation in Mandalika, one of the seaweed producing sites in Indonesia. Their study recorded a TE of 0.861, indicating a high level of production efficiency. Their study found that area, seeds, and labour significantly influenced their seaweed production. In the present study, infrastructure (Const), number of lines, education, and age were found to significantly influence production levels. This suggests that medium-scale farmers are better utilising their inputs to achieve higher seaweed production. In this study, experience was not significant; it was noted that a large number of experienced farmers did not significantly affect production. Their farming systems and approaches were similar to those of less experienced farmers. In contrast, labour, farm size, seeds per line, training, and household size were identified to negatively affect production in medium-scale farming. Regarding labour, (Otitoju et al., 2017), have found that an addition of labour will reduce production due to increase in expenses in managing the labour. According to Valderrama (2012), farm size is a challenge for farmers when it comes to management, leading to lower productivity (Jumiati et al., 2023); the same challenge also applies to increasing the number of seeds per line. According to the present study, training may reduce efficiency, whereas approximately 91% of the farmers surveyed had zero training in seaweed but performed well. In addition, according to the present study, increasing household size led to reduced efficiency. This is in contrast to what other studies have found (Riatiga et al., 2017); however, the data clearly showed that small and medium-scale farmers are more comfortable managing smaller households. Increased household size involves more coordination and decision-making because efficient management is crucial for success in seaweed.

4.4.4. Profitability analysis

Studies have shown that seaweed farming is profitable and has a shorter payback period (Mantri et al., 2022; Nogueira & Henriques, 2020; Samonte, 2017; Valderrama, 2012) than other aquaculture species such as tilapia (Salia, 2008) and catfish (Aheto et al., 2019). The profitability analysis in this study showed that small, medium, and overall farms had positive annual returns at varying revenues. Small-scale farmers had a lower total investment but also lower annual benefits than medium- and overall-scale farmers. Medium-scale farmers achieved a higher IRR, indicating better financial performance than small-scale farmers. Overall farmers had the highest NPV and annual return, but their investment was also significantly higher. This suggests that medium- and small-scale farmers are more suitable for Wagina farmers for livelihood support and economic benefits. Any support for these two scales should focus more on infrastructure (drying tables) and the length of seaweed farming lines. Having more than one table with a proper structure will enable a smooth flow of harvest and drying. Increasing the length of seaweed lines allows for more seaweed to be planted; the most efficient length of lines is between 20 and 30 m. The large gap between overall farmers and medium- and small-scale farmers was due to investments in terms of infrastructure (number of boats, drying tables, and proper storage facilities) and farming inputs, such as the number of plots, number of lines, and experience. Hence, the results emphasise the significance of investment; the higher the investment, the greater the profit.

4.5. Challenges

The data reveal various combinations of challenges and highlight the multifaceted nature of obstacles encountered by Wagina seaweed farmers. Analysing the challenges faced by seaweed farmers reveals a hierarchy of obstacles, with strong currents and tides emerging as the most prevalent and significant challenge, as observed by 35 farmers. These environmental factors are commonly encountered by every seaweed farmer and pose substantial difficulties. According to Zhang et al. (2022), strong currents and tides impact the stability of seaweed cultivation structures, affecting growth and yield. In Wagina, approximately 6% of the seaweed harvest is lost every month due to the impact of strong currents and tides. Another challenge is algae infestation on seaweed ropes. This infestation competes with cultivated seaweed for nutrients and space, potentially reducing yield. This has also been observed in Madagascar, where it has disastrous effects on local farmers by significantly altering the growth of farmed seaweed and leading to the collapse of operations in numerous locations (Tsiresy et al., 2016). Another common issue is fish grazing, which is a well-known challenge reported by seaweed farmers globally (Bindu & Levine, 2011; Ganesan et al., 2006; Kasim et al., 2024a; Veeragurunathan et al., 2021). The grazing activity of herbivores on seaweed tissues can lead to unpredictable crop yields and diminish the economic feasibility of commercial seaweed farming (Kasim et al., 2024a). Typically, approximately 10% of the accessible seaweed biomass is consumed by these herbivorous fish. According to (Kasim et al., 2024b; Kronen, 2010), fish attacks are linked to the longline method, which is an exposed approach that exposes the seaweed crop to grazing by fish and turtles. In Wagina, seaweed farmers employ the longline method of seaweed cultivation; therefore, fish grazing is impacting their farms. These combinations highlight the compounding effects of environmental and biological factors on seaweed farming, necessitating comprehensive management strategies. According to a study by Kasim and Mustafa (2017), floating cages offer ample space and enhanced protection for propagules to flourish by shielding them from herbivorous threats. Limited space emerges as another notable challenge, although fewer responses reported this, it underscores the constraints faced by farmers in optimising cultivation areas amidst competing land uses. Theft, although infrequent, introduces an element of socioeconomic risk, emphasising the need for security measures to protect investments. These findings underscore the importance of adopting holistic approaches that address both environmental and socioeconomic factors to ensure the resilience and sustainability of seaweed farming practices.

4.6. Collaboration

The data provided offer valuable insights into the dynamics between farmers, buyers, and fisheries officers, as well as the perspectives of farmers regarding fisheries support and suggestions for improvement. Notably, the relationships between farmers and buyers are predominantly positive, characterised by a strong sense of community and cooperation. Most farmers perceive their interactions with each other and buyers as "very good," indicating a high level of satisfaction and trust within these relationships. However, a clear contrast emerges when considering the relationship between farmers and fisheries, with the vast majority rating it as "poor." Dissatisfaction stems from the perceived inadequacy or lack of effectiveness in assistance provided by fisheries authorities to farmers. The suggestions for improvements provided by farmers offer valuable guidance for addressing these concerns. Key suggestions include increasing material supply, providing more training, enhancing communication and engagement through regular visits to farmers, and addressing specific issues such as price increases of materials and support for new entrants into farming. These recommendations underscore the importance of building trust, enhancing support mechanisms, and fostering a more collaborative relationship between farmers and fisheries authorities.

4.7. Value adding

In 2021, the first value-adding training for seaweed farmers was held in the Wagina and Manaoba communities by the MFMR and SPC (Diake et al., 2021). The collected data provide insights into the extent of value-adding activities among farmers and their perceptions regarding such activities. Firstly, it is evident that a significant portion of farmers (87.2%) are not currently involved in value-adding processes. However, it is encouraging to note that 10.3% of farmers are actively involved in value adding, indicating a willingness among some to explore and pursue opportunities for adding value to their seaweed products. Upon examining the reasons for why farmers are not involved in value adding, several key factors emerge. The most prevalent reason, cited by 39.7% of respondents, is the lack of training. Owing to limited space, only a few participants were able to attend value-adding training. This highlights a critical gap in skills and knowledge among farmers regarding value-adding techniques and processes. Additionally, 29.5% of farmers mentioned that value-adding activities are not perceived as profitable. They prefer to spend more time on seaweed cultivation and selling their dried products to buyers, which fetch much higher profits. Moreover, 24.4% of farmers stated that the necessary resources or infrastructure for value adding are not available to them, indicating limitations in access to equipment, ingredients, or facilities. A smaller percentage of farmers offered no specific reason (5.1%).

Although a notable proportion of farmers are engaged in value-adding activities, a significant number are not currently involved, primarily because of barriers such as a lack of training, perceived lack of profitability, and limited access to resources. Addressing these barriers and providing support in the form of training, access to resources, and market incentives could potentially encourage more farmers to explore value-adding opportunities, thereby enhancing the overall competitiveness and sustainability of the seaweed industry. Additionally, efforts to raise awareness about the benefits of value adding and provide technical assistance could further empower farmers to capitalise on value adding to improve their livelihoods and contribute to the growth of the seaweed economy.

5 CONCLUSION

This study reveals a suboptimal level of efficiency for the overall seaweed farm in Wagina. However, at the production scale level, small- and medium-scale farms are highly efficient. While profitability exists across all production scales, small- and medium-scale farming demonstrate much more comfortable farming scales in terms of input and output, indicating a better investment for livelihood support for local seaweed farmers. Seaweed farming in Wagina primarily involves individuals in the age groups of under 30 and between 30 and 40 years, with both men and women participating in the industry. Most farmers have attained up to junior secondary education, and while formal training in seaweed farming is lacking, experience plays a significant role in skill development. Environmental challenges, such as strong currents, algae infestation, and fish grazing, pose significant obstacles to seaweed farming. Limited space, theft, and socioeconomic risks also affect farming operations, necessitating holistic management strategies. Positive relationships exist between farmers and buyers, highlighting community cooperation. However, there is dissatisfaction with fisheries support and communication, indicating a need for improved engagement and assistance from authorities. While some farmers are involved in value-adding activities, many are not due to factors such as lack of training, perceived profitability, and limited resources. Addressing these barriers could enhance competitiveness and sustainability in the industry.

6 RECOMMENDATIONS

1. *Focus on Small and Medium-Scale Farmers*: Small and medium-scale farmers exhibit higher technical efficiency (TE) compared to overall farm performance. This suggests that efforts to increase seaweed production should primarily target these farmers. Supporting them with resources, training, and technology could further enhance their efficiency and overall production.

2. *Tailored Support for Medium-Scale Farmers*: While both small and medium-scale farmers show significant technical efficiency, medium-scale farmers exhibit slightly higher efficiency with some variables being significant. Therefore, specific interventions and support programs could be designed targeting medium-scale farmers, focusing on significant variables, such as infrastructure (Const), number of plots, number of lines, and length of lines.

3. *Investment Attraction for Large-Scale Farms*: Large-scale farms demonstrate the highest profitability, as indicated by the Net Present Value (NPV) and Internal Rate of Return (IRR) figures. This suggests that there may be room for investment attraction in large-scale seaweed farming operations. Government incentives or private investment initiatives could be encouraged to promote the expansion of large-scale seaweed farms.

4. *Farmers' Focus*: Farmers should focus on improving farming techniques, such as optimising seed density and effectively managing environmental challenges. Investing in infrastructure, such as drying tables and storage facilities, can also enhance productivity and profitability. Moreover, exploring value-adding opportunities with appropriate training and access to resources can further improve income generation and sustainability.

ACKNOWLEDGEMENTS

I owe my success in the six-month fisheries training programme to the unwavering support and encouragement of several organisations, institutions, and individuals. First, I express my deepest gratitude to the Icelandic government and the GRÓ Centre for their funding of this invaluable training through GRÓ FTP. Their conscientious planning and logistical assistance were instrumental throughout the entire programme. Special thanks are extended to the University of Akureyri for graciously hosting the GRÓ FTP (FPM) team and providing a supportive environment that fostered learning and teamwork.

I am profoundly grateful to my supervisors, Associate Professors Thanh Viet Nguyen and Rannveig Bjornsdottir, whose guidance, mentorship, and vast knowledge were integral to the success of my project. The Solomon Islands Aquaculture team deserves recognition for their kind assistance and provision of crucial materials that enhanced my understanding of the subject matter.

I extend my appreciation to Joy Pugeva, an aquaculture officer, for meticulously carrying out the questionnaire survey on my behalf, which significantly enriched my research. Additionally, I thank my institution, the Ministry of Fisheries and Marine Resources (MFMR), for its consistent support throughout the training programme.

Finally, I would like to express my gratitude to the entire GRÓ FTP (FPM) specialist team for their collaborative efforts and teamwork. Your collective contributions greatly influenced my time in Iceland and significantly improved my fisheries management abilities. I am sincerely grateful for your valuable support.

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ANNEX 1. STOCHASTIC FRONTIER ANALYSIS FOR SMALL, MEDIUM AND THE OVERALL FARM

Variables	Estimates			Std. Error			Z value			P-value		
	Small scale	Medium scale	Overall	Small scale	Medium scale	Overall	Small scale	Medium scale	Overall	Small scale	Medium scale	Overall
(Intercept)	6.64921360	6.8270e+00	6.9631e+00	0.98408984	3.2076e-01	4.7118e-01	6.7567	21.2838	14.7780	1.412e-11	< 2.2e-16 ***	< 2.2e-16 ***
log(Mfuel)	-0.01270409	1.6207e-01	3.3387e-02	0.62011670	4.7458e-02	6.9711e-02	-0.0205	21.2838	0.4789	0.98366	0.0006379 ***	0.6319794
log(Mlabour)	-0.00243947	-1.9930e-02	8.2701e-02	0.50441807	3.9145e-02	7.9143e-02	-0.0048	-0.5091	1.0449	0.99614	0.6106599	0.2960468
log(Mconst)	0.11571753	1.9406e-02	2.1295e-01	0.82670415	9.5585e-02	1.3519e-01	0.1400	0.2030	1.5752	0.88868	0.8391173	0.1152218
Z_(Intercept)	0.00356437	9.2630e-02	1.4369e+00	0.99995404	1.8704e-01	6.0911e-01	0.0036	0.4952	2.3589	0.99716	0.6204358	0.0183275 *
Z_Experience	-0.07904416	7.2064e-03	1.3391e-02	0.47345095	1.0280e-03	1.2995e-02	-0.1670	7.0101	1.0305	0.86741	2.381e-12 ***	0.3027976
Z_Fsize	-0.00035483	-1.8325e-04	3.3235e-05	0.00278249	2.0503e-06	8.6351e-05	-0.1275	-89.3753	0.3849	0.89853	< 2.2e-16 ***	0.7003237
Z_NPlots	0.01823095	6.9815e-02	-5.3207e-02	0.99649551	1.8620e-02	1.0657e-01	0.0183	3.7494	-0.4992	0.98540	0.0001772 ***	0.6176077
Z_Nlines	-0.00174847	2.0815e-04	-1.2963e-03	0.01076406	9.8768e-05	8.4317e-04	-0.1624	2.1074	-1.5374	0.87096	0.0350791 *	0.1241859
Z_Sline	0.00555821	-5.4051e-03	-8.7581e-03	0.23068353	1.2434e-03	7.3771e-03	0.0241	-4.3469	-1.1872	0.98078	1.381e-05 ***	0.2351513
Z_Llines	-0.05892817	1.2492e-02	2.0327e-03	0.78349214	2.2297e-04	2.0450e-02	-0.0752	56.0253	0.0994	0.94005	< 2.2e-16 ***	0.9208224
Z_Training	0.00197029	-5.3400e-01	-6.6518e-02	0.99893003	9.1931e-02	2.2407e-01	0.0020	-5.8087	-0.2969	0.99843	6.294e-09 ***	0.7665720
Z_Household	0.04968456	-4.3500e-02	-1.4858e-02	0.98852510	1.0162e-02	3.1194e-02	0.0503	-4.2806	-0.4763	0.95991	1.864e-05 ***	0.6338563
Z_Edu	0.04885210	1.3698e-01	1.0435e-01	0.99771825	3.7368e-02	1.2647e-01	0.0490	3.6657	0.8251	0.96095	1.864e-05 ***	0.4093125
Z_Age	0.05809335	2.0559e-03	7.8395e-03	0.15345425	1.6065e-03	6.1976e-03	0.3786	1.2798	1.2649	0.70501	0.2006322	0.2059009

ANNEX 2. QUESTIONNAIRE: SEAWEED FARMING IN WAGINA SOLOMON ISLANDS

Section 1: General Information

1.0 Personal Details

1.1 Name: ________________ 1.2 Sex: ____ 1.3 Age: 1.4 Village: ___________

2.0 Location Details

2.1 Province: ____________ 2.2 Island: ____________

3.0 Household Composition

3.1 Number of persons in household (permanent):

Men	Age	Women	Age

4.0 Education and trainings (leading farmer)

4.1 What is the level of education reached? (Tick)

Education level	*Tick*
No education	
Primary level	
Secondary level (Junior) F1-3	
Senior secondary level F4-7	
University	
Others (Specify)	

4.2 What training(s) have you attended? Please list.

Trainings attended related to seaweed

5.0 Household Income Details

5.1 Average cash income of your household: ___________(Specify time period, e.g., monthly or annually)

5.2 When did you start your seaweed farming?____________

5.3 What did you do before going into seaweed farming? ______________________________

5.4 Did your household have other income sources before seaweed farming?

No

Yes (Specify)____

6. Contribution to Total Income

6.1 Contribution of each income source to the total household income (in percentage or SBD$):

Income source	Contribution (%) or Amount (SBD$)	Time period (e.g. monthly)
Agriculture		
Wild caught fisheries		
Aquaculture		
Salary		
Others		

Section 2: Farming Details and Practices

7.0 Seaweed Farm Details

7.1 Size of seaweed farm:_____________

7.2 Total number of plots: _____________

7.3 Total number of lines: _____________

7.4 Cultivation method (e.g., floating, bottom culture, etc.): _____________

7.5 Length of lines (m): _____________

7.6 Seedlings per line: _____________

8.0 Infrastructure and Equipment

8.1 Describe the infrastructure and equipment used in seaweed farming (previous years).

8.2 Any recent upgrades or investments in infrastructure now? _____________

Section 3: Economic details

Production Efficiency

9.0 Cultivation Process

9.1 Duration of the seaweed cultivation cycle: _____________

9.2 Steps involved in the cultivation process: _____________

9.3 Challenges faced during cultivation: _____________

10.0 Cost of Operations in 2023

10.1 Seedlings:

- Do you buy seedlings?_____________
- If yes, how much: _____________
- Was it more, less or similar to the year before? (please take note of any changes)

  ____

10.2 Labour:

- Do you employ labor?_________________
- If so, at which stage and how much do you pay: _____________
- Was it more, less or similar to the year before?_________________

10.3 Transportation:
- Do you hire a boat? ______________
- If yes, at which stage and what is the cost: ____________
- How much fuel do you use and its cost: ____________
- Was it more, less or similar to the year before? ______________

10.4 Drying:
- Do you use a table for drying harvest? ______________
- Do you pay for the construction of the table? If yes, how much: ____________
- Labour and transportation costs for construction: ____________
- Was it more, less or similar to the year before? ______________

10.5 Packaging:
- Who does the packaging? ______________
- Is labor involved, and how much do you pay? ______________
- Do you pay for the bags, and how much: ____________
- Was it more, less or similar to the year before? ______________

10.6 Any assistance in planting and harvesting:

Activity	**Who is helping you?**	**How long (Duration)**	**Do you appreciate them?**
Planting			
Harvesting			
Drying			
Packaging			

11.0 Production

11.1 Harvesting Methods:
- Methods used for harvesting seaweed: ____________

11.2 Production Quantity:
- Average harvest per line (e.g.48 plant/20m) ____________

11.3 Planting and Harvesting Details (either use month or year, use whichever applicable)

	Month	**Year**
How many times do you plant		
How many times do you harvest		

12.0 Quality
12.1 Drying
12.1.1 What is the distance between farmers and drying table? (estimate in m or km)
12.1.2 How do you transport seaweed harvested to drying table?
12.1.3 How long do you dry your seaweed? (please specify range, e.g. 2-3 days)

- In rainy seasons?
- Cloudy days?
- Dry seasons (Sunny day)?

12.1.4 Do your table have a roof/ plastic cover?
12.1.5 If no! How do you dry your products during rainy conditions?
12.1.6 How do you ensure that your dried seaweed produces good quality?

12.2 Storage and packaging
12.2.1 Where and how do you store your dried seaweed? (please describe)
12.2.2 Do you do the packing at the Islands or villages?
12.2.3 How do you pack your seaweed into the bag, what materials do you use? (Please describe)
12.2.4 If you are packing on the islands. How far do you have to travel to the buyer/ agent/ warehouse? And by what means?

13.0 Additional information
13.1 What do you think about stakeholder collaboration between farmers. Please rank!
1 = Poor. 2 = Fair. 3 = **Good.** 4 = Very **Good.** 5 = Excellent.

Collaboration	**Rank**
Between farmers	
Farmers-buyers	
Farmers -government (fisheries) officers	

13.2 What do you think about the support from the government (MFMR). Please rank!
1 = Poor. 2 = Fair. 3 = **Good.** 4 = Very **Good.** 5 = Excellent.

13.3 What do you think is the best way forward for MFMR?

14.0 Value adding
14.1 Are you currently involved in any value-adding processes for seaweed?
If yes proceed to 14.2-14.4.
If not, why?
14.2 What product(s) are you producing?
14.3 What markets do you currently target for your seaweed product(s)? (e.g., schools)
14.4 How much do you produce (qty)? And how often do you produce (e.g. every day, weekly etc?

14.5 What are the costs involved? Please list.

Items	Cost

14.6 How much do you sell your product for?

15.0 Changes in Income Sources in your community
15.1 Have the majority of households in the community either decreased their cash income sources or maintained them without any changes, while also incorporating seaweed farming?
Reduced
Maintained

15.2 What is, in your opinion, the main contribution (impact) of the seaweed industry in your community?

15.3 What do you believe are the major changes for your household?