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The Cultivation of *Ulva lactuca* in Jambiani, Zanzibar: A Case Study

Jazmine Compton

Introduction

Commercial seaweed (Kiswahili: *mwani*) farming was introduced to Zanzibar in 1989 and has since expanded to neighboring island Pemba and mainland Tanzania.[1] In Zanzibar, seaweed is typically cultivated using the "off-bottom" method, where the seaweed is attached to ropes and secured to the substrate in the intertidal zone using mangrove stakes (Figure 1).[2] The seaweed industry employs twenty-five thousand people in Zanzibar, ninety percent of whom are women.[3] The introduction of seaweed farming in Zanzibar has contributed to the improved quality of life for women and their families, with income being used to pay for school fees, clothing, and home improvements.[4] Commercial production has been limited to the red (Rhodophyta) algae species *Kappaphycus* ("cottonii") and *Eucheuma* ("spinosum"), but local stakeholders have expressed interest in expanding the seaweed industry in Zanzibar by cultivating *Ulva lactuca* (*U. lactuca* hereafter), a green algae species of the *Ulva* genus.[5] This case study explores the feasibility of *U. lactuca* cultivation in Jambiani, Zanzibar which uses red algae cultivation techniques.

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[1] Flower E. Msuya, "Seaweed Resources of Tanzania: Status, Potential Species, Challenges and Development Potentials," *Botanica Marina* 63, no. 4 (August 1, 2020): 371–80. https://doi.org/10.1515/bot-2019-0056.
[2] Flower E. Msuya et al., "Seaweed Farming in Africa: Current Status and Future Potential," *Journal of Applied Phycology* 34, no. 2 (April 1, 2022): 985–1005. https://doi.org/10.1007/s10811-021-02676-w.
[3] Msuya, "Seaweed Resources of Tanzania"; Danilo B. Largo, Flower E. Msuya, and Ana Menezes, "Understanding Diseases and Control in Seaweed Farming in Zanzibar," *FAO Fisheries and Aquaculture Technical Paper*, no. 662 (2020): 1-49. https://openknowledge.fao.org/handle/20.500.14283/ca9004en.
[4] Flower E. Msuya and Anicia Q. Hurtado, "The Role of Women in Seaweed Aquaculture in the Western Indian Ocean and South-East Asia," *European Journal of Phycology* 52, no. 4 (2017): 482–94, https://doi.org/10.1080/09670262.2017.1357084.
[5] Msuya, "Seaweed Resources of Tanzania."

Figure 1. A seaweed farm at low tide using the traditional off-bottom method in Jambiani, Zanzibar. Photo by Jazmine Compton.

The seaweed farming industry in Zanzibar is being threatened by increased occurrence of crop failure caused by disease and high rates of epiphyte growth. These issues have caused farmers to leave the industry or only operate seasonally, resulting in a decrease in yearly production since its peak in 2012.[6] The effects of climate change, such as a rise in water temperature, are only exacerbating these issues.[7]

Many ideas have been proposed in the scientific literature to address these issues, using new cultivation methods and introducing new species of seaweed for production at the commercial scale.[8] Suggested new cultivation methods include floating lines in deeper water,

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[6] Msuya, "Seaweed Resources of Tanzania."

[7] Flower E. Msuya, "Environmental Changes and Their Impact on Seaweed Farming in Tanzania," *World Aquaculture* 42, no. 4 (2011): 34–71.

[8] Johan S. Eklof, Rebecka Henriksson, and Nils Kautsky, "Effects of Tropical Open-Water Seaweed Farming on Seagrass Ecosystem Structure and Function," *Marine Ecology Progress Series* 325 (2006): 73–84,

tubular netting to secure the seedlings to the lines, and securing seedlings to rocks using rubber bands (the cast method).[9] The green algae *Ulva* has been proposed for commercial cultivation in Zanzibar.[10] The overarching goal of these approaches is to improve the success of seaweed farmers which has the potential to preserve, or even improve, coastal marine ecosystems.[11]

Ulva is a genus under the division *Chlorophyta*, which is widely distributed in both tropical and temperate regions.[12] *Ulva* species can withstand harsh environmental conditions, making them commonly found in heated intertidal pools.[13] Due to its ability to adapt to various conditions, *Ulva* can be found near urban environments and can be an indication of eutrophication.[14] *Ulva* is used to produce abalone feed, but green algae can also be used to produce fertilizer, pharmaceuticals, and cosmetics. It can be used in waste treatment and is suitable for human consumption.[15] *U. lactuca* has been cultivated free-floating in continuously aerated tanks, seeded directly onto lines, and in mesh cages in high-flow areas or with a

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https://doi.org/10.3354/meps325073; Flower E. Msuya et al., *A Comparative Economic Analysis of Two Seaweed Farming Methods in Tanzania*, (The Sustainable Coastal Communities and Ecosystems Program. Coastal Resources Center, University of Rhode Island and Western Indian Ocean Marine Science Association, 2007); Renata Perpetuo Reis, Roberta Rodrigues das Chagas Pereira, and Henrique Geromel de Góes, "The Efficiency of Tubular Netting Method of Cultivation for *Kappaphycus Alvarezii* (Rhodophyta, Gigartinales) on the Southeastern Brazilian Coast," *Journal of Applied Phycology* 27, no. 1 (February 1, 2015): 421–26, https://doi.org/10.1007/s10811-014-0330-6; Derick Msafiri, *Enhancing Competitiveness of Seaweed Industry in Zanzibar*, (Tanzania: Research on Poverty Alleviation (REPOA), May 24, 2021), https://policycommons.net/artifacts/1849487/enhancing-competitiveness-of-seaweed-industry-in-zanzibar/2595739/; Msuya, "Seaweed Resources of Tanzania."

[9] Msuya, "Seaweed Resources of Tanzania."

[10] Msuya, "Seaweed Resources of Tanzania."

[11] Rebecca R. Gentry et al., "Exploring the Potential for Marine Aquaculture to Contribute to Ecosystem Services," *Reviews in Aquaculture* 12, no. 2 (2020): 499–512, https://doi.org/10.1111/raq.12328.

[12] Matthew Richmond, *A Field Guide to the Seashores of Eastern Africa and the Western Indian Ocean Islands* (SIDA/WIOMSA, 2011).

[13] Richmond, *A Field Guide to the Seashores of Eastern Africa and the Western Indian Ocean Islands.*

[14] Richmond, *A Field Guide to the Seashores of Eastern Africa and the Western Indian Ocean Islands*.

[15] Junning Cai et al., *Seaweeds and Microalgae: An Overview for Unlocking Their Potential in Global Aquaculture Development*, FAO Fisheries and Aquaculture Circular 1229. Rome, Italy: FAO, 2021. https://doi.org/10.4060/cb5670en; Jesmi Debbarma et al., "Nutritional Profiling of the Edible Seaweeds *Gracilaria Edulis*, *Ulva Lactuca* and *Sargassum Sp*." *Indian Journal of Fisheries* 63, no. 3 (2016): 81-87. https://doi.org/10.21077/ijf.2016.63.3.60073-11.

supplemental air supply.[16] Studies conducted in Zanzibar have shown that *U. reticulata*, a different *Ulva* species, is effective at nitrogen removal and that *Ulva* can filter fishpond effluent.[17] Other work in South Africa has shown that *Ulva* has the ability to remove excess ammonium, remove dissolved carbon from the water, and raise water pH.[18]

This project aims to address the issues the seaweed industry in Zanzibar is facing by exploring the feasibility of *U. lactuca* cultivation. This species has not been cultivated in the archipelago, and locals are unaware of its potential value, with some referring to it as trash (Kiswahili: *taka taka)* or plastic (Kiswahili: *plastiki)*.[19] The NGO Marine Cultures has expressed interest in the cultivation of *U. lactuca* due to the desire of local resorts and hotels to buy it for culinary uses in their restaurants.[20] *U. lactuca* is typically cultivated in tanks or under laboratory

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[16] Thomas A. DeBusk, M. Blakeslee, and John H. Ryther, "Studies on the Outdoor Cultivation of *Ulva Lactuca L*." *Botanica Marina* 29, no. 5 (January 1, 1986): 381–86. https://doi.org/10.1515/botm.1986.29.5.381; Iris Cohen and Amir Neori, "*Ulva Lactuca* Biofilters for Marine Fishpond Effluents. I. Ammonia Uptake Kinetics and Nitrogen Content" *Botanica Marina* 34, no. 6 (January 1, 1991): 475–82, https://doi.org/10.1515/botm.1991.34.6.475; Amir Neori et al., "A Novel Three-Stage Seaweed (Ulva Lactuca) Biofilter Design for Integrated Mariculture," *Journal of Applied Phycology* 15, no. 6 (November 1, 2003): 543–53, https://doi.org/10.1023/B:JAPH.0000004382.89142.2d; Tomer Ben-Ari et al., "Management of *Ulva Lactuca* as a Biofilter of Mariculture Effluents in IMTA System," *Aquaculture* 434 (October 20, 2014): 493–98, https://doi.org/10.1016/j.aquaculture.2014.08.034; Mette Møller Nielsen et al., "Cultivation of *Ulva Lactuca* with Manure for Simultaneous Bioremediation and Biomass Production," *Journal of Applied Phycology* 24, no. 3 (June 1, 2012): 449–58, https://doi.org/10.1007/s10811-011-9767-z; Alexander Chemodanov et al., "Feasibility Study of *Ulva Sp*. (Chlorophyta) Intensive Cultivation in a Coastal Area of the Eastern Mediterranean Sea," *Biofuels, Bioproducts and Biorefining* 13, no. 4 (2019): 864–77, https://doi.org/10.1002/bbb.1995; Flower E. Msuya and Amir Neori, "*Ulva Reticulata* and *Gracilaria Crassa*: Macroalgae That Can Biofilter Effluent from Tidal Fishponds in Tanzania," *Western Indian Ocean J. Marine Science* 1, no. 2 (2002). https://aquadocs.org/handle/1834/33; Beatriz Castelar, Renata P. Reis, and Ana Carolina dos Santos Calheiros, "*Ulva Lactuca* and *U. Flexuosa* (Chlorophyta, Ulvophyceae) Cultivation in Brazilian Tropical Waters: Recruitment, Growth, and Ulvan Yield," *Journal of Applied Phycology* 26, no. 5 (October 1, 2014): 1989–99, https://doi.org/10.1007/s10811-014-0329-z; Sophie Steinhagen et al., "Harvest Time Can Affect the Optimal Yield and Quality of Sea Lettuce (*Ulva Fenestrata*) in a Sustainable Sea-Based Cultivation," *Frontiers in Marine Science* 9 (2022), https://www.frontiersin.org/articles/10.3389/fmars.2022.816890.

[17] Msuya and Neori, "*Ulva Reticulata* and *Gracilaria Crassa*"; Flower E. Msuya, Margareth S. Kyewalyanga, and Dotto Salum, "The Performance of the Seaweed *Ulva Reticulata* as a Biofilter in a Low-Tech, Low-Cost, Gravity Generated Water Flow Regime in Zanzibar, Tanzania," *Aquaculture* 254, no. 1 (April 28, 2006): 284–92, https://doi.org/10.1016/j.aquaculture.2005.10.044.

[18] Albert. O. Amosu et al., "Biofiltering and Uptake of Dissolved Nutrients by *Ulva Armoricana* (Chlorophyta) in a Land-Based Aquaculture System.," *International Journal of Agriculture and Biology* 18, no. 2 (2016): 298–304, https://doi.org/10.17957/IJAB/15.0086.

[19] Personal communication, November 13, 2022.

[20] Ali Mahmudi, personal communication, November 11, 2022.

settings, requiring resources that are not accessible to seaweed farmers in Jambiani. If red algae cultivation techniques can be successfully applied to *U. lactuca*, it would provide an alternative livelihood for the community utilizing readily available materials. For women in Jambiani, seaweed farming is a source of empowerment and financial independence that needs to be protected.

Study Location

Unguja Island, also known as Zanzibar Island, is located in the Western Indian Ocean, thirty-five kilometers east of the coast of mainland Tanzania (Figure 2). It is the largest island in the Zanzibar archipelago with an area of 1,666 square kilometers and approximately 270 kilometers of coastline. Located on the southeast coast of Unguja is Jambiani, a village known for its wide intertidal zone which provides a multi-use space for the aquaculture industry, tourist activities, and the community.[21]

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[21] Nils Hedberg et al., "Habitat Preference for Seaweed Farming – A Case Study from Zanzibar, Tanzania," *Ocean & Coastal Management* 154 (March 15, 2018): 186–95, https://doi.org/10.1016/j.ocecoaman.2018.01.016.

Figure 2. Location of Jambiani, Zanzibar in relation to the East African coast and the African continent. Map created in ArcGIS Pro by Jazmine Compton.

The intertidal zone in Jambiani is approximately one kilometer, with a plethora of pools containing organisms such as urchins, anemones, and brittle stars. There is a rocky-sandy substrate with sparse seagrass beds. *U. lactuca* is found in abundance in the intertidal zone attached to rocks, boat anchor lines, and abandoned mangrove stakes (used for red algae cultivation) (Figure 3).

Figure 3. *U. lactuca* found in the upper intertidal zone at low tide approximately 15m from the beach crest. Photo by Jazmine Compton.

Methods

Two experiment plots were created using the recently introduced floating line method and the off-bottom method traditionally used in red algae cultivation. At the floating line plot, four attachment techniques were used to secure the seedlings to the lines including (1) *tie tie* (thin nylon or plastic rope used in red algae cultivation), (2) tubular netting, (3) mesh bags, and (4) the cast method. At the off-bottom plot, seedlings were attached to nylon rope using *tie tie*. The seedlings were cultivated for fourteen days when possible, aligning with the optimal cultivation period for *Ulva* species.[22] Plots were visited regularly at low tide to make observations on growth, epiphyte presence, seedling loss, discoloration, and signs of bleaching.

U. lactuca collection

The seedlings used for cultivation were collected from the intertidal zone where *Ulva* is in abundance (Figure 3). Each seedling was trimmed by hand to be approximately ten centimeters long and within the range of four to eight grams in mass. The seedlings were placed into a mesh transport bag, shaken for thirty seconds to remove all the excess water, and weighed using a hanging scale. Due to the logistics of conducting fieldwork in the water and the lack of a more precise scale, the seedlings were weighed collectively for each attachment method instead of individually. The total mass was divided by the number of seedlings to find the average weight of each seedling on the line.

Floating line plot

Access to the floating line plot was graciously provided by Marine Cultures, which is used by members of the community for sea sponge cultivation. The floating line plot was located 600 meters from the beach crest (Figure 4). Five lines of *U. lactuca* were cultivated at the floating line plot using four different techniques to attach the seedlings to the lines (Figure 5). Two lines of *U. lactuca* were cultivated for fourteen days using *tie tie* (labeled *tie tie* 1 and *tie tie* 2) to attach ten seedlings on each line. Eight seedlings were cultivated inside eight by ten centimeters mesh bags, and seven seedlings were cultivated on one line using the cast method,

[22] Christina Carl, Rocky de Nys, and Nicholas A. Paul, "The Seeding and Cultivation of a Tropical Species of Filamentous *Ulva* for Algal Biomass Production," *PLoS ONE* 9, no. 6 (June 4, 2014), https://doi.org/10.1371/journal.pone.0098700; Castelar, Reis, and dos Santos Calheiros, "*Ulva Lactuca* and *U. Flexuosa* (Chlorophyta, Ulvophyceae) Cultivation in Brazilian Tropical Waters."

each for fourteen days. Ten seedlings were attached to the line using *tie tie* and enclosed in a tubular mesh net for eight days (see Appendix A for details on plot construction and attachment methods).

Figure 4. Location of the off-bottom 250 meters from the beach crest (A) and floating line 600 meters from the beach crest (B) plots in the intertidal zone in Jambiani, Zanzibar. Image from Google Earth, accessed February 14, 2024, modified by Jazmine Compton.

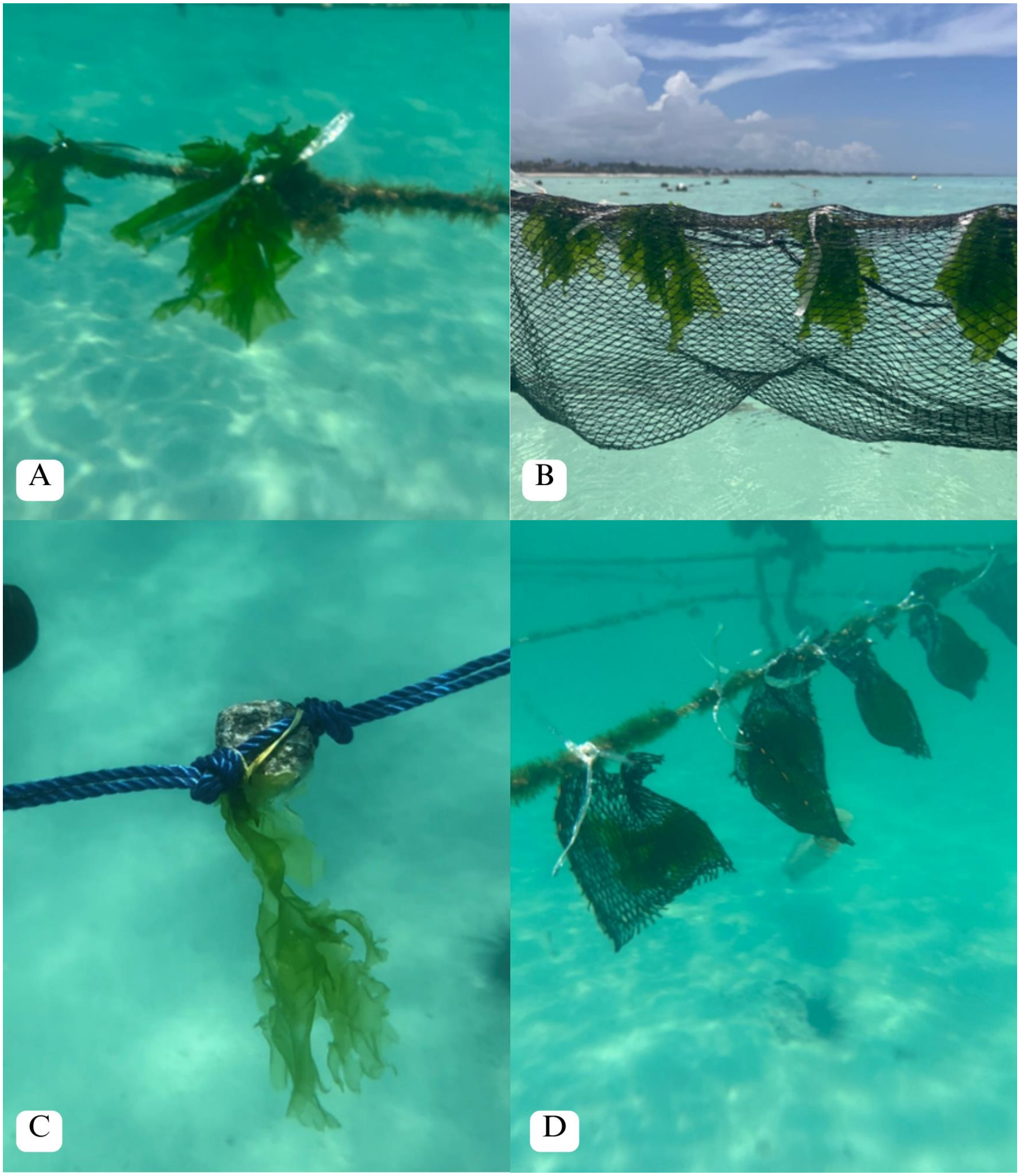

Figure 5. Methods used to attach *U. lactuca* seedlings to the lines at the floating line plot. Seedlings were 0.5 meters from the water surface at low tide and (estimated) 4 meters from the water surface at high tide. (A) *Tie tie*. (B) Mesh bag. (C) Cast method. (D) Tubular netting. Photos by Jazmine Compton.

Off bottom plot

Over a fourteen-day period, two lines of ten seedlings were cultivated using the off-bottom method (Figure 6). The two lines were positioned parallel to each other, perpendicular to the shoreline, and 250 meters away from the beach crest (Figure 4). The water depth at low tide was approximately one meter (see appendix A for details on plot construction).

Figure 6. The off-bottom plot located 250 meters from the beach crest. The two lines each had ten *U. lactuca* seedlings and were attached using *tie tie*. Seedlings were 15 centimeters from the water surface at low tide and (estimated) 2m from the water surface at high tide. Photo by Jazmine Compton.

Collection and data analysis

When the *U. lactuca* was ready to be harvested, it was collected and placed in mesh transport bags to be moved to shore. The bags were shaken for thirty seconds to remove all excess water before being weighed. Using the initial and final weight of the *U. lactuca*, the growth rate was calculated for each method that was used. The specific growth rate (SGR) was calculated using the equation outlined by Carl, de Nys, and Paul [23]:

$$\text{SGR } (\%\ \text{day}^{-1}) = \ln(B_2/B_1)/(t_2 - t_1) * 100$$

Where:
B_1 and B_2 = biomass (g)
t_1 and t_2 = time (days)

The growth rate was calculated using the total mass of the seedlings attached to each line and again after adjusting for the seedlings lost during cultivation. This was done by multiplying the average seedling mass for each method by the number of seedlings left on the line at the end of the cultivation period. The percent seedling loss was calculated for each attachment method using the equation:

$$\%\ \text{loss} = \text{number of lost seedlings/total number of seedlings}$$

Results

The SGR and percent seedling loss for each method were calculated and are reported below (Table 1).

Table 1. The calculated standard growth rate and percent seedling loss for each cultivation method.

Cultivation Method	SGR (%)	SGR of Remaining Seedlings (%)	Average Starting Weight/Seedling (g)	Percent Seedling Loss	Cultivation Days
Tie tie 1	3.57	5.16	4.55	20%	14
Tie tie 2*	-1.12	-0.36	6.08	10%	14
Mesh Bag	4.27	4.27	7.22	0%	14
Cast Method	-7.01	-0.95	5.71	57%	14
Tubular Netting*	-4.58	-4.58	7.5	0%	8
Off-Bottom	3.3	4.9	4.77	20%	14

*Technical difficulties may have resulted in inconsistencies in SGR.

[23] Carl, de Nys, and Paul, "The Seeding and Cultivation of a Tropical Species of Filamentous *Ulva* for Algal Biomass Production."

Due to technical difficulties with the digital scale during the collection of the *tie tie* 2 and tubular netting lines, the samples were transported a longer distance and were weighed with a less precise scale than the other samples. More time out of the water allowed the samples to dry out more, likely contributing to the low final weight of the samples (see Appendix B), and thus lower SGRs for these methods.

Bleaching was observed in all seedlings (Figure 7). All seedlings were dark green when collected from the intertidal but lightened in color over after the first week of cultivation. The degree of color change in the seedlings was similar no matter the plot location, cultivation method, or the length of cultivation. The cause of this change in color and the impact on the health of the seedlings are unknown.

Figure 7. Harvested *U. lactuca* from the floating line plot exhibiting the yellow-green color that was seen in all seedlings. At both plots and using all attachment methods, all seedlings reached this shade around day seven and remained this color for the rest of the cultivation period. Photo by Jazmine Compton

Instances of epiphyte growth were anticipated due to its prevalence in red algae cultivation but were only recorded on three of the seedlings, two of which were on the seedlings using the cast method (Figure 8). Filamentous algae quickly began to grow on the ropes, mesh, and *tie tie*, but appeared to have no impact on the seedlings, and was never found to be attached to the seedlings.

Figure 8. Examples of seedlings using two of the attachment methods. Epiphyte growth on a seedling using the cast method (left), and a seedling growing through the mesh bag netting (right). Filamentous algae growth can be seen on the ropes and the mesh bag. Photos by Jazmine Compton.

Floating line plot

The floating line plot could be accessed by walking during low spring tide, with the water reaching chest height. Protective water booties were necessary to avoid stepping on urchins that are densely populated in the intertidal. During neap tide, the plot could only be visited by swimming. At low tide, the seedlings were positioned less than 0.5 meters from the surface. Many herbivorous reef fish were found in and around the floating line plot. During the cultivation period, no fish were seen eating the *U. lactuca* and there was no physical evidence that such was occurring.

Off-bottom plot

The off-bottom plot was easily accessible during low tide at any point during neap and spring tide. There were issues associated with properly securing the stakes in the off-bottom plot. This resulted in the need to change the location two times during the fourteen-day cultivation period but stayed within five meters of the original location. Twenty-four hours after the plot was established, the stakes securing the lines had become dislodged, and the seedlings were out of the water, being desiccated by the sun. The plot was then moved to an adjacent pool. Forty-eight hours after the plot was moved, all four stakes had been dislodged by the current, and the lines were caught in a nearby rock formation. The plot was then moved to its final location and was angled at forty-five degrees to align with the current. Between the two lines at this point in the cultivation, one seedling was lost, three sustained tissue damage, and five had transparent tissue at the tips of the seedlings. The discoloration resolved itself after day seven of cultivation when the damaged tissue was shed.

When the plot was positioned perpendicular to the shoreline, the current caused the seedlings to move down the lines and bunch together at the ends. Once the plot was moved at a forty-five-degree angle, the movement of the seedlings along the lines was minimal for the rest of the cultivation period.

Attachment methods

Using the *tie tie* method of attachment, the seedlings had a high SGR, but a high loss percentage reduced its efficiency. It is the easiest and most accessible method for seaweed farmers, but it leaves the seedlings the most vulnerable. Unlike the mesh bag or the tubular netting method, there are no safeguards in place to prevent seedling loss from the current. One of the largest seedlings broke off of the line on day thirteen due to its weight, which was not included in the final sample. The current caused the seedlings to be pushed down the line, so additional pieces of *tie tie* were tied directly onto the line where necessary to prevent the seedlings from bunching together.

The mesh bag method had a high SGR and zero lost seedlings but required specialized material and took the most time to prepare. This is the only method tested that did not provide a single point of attachment for the base of the seedlings, potentially preventing damage from tying them directly onto the lines. After the first week, the *U. lactuca* began to grow through the holes in the mesh (Figure 8). Filamentous algae grew on the mesh but did not seem to obstruct the seedlings.

The cast method had the lowest SGR and the highest percent seedling loss. This method required more than double the rope than any of the other methods. The rubber bands held the seedlings tightly against the rocks and may have caused damage to the seedlings. A float made of a 1.5-liter plastic bottle was needed to keep the seedlings near the surface of the water due to the weight of the rocks.

The tubular netting was easier to construct compared to the mesh bags and achieved the same result of zero lost seedlings. The mesh is typically used for fishing and is easily accessible in Jambiani. Despite the short cultivation period of eight days, the same change in color of the seedlings occurred that was seen in the other seedlings (Figure 7).

Discussion

The most successful method of cultivation as measured by SGR and seedling loss percentage was the mesh bag method, but the *tie tie* and tubular netting method show greater potential for application. Overall, the seedlings were successfully harvested from the intertidal zone, trimmed down to the desired size, and transferred to the plots in spite of the delicate nature of their tissue. Over the fourteen-day cultivation period, most of the seedlings withstood the water current and wave energy associated with the tidal cycle. Therefore, the additional time and resources necessary to construct the mesh bags were not worth the slight increase in the SGR.

Around thirteen days of cultivation, the mass of some of the seedlings became too great to stay attached to the lines, which aligns with the optimal cultivation period for *Ulva* species reported by Carl, de Nys, and Paul and Castelar, Reis, and dos Santos Calheiros.[24] Carl, de Nys, and Paul found that thirteen days of outdoor cultivation resulted in the highest biomass yield for filamentous *Ulva*, and Castelar, Reis, and dos Santos Calheiros calculated the highest specific growth rate for *U. flexuosa*, another *Ulva* species, at fifteen days. Although the SGRs for *Ulva* species cultivated using various methods have varied greatly (1.2% - 18%), the SGRs for the methods in this study fall within this range.[25]

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[24]Carl, de Nys, and Paul, "The Seeding and Cultivation of a Tropical Species of Filamentous *Ulva* for Algal Biomass Production."; Castelar, Reis, and dos Santos Calheiros, "*Ulva Lactuca* and *U. Flexuosa* (Chlorophyta, Ulvophyceae) Cultivation in Brazilian Tropical Waters."

[25] Amir Neori, Iris Cohen, and H. Gordin, "*Ulva Lactuca* Biofilters for Marine Fishpond Effluents. II. Growth Rate, Yield and C:N Ratio" *Botanica Marina* 34, no. 6 (January 1, 1991): 483–90, https://doi.org/10.1515/botm.1991.34.6.483; Marcel Tutor Ale, Jørn Dalgaard Mikkelsen, and Anne S. Meyer, "Differential Growth Response of *Ulva Lactuca* to Ammonium and Nitrate Assimilation," *Journal of Applied Phycology* 23, no. 3 (June 1, 2011): 345–51, https://doi.org/10.1007/s10811-010-9546-2; Msuya, Kyewalyanga, and

The similar SGRs at the floating line and off-bottom plots speak to the resilience and stress tolerance that *Ulva* is known for and indicate that the plot location is not the most important factor for determining cultivation success. The ideal location for a *U. lactuca* plot depends on the resources available to the farmer. An off-bottom plot is cheaper and easier to access, but there is more competition for space in the upper intertidal. A floating line plot is more secure and less trafficked but is expensive to construct and is difficult to access during neap tide.

The flexibility in the cultivation method means that *U. lactuca* can be applied in a variety of conditions, environments, and locations depending on the needs of the farmer. An off-bottom plot may be sufficient for farmers looking to cultivate and sell only *U. lactuca.* If a floating line plot has already been established, such as with Marine Cultures, *U. lactuca* would be a simple addition. In recent years, initiatives have worked to train and provide resources for women farmers to practice seaweed farming in deeper water.[26]

Conclusion

The seaweed industry in Zanzibar is currently at a crossroads. With the threat of climate change, farmers are left to adapt to the environmental challenges or abandon the industry. The results of this study show that there are avenues for success in the cultivation of *U. lactuca* on the Jambiani coastline. Despite the adjustments that need to be resolved before commercial implementation, this is a realistic opportunity for the diversification of the seaweed industry in Zanzibar.

Salum, "The Performance of the Seaweed *Ulva Reticulata* as a Biofilter in a Low-Tech, Low-Cost, Gravity Generated Water Flow Regime in Zanzibar, Tanzania"; Msuya and Neori, "*Ulva Reticulata* and *Gracilaria Crassa*."

[26] Cecile Brugere et al., "Can Innovation Empower? Reflections on Introducing Tubular Nets to Women Seaweed Farmers in Zanzibar," *Gender, Technology and Development* 24, no. 1 (January 2, 2020): 89–109. https://doi.org/10.1080/09718524.2019.1695307.

Further research on *U. lactuca* cultivation in Jambiani should utilize the *tie tie* method with the optional addition of tubular netting to prevent seedling loss. Efforts should be focused on the cause of the observed bleaching and if there is an impact on the health, quality, and nutritional value of the harvested seedlings. Because of *Ulva*'s environmental tolerance, there is also the potential to expand farming to areas where there is more nutrient pollution, such as near urban environments, where red algae cultivation may not be suitable.

As a coastal community that relies heavily on the marine environment, sustainable practices are integral to the future success of farmers. Twenty-five thousand people in Tanzania are involved in the seaweed industry as their source of income, and even more depend on it indirectly.[27] The development of sustainable and realistic strategies for seaweed cultivation is a means of supporting the women who dominate the industry. In the case of *U. lactuca* in Jambiani, commercial cultivation should continue to be pursued considering the success of this study and the potential market that has been presented.

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[27] Msuya, "Seaweed Resources of Tanzania."

Appendix A

Floating line plot

For each attachment method using *tie tie*, fifteen-centimeter pieces of *tie tie* were positioned at the base of the seedling with the branches on each side. The *tie tie* was knotted directly onto the lines to secure the seedlings. The mesh bags were constructed using fish netting, cotton embroidery thread, and a needle. The mesh was cut into fifteen by ten-centimeter pieces, folded in half, and sewn along two sides to create a pouch. The seedlings were then placed inside before looping a fifteen-centimeter piece of *tie tie* through the open side and tying it onto the line. To construct the line using the cast method, the rope was folded in half and a series of knots were used to evenly space the rocks across the line. The rubber bands were wrapped around the rocks before they were tied to the rope and a float made of a plastic 1.5-liter bottle was attached to the middle of the line using a one-meter-long string.

Table 2. Materials needed for each attachment method at the floating line plot. All materials except the cotton embroidery thread were locally sourced.

Attachment Method	Materials
Tie tie	Nylon rope: 4m *Tie tie*: 1.5m
Mesh bag	Nylon rope: 4m Mesh netting: 0.5m^2 Cotton embroidery thread: 1.5m *Tie tie*: 1.5m
Cast method	Nylon rope: 10m 5cm rocks: 7 Rubber bands: 7 1.5L water bottle: 1 String: 1m
Tubular netting	Nylon rope: 4m Mesh netting: 1.5m x 30cm *Tie tie*: 3m

Personal equipment	Mask Snorkel Water booties Fins Knife

Appendix B

Off-bottom plot

A 0.5-meter mangrove stake was tied to each end of a four-meter nylon rope, and the stakes were secured in the sandy substrate. The seedlings were spaced twenty centimeters apart and were attached to the rope using fifteen centimeters strands of *tie tie*. The two lines of seaweed were oriented perpendicular to the shoreline and thirty centimeters away from each other. The materials needed to create each four-meter line using the *tie tie* method of attachment included: two 0.5-meter mangrove stakes, four-meter of nylon rope, and ten fifteen-centimeter pieces of *tie tie*.

Table 3. All collected data during the case study

Cultivation Methods	Starting Weight (g)	Ending Weight (g)	Avg Weight/ Seedling	Avg * # at End	# on Line at Start	# on Line at End	Cultivation Days	SGR (%)	SGR of Seedlings Left	Biomass Yield (g)
Tie Tie 1	45.5	75	4.55	36.4	10	8	14	3.57	5.16	29.5
Mesh Bag	57.78	105	7.22	57.76	8	8	14	4.27	4.27	47.22
Cast Method	40	15	5.71	17.13	7	3	14	-7.01	-0.95	-25
Tie Tie 2*	60.83	52	6.08	54.72	10	9	14	-1.12	-0.36	-8.83
Tubular Netting*	75	52	7.5	75	10	10	8	-4.58	-4.58	-23
Off-Bottom	95.45	151.5	4.77	76.32	20	16	14	3.30	4.90	56.05

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