# Tanzania Seaweed Guide: Opportunities for Increased Productivity, Traceability, and Sustainability

The Nature Conservancy


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**Diadromous LLC**
Gretchen Grebe, Principal

**The Nature Conservancy**
George Maina, Africa Fisheries Strategy Manager
Mondy Muhando, Seaweed Farming Trainer
Peter Limbu, Fisheries Technical Lead
Lucy Magembe, Tanzania Country Director
Tiffany Waters, Global Aquaculture Manager
Robert Jones, Global Aquaculture Lead

**Design, Illustrations, and Photographs**
Alison Bradley / Wacky Puppy LLC, Designer
Colin Hayes, Illustrator
Roshni Lodhia / TNC

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# Contents

# Introduction

The Nature Conservancy (TNC) works to create a world where people and nature thrive and has an ambitious agenda to put the world on a path towards sustainability by 2050. We build from our more than 65-year history of protecting important natural places around the world and have steadily expanded the scale and scope of our work. Our global priorities are tackling climate change, protecting land and water, and providing food and water sustainably for a growing population. Part of our plan to make that happen is to work with farmers to create sustainable supplies of food for future generations. Our aquaculture program is focused on creative solutions to minimize potentially negative impacts of food production. We work with farmers to maximize benefits aquaculture can provide to the environment and promote smart and sustainable economic growth. Using market-based initiatives coupled with new farming methods and policies, we believe aquaculture can be an ecologically beneficial part of the global food system.

TNC has been working in Africa since 2006. As the program continued to grow and evolve, the need for TNC to have an on-the-ground presence on the continent became clear and TNC's first office in Africa was established in Arusha, Tanzania. When we began working in Africa, we used science to identify the most ecologically important places to protect. We ranked terrestrial, freshwater, and marine ecoregions using multiple threat- and biodiversity-value datasets. We then identified geographies where terrestrial and freshwater priorities overlap, knowing that investing in these areas would deliver dual benefits. We determined that the ecoregions identified within Tanzania, including the marine areas where seaweed farming is ongoing, were among the highest priority regions in the continent.

In addition to being in high priority conservation areas, seaweed farming also has huge potential as an environmentally friendly source of income for coastal communities around the world, and especially for women, who make up 70% of the seaweed aquaculture workforce worldwide. Seaweed farming requires nearly zero feed, fresh water, land, or carbon emissions to produce. At the same time, seaweed farming, when done well, can be restorative to the environment by improving water quality, buffering water against acidification at the local level, and providing habitat for fish and other marine species.

When farmed unsustainably though, seaweed farming can compete for space in the nearshore environment, with negative impacts to corals, mangroves, and seagrasses. Partnering with companies and local farmers to encourage environmentally sustainable practices is a key strategy for ensuring that seaweed farming is a win-win for both people and nature.

The guide presented here is intended to serve as a foundation that key players within the seaweed industry, regulators, scientists, and community leaders can use to understand the challenges, opportunities, and better management practices for seaweed aquaculture in Tanzania. It is our hope that this will support collective action towards greater environmental sustainability and improved livelihoods throughout the seaweed supply chain. We also acknowledge that the development, recognition, and adoption of better practices is an iterative process. As such, we welcome additional information and guidance that further enrichens or complements the information presented here, and we will revise this document accordingly.

# Chapter 1: Status of Seaweed Aquaculture in Tanzania

## 1.1 THE HISTORY OF SEAWEED PRODUCTION IN TANZANIA

The harvest and sale of wild seaweeds was a prominent activity in Tanzania long before seaweed farming began in the region. As early as the 1930s, wild seaweeds were collected for export to Europe and the United States.[1,2] Approximately 4,000 tons of dry, wild-harvested seaweeds were exported annually from Tanzania in the 1950s.[3] This level of wild-harvest and export continued until the late 1970s when overharvesting led to the collapse of wild populations and cease of wild seaweed harvesting and export.

Seaweed farming was first introduced to the United Republic of Tanzania as an exploratory effort led by Copenhagen Pectin (now CP Kelpco) in which several kilograms of *Kappaphycus alvarezii* seedlings were brought from the Philippines to Unguja Island, in the Zanzibar Archipelago.[4] In 1989 private entrepreneurs brought *Eucheuma denticulatum* (previously *Eucheuma spinosum*) seedlings over from the Philippines and established the first commercial farm. Soon thereafter the practice spread to nearby Pemba Island, and then mainland Tanzania in the early 1990s (Fig. 1).[3] At that point, seaweed production began to increase linearly.

By 1996, seaweed farming was practiced in the eastern mainland (Tanga, Bagamoyo and Mafia Island) and southern mainland (Mtwara, Lindi and Kilwa) regions.[5] By 2009, more than 16,000 seaweed farms across 50 villages were in operation within the Zanzibar archipelago alone.[6] Recent estimates are

*Figure 1. Tanzanian coast and main islands of the Zanzibar Archipelago. Zanzibar has two main islands, Pemba (north; 988 sq km) and Unguja (south; 1666 sq km), and many small isles. Source: Google Maps*

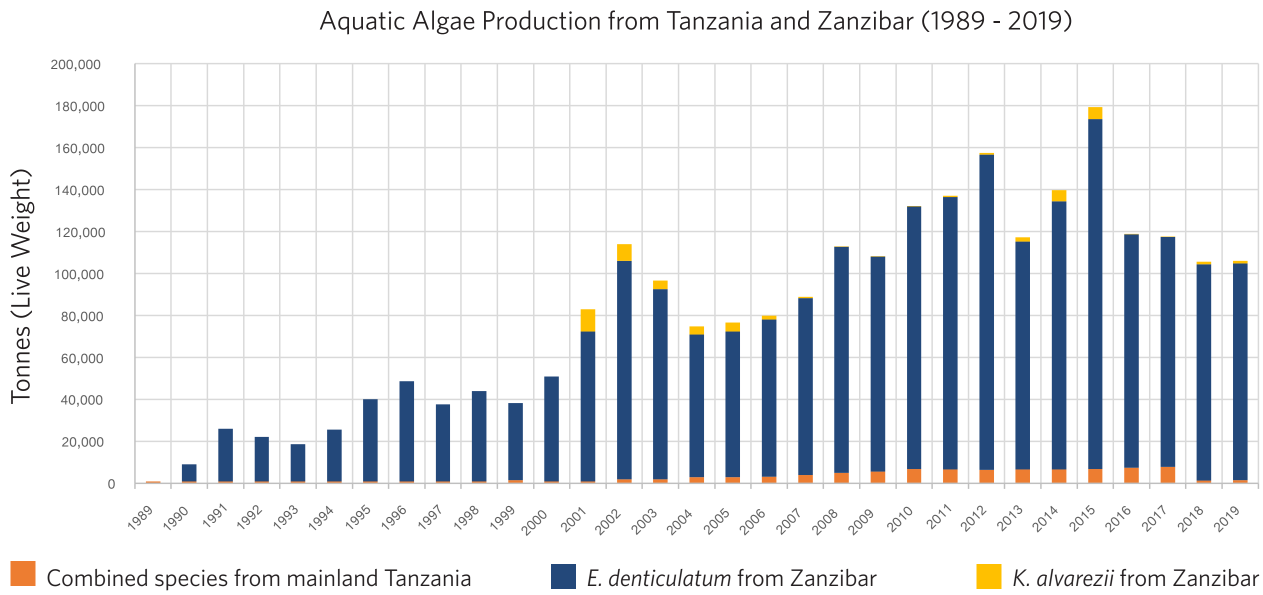


*Figure 2. Source: FAO 2020.*

that 83 villages across Zanzibar are currently farming seaweed: 50 across Unguja Island and 33 across Pemba Island. Notably, 25% of Zanzibar's current production is from Unguja, whereas 75% is from Pemba. Production from Unguja Island has declined in recent years, but it is stable/semi-declining around Pemba, Island and on the mainland.

In 2019, Tanzania's country-wide estimated seaweed production was 106,069 wet tonnes (Fig. 2).[7] Despite the reduced production in recent years, seaweed farming remains the third largest foreign exchange or "forex" earning industry, behind tourism and the clove trade. The industry employs approximately 30,000 farmers.[8]

In Tanzania, seaweed aquaculture is an activity that has offered an alternative or supplemental livelihood for women and former fishermen.[9,10] The majority (78 - 88%) of Tanzanian seaweed farmers are women,[11,12] and seaweed farming has been recognized as an activity that has resulted in multiple economic and social benefits for them.[5,13,15] Women engaging in seaweed farming activities report a reduced dependency on family income (typically earned by men) and more respect in their community.[8] It is one of only a few opportunities for women in coastal Tanzania to earn money.

Initially seaweed farming activities were built around a model of seaweed farmers working on farms managed by a larger business, with farmers receiving monthly salaries. However, the industry has shifted mostly to individual or family-scale enterprises that were started using private capital.[15] A few small farming cooperatives exist; some are registered, and others are not. Some fishing communities also manage seaweed farming activities in the Zanzibar islands and Songosongo[1,13] which has brought benefits to the communities as Tanzania fisheries are artisanal and experiencing the negative effects of overfishing in ways like the rest of the world; increasing effort for the same quantity of fish and use of destructive fishing methods.[16]

## 1.2 SPECIES AND TAXONOMY

Two species of tropical red seaweeds presently comprise almost all seaweed production in Tanzania. The species *Eucheuma denticulatum*[a] is predominantly farmed now,


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but *Kappaphycus alvarezii*[b] is also cultivated in small volumes. Taxonomically, the two species are closely related. In fact, until recently *K. alvarezii* was named *Eucheuma alvarezii* or *Eucheuma cottonii*, but molecular studies of the species' genotype led to its renaming. Both species are multi-axial, composed of spine-like branches which narrow to acute tips. The branches are densely covered with 1-8 mm long branchlets.

Sometimes these species are called *Eucheumatoids*, which is a designation including approximately 35 other closely related species. Neither *K. alvarezii* nor *E. denticulatum* are native to Tanzania. As previously stated, they were introduced from the Philippines where wild populations of *K. alvarezii* and *E. denticulatum* are most commonly found on coastal, limestone-rich substrates, in water less than 0.5 m deep[c]; although they have been found as deep as 48 meters below the water's surface.[17] Generally, brightly-lit waters where coral reefs form are also conducive for *K. alvarezii* and *E. denticulatum* growth, and there is a positive correlation between ambient light and growth rate of both species.

*K. alvarezii* and *E. denticulatum* exhibit the triphasic life history that is common for red algae. In the diploid vegetative phase, the alga produces haploid non-motile spores (tetraspores). The tetraspores produce haploid gametophytes, that then produce diploid carposporophytes. These carposporophytes release diploid carpospores and the diploid vegetative stage starts again.[18]

To date, commercial farming of *Kappaphycus* spp. and *Eucheuma* spp. focuses solely on the diploid vegetative stage. A mature vegetative bunch is cut into smaller pieces, and then these pieces are raised to harvest size. This practice of using the same algal material for new outplanting is known as *vegetative propagation* or *clonal propagation*. The propagules used are almost always sterile. Individual vegetative pieces of *K. alvarezii* have lived for 14 months, but stocks have been observed to live >10 years through vegetative cuttings.[16,19]

When the farming of *K. alvarezii* and *E. denticulatum* was initiated in Tanzania, they both adapted well and exhibited no differences in growth.[20] However, around

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[a] *Eucheuma spinosum* (Agardh, 1847) is now an invalid synonym of *E. denticulatum* (N.L. Burman) Collins & Hervey, 1917, but similarly still frequently referred to as 'spinosum' in the trade (Neish *et al* 2017; Guiry & Guiry 2020)

[b] *Eucheuma cottonii* (Weber-van Bosse, 1913) and *Eucheuma alvarezii* (Doty 1985) have been reclassified as *Kappaphycus alvarezii* (Doty) Doty ex P.C. Silva, 1996 (Guiry & Guiry 2020). However, this alga is still frequently referred to as 'cotoni' or 'cotonii' within the industry (Neish et al 2017). Additional *Kappaphycus* species (e.g., *Kappaphycus striatum* grown in the Eastern Pacific) are also known commercially as 'cottonii' (Nor *et al.* 2020)

[c] When measured at extreme low tide.

2011, increased incidences of disease, extensive herbivory, and die-offs began to occur on *K. alvarezii* farms.[8,10] General consensus is that these issues are associated with the loss of vigor due to clonal propagation, reduced access to pristine farming areas owing to coastal development, and higher water temperatures and greater variations in salinity resulting from climate change.[8,10] (See Section 2.4 for more discussion of this). Some reduction in growth has been observed in *E. denticulatum*, although much less.[8,10] For these reasons, many seaweed farmers in Tanzania have transitioned to producing solely *E. denticulatum*.


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## 1.3 CULTIVATION SYSTEMS

Tanzanian seaweed farms are generally located in shallow, intertidal and subtidal areas, and sometimes in lagoons and sheltered bays. Traditionally these farms consist of parallel rows of stakes with polypropylene or nylon rope tied between them. The stakes are sourced from nearby forests or mangroves. As briefly mentioned above, Eucheumatoid aquaculture practitioners obtain new material for outplanting by breaking off small pieces (50 - 100 grams) from a mature piece of seaweed and then tying these small pieces onto the polypropylene growing line using short sections of thinner line. This farm design is commonly referred to as *peg and line* or *off bottom* and it is the most common system used by Tanzanian seaweed farmers. On Unguja Island, Zanzibar, 88% of seaweed farmers surveyed near the villages of Bwejuu and Paje in 2018 used this method,[10] and observations from our recent work suggest that off-bottom farm designs are used at a similar proportion around Pemba.

Farm sites with level, sandy bottoms are better because they allow for uniform farm structures in which the lines are a standardized length, and the stakes are located on the same parallel transect to the cultivation lines. Level and sandy bottom locations also facilitate easy manoeuvring by the farmer while conducting maintenance on the farm. Ideally seaweed farms should be in places that still have some standing water during low tides so that the seaweed is not exposed to air for extended periods of time.[d] Exposure to air, and fluctuations between air and water temperatures, can exert stress on the seaweed.


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Water movement is an additional important siting consideration.[e] Water motion is arguably more important than light and temperature for *E. denticulatum* and *K. alvarezii* growth[21]; because materials move in and out of these seaweeds by diffusion, more water motion is correlated with higher growth rates. Water motion also influences the degree of suspended sediment in the water column, which in turn affects light available to the seaweed. Water movement across the farm also works to prevent the settling of fouling algae.

The optimal cultivation cycle for *E. denticulatum* and *K. alvarezii* in intertidal Tanzanian waters is generally 45 - 60 days. The exact weight of each clump might differ, but previous growth trials suggest that 10m of growline with 100 seedlings will produce 70 – 100 kg of wet seaweed (and 8 – 9 kg of dried material). Farmers transport their seaweed to shore using plastic sacks[f] (carried on their heads) or small boats called *burges* or *vihori*.

Once on land, the seaweed is dried on nets laid on rocks or grass. Drying takes 2-3 days during sunny periods and up to 7 days during the rainy season. Quality control during the drying process is important to ensuring a high-quality product. The seaweed needs to be turned regularly so that it dries in a uniform manner, and it must be protected from rain. When the seaweed reaches approximately 35% moisture content, it should be stored in a dry, well-ventilated area until it is sold.

[d] The ideal depth is approximately 30 cm below the water surface during low tide (Mateo *et al.* 2021).

[e] Suggestions are that water exchange of 0.2 – 0.5 meters per second is optimal (Kambrey et al. 2021)

[f] Repurposed flour or rice sacks.

## 1.4 TANZANIA'S COASTAL ECOSYSTEMS

Tanzania's coastal zone is biologically productive and highly varied. Major estuaries, muddy tidal flats, sandy beaches, limestone cliffs, mangrove forests, seagrass beds, and fringing coral reefs can all be found along the country's approximately 1,424 kilometres of coastline. This diverse habitat harbours high biodiversity and the large tidal amplitude creates, in many places, an extensive tidal zone between the coastline and the fringing coral reefs. As an activity occurring the intertidal and subtidal area, seaweed farming activities often interact directly or indirectly with these ecosystems. In turn, the health of these environments is also essential to the productivity of the seaweed farms and well-being of the seaweed farmers.

### SEAGRASSES

Seagrass beds are widely distributed along much of the Tanzanian coastline. At least 12 species of seagrasses comprise these beds, which are often mixed communities of several species.[22] Seagrass beds are some the most biologically productive ecosystems on the planet.[23] As *keystone species*, they play a critical role in supporting a diverse array of animal and plant species (Box 1) and are critical components in the conservation of marine biodiversity. Seagrass beds provide important nursery areas for juvenile fish and foraging areas for herbivorous fish such as rabbitfish (*Siganidae* spp.), parrotfish (*Scaridae* spp.), and surgeon fish (*Acanthuridae* spp.). Two endangered species, the green turtle (*Chelonia mydas*) and the dugong (*Dugong dugon*) feed on the seagrasses.[24,25,26] The green and hawksbill turtles travel through the seagrasses to their nesting sites on the sandy beaches.


### Box 1. Ecological studies of Tanzanian seagrass beds have documented:

- 100+ fish species
- 75+ species of benthic invertebrates
- 50+ species of macroalgae
- 18+ species of algal epiphytes
- 7+ urchin species
- Several species of sea cucumbers, shrimp, lobster, and crabs

*Source: Ocheing & Erftemeijer (2003) and sources therewithin.*

**In Tanzania, seaweed is cultivated for 30 – 45 days before it is harvested and dried.**

In addition to their role provisioning habitat and food, seagrasses provide regulating ecosystem services. As they photosynthesize, seagrasses take up carbon dioxide and release oxygen. Seagrasses also assimilate excess nutrients that could otherwise trigger nuisance algal blooms. Seagrasses help to stabilize and retain sediment along the shoreline which mitigates beach erosion.

**The extent of Tanzania's seagrass beds has declined due to the combined impacts of anchoring boats, trawl fisheries, coastal erosion, water pollution, and unsustainable seaweed farming.**

## CORAL REEFS

Tanzania's reefs are important habitat for reef fish, including several rare and vulnerable reef fish species such as the Napoleon wrasse *(Cheilinus undulatus)*, coelacanth *(Latimeria chalumnae)*, Blacksaddle grouper *(Plectropomus laevis)*, and spanning aggregations of the Giant grouper *(Epinephelus lanceolatus)*. Pelagic species commonly found in the region include whales (principally Humpback whales; *Megaptera novaeangliae*), Indo-Pacific bottlenose dolphins *(Tursiops aduncus)*, Humpback dolphins *(Sousa chinensis)*, seabirds, green turtles, and hawksbill turtles.

## MANGROVE FORESTS

Mangrove forests are another highly important coastal habitat. They provide critical habitat for juvenile fish, invertebrates, birds, and amphibians. Mangroves also protect the coastline from erosion by acting as a physical barrier that reduces the force of waves and storm surges. This role, in turn, means that they also prevent against coastal flooding. In Zanzibar alone, over ten mangrove species have been recorded between the two islands of Pemba and Unguja.

Seagrasses, coral reefs, and mangroves are connected by the species that move between them. Some species move between these habitats daily, while others may actively relocate from one system to another only once in their lifecycle, or as planktonic larvae (Fig. 3).[27]

### RESOURCE MANAGEMENT, CONSERVATION, AND AQUACULTURE

Eighty percent of the seaweed farms around Zanzibar are in Marine Conservation Areas (MCAs).[28] In the 1980's, Zanzibar's government began efforts to promote sustainable use of the island's coastline. A key piece in this effort was the establishment of the MCAs that are "co-managed" by local communities and the government. These areas, and any privately managed marine areas, are the jurisdiction of the Department of Fisheries Development, under the Ministry of Blue Economy and Fisheries. The objective of these MCAs is to promote sustainable resource utilization.

## 1.5 CARRAGEENAN

Most of the seaweed exported from Tanzania is processed into carrageenan, which is a long-chain carbohydrate, or polysaccharide. Carrageenan can be obtained from a variety of red seaweeds, which are sometimes grouped and referred to as *carrageenophytes* due to this characteristic. Carrageenophytes make and store large quantities of carrageenan in their cell walls because it provides flexible rigidity, allowing the algae to grow wide while also being able to bend in currents and waves. Depending on the species, carrageenan can comprise 30 - 75% of the seaweeds' salt-free weight.[16,29] Most carrageenophytes are farmed in tropical waters, but some of them are farmed in subtropical regions too. Across the world, farmed *K. alvarezii* accounts for approximately 70% of biomass used for carrageenan production, followed by roughly 20% cultivated *E. denticulatum* biomass. The remainder of the seaweed biomass used for carrageenan production is obtained from wild populations of temperate-water species like *Gigartina* spp. and *Chondrus* spp.

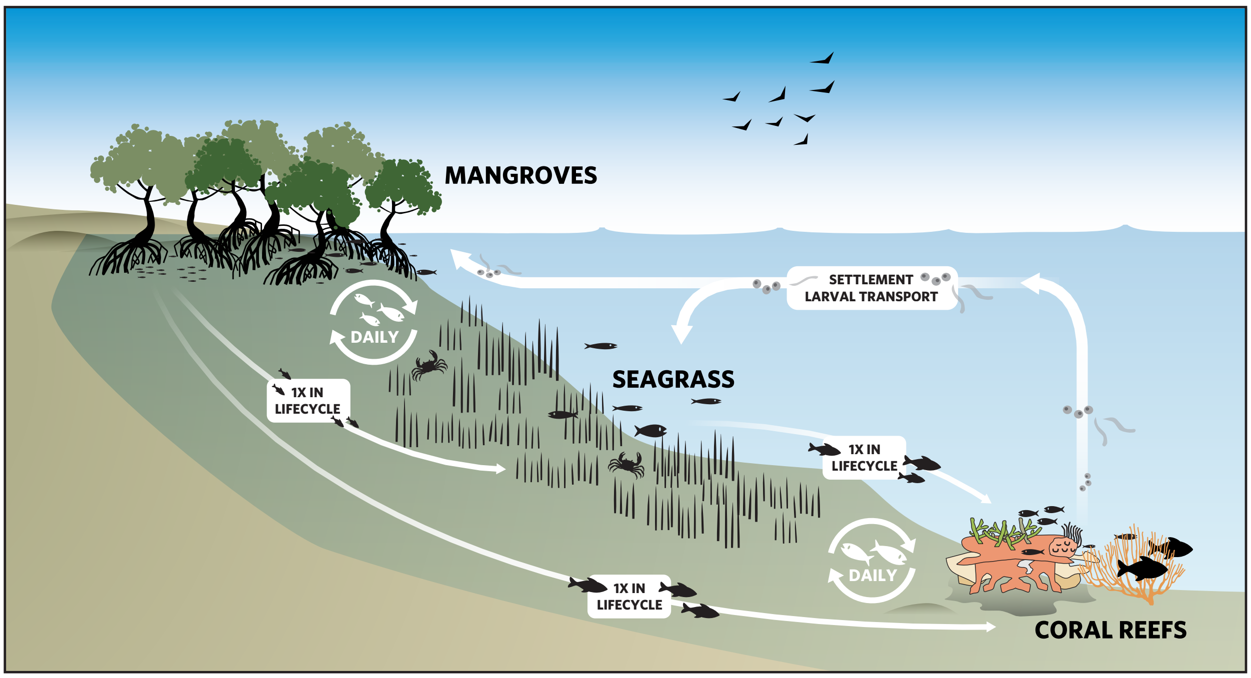


*Figure 3. Interconnections between mangroves, seagrasses, and coral reefs. Diagram modified from Kimirei et al. 2016*


Carrageenan is part of a class of *hydrocolloids*[g], or substances that form a gel in the presence of water. Hydrocolloids are used in many processed foods, animal feeds, nutraceuticals, and cosmetics as stabilizers that increase water holding capacity and shelf life, enable suspension and thickening, and in the case of food – a "desirable mouth feel". In many cases, blends are commonly made with other hydrocolloids or gums, and carrageenan is recognized for being easy to manipulate and integrate into these combinations in synergistic ways. Substituting hydrocolloids is also possible to some degree, but carrageenan is considered by many to be the superior hydrocolloid for milk-based products.

There are several different ways of obtaining carrageenan, so the market typically distinguishes between them by using the labels *extracted carrageenan* or *non-extracted carrageenan*. Extracted carrageenan is produced by heating the raw seaweed biomass (usually dry) in a neutral or alkaline broth and then isolating the exuded material using alcohol, precipitation, potassium gel pressing, or some combination of the three. Once extracted, the carrageenan is dried and then sold as whole or as a milled powder. The principal costs associated with this method are related to heating the broth and recovering the carrageenan from the water that was used for the extraction. Extracted carrageenan is preferrable when the application requires a clear gel.

Non-extracted carrageenan, also sometimes referred to as *alkali-modified, alkali-treated,* or *semi-processed carrageenan*, is far less expensive than extracted carrageenan because it does not use heat or require the recovery of material. Non-extracted carrageenan is not separated from the cell wall of the seaweed, which makes the acquisition of the carrageenan more efficient and far less expensive, but the product is cloudy due to the presence of the cellular material. Due to these characteristics, non-extracted carrageenan is favoured as an input for products that do not require clarity, such as pet food. Non-extracted carrageenan is sold powdered, granulated, or as a hydrated gel.

[g] The term phycocolloid is sometimes also used to describe products with these characteristics, which adds additional specificity by indicating that the material originated from seaweeds.


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Like many agricultural products, the characteristics of carrageenan can vary substantially. Variations in the molecular structures of carrageenan can result in different solubilities in water at different temperatures, different reactions to salt solutions, and different physio-chemical gelling properties. These distinctions are especially important because carrageenan is used as an ingredient in a wide array of product formulations with unique compositions. The industry grades carrageenan into three distinct categories that capture most of the variation in the carrageenan's characteristics: kappa, lambda, and iota. carrageenan. *K. alvarezii* produces kappa carrageenan which is normally thicker and stronger than the iota carrageenan produced by *E. denticulatum*.[1,30,31]

## 1.6 GLOBAL SEAWEED PRODUCTION

Seaweed farming is currently practiced in over 50 countries, and interest in the practice is growing.[32] Global seaweed production doubled between 2005 to 2015, and the booming industry is now valued at more than $6 billion USD. Despite the widespread geographical locations of the practice, only approximately twenty species are cultivated at scales that are commercially significant. *Eucheuma* spp. and *Kappaphycus* spp. are within the top 5 most-cultivated species in terms of production.

Research and commercial cultivation of the Eucheumatoids began in the Philippines in the 1960s, and was then introduced into Asia, the Western Indian Ocean, and the Americas[h].[33,34] During this time, approximately 43 countries have engaged in Eucheumatoid production.[35] In 2018, the FAO estimated that the total annual production of Eucheumatoids was > 12 million wet tonnes worldwide, worth approximately $1.3 billion USD. Indonesia has been the world's top producer of Eucheumatoids since approximately 2007,[36] however Malaysia and the Philippines are also large contributors to the global production of these species. Just as in Tanzania, Eucheumatoid farming is a major activity in many of these low to middle-income regions and an income generator for individuals with limited means.[34,37]

[h] Predominantly Brazil

# Chapter 2: Strengths, Threats, and Opportunities for Seaweed Farming in Tanzania

Seaweed aquaculture has been practiced in Tanzania for over 30 years. During this time, large environmental phenomena like anthropogenic climate change, rapid biodiversity and species loss, and ubiquitous plastic pollution have risen to the forefront of environmental issues that require swift and attentive attention. Similarly, social movements like fair-trade and women's empowerment have become priorities within our global commerce and rural development goals. As such, it is logical that some cultivation practices that were either originally taught or developed in response to associated societal or economic pressures, may not meet the high environmental and social standards set before us today.

In this chapter we take a deeper look at the current state of seaweed farming in Tanzania and identify areas and practices that are either strengths or weaknesses. When an area or practice is identified as a weakness, we provide recommendations for actions that could be adopted by the seaweed farmers and their communities or governments to bring these practices into greater alignment with the currently accepted Better Management Practices (BMPs).

## 2.1 BIGGEST STRENGTHS OF SEAWEED AQUACULTURE IN TANZANIA

The biggest strengths of Tanzania's seaweed aquaculture industry are the employment opportunity that it offers for women, the associated economic gains within coastal communities, the regulating ecosystem services supporting good water quality, habitat provision for marine animals, and the interdependence between successful farming and the good condition of other economic activities.

### EMPLOYMENT FOR WOMEN

Aquaculture activities provide a direct income for women in Tanzania's coastal villages. The women in turn, transfer a large portion of these benefits to their families and communities. For example, sixty-five percent of the women that Kalumanga (2018) interviewed in the communities of Bwejuu and Paje, Zanzibar reported earning more than 900,000 TZS (roughly $412 USD) in 2016 - 2017 from seaweed farming.[11] They used this money to pay for: school fees for their children, housing, transportation, housewares, and other basic needs like food and clothing.[11] In addition to the direct monetary benefits, the economic gains from seaweed farming have empowered women with more authority to participate in household decision-making.[10] Seaweed farming is an attractive economic activity for many Tanzanian women because it can be done almost continuously throughout the year, and it is a part-time occupation which enables them to combine work with other responsibilities such as caring for children and the household. It is also a free-enterprise activity which rewards fastidiousness.

## REGULATING ECOSYSTEM SERVICES AND HABITAT

Cultivated seaweeds naturally remove dissolved nutrients, minerals, and carbon dioxide from the seawater where they are grown. Bioextraction by seaweeds, also sometimes referred to as *bioremediation* or *phycoremediation*, is the practice of strategically cultivating seaweeds for the purpose of capturing these nutrients, minerals, or carbon dioxide. This strategy can be part of an integrated approach to watershed or coastal management when nonpoint source pollution is a primary concern. Left unchecked, the delivery of excess nutrients like nitrogen and phosphorus to waterbodies with little water exchange can result in areas of oxygen-poor water where marine life has difficulty surviving.

When seaweed is primarily cultivated for another purpose, like it currently is in Tanzania, the extraction of excess nutrients, minerals, and carbon dioxide is considered a *regulating ecosystem service*. This term encompasses all the natural systems and organisms that play a role in maintaining good water quality as part of their own biological processes. Most primary producers contribute to regulating ecosystem services, but mangroves, wetlands, seagrass beds, and wild seaweed populations are especially good at it. Like these wild features, cultivated seaweed beds can offer the same benefits. They have been shown to compete with harmful algal blooms and opportunistic macroalgae like *Ulva* spp. for nutrients in the surrounding water.[38,39,40] Additionally, by taking up carbon dioxide from the water, these seaweed farms can also help to alleviate ocean acidification at a local scale.

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Seaweed farms also provide refuge or food for fish and other marine organisms. In most cases, tropical seaweed farms have a higher biodiversity and abundance of fish and invertebrates than sandy-bottom areas without seaweed farms or 3-D structures.[41]

### COLLECTIVE BENEFITS FROM GOOD ENVIRONMENTAL MANAGEMENT

There is a shared interest between aquaculture, coastal conservation, tourism, and fisheries which all require healthy marine ecosystems. When these sectors are well-managed, benefits can be transferred between them. For example, when seaweed aquaculture is ecologically sustainable and economically profitable it can support coastal conservation because the people engaged in seaweed farming can sustain their livelihoods with this activity rather than less sustainable practices like overfishing. As another illustration, if seaweed farming is an important and sustainable livelihood provider, then there is more incentive for coastal communities to create and maintain conditions like good water quality that is required for successful seaweed farming.

## 2.2 DEVELOPMENT THREATS TO TANZANIAN SEAWEED PRODUCTION

Many of the threats to seaweed production in Tanzania stem largely from poor practices. Therefore, some of TNC's first efforts in our Tanzanian seaweed project strategy involve identifying and teaching commonly accepted better practices (see examples in Chapter 4). Here we describe these development-related local impacts, production-related local impacts, and regional environmental and ocean threats.

### COASTAL DEVELOPMENT AND WATER QUALITY

Like many coastlines around the world, destructive fishing techniques, coastal development, tourism, pollution, and climate change are affecting the health of Tanzania's coastal waters and reefs. Development along the Tanzanian shoreline has resulted in the loss of coastal thickets and mangroves, which impacts numerous ecosystem and habitat services. The destruction of coastal thickets is of relevance to seaweed farmers because the thickets are where they would normally obtain the stakes used to secure their seaweed lines in the off-bottom farm design. Without this source of material seaweed farmers are driven to harvest stakes from mangrove forests. This puts added pressure on the forests that are already impacted by over-harvesting of mangrove materials for building poles and firewood or charcoal.

Mangroves and wetlands areas are important habitat and nursery grounds for many marine animals, but they also play a fundamental role in maintaining coastal water quality. They intercept and process runoff, and sediment that it may carry, before it reaches the coastal water and reefs. Loss and fragmentation of mangroves and wetlands results in this runoff and sediment being delivered to seaweed farms. If this occurs frequently, or at high quantities, or in areas with low water flow, the sediment leads to reduced light levels, diminished photosynthesis within the seaweed, and thus restricted growth.

The discharge of wastewater into coastal areas also presents a threat to seaweed farmers and their activities. Untreated or minimally treated wastewater can harbour bacteria and other pathogens that increase the risk of infection in the cultivated seaweeds. If farmers tending to these crops have an open wound that is exposed to the water, these pathogens can present health hazards for them too.

Wastewater that has received primary treatment to remove most pathogens is safer for both seaweeds and humans, but this water still contains very high levels of nitrogen and phosphorus. The delivery of these excess nutrients into the nearshore environment can trigger blooms of phytoplankton or nuisance macroalgae (*e.g., Ulva* spp., EFA). Phytoplankton blooms can compete with the cultivated macroalgae for nutrients and light, and in some cases harmful algal blooms can cause skin irritation and respiratory distress for seaweed farmers and other water users in the area. The impacts of large phytoplankton blooms also extend to other marine organisms because when the phytoplankton die, the bacteria that feed on this organic matter bloom and draw a lot of oxygen out of the water. Lower oxygen levels can kill fish and other sessile organisms.

## CONFLICTING WATER USES

Fishing is the main socio-economic activity in most of Tanzania's coastal villages. For example, in Zanzibar, fishing employs more than 28% of the total coastal population and provides 98% of the animal protein diet.[13] The majority of fishing[i] along Tanzania's coast is artisanal; meaning that it is non-selective and it may employ use of traditional implements like wooden boats, canoes, traps, and nets of various kinds.[5] Potential conflicts between seaweed farming and fisheries are mostly an issue of spatial distribution and appropriation of space in the intertidal zone. For example, some seaweed farms are sited in or near the landing sites for local fishing boats. When this occurs, fishing boats that are passing by can accidentally knock down stakes securing the seaweed lines when they use the landing. Additionally, some fish that are attracted to seaweed farms (i.e., rabbit fish) are also targeted by fishers, and their boats may damage the crop or the lines if they get to close to the farm.

Siting conflicts can also occur between tourism activities and seaweed farms. In certain communities that have been most significantly impacted by increasing tourism (e.g., Pwani Mchangani, Zanzibar which has seen multiple hotels built within the past 7 years), these impacts have included restricted access to the beach and farm sites (i.e., land access from villages to the beach is restricted by construction and development of hotels). These conflicts have led some seaweed farmers to relocate their sites further from shore to avoid conflict with beachfront hotels. However, these new areas are also typically more exposed to wind and wave activity which can damage the farming gear. Sites further from shore are also more prone to herbivory.

Conflicts with tourism interests extend beyond issues of water access. Water-based activities like SCUBA diving and nautical sports (e.g., kitesurfing) that attract tourists to Tanzania's coasts, can compete with seaweed farms for intertidal and subtidal ocean area. Access to optimal drying space has become a challenge for many seaweed farmers who previously dried their seaweed harvest on the sand. Hoteliers and other beachside establishments discourage or inhibit this activity in proximity to their businesses because it is perceived as unsightly. For example, a recent decline in production associated with increasing tourism development is especially apparent around Unguja Island, Zanzibar. In contrast, large amounts of seaweed are farmed around Pemba Island, Zanzibar, and tourism activities there are minimal.

[i] Commonly caught species include emperors, groupers, kingfish, tuna, octopus, squid, parrot fish, sharks, and rays.

## ATTRACTIVENESS OF SEAWEED FARMING

Tanzania, a notable decline in the attractiveness of seaweed farming has occurred in recent years. This disinterest is attributed to an increased attractiveness of jobs in tourism, low and fluctuating revenue from the sale of seaweed, and the frequency, quantity, and timing of attention required to maintain seaweed crops.[26] Seaweed aquaculture is not the only primary sector activity where this reduced interest has been observed: work in agriculture and fisheries is also notably less attractive for Tanzanians, and especially young people, than in the past.[26] Before the 1980s, and when seaweed aquaculture was introduced into the country, the production of cloves was the mainstay of the Tanzanian economy. So, seaweed cultivation that closely resembled the already-familiar agrarian practices, was easily accepted by a wide swath of people. However, tourism to Tanzania has grown substantially since then[j]; the tourism sector now accounts for approximately 16% of Tanzania's GDP and 25% of the country's total export earnings.[42] For coastal communities, the tourism industry offers an income generator that is very different from agrarian and aquacultural practices. While little direct migration of workers from seaweed farming to tourism has been witnessed, the growth of the tourism sector may ultimately result in fewer young people electing to pursue seaweed farming.

The cultivation sites that currently provide the better conditions for the seaweed and farmers enable the seaweed to remain submerged in water throughout the tidal cycle. This requires farmers to conduct maintenance on their farms around the low tide because it is much easier to work in shallower water. However, the need to work around a tidal schedule can make it difficult to incorporate seaweed farming with another form of employment that has a rigid daily schedule.

Revenue earned by Tanzanian seaweed farmers is heavily influenced by fluctuating prices in the global carrageenan market because so much of the existing production is exported for this purpose. There is no clear institutionalized platform for farmers to know and negotiate the market price and this is an additional limitation on the bargaining power of the seaweed farmers.[10] Moreover, the shift away from production of the higher-valued *K. alvarezii* towards more production of the lower-valued *E. denticulatum* resulted in a decline in earning potential of seaweed farming.[10] For some, this reduced earning potential does not justify the long hours[k] required to seed, maintain, harvest, and dry the seaweed. The added risk of seasonal and repeat crop losses has led various farmers to focus on farming only during the rainy season and others have simply decided to quit farming.[43]

For some would-be or former seaweed farmers in Tanzania, the insolation, stooping posture required for maintaining off-bottom farm systems, and interactions with flora and fauna at the farm site dissuade them from participating in the activity. The Tanzanian mid-day sun is strong, and because of the need to time visits to the farm sites with low tides, seaweed farmers often end up spending long periods of time in the most direct sun. The same sandy ocean bottom ideal for seaweed farming is also where bivalves, urchins, sting rays, and stony fish commonly reside. However, many Tanzanian seaweed farmers do not have shoes or boots to wear

[j] In 2018, an estimated 520,000 tourists visited Zanzibar alone (RGoZ 2019).

[k] Brugère et al. (2019) share that some seaweed farmers report spending six hours a day tending to their lines.


while working on their farms. Thus, foot lacerations and impaled urchin or sting ray spines are a common injury reported by seaweed farmers. They have also reported skin irritation, eye irritation, and respiratory distress while tending to their farm or after visiting the farm site.[2,44,45] These symptoms presumably result from exposure to biotoxins produced by microalgal blooms of blue-green algae.[10]

## 2.3 PRODUCTION-RELATED THREATS TO TANZANIAN SEAWEED AQUACULTURE

### CROP LOSS DUE TO DISEASE AND EPIPHYTES

The colour of *K. alvarezii* and *E. denticulatum* can provide an indication of the seaweeds' health and nutritional status. Healthy specimens typically have a rich olive, green, or yellow tone. Discoloration or darkening usually indicates that the seaweed is experiencing stress associated with disease or unfavourable environmental conditions.

One of the most ubiquitous examples of colour change resulting from stress is often referred to as 'ice-ice'[l]. Ice-ice usually begins with the greening of segments between the seaweed's branches, which then turn pale white within a couple of days (Fig. 4). Ultimately, the bleached portions dissolve away. Since ice-ice occurs more commonly in the basal region of the thalli[m], the dissolving of tissue results in the loss of the mid and upper portions of the thalli and an overall loss of seaweed biomass from the farm. Ice-ice does not normally spread to adjacent segments. The cause of ice-ice is still poorly understood but generally believed to be related to physio-chemical stresses. Some correlation between warm water temperatures exceeding the species optimal temperature ranges and the prevalence and virulence of ice-ice outbreaks have been observed.[46] Another line of research is actively investigating if temperature-stressed seaweeds produce or release compounds that attract marine bacteria.

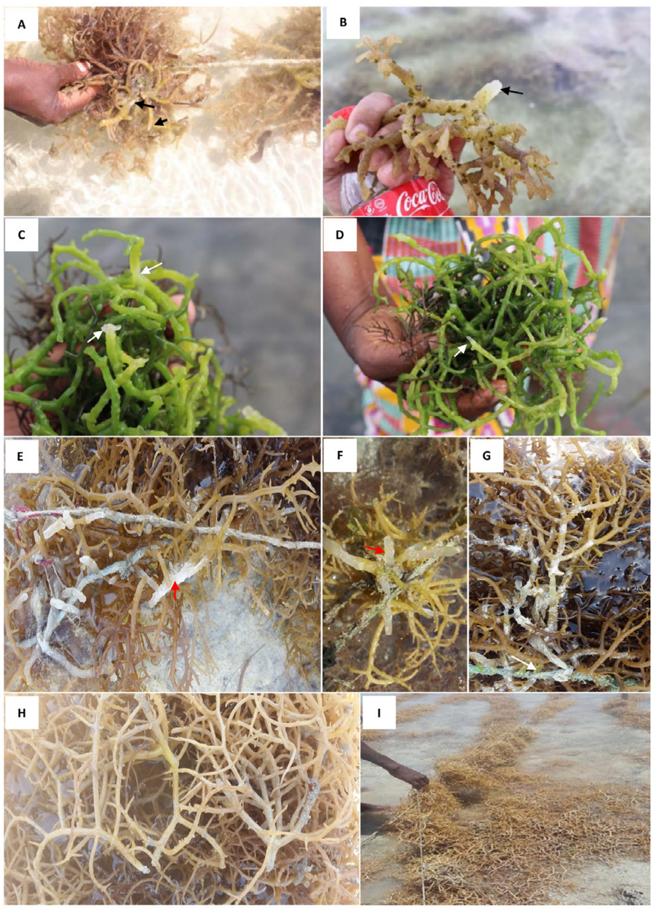
Tip discoloration and darkening are also commonly observed in stressed *K. alvarezii* and *E. denticulatum*. Tip discoloration usually begins with a shift towards pinkness in the tips, then softening, further discoloration, bleaching, and ultimately tissue disintegration. The most common conditions leading

[l] Term of Filipino origin.

[m] The term thalli is used to describe the main, central branch of seaweed tissue from which all other smaller branches originate.

to tip discoloration are understood to be warm water temperatures or extended exposure to air. Tip darkening initially manifests as increased colour of the thallus tips, and when severe, it too can result in the disintegration and loss of seaweed tissue. However, if tip darkening is caught early on and modifications are made, the tips may resume growth. Cold weather and old age are believed to be the most common conditions leading to tip darkening.

*Figure 4. Ice-ice disease occurring in older parts of the thallus. A. A cultivar with both ice-ice (arrow) and hairy branches caused by epiphytic filamentous red alga Polysiphonia-Neosiphonia complex. B. An old K. striatum cultivar with ice-ice disease and epiphyte. C, D. E. denticulatum cultivars (green strain) in Bweleo with ice-ice disease. E, F, G . E. denticulatum cultivars (brown strain) in Chokocho, Pemba, with ice-ice at the point of the tie-tie (arrows); otherwise, the rest of the thallus remained intact but lost its colour after breaking off (H, I). Source: FAO/D. B. Largo and A. Menezes*




Two types of nuisance algae settle on Tanzanian seaweed farms: dislodged and floating macroalgae (e.g., *Ulva* spp., *Gracilaria* spp.) and *epiphytic filamentous algae* (EFA). The former, dislodged, and floating macroalgae, compete with the cultivated algae for light, space, and nutrients. They usually settle in greater quantities on farms that are further offshore, where this is less fluctuation in water quality, and more waves and currents.[47] This fouling is also more present on Tanzanian farms in the dry season,[44] and in some cases the fouling can completely smother the cultivated seaweed.

Epiphytic filamentous algae are parasitic red seaweeds belonging to the genus *Melanothamnus* (formerly *Polysiphonia* or *Neosiphonia*). These EFA species routinely parasitize cultivated *E. denticulatum* or *K. alvarezii*. In addition to their prevalence on Tanzanian seaweed farms, they also commonly infest Eucheumatoid farms in Chile, Madagascar, the Philippines, Indonesia, Malaysia, and China.[32,44,48,49,50] Seaweeds affected by EFA can present small, elevated pores on the surface of the thalli around a filamentous epiphyte,[51] or in some cases, black spots appear on the thallus prior to visible hairs.[n,44,52] Infestations can also alter bacterial communities on the Eucheumatoid thalli, promoting the spread of pathogenic bacteria and resulting in secondary bacterial infections.[44] On other species of seaweeds, *Polysiphonia* sp. has been observed to penetrate deep between the cells of the host seaweed, compressing the host's cells and partially digesting the host's cell well.[46] Infestations and damage from EFA are typically greater in certain environmental conditions. Low water velocity at a farm site and exposure of the cultivated seaweed to high

[n] Has been previously reported as 'bulubabi' in the Philippines, which translates to 'pig bristles'.

light levels have been associated with EFA.[32,48] Extreme fluctuations in salinity[o], pH, nutrient levels, minerals, and temperature[11] also render the cultivated seaweed more susceptible to EFA infestations.[44,48] Some of these environmental fluctuations are seasonally induced and occur along large stretches of coastline. However, careful site selection can still help to identify sites that are less affected either in length of time, or compounding stressors, than other sites.

## GRAZERS AND PESTS

As previously discussed, the coastal area used for seaweed cultivation has diverse marine fauna; a portion of which like to graze on the cultivated seaweed. Echinoderms (e.g., starfish, sea urchin, and sea cucumber) are commonly found on Tanzanian seaweed farms. In their planktonic life stage, they recruit to the farms by floating and settling on the seaweed. In their benthic adult form, they can crawl onto the *Eucheuma* thalli if the cultivation lines are resting on, or very near, the seafloor. The sea stars invert their stomachs over the *Eucheuma* branches, and the branches die where they are covered, causing them to be lost. The sea urchins (*Tripneusteus gratilla, Echinometra mathaei*) hollow the central thalli which results in a weakened connection between it and the branches. Thus, the branches not tied to the longline are lost when they break off. The sea cucumbers tend to prefer feeding on the branch tips which prevents seaweed growth. Herbivorous fish and sea turtles also commonly graze seaweed lines. Rabbit fish and puffer fish will either nibble the tips and branches or the cortex and leave the algal skeleton. Green turtles will take large bites of seaweed, and they can cause damage and breakage by crawling over the lines.

[o] Water salinities between 29 – 34 and water temperatures between 23 - 33°C are optimal for Eucheumatoids.

Epiphytic sponges, barnacles, settling settlement, and biofilms create a habitat that is conductive for other micro-organisms to breed and infect the seaweed crop.[53] Nuisance algae like *Ulva* sp. can be vectors for disease, and, like biofilms, in abundance they can reduce the crop's growth rate by restricting its access to light and nutrients.[51]

## REDUCED GENETIC DIVERSITY AND STRAIN FATIGUE

Vegetative propagation means that the genetic diversity of the crop is never replenished; large portions of the *E. denticulatum* and *K. alvarezii* crops likely originate from just a few clones. This is problematic because species survival, adaptation potential, and resistance to biotic and abiotic stressors is enabled by intra-specific genetic diversity. This lack of genetic diversity within the farmed *K. alvarezii* and *E. denticulatum* crops in Tanzania, and worldwide, likely translates into a decreased resilience to disease and other stressors, including ice-ice.[54] It may also have resulted in a slow deviation away from the desirable characteristics that the stock was initially selected for. Most notably, the viscosity of the seaweeds produced today is much lower than that of seaweeds grown in the 1990s. More viscous seaweeds fetch a higher price, so the industry has a vested interest in R&D to regain viscosity in the seaweeds.

## ENVIRONMENT AND HABITAT DEGRADATION

Poorly managed seaweed farming can have adverse impacts on the marine environment. Poor management usually occurs because the seaweed farmer has not received instruction on better practices, due to a lack of incentives for better practices, or as the result of external pressures. For example, seaweed aquaculture can have negative impacts on seagrass beds if sited on top of the beds due to shading or space competition if they are sited too close.[5,55,56,57] Foot traffic to and from the farm can also damage the seagrass, reduce overall seagrass biomass, and potentially impact the diversity of macrofauna in these areas if farmers use more than one designated path to access their farm.[58,59] In some instances, seaweed farmers have also physically cleared seagrass from their desired farm site.[5]

## 2.4 THREATS TO THE REGIONAL ENVIRONMENT AND OCEAN THAT AFFECT TANZANIAN SEAWEED FARMING

### CLIMATE CHANGE AND WARMING WATERS

Tanzania's coastal waters are hotter than they were in the past. As an example, the maximum water temperature measured in Zanzibar's shallow waters in 1990 was 31°C, but now 38°C water is frequently recorded.[48] These warmer water temperatures correlate with increased incidence of ice-ice across Tanzanian seaweed farms. If this warming trend continues, it may severely impact the suitability of Tanzanian waters for Eucheumatoid production. Already this temperature shift has meant that Tanzanian waters exceed the tolerance range of *K. alvarezii* for part of the year, and this period of unsuitably warm water is getting longer.

Impacts of the warmer coastal waters may be somewhat mitigated by more selective cultivation of *E. denticulatum*. Research on photosynthesis and respiration at different temperatures indicates that *E. denticulatum* may fare better at high seawater temperatures than *K. alvarezii*.[60,61] Glenn & Doty (1981) observed similar maximum photosynthesis peaks in both species in water temperatures at 30-32°C, but, *E. denticulatum* had a much slower decline in photosynthesis above this peak than the *Kappaphycus* species tested.[55] The researchers interpreted this as an indication that *E. denticulatum* should be more is likely better equipped sustain respiration and other metabolic functions at higher temperatures.[55] More recently, Borlongan et al. (2017) studied temperature tolerance of Eucheumatoids and found that *E. denticulatum* tolerated temperatures up to 33°C.[56] A green strain of *K. alvarezii* tolerated the widest range of temperatures (17-32°C), and a brown strain of *K. alvarezii* tolerated temperatures between 20-29°C.[56] Caution is warranted though, because even the more tolerant *E. denticulatum* has been recently affected by long periods of heat in Tanzania.[62]

> **Physiological responses of tropical seaweeds to warming and ecological responses to climate change are only starting to be understood.**

Unfortunately, even if a particular species or strain can tolerate brief periods of warmer water temperatures, prolonged exposure to high temperatures can cause the seaweed to reallocate its energy for protection and repair rather than growth.[64] Seaweeds with temperature stress have been shown to have significantly lower carrageenan yield, strength, and viscosity.[65,66] High temperatures can also affect the antioxidant activity and reduce other bioactive compounds like chlorophyll-*a*, carotenoids, and phycobiliproteins.[63,67] Efforts to select and develop temperature-tolerant strains through long-term acclimation efforts may help to lessen the impact of high temperatures on seaweed performance. More details on this approach are provided in Section 3.3 - Seaweed nurseries, breeding programs, and biobanks.

Moving seaweed farming activities to deeper, cooler waters may be required if Tanzanian seaweed production is to continue in a warmer climate. However, this adaptation will require a shift in farming systems and more investment in materials and vessels to access the farms. It may also result in an archetypal shift of the 'Tanzanian seaweed farmer'. (This opportunity is discussed in more detail in the next section).

Apart from warming waters, climate change will likely result in a change in terrestrial run-off patterns and an increased intensity of storms. A change in run-off patterns may affect the salinity and water chemistry along the coast and near river-mouths, potentially rendering sites that have been historically productive farming sites vulnerable to increased incidence of disease. Storms of increased intensity pose a threat to farm structures and may result in breakage and loss of cultivated biomass.

## 2.5 OPPORTUNITIES FOR FARMERS AND THE ENVIRONMENT

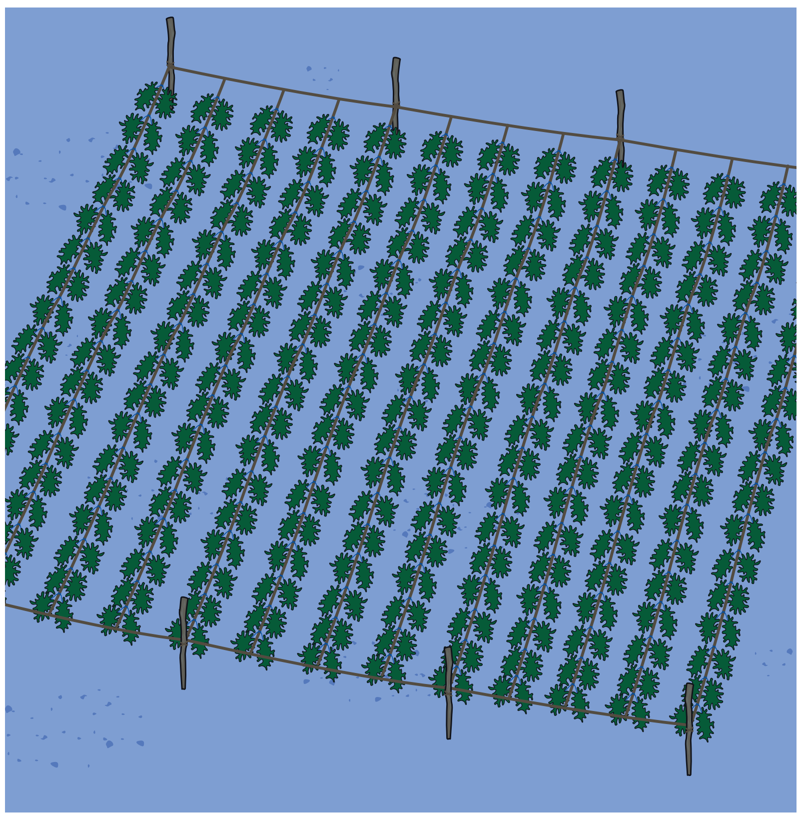
Within the past decade, researchers from national institutes, government agencies (including the Ministry of Trade and the Zanzibar Department of Fisheries), NGOs, international experts, local export companies, and buyers have partnered to tackle the challenges of the seaweed industry in Tanzania and secure and improve the seaweed farmers' incomes. Many of the opportunities presented here are the result of these tireless efforts.

### BMPS FOR IMPROVED YIELDS

Several BMPs may help Tanzanian seaweed farmers to obtain higher and more consistent harvest yields. Establishing a standardized farm design can help to reduce the risk of seaweed loss and reduce maintenance time (Fig. 5). If cultivation lines are a uniform length and connected to a common structural line, then the farm is more resilient during unfavourable weather and the removal and replacement of these lines is much quicker. This well-constructed and standardized structure also requires fewer stakes. Implementing routine farm maintenance practices can prevent many issues of fouling, herbivory, breakage, and dislodgement. Frequent and routine inspection of the farm structure, cultivation lines, and seaweed crop can stop a small issue from becoming a much larger one.

Using a Double Made Loop (DML) to attach seedlings to the cultivation line has been shown to triple production on several pilot farms. Some farmers have been reluctant to adopt this method because it requires additional effort to prepare and seed the line. However, because it enables more biomass to be cultivated within the same amount of ocean area, it is not only beneficial for the farmers, but it also reduces the amount of rope needed to produce the same amount of seaweed.

*Figure 5. Standardized off-bottom seaweed farm. Illustration: Colin Hayes.*




The selection and careful treatment of seedlings will also help to improve yields.[p] The optimal seaweed pieces to use for new propagules are mature, thick, sturdy, and free from epiphytes. Ideally the new propagules should be tied onto the cultivation line while in water at the farm site. If the propagules must be transported, they should be covered from the sun and kept moist. When attaching the new material, only one propagule should be placed in each attachment loop.

Developing a regional and site-specific seasonal calendar will help seaweed farmers anticipate changes in the marine environment that might be favourable or unfavourable for seaweed cultivation. Measuring and recording changes in water salinity, water temperature, currents, wind, and the associated response of the seaweed are the first steps to creating a seasonal calendar. This information can then be aggregated across several sites or seasons and refined over time. Seasonal calendars can be used by farmers to make decisions about rotating production between multiple farm sites according to commonly observed seasonal variations in the water conditions.

[p] Developing national seedstocks and bio-secure onshore nurseries are also critically needed to improve yields. More details one these measures are provided in Section 3.3 - Seaweed nurseries, breeding programs, and biobanks

## STRONG AND SUSTAINABLE MATERIALS

The polypropylene ropes used for the seaweed farm structural and cultivation lines are exposed to strong sun and salt water which, over time, leads them to become brittle and more susceptible to breakage. Moreover, high wave energy and/or abrasive sediment can further accelerate wear on cultivation lines. To extend the life of the ropes, they should be cleaned after each cultivation cycle to remove fouling seaweed.

If the ropes are removed from the farm, they should be dipped in fresh water and then stored in a cool, dry, and dark place. If damaged or cut, the ropes can be repaired to the correct length and used again. Polypropylene ropes maintained in this manner should last a minimum of two years. Once polypropylene ropes are too brittle or short to be used, they should be recycled at a facility equipped for this purpose, repurposed for other uses, or disposed of in a landfill.

Ideally seaweed cultivation would not involve the use of plastic in the marine environment. However, the non-plastic ropes that are currently available do not fare well in the extreme sun and salinity. They degrade quickly and/or absorb the water which makes them heavy and difficult to work with. Additional research and development into non-plastic materials for seaweed cultivation lines is needed. In the meantime, farmer education in better practices and the establishment of additional collection sites for old rope will facilitate farmer participation in recycling initiatives.

In addition to reducing plastic pollution from cultivation lines, there is a need for experimentation and identification of alternative materials for the wooden stakes that are commonly used in the off-bottom farm design. As previously mentioned, deforestation of coastal thickets along Tanzania's coastline has led some farmers to make stakes out of wood from mangrove trees, which is negatively impacting these vital landscapes. It is essential that seaweed farmers refrain from using mangrove wood for farming stakes, and furthermore, from using wood of any kind for seaweed farming.

## BIOSECURITY PROTOCOLS AND PEST MANAGEMENT

Disease outbreaks reduce seaweed farm yield and farmer income. Biosecurity protocols are procedures intended to protect the cultivated crop against harmful biological agents that may cause disease or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damage the seaweed. There are ample opportunities to develop and apply increased biosecurity measures on Tanzanian seaweed farms. Prior to commencing any farming activities, farmers should wash their hands before handling seeds and equipment, and if possible, they should use sanitized gloves. They should also wash all equipment and materials used on the farm (ropes, stakes, DMLs) with sterilized or filtered seawater. If available, a natural disinfectant can also be used, but if it is applied, then the equipment should be completely dry before returning it to the farm site. Matoju et al. 2021 recommend these sanitation measures for their effectiveness at reducing the transfer of microbes to new cuttings.[51] Additionally, everyone working on the farm should be trained in biosecurity handling procedures, including appropriate clothing, equipment sanitation, and good hygiene practices.

When preparing seeds, farmers should remove physical debris and inspect the algae for epiphytes and signs of bleaching or spots. If any of these are present, and more seed is available, then forgo using these seeds. If they must be used, remove any dead or degrading tissue with a sharp and sanitized razor blade. Then farmers should wash seeds using sterilized seawater (if available) or seawater filtered through a cloth. Lastly, they can disinfect selected seeds by dipping them quickly in freshwater or using a natural disinfectant such as lime water or diluted iodine.

Effectively managing pests and sediment deposition will help prevent disease outbreaks. Careful biosecurity measures are important for the quarantine and disposal of unhealthy or infested seaweeds. If a potential outbreak or infestation is suspected, farmers must act swiftly to remove and isolate those seeds. These seaweeds of concern should be disposed of on land (not in the ocean). If the disease or infestation is not easily identified, a photo should be taken and saved along with any other observations about the environmental conditions and seaweed tissue characteristics leading up to the outbreak.

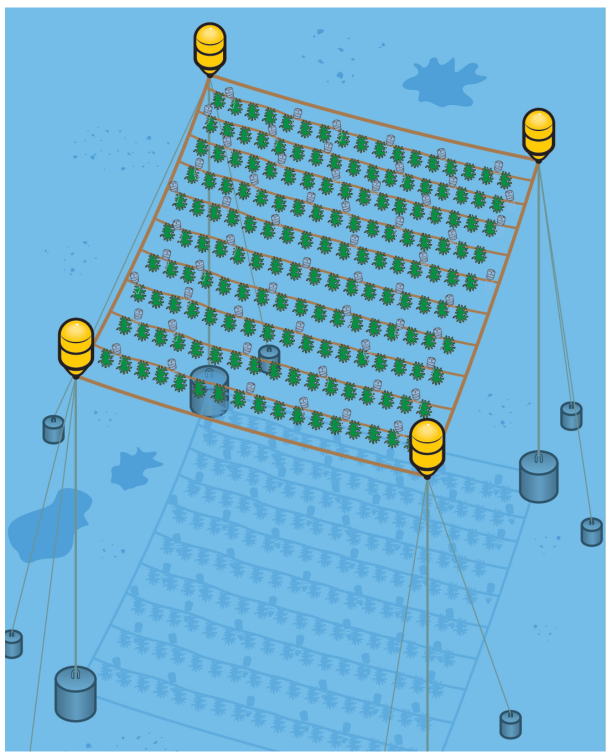
The Standard Operating Procedure of Eucheumatoid Cultivation Using Biosecurity-Based Approach,[68] and Campbell et al. 2020[70] are both excellent resources providing additional justification for, and instruction in, the development of biosecurity BMPs.

## EXPANSION TO DEEPER WATER, SUSPENDED LONGLINE SYSTEMS, AND TUBULAR NETS

There is considerable interest in relocating Tanzanian seaweed farms further from the coast into water that is 2 - 6 m deep during low tide. At this depth the water temperature is cooler and more stable. Proponents of this move believe that the cooler water may help

[q] North Pemba, Zanzibar

*Figure 6. Floating seaweed aquaculture: Colin Hayes*



to prevent ice-ice outbreaks. Indeed, substantial performance improvements have been reported in areas like Tumbe Village[q] where deeper water farming production methods have been tested. *K. alvarezii* grown at these locations had reduced incidence of disease, higher growth rates, and minimal mortality (Pers. Corres. Flower Msuya).

Despite this promise, shifting production to deeper waters presents unique siting, access, maintenance, harvest, and safety challenges. Near Pemba and Ungunja, there is a limited amount of ocean space that protected enough by the barrier reef to facilitate safe farm access and crop protection from thrashing waves. Moving farms to deeper water also requires additional materials to build the cultivation array. It is not feasible to use the current stake and line cultivation system in deeper waters. Instead, the lines are typically suspended in the water using floating plastic bottles and then attached via another line, to bags of sand on the seafloor. This method has also been previously referred to as the "deep water floating method".[11]

More equipment is required to access and maintain farms in deeper water. A boat is needed to install and maintain farms further from the coastline, and snorkel or dive equipment may also be required. Existing seaweed farmers have limited existing access to boats and typically little capital to purchase this gear. Training in boat operation and scuba diving is thus required, or alternatively, a skilled operator can be hired for specific tasks. The acquisition of additional equipment or skilled labor to access these sites results in an increased cost of production. Nonetheless, deep water techniques are widely used in South-East Asia by small-scale farmers, and this provides useful case studies for the adaptation of such techniques in Tanzania.

Moving seaweed farming activities to deeper water could require a significant redefinition of the Tanzanian seaweed farmer archetype and a greater reliance on men and/or shared community resources like boats. Women may not have interest in working in deeper water, know how to swim, or have access to boats and other equipment required to work in deeper water. Furthermore, even if they are interested, there may be cultural hurdles to overcome. Additional research is required to gauge if men would be interested in seaweed farming if it was in deeper water, what level of income would be required to capture their interest, and if other shifts in farming practices would result from the move to deeper water that would facilitate or discourage their participation. For example, maintenance of off-bottom farms in the intertidal zone is usually conducted by women during low tides. Because low tide is not the same time every day, having flexibility during the day enables women without full-time employment elsewhere to accommodate the tidal shifts. However, farms in deeper water may not be accessible during low tide, so maintenance schedules could potentially be decoupled from the tides. Perhaps these more flexible maintenance schedules will attract prospective seaweed farmers that would otherwise not be able to participate.

Relocation of farming practices to deeper water could be combined with modifications in seaweed attachment methods like the Double Made Loop or tubular nets to obtain additional production benefits. In Brazilian waters, using tubular netting for *K. alvarezii* farming resulted in overall lower farming costs[r] than the tie-tie method, and better retention of seedlings.[69]

[r] The approximate cost of tubular netting in 2014 was $0.25 USD per meter (Reis et al. 2014).


The tube netting facilitates the preparation of new lines because the net can be stuffed manually or mechanically, instead of tying individual seedlings onto the cultivation line. Furthermore, in the tie-tie method, seedlings are only attached via a single point, so if breakage occurs the un-attached material must be either re-attached or it is lost to the environment. However, with tube netting, if the breakage occurs along the main branch, it is likely that the pieces will be retained within the net. (Tip-breakage may still result in loss). Together, this facilitated seeding and reduced need for reattachment of broken seedlings has been shown to result in a 50% reduction of farming costs.[60] Encouragingly, Reis et al. (2014) also observed that *K. alvarezii* in tubular nets had higher daily growth rates and no significant differences in carrageenan yield when compared to K. alvarezii grown with tie-tie method.[61] The use of tubular nets may also help to reduce breakage of Eucheuma afflicted with ice-ice.

## 2.6 HOW DOES SEAWEED AQUACULTURE IN TANZANIA COMPARE GLOBALLY?

Many of the Eucheumatoid producing countries are faced with agronomical, ecological, and societal challenges like those presented in this chapter. These shortcomings must be addressed before the cultivation of Eucheumatoid algae can reach its full potential as a resilient crop production system that has a minimal environmental impact. Luckily, many of the Better Management Practices presented in this chapter are directly applicable to other geographic regions and tropical red seaweeds. Adopting BMPs throughout the supply chain can help to incentivize and accelerate progress towards responsible seaweed aquaculture.

In Chapter 3, we provide an overview of the supply chain using seaweed from Tanzania and provide recommendations for supplier, product, and market specific BMPs that can complement producer-side improvements.

# Chapter 3: Sustainable Seaweed Supply Chains

Sustainable supply chains integrate and conserve the holistic benefits of BMPs throughout the production, processing, and consumption of a product. When managed in a strategic and transparent way, sustainable supply chains enable each actor in the chain to maintain or improve their economic performance. The demand for sustainable supply chains is becoming increasingly prevalent in primary production sectors, and especially in middle- and high-income countries.

In this chapter we take a closer look at the Tanzanian seaweed supply chain and identify areas and practices that are either strengths or weaknesses. Then we provide recommendations for actions that could be adopted by the seaweed farmers, buyers, processors, users, and Tanzania's regional and national governments to promote the longevity of seaweed farming in Tanzania. More specifically, these recommendations are intended to enhance profit for communities, improve price stability, maximize employment opportunities, diversify markets and products, increase downstream economic benefits, and develop an overall strategy to boost economic value of the Tanzanian seaweed sector.

## 3.1 OVERVIEW OF THE TANZANIAN SEAWEED SUPPLY CHAIN

As previously described in Chapters 1-2, seaweed farmers in Tanzania are responsible for harvesting and drying their seaweed crop. Although several exceptions exist, most farmers work independently on the harvesting and drying process. In some instances,

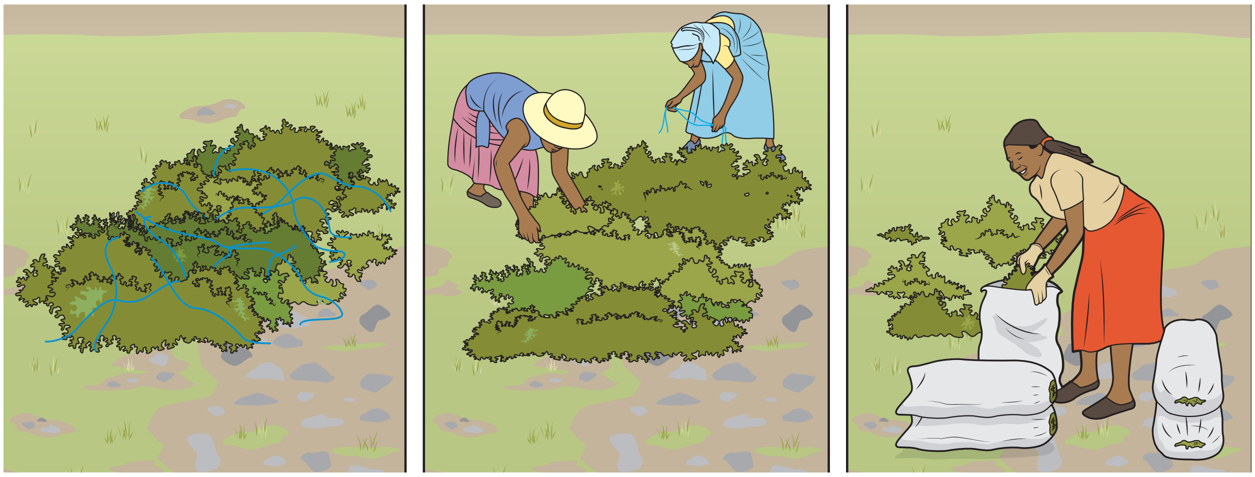


*Figure 7. Seaweed drying on grass and sand in Tanzania*. *© Colin Hayes*

farmers are provided burges or vihori by suppliers, which facilitate the efficient transport of seaweed from the farms to the shoreline. Then the farmers use both private spaces like front yards and public spaces like beaches to dry their crop (Fig. 7).

Intermediate buyers and exporters in Tanzania source seaweed from individual farmers, aggregate the material, and prepare it for sale and export to international buyers and processors. These businesses see that the seaweed has been dried to export quality and then conduct additional cleaning of the seaweed prior to export. The required export permit, which has historically been moderately difficult to acquire, can now be expeditiously obtained.

International buyers and processors work with the intermediate buyers and exporters to obtain Tanzanian seaweeds. These buyers typically source dried seaweed biomass from multiple seaweed-producing regions. On a $/kg basis, Tanzanian seaweed is more expensive than seaweed from Indonesia, Malaysia, and the Philippines, but international buyers and processors continue to buy it because the stability of their supply chain is improved with a geographically diverse portfolio of sourcing locations. A reliable supply of raw seaweed material has, at times, been the most critical and limiting factor in the carrageenan value chain.[4] After processing the seaweeds, the seaweed processors export the finished products to Europe, the Americas, Asia, and the Middle East.

## 3.2 THREATS WITHIN THE TANZANIAN SEAWEED SUPPLY CHAIN

### ATTRACTIVENESS OF INVESTMENT

The quantity and quality of carrageenan extracted from *K. alvarezii* and *E. denticulatum* can fluctuate according to the age of the seaweed tissue, the season, and the post-harvest drying and storage conditions. Older[s] *K. alvarezii* and *E. denticulatum* tissue produces a higher quality gel and more carrageenan per ton of seaweed. If the seaweed is harvested too young, the quantity and quality of carrageenan extracted from that seaweed will generally be lower. However, higher total yields are obtained with more frequent harvesting.

[s] The highest quality material is obtained from older material growing at roughly 3% per day (Doty et al. 1987).

Inadequate drying conditions such as drying the seaweed on the ground or failing to cover it with a tarp during rainstorms can result in lower quality carrageenan. However, drying tables are expensive to build and maintain, and they require significant space, so this is not a common practice in this region. Additionally, beach access for drying is becoming more restricted due to competing interests with tourism outfits.

A negative product quality and price feedback loop has also emerged within some Tanzanian farming communities. To obtain more compensation for their labour, there have been instances wherein it's reported that some seaweed farmers have added freshwater or sand to their crop to increase the sale weight and earnings. Unfortunately, this results in a lower quality product, which further perpetuates stagnant or low prices for dry seaweed biomass.

Given existing and growing challenges associated with seaweed production in Tanzania, many seaweed buyers and exporters are evaluating opportunities to expand production in Kenya, Mozambique, and other neighbouring countries rather than within Tanzania.

## LACK OF FARM-LEVEL FINANCING

One of the biggest financial drawbacks for seaweed farmers is the lack of access to lines of credit for the purchase of farm materials or tools. Currently seaweed farmers must be able to purchase their supplies outright. This may become an even bigger issue with the relocation of cultivation systems into deeper water which will require additional farm materials and a boat to access the farms. In Tanzania there are no mechanisms currently in play that offer insurance for lost seaweed crops. So, in the event of a disease outbreak, damage from storms or other water users, or other unanticipated events, the farmers can experience a significant economic loss.

Previous models of seaweed production in Tanzania involved seaweed buyers investing in the farm materials (i.e., line, stakes) used by farmers. In return, farmers were legally obligated to sell their product to the buyer. A perceived benefit of this arrangement was that the seaweed buyers had incentive to invest in the sector, and reassurance that their investments would directly return to them. A perceived drawback was that this arrangement resulted in a strong dependency of farmers on the buyer, which was thought by some to be inequitable.

Within the last decade, a shift in national government policy towards 'free trade', coupled with an increasing number of foreign buyers, has led to a change in this arrangement. Now many seaweed farmers sell to whichever buyer offers a higher price per kilogram. A perceived benefit of this free-market system is that farmers have more autonomy in their sales. A perceived drawback of this system is that it has both impacted the price farmers view as acceptable and limited the willingness of incumbent businesses to invest in materials used by farmers. In some locations[t], farmers have not been able to sustain high levels of seaweed production without assistance acquiring these materials. In other locations, the incumbent businesses are providing farmers with cheaper, lower quality materials that have a greater tendency to break down and yield plastic pollution. Another larger policy-related issue has been that products used for seaweed farming (e.g., ropes) have an import VAT that increases the cost of the materials.

[t] The remote nature of some Tanzanian villages makes it difficult and expensive to independently acquire the materials needed for farming.

### PRICE STAGNATION, MARKET VOLATILITY, AND SUBSTITUTABILITY OF CARRAGEENAN

As previously described, the Tanzanian seaweed supply chain is narrowly oriented on the production of carrageenan. The carrageenan industry has developed so that there is minimal differentiation between products, and this results in intense price competition and the commoditization of carrageenan.[4] Furthermore, carrageenan has many substitutes and few new product applications.[4] Thus, if the price of carrageenan is too high relative to other substitutes, it will not be purchased or utilized. This availability of alternatives presents a barrier against the use of more expensive seaweed production technologies like deeper water cultivation which could result in a higher total cost of raw seaweed biomass. If the price of Tanzanian seaweed exceeds the globally accepted commodity price for red seaweed, then buyers will look to source biomass from other locations.

### LACK OF ADEQUATE POLICIES

Tanzania does not currently have an international body regulating seaweed cultivation, trade, and biosecurity.[33,70] At national level, seaweeds can fall either under legislation related to aquaculture and fisheries, or to legislation related to agriculture. As a result, the needs of the seaweed industry may be overlooked, under documented, or insufficiently addressed.

Tanzania has some aquaculture biosecurity policies in place. Yet, of the 13 that were identified in a recent study, only four were considered applicable to the seaweed industry, and none of these were developed by governmental agencies.[8] This may be in part because Tanzania's existing national aquaculture biosecurity frameworks were largely designed to support finfish production.[68] There are also gaps in policies intended to safeguard seaweed crop genetic diversity. Thus, many government agencies and their representatives lack the expertise and scientific basis to prevent, identify, and mitigate seaweed-related pest and disease outbreaks. There is the added challenge of two operating governments,[u] which means that none of the reviewed biosecurity frameworks were applicable to both the mainland and Zanzibar.[68] This is problematic as farms exist in both regions and crops are actively moved between them.

Additionally, a strong national roadmap for the improvement of the seaweed industry is absent.[71] This is not unique to Tanzania; other seaweed producing countries like the Philippines, Indonesia, and Malaysia are also lacking robust policies specific to seaweed cultivation or national roadmaps for the sector. Just as with Tanzania's national policies for other crops, a cohesive vision and guiding document for the improvement of the seaweed industry would convey the government's commitment to the sector in a manner that all participants in the supply chain could see. It could also establish expectations for farm practices, biosecurity, and safeguarding the genetic diversity of the seaweed crops.[72,73]

## 3.3 OPPORTUNITIES FOR INCREASED VALUE AND RESILIENCY WITHIN THE TANZANIAN SEAWEED SUPPLY CHAIN

Efforts towards establishing more value and resiliency within the Tanzanian seaweed supply chain could take different forms depending on the constraints and goals

[u] The Government of Tanzania (GoT) and the Revolutionary Government of Zanzibar.

of the seaweed buyers, processors, and end-users. Here we draw on examples from successes within Tanzania, the global aquaculture and fisheries communities, and the agri-food sector to recommend actions that are likely to be effective. More specifically, we highlight the need for seaweed nurseries and breeding programs, provide a brief overview of the value that can be extracted from sustainable and traceable practices, offer examples of a few sustainability approaches and traceability initiatives, and discuss the current limitations of each. We also provide details on emerging opportunities that may diversify and increase resiliency of the Tanzanian seaweed supply. These opportunities include the co-culture of marine organisms, local markets for seaweed-based products, and research and development efforts for new uses of seaweed biomass.

## SEAWEED NURSERIES, BREEDING PROGRAMS, AND BIOBANKS

The availability of high-quality seeds, and the development of more diverse and resilient cultivars, is crucial to maintaining and increasing the productivity of seaweed farming in Tanzania (and worldwide). These needs can be addressed with the establishment of onshore nurseries and breeding programs. Onshore seaweed nurseries can ensure a source of healthy seeds that farmers can use for cultivation. Sanitary protocols can be strictly regulated in onshore facilities, so if farmers can obtain seeds from these nurseries it will reduce the potential biosecurity implications associated with indiscriminate seed sourcing.[66] Environmental conditions in the nursery can also be acutely controlled, which may ensure improved initial health of the seeds. Presently there are no onshore seaweed nurseries in Tanzania or the along the Western Indian Ocean. Despite the clear need for these facilities, the required capital investment is well beyond the financial means of the individual farmers and their communities. Thus, an investment of this scale will rely on the leadership of the Tanzanian government, academic partners, and private investors.

The establishment of a national facility can work to ensure that the seeds used by Tanzanian seaweed farmers are of good quality and that there is a sufficient supply of seeds for future cycles. It will also empower farmers by enabling them to set fair prices for their own crops  and reduce any potential dependence on out-sourcing seeds from abroad or from unreliable sources. The availability and use of pathogen-free seedlings (as currently produced in Asia) will also help the industry recover.[71] However, for them to be used ubiquitously, they must also be affordable, which is another point in support of a federally-funded nursery system.[71]

Breeding programs are commonly used in conventional agriculture, and in the cultivation of other algal species, to improve and 'renew' the vigour and genetic diversity of cultivated strains. They can be used to obtain seaweed varieties that are more resistant to diseases and adapted to local environmental variations associated with climate change.[33,75] Unfortunately, even at a global scale few successful breeding programs for Eucheumatoids have been established to date because they require control of the reproduction and life history of the alga, and these species have proved difficult to keep and cultivate in tank or laboratory cultures.[33] Some initial micro-propagation has been successfully conducted for Kappaphycus, but additional resources and effort are required for further development of this technique. Some research and development of breeding programs and other strategies to address diseases and replenish strains has recently been conducted by the UK-funded Global Seaweed STAR Program (globalseaweed.org). Additional molecular studies of Eucheumatoids will also support the development of breeding efforts because methods for biobanking germplasm and producing seed stock are species specific.[33]

Encouragingly, breeding, and genetic studies are included in the plan for a new government research institute. Within the breeding program, mesocosm-based multivariate studies can be used to test the heat tolerance of various candidate strains, to identify which ones are likely to fair better in Tanzania's changing coastal environment.[63] Further, long-term, lab-based acclimation efforts could be initiated on strains that are already in cultivation.

Seaweed biobanks are repositories of genetically distinct germplasm that is conserved for sustainable seedstock supply. In the case of Tanzania, this biobank should contain germplasm for both currently available cultivars and natural populations so that they can be used as a source for breeding. No such collection or effort currently exists in the country. However, models for biobank partnerships between industry, government, and public and private research institutions do exist in other countries with high cultivated seaweed production. In addition to providing access to specific seaweed germplasm, biobanks can maintain a comprehensive record of available variants which is important to the development and selection of new cultivars.[66]

## FARMING NATIVE SPECIES

In the past, seaweed species native to the Tanzanian coastline were experimentally trialled for cultivation. At the time, these pilot projects did not produce a biomass per unit area that was competitive with *E. denticulatum* and *K. alvarezii* production (Flower Msuya, Pers. Corres.). However, given the challenges facing the currently cultivated foreign species of red seaweeds, researchers from the Institute of Marine Science in Zanzibar and the department of Botany from the University of Dar es Salam have begun to revisit the potential for farming native species. Even at lower biomass yields, the production of previously uncultivated, native seaweed species could enable Tanzanian seaweed farmers and suppliers to access new markets that are potentially less price-constrained than the carrageenan market.

This work has been hindered in part by challenges in finding the native species in the areas where they have historically occurred. For example, in 2002 Msuya & Neori described collecting wild stocks of *Ulva reticulata, Chaetomorpha crassa,* and *Gracilaria crassa* around Unguja Island, Zanzibar.[76] More recently, in 2019 and 2020, researchers involved in the Global Seaweed STAR programme conducted an extensive seaweed survey. The objective of this work was to enrich and refresh the herbarium at the Botany Department of the University of Dar es Salam. This effort included, but was not limited to, farmed and wild eucheumatoids. Researcher Dr. Sadock Rusekwa has now reportedly collected 400 different specimens of macroalgae to be included in the University of Dar es Salaam herbarium and generated a database on the macroalgae specimens that have been collected since 1976.[v]

Experiments with several native, red seaweed species have shown promise for cultivation. These include several *Gracilaria* species (*G. salicornia*[w]*, G. corticate, G. debilis, G. edulis)* and others in the genera *Gracilariopsis, Gelidium, Pterocladia,* and *Gelidiella*.[51] These seaweeds produce agar, which is another hydrocolloid that has commercial value. Several native brown seaweeds (*Sargassum, Turbinaria, Hormophysa,* and *Cystoseria*) are also candidate species for cultivation and processing for alginate.[51] While wild *Ulva* sp. may be considered a nuisance species on other crops, if it is intentionally cultivated it could be used as a biofilter, fish bait, ingredient in animal feed, or consumed as human food.[51]

[v] This database is available through the following link: https://www.gbif. org/dataset/631cec26-8d92-4fcc-98ba-a4ab9bcb75e7

[w] formerly *G. crassa*

It is important to note that Tanzania is a party to the Nagoya Protocol, which has implications for researchers and companies interested in further experimenting with these native seaweeds.[x] The Nagoya Protocol mandates that all new native strain prospecting must be done with the approval of the local legislation to access these genetic resources.

## COMBINING INCOME GENERATING ACTIVITIES THROUGH CO-CULTURING

Farming more than one species in the same area is sometimes called co-culturing. Co-culturing is often viewed favourably because it can result in ecological and economic benefits.[12,14] From an economic perspective, combining income generating activities via co-culturing can result in a higher total production (harvest) from the same amount of cultivated area. This may translate into more income for the farmer and perhaps greater total biomass produced for human benefit. From an ecological perspective, the exchange of nutrients between species may lessen the total impact of the aquaculture practice on the surrounding environment. There may be other beneficial aspects to having the organisms sharing the same place, such as increased habitat/shelter, protective shading, and auxiliary food sources (i.e., detritus).

Co-culturing is not widely practiced by Tanzanian seaweed farmers, but there are several species that would be good candidates for piloting co-culture on Tanzanian seaweed farms, including: mud crab, sea cucumber (*Holothuria* spp.), milkfish, sponges, and molluscs for pearls.[14] The Zanzibar Fisheries Department has recently established a hatchery and training program for milkfish, mud crab, and sea cucumber to encourage the cultivation of these new species.[14] This is an important step in supporting co-culture, because farmers will need a supply of smaller organisms for grow-out, but the costs of building a hatchery is a barrier to entry for many. In addition to the efforts by the Zanzibar Fisheries Department, Marine Cultures, a local NGO operating on Unguja Island, Zanzibar, is promoting sponge and mollusk farming around the island. The Tanzanian Ministry of Agriculture, Natural Resources, Livestock and Fisheries (MANLF) has a mobile sea cucumber hatchery and several international groups and researchers have contributed to efforts focused on shellfish co-culture in Zanzibar.

The co-culture of Eucheumatoids and sea cucumbers is particularly attractive because it can potentially bring increased economic benefits for farmers and address two conservation concerns: poaching of wild sea cucumber stocks and potential impacts to the benthos under aquaculture installations. The market for dried sea cucumbers in Asia is strong and thought to have risen in recent years.[77] Some of this demand is supplied by aquaculture farms, but the high value of sea cucumbers has also resulted in the poaching of wild stocks. A ready source of farmed sea cucumbers from elsewhere could help to address the market dynamics encouraging poaching. Simultaneously, the strong market for sea cucumbers reduces the risk of entry into the new practice for seaweed farmers. Co-culturing sea cucumbers under seaweed farms could help to prevent broken or sloughed seaweed from accumulating under the seaweed lines because sea cucumbers are detritivores that naturally feed off dead and decaying matter. Some extension activities and research have been conducted by the FAO and other partners (e.g., Dr. Flower Msuya at the Institute of Marine Science) to explore the idea that co-culture of seaweed and sea

[x] The Nagoya Protocol on Access to Genetic Resource and the Fair and Equitable Sharing of Benefits Arising from their Utilization (ABS) to the Convention on Biological Diversity. The is an international and legally binding framework guiding the transparent collection and use of genetic resources. Read more here.

cucumbers could provide an additional income-earning opportunity for seaweed farmers. Unfortunately, a lot of the sea cucumbers were stolen off the farm plots.

## SUSTAINABILITY AND TRACEABILITY

A *sustainable* seaweed supply chain uses farming and processing practices that minimize impact to the natural environment and incorporate safe human health and appropriate social guidelines. A *traceable* seaweed supply chain ensures that sustainably produced seaweed biomass can be tracked from the farm to the consumer, with the farms and suppliers subject to monitoring and evaluation. Both sustainability and traceability can contribute to increased valorisation of the Tanzanian seaweed supply chain. Buyers interested in these initiatives can either implement existing third-party certifications and traceability standards or develop their own internal purchasing standards.

## THIRD-PARTY CERTIFICATIONS AND STANDARDS

Product or process-oriented certifications can efficiently communicate a value proposition to the prospective or returning customer. They can help alleviate buyer concerns about production practices and thereby expand demand for the certified product.[78] Standards can provide targets to eliminate marginalization of various groups of individuals, including women and at-risk youth. They can ensure that occupational safety and farmer health are prioritized. Standards can also reduce and prevent damage to fragile ecosystems like seagrass beds and coral reefs by incentivizing BMPs.

There are several regional and international certifications that can be applied to cultivated seaweed, so seaweed producers and buyers can choose to adopt a standard that is relevant to their product and target market. However, each certification has varying costs associated with implementation and may therefore not be suitable for all business sizes. TNC does not actively endorse any specific certification program, but we aim to help buyers and all parts of the supply chain understand certification options for Tanzanian seaweed. As such, we provide a brief introduction to several programs currently available.

### ASC-MSC

The ASC-MSC Best Aquaculture Practices certification is a joint, global standard combining the expertise of both aquaculture and fisheries experts. The standards were developed by the Aquaculture Stewardship Council and the Marine Stewardship Council to address each step in the 'seafood' supply chain. The objective of the seaweed-specific certification is to ensure environmentally sustainable, and socially responsible seaweed cultivation through the adherence to five principles of sustainable seaweed cultivation: 1.Sustainable wild seaweed populations, 2. Environmental impacts, 3. Effective management, 4. Social responsibility, and 5. Community relations and interaction. Motivation for the development of the standard came from observing increased seaweed production, demands for certification, and an identified opportunity to provide a benchmark for guiding improvements in the industry. Learn more about this certification at: bapcertification.org.

### Friend of the Sea

Friend of the Sea (FOS) is a project of the World Sustainability Organization, which is an international trademark for humanitarian and environmental efforts. Friend of the Sea offers certification and accreditation for a variety of marine products. The FOS certification consists of ten main criteria for seaweed harvesting and farming: *1. Management system, 2.Legal compliance, 3. Biomass and Environmental Impact Assessment, 4.*

*Water monitoring, 5. Air emissions monitoring, 6. Waste management, 7. Chemicals and hazardous substances, 8. Energy management, 9. Social accountability, and 10. Traceability.* Learn more about this certification at: friendofthesea.org.

### ECOCERT

ECOCERT is a third-party certifier with expertise in the 'best environmentally friendly and socially conscious' practices across agri-food, forestry, textiles, cosmetics, and eco-products sectors. The ECOCERT certification is oriented towards farms or farmers interested in receiving organic certification. It includes, but is not limited to, the review of: 1. Waste management, 2. Use of renewable resources, 3. Sustainable wild harvesting of seaweeds, and 4. Water quality considerations. Learn more about this certification at: https://www.ecocert.com/en/certification.

## ORGANIC SEAWEED STANDARDS

Organic certifications typically require that the certified crop was grown without prohibited substances (i.e., certain fertilizers, herbicides, pesticides) and prohibit methods (i.e., genetic engineering). Farms and farmers are required to maintain stringent product quality, while also ensuring that negative social, ecological impacts are minimal. However, organic certification criteria and processes are region and market specific. For instance, the United States Department of Agriculture has their own National Organic Program. In this program, seaweeds can be certified under the organic 'aquatic plant' category. In other cases, it may not be possible to have seaweeds classified as organic. Most organic seaweed standards were designed for raw whole seaweed, but they may be relevant to carrageenan producers or buyers targeting specific markets or geographies.

Obtaining organic certification for products generally requires an in-depth review of practices. This requires significant financial and time investment from the applicant. Still, this investment may be increasingly justified as consumers in many countries are requesting and purchasing organic products at higher rates than ever before. Depending on the intended use of the seaweed, organic certification may also ultimately offer more value to the applicant than other certification programs because of this ubiquitous presence in many markets.

Certifications can offer benefits along the supply chain, but they do have constraints – namely cost and suitability. Obtaining a certification can be prohibitively expensive for individual farmers to pursue. It may be more feasible for a region or a buyer to finance the certification review process, but then the cost is likely to be passed on to the consumer or the farmer. This additional cost is challenging given the inelasticity of the current commodity market for carrageenan, but it may be more feasible for the alternative local or emerging markets. Additionally, many existing third-party standards are rigid, meaning that they may not be specifically tailored to tropical or subtropical conditions, or to Eucheumatoid value chains, or conducive of an iterative process towards establishing sustainability or traceability.

## DEVELOPMENT AND IMPLEMENTATION OF INTERNAL PURCHASING STANDARDS

Developing and implementing internal purchasing and traceability standards is another option for buyers and suppliers seeking to improve the sustainability or traceability of their seaweed. A benefit of this approach is that seaweed buyers have the flexibility to adapt sustainability criteria to regional environmental conditions and production practices. Additionally, the application of internal purchasing standards can be designed to be iterative – asking seaweed producers to make incremental improvements over time rather than all at once.

When possible, internal standards should be audited by a third party to ensure that the criteria are appropriate and effective measures of sustainability. Third-party certifications also add external accountability and credibility to the standard. With the right communications strategy, internal sustainability and traceability generate value for the buyer or supplier through the outward demonstration of corporate social responsibility. (See Box 2 for an example of an internal sustainability and traceability initiative: Cargill's Red Seaweed Promise).

Traceability does come with a cost. It becomes increasingly challenging with large quantities of producers, like the ones comprising the Tanzanian seaweed industry, to ensure that all product meets the same rigorous standards. The costs of certification, product accounting, and enforcement can ultimately be passed on to consumers.

## Box 2: Cargill's Red Seaweed Promise

Cargill is a privately held, global agribusiness working in food, agriculture, nutrition, and risk management. Cargill has been a major player in the hydrocolloid industry for more than 50 years, sourcing and processing red seaweeds from four continents. They are a recognized as a supplier of high-quality carrageenan.

In 2019, Cargill launched the Red Seaweed Promise™, which is an initiative that established internal standards for sourcing red seaweed to advance traceability and transparency in the global seaweed supply chain. The program is unique within the seaweed industry because it is designed with the continuous improvement philosophy, or the practice of constantly re-examining and improving processes. Through the Red Seaweed Promise, Cargill has also pledged that 60% of their red seaweed feedstock will come from sustainable sources by 2025. With these commitments, Cargill hopes to improve the prosperity of seaweed farmers and promote environmentally sustainable aquaculture practices. More specifically, Cargill aspires to:

- **Support seaweed producers** by providing training, coaching, and tools to encourage the best environmental and safe production practices.
- **Conserve the marine environment** by promoting plastic circularity and enhancing protected marine habitats.

Cargill®
Helping the world *thrive*

**Declaration of interest: Cargill is a supporting partner in TNC's Tanzanian Seaweed Project.**

- **Improve community prosperity** by promoting gender equality and breaking down barriers to economic empowerment for seaweed producers and their communities.

At the launch of the Red Seaweed Promise, Cargill used an externally verified[y] evaluation tool to conduct assessments in each of the regions where they source red seaweeds. The assessments were then used to create region-specific, continuous improvement plans.

Cargill is strengthening partnerships with their supplier networks to accomplish the environmental sustainability, safe production, and traceability objectives of the Red Seaweed Promise. For example, in Tanzania, Cargill has partnered with seaweed supplier C-Weed Corporation and TNC to establish an improvement program that focuses on improving seaweed producers' knowledge of better practices for seaweed cultivation and marine conservation.

**Learn more about the Red Seaweed Promise at www.cargill.com**

[y] The evaluation tool received third-party review from Proforest, a global organization supporting responsible agricultural commodity production and sourcing (https://www.proforest.net/).

## GOVERNMENT LEADERSHIP IN POLICY DEVELOPMENT, CAPACITY BUILDING, AND CAPITAL INVESTMENTS

Government leadership, through the development of additional policy and regulatory strategies, can be enacted to increase the sustainability of seaweed produced in a specific region. At an international level, extensive recent research under the Global Seaweed Star project has led to the publication of global recommendations for policy makers.[z]

The recommendations are:

1. Develop clear international seaweed related policies and regulations to improve biosecurity and genetic diversity.
2. Develop global, regional, and national technology transfer and capacity building initiatives, focusing on biosecurity and genetic diversity.
3. Develop regional and national seed stocks and bio secure nurseries.
4. Maintain the genetic diversity in wild stocks by conserving wild seaweed populations through encouraging conservation zones.
5. Further develop assessment tools for balancing environmental and economic risks with the potential benefits of seaweed production (e.g., cost-benefit analysis) and to enable risk-based analysis of management options at multiple scales.
6. Incentivise the integration of seaweed production with other extractive and fed aquaculture species and maritime activities.
7. Channel support for long-term investments to promote the beneficial aspects of the industry.
8. Establish international seaweed research networks.[79]

[z] Learn more about the project and recommendations at: globalseaweed.org and Ensuring the Sustainable Future of the Rapidly Expanding Global Seaweed Aquaculture Industry – A Vision.

In Tanzania more specifically, there are presently opportunities for government leadership specific to beach access, import taxes, biosecurity policies, capacity building, and capital investments. The challenge of adequate seaweed drying space can be addressed by the government through the enforcement of government policy of allowing public access to the areas 30 m above the high tide mark in Zanzibar, and 60 m above the high tide mark in mainland Tanzania. To reduce the economic burden of sourcing seaweed farming materials, the government could eliminate the VAT on imported seaweed cultivation line (most other agricultural products sold to Tanzania are not subject to VATs).

As previously highlighted in other sections, the Tanzanian seaweed industry needs more robust biosecurity measures. The creation of a national, binding, biosecurity strategy for seaweed farming that spans both mainland Tanzania and Zanzibar would be a huge asset to participants in the industry.[68,70,74] Or, alternatively, two biosecurity protocols (one by the Government of Tanzania, and the other by the Revolutionary Government of Zanzibar) would be acceptable if they are aligned and include a plan for clear communication between the authorities of each government.[68] Similarly, regional management (i.e., adaptive governance) could also be effective if robust plans for communication between the regions are integrated into the biosecurity strategy.[68] Incorporating biosecurity management initiatives within regional and national government agencies would provide substantial support towards establishment of biosecurity measures at different scales throughout the seaweed production system.[80,81] Biosecurity strategies are most effective when a variety of measures are used together.[14]

The development, implementation, and enforcement of these biosecurity measures will help to restore and protect the Tanzanian seaweed industry. Once these strategies are developed, government employees can conduct routine farm monitoring visits to ensure that the appropriate biosecurity measures are being used. These should be recorded and used to evaluate the effectiveness of existing protocols and determine whether additional actions are needed. An example farm checklist for farmers and government officers is provided by Kambey et al. 2021.[68]

Regional and national government agencies can partner with seaweed buyers and other organizations focused on economic development to contribute to the increased resiliency of the Tanzanian seaweed supply chain. Together they can provide instruction in better practices, vocational training, provision of personal protective equipment, and marketing campaigns. Presently the government is working to establish a community seaweed farm where they intend to demonstrate the Double Made Loop attachment method. Vocational trainings can include elements of financial and business management, in addition to instruction in crafting value-added products. While developing vocational trainings, practitioners can build on learnings from other regions where seaweed farming occurs to identify which value-added products are likely to maximize earnings for the seaweed farmers. Regional and national government agencies could also offer swimming lessons for women to help them prepare for a potential transition to seaweed farming in deeper waters. Tanzanian regional and national governments can engage in valorisation of seaweed in country, through marketing campaigns to educate the public about Tanzanian seaweed and create regional demand for products from cultivated seaweeds.

Seaweed sustainability efforts initiated by TNC in Belize illustrate how potential producer and buyer gains can be obtained through the engagement and collaboration between government and industry. More specifically, TNC is working with the Belizean Bureau of Standards, which is the national agency responsible for establishing product standards throughout the country, to develop specific regulations for the seaweed aquaculture industry. By engaging the Belizean Bureau of Standards in this process, TNC is helping to create space for all stakeholders in the industry to provide input guiding the development of these regulations.

## SEAWEED CLUSTER MODEL FOR BILATERAL ENFORCEMENT OF QUALITY AND PRICE

The Zanzibar Seaweed Cluster Initiative (ZaSCI) on Unguja Island, Zanzibar is a unified group of seaweed farmers, processors, buyers, exporters, academics, and government representatives. This group has demonstrated the feasibility of adding 'seaweed clusters' to the current supply chain as a bilateral enforcement mechanism. In this model, individuals or cooperatives sell their crop to the Seaweed Cluster which maintains agreements with the buyer. This model could help to ensure compliance with agreed-upon standards (e.g., reduce 'cheating' and promote efforts to meet production targets) and allow for collective bargaining to improve prices received for seaweed. An approach like the ZaSCI on Unguja Island could be developed for Pemba Island and mainland Tanzania.

## LOCAL PRODUCTS, MARKETING, AND ECOTOURISM

An estimated 3% of seaweed produced in Tanzania is retained and used by several small organizations that process and sell seaweed-based goods locally.[43]

The Zanzibar Seaweed Cluster Initiative currently produces artisanal soaps from Eucheumatoids and sells them in the local markets and directly to hotels and resorts. Another group, Seaweed, is a vertically integrated social enterprise that sells finished soaps, oils, scrubs, and body lotions. Mwani Zanzibar, a vertically integrated seaweed and skincare company, is producing 'macroalgae-based skincare'. Additionally, some hotels in Zanzibar now preparing and serving seaweed salads on their menus (Msyua, Pers. Corres).

Across these organizations and other entrepreneurial individuals, there are more than twenty local, value-added products that are being produced from Tanzanian seaweed and sold to hotels, touristic or local business exhibitions, at village centres of production, or government agriculture stores. These products include seaweed powder, cosmetics (liquid soaps, shampoos, body lotions and creams) and foods such as seaweed juice, cakes, cookies, jam, pickles, and fresh salads.[aa] These products can be sold at higher prices than the raw unprocessed seaweed, so this value addition has increased the economic contribution of seaweed farming to the livelihoods of these farmers.[12]

There may be room to increase production and sales of these value-added products through additional product development and strategic marketing (Box 2). For example, in Indonesia, local cooperatives are experimenting with preserving seaweed using sugar, to produce a seaweed candy. In Belize, fresh Eucheuma is commonly blended into non-alcoholic beverages like shakes and smoothies. These approaches could be attempted in Tanzania, and other applications may be identified in the process. Further research and

[aa] Eucheumatoids are consumed as fresh food in moderate amounts in China, Malaysia, and Belize.

## Box 3: Case study of seaweed marketing and packaging in Belize

Well-crafted marketing and packaging will likely increase the attractiveness of value-added seaweed products for tourists. In Belize, Moritz (2020) found that the most successful retailers of value-added seaweed products advertise them as 100% *natural, organic,* and *produced entirely with locally available materials*. These entrepreneurs also use high quality packaging.

Moritz also asked the tourists to rank their preferences for content marketing terms. The results were, in order from most preferred to least preferred: *seaweed, sea moss, carrageenan, Eucheuma, algae*. Moreover, the terms *carrageenan, Eucheuma,* and *algae* generated negative associations for the survey respondents, which likened these terms to disease and undesirable biological growth.

With regards to processing, the marketing terms were ranked by consumers in order from most to least preferred as: *sustainably grown, hand-harvested, wild crafted*. Additionally, *farmed* algae were perceived to be less desirable than *wild* algae. Mortiz concluded that these reported perceptions present an opportunity to improve communication about the potential environmental benefits of seaweed farming in marketing efforts.

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development into seaweed-based products for the tourism industry could be especially productive for communities in Zanzibar, where tourist activity is high.

Seaweed farmers, and their local communities, may be able to extract additional value from their activities by integrating seaweed farming into existing or new eco-tourism avenues. Eco-tourism has become a major motivator for travel, especially with the younger generation. Tours that educate travellers about tropical seaweed farming, through observations of seaweed farms, drying, and local processing could be run by the farmers themselves, a seaweed cooperative, or an external NGO to bring more people to a region and generate additional income.

## EMERGING MARKETS

Recently, seaweed biomass has received considerable attention from researchers and industry interested in using it for additional manufacturing purposes that extend beyond hydrocolloids. This R&D is evaluating the use of raw seaweed biomass for biofuels and bioethanol, commercial liquid fertilizers or bio-stimulants, a substitute for plastic film, textiles, and paper. The secondary metabolites from seaweed (e.g., antioxidants, anti-inflammatory agents, and other bioactive compounds) are also receiving attention in the biochemical field for their potential applications against viruses, bacteria, and fungus.[82] The seaweed biorefinery concept, in which the same seaweed biomass is used to produce several products, is also gaining traction.[83]

In addition to these production-intensive uses, there is renewed interest in the use of seaweeds as whole or minimally processed food ingredients.[84] Both *K. alvarezii* and *E. denticulatum* contain high amounts of fiber and relatively low amount of lipids. The average protein content observed in these species is 5 – 6% of their dry weight. However, there is a need for both additional research into direct food consumption market possibilities of red seaweeds and the nutritional contributions of Eucheumatoids, so that they can be included on the nutrition facts labels of minimally processed foods.

Eucheumatoids may also hold promise as an additive in several agricultural processes. For example, filtered waste from carrageenan extraction could be used as a soil conditioner. Unprocessed Eucheumatoids can be rinsed, composted, and mixed with topsoil as an alternative to commercially available growing media.[85] The use of seaweed in livestock feeds has gained significant attention in recent years, primarily due to the discovery that the halogenated compounds produced by several red seaweed species can significantly reduce methanogenesis in the bovine rumen, which ultimately reduces methane emissions by livestock that otherwise are a strong contributor (per unit) to global carbon emissions. *Eucheumatoids* do not appear to produce these same compounds in a way that would warrant incorporating them into livestock feed for this purpose. Nonetheless, with increased research into agricultural uses of seaweeds, other applications may be brought to light in the coming years. For example, cassava and other human-consumed agricultural products are used as binding agents for agricultural feeds, but red seaweeds and derivative products could possibly be used for this purpose. More research and development around these alternative applications of seaweeds is still needed.

# Chapter 4: Motivation and Strategy for Tanzanian Seaweed Program

> **"Seaweed aquaculture for conservation gains and sustainable livelihoods"**

## 4.1 MOTIVATION AND SCOPE

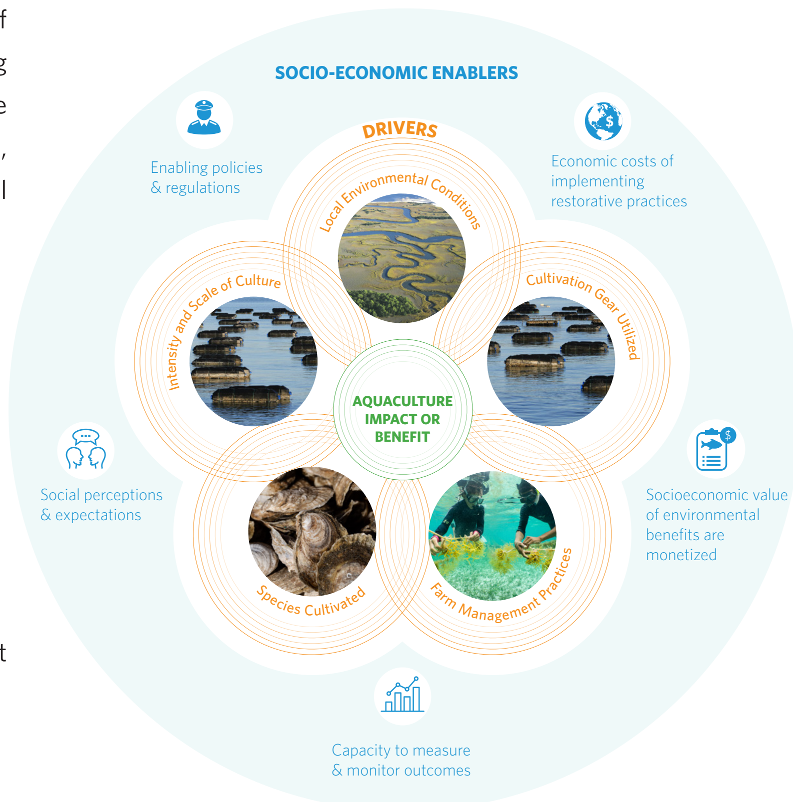
The Nature Conservancy believes that coastal aquaculture, when practiced in a socially and environmentally sustainable way, can be a powerful tool for conservation, uplifting marginalized communities, and supporting the resilience of coastal ecosystems. Furthermore, we believe that certain organisms like seaweed can, when cultured well, be even ecologically restorative to the marine environment.

We understand the environmental benefits of restorative aquaculture to be subject to several driving factors including: the intensity and scale of culture, the type of farming gear used, farm management practices, the species cultivated, and local environmental conditions. These factors are often interacting, and their contribution to the restorative potential of aquaculture varies with time, geography, a species being cultivated (Figure 8).

TNC currently operates longer-standing seaweed farming programs in Belize and Indonesia. Our experiences in these programs have illustrated the importance of a holistic approach to implementing restorative aquaculture activities. To be successful, we believe that this approach must encompass robust ecological and social science, the implementation of BMPs, strong governance and policy, market and business development, and progress towards equity and empowerment for everyone involved.

Our work in Tanzania is motivated by a vision of a seaweed farming industry with improved environmental performance and livelihood benefits for Tanzanian coastal communities. The scope and initial area of focus for our Tanzania project was determined in partnership with the Government of Zanzibar, local village leaders, seaweed buyers,

*Figure 8. The Drivers and Enablers of Restorative Aquaculture. Source: The Nature Conservancy*



Mondy Muhando teaching a seaweed training class © Roshni Lodhia | TNC

and the Ministry of Agriculture, Natural Resources, Livestock and Fisheries (now the Ministry of Blue Economy and Fisheries). In 2018 and 2019, we held a series of meetings and events to scope opportunities for intervention within the seaweed farming sector in Tanzania. These robust, stakeholder-driven discussions identified a set of mutually beneficial goals to improve the environmental performance of seaweed farming, increase livelihoods and empower women, and improve the quality, consistency, and traceability of seaweeds.

In our Tanzanian Seaweed program, we are working towards attaining these identified mutual goals by combining the best available knowledge about the seaweed industry in Tanzania with TNC's approach to community-based conservation and sustainability initiatives. In Phase I of the program, TNC, in collaboration with Cargill and C-Weed Corporation, provided hands-on trainings for seaweed farmers within three villages on the islands of Pemba and Unguja. The objective of the trainings was to offer capacity-building workshops with examples of BMPs that can increase the yields and sustainability of seaweed farming activities in Zanzibar. For example, we would like to see the cessation of mangrove harvesting for seaweed farming stakes and increased plastic circularity through the proper collection and recycling of farming ropes. We also hope to see farmers adopt DML practices and benefit from improved yields.

> **Local women seaweed farmers are excited to gain insight into how to improve our seaweed production, so we can earn more for our families but also look after our environment.**
>
> **- Sada Himidi Selemani, seaweed farmer in Pemba and TNC pilot program participant**

In future phases, TNC aspires to expand beyond the pilot villages and engage more than 1,000 farmers in capacity-building workshops. As the reach of our program grows, we would like to see increased government engagement and support for nurseries, seed banks, the development of enforceable biosecurity measures, and post-harvest processing facilities. We also intend to focus more on opportunities for increased resiliency and innovative techniques for culturing native seaweed species, transitioning to deeper water cultures, the application of crop calendars, and the inclusion of seaweed farming in conservation-oriented financial schemes.

## 4.2 SYNERGIES WITH TNC'S AFRICA OCEAN PROTECTION AND RESILIENCE STRATEGY

The TNC Africa Ocean Strategy approaches coastal resource management in a way that blends complementary national-level planning and protection with community-led conservation. National-level planning is critical because it offers the system-scale perspective needed to identify and safeguard the most ecologically critical areas and direct development to less-sensitive zones. In acknowledgement of existing competing uses and threats to oceans, TNC's Africa Ocean's strategy centers on protecting vast areas of high-priority habitat by blending science, multi-stakeholder negotiations, government relations, and innovative financing. Through this work TNC mobilizes national governments and stakeholders to expand conservation and protection of the marine environment and the sustainable use of Africa's oceans.

Empowering coastal communities with knowledge, tools, and information is essential as it positions local people to sustainably manage their fisheries, coastal habitats, and marine resources so that they continue providing vital food and livelihoods into the future. Blending these strategies holds the greatest potential to deliver durable, large-scale conservation that respects the needs of local people and sustains productive ecosystems for generations to come. The fisheries work aims to safeguard productive marine fisheries and the ecosystems they depend on, and design sustainable aquaculture initiatives, ensuring a foundation for food and livelihood security. The community-led conservation work envisions a coastal and marine resource management system that empowers communities to effectively manage and conserve coastal resources, secures sustainable and resilient livelihoods and sources of food, and achieves healthy coastal ecosystems. These strategies help improve, and are advanced by, TNC's global Ocean Protection, FishPath, Sustainable Aquaculture and Tuna Shared Conservation Agenda strategies and outcomes.

Throughout the Western Indian Ocean (WIO), conflict among competing uses (e.g., artisanal and commercial fishing, oil and gas development) is causing degradation of marine resources. The TNC WIO Seaweed Program is working to link the generation of economic benefits with conservation and sustainable management. Furthermore, we are prioritizing actions that directly reach women, like disseminating BMPs for seaweed farming. The restorative aquaculture work seeks to advance development of seaweed aquaculture to not only grow with the least environmental impact, but in a manner that contributes to ecosystem recovery, sustainably increases seafood production to meet food security needs, and provides livelihoods in coastal communities.

## 4.3 RECOMMENDED RESEARCH AND POLICY DEVELOPMENT

Several potentially transformative research courses have been repeatedly emphasized during our work with Tanzanian seaweed farmers, seaweed buyers, and local and international researchers. These research needs can be broadly described as improved biosecurity protocols, increased biobanking and knowledge of seaweed physiology, and new applications and processing techniques for native and "lower-value" species. Further context and justification for each of these research and strategy development themes are provided in the proceding pages of this guide. For ease of reference, they are briefly listed here and cross-referenced to their corresponding section.

- Establish and support research facilities and nurseries to oversee the production of healthy seaweed seed and strengthen genetic diversity of the cultivars. Pursue capacity building and technology transfer between entities with more advanced knowledge in the production of pathogen-free seaweed varieties. (Section 3.3 - Seaweed nurseries, breeding programs, and biobanks)
- Develop, adopt, and enforce appropriate biosecurity protocols for maintaining farmed seaweed health. (Section 2.5 - Biosecurity protocols; Section 3.3 - Government leadership in policy development, capacity building, and capital investments)
- Conduct additional physiological studies on long term acclimation of *E. denticulatum* and *K. alvarezii* to elevated water temperature. (Section 2.4 - Climate change and warming waters)
- Create a strategy for conserving native, wild seaweed stocks that may be used to support diversified seaweed production. (Section 3.3 - Farming native species)
- Identify and biobank heat-tolerant strains of *E. denticulatum, K. alvarezii*, and native Tanzanian seaweeds to support sustainable seaweed cultivation in a changing climate. (Section 3.3 Seaweed nurseries, breeding programs, and biobanks)
- Perform additional research into new applications, processing techniques, and markets for native and "lower-value" seaweed species. (Section 3.2 - Price stagnation, market volatility, and substitutability of carrageenan)

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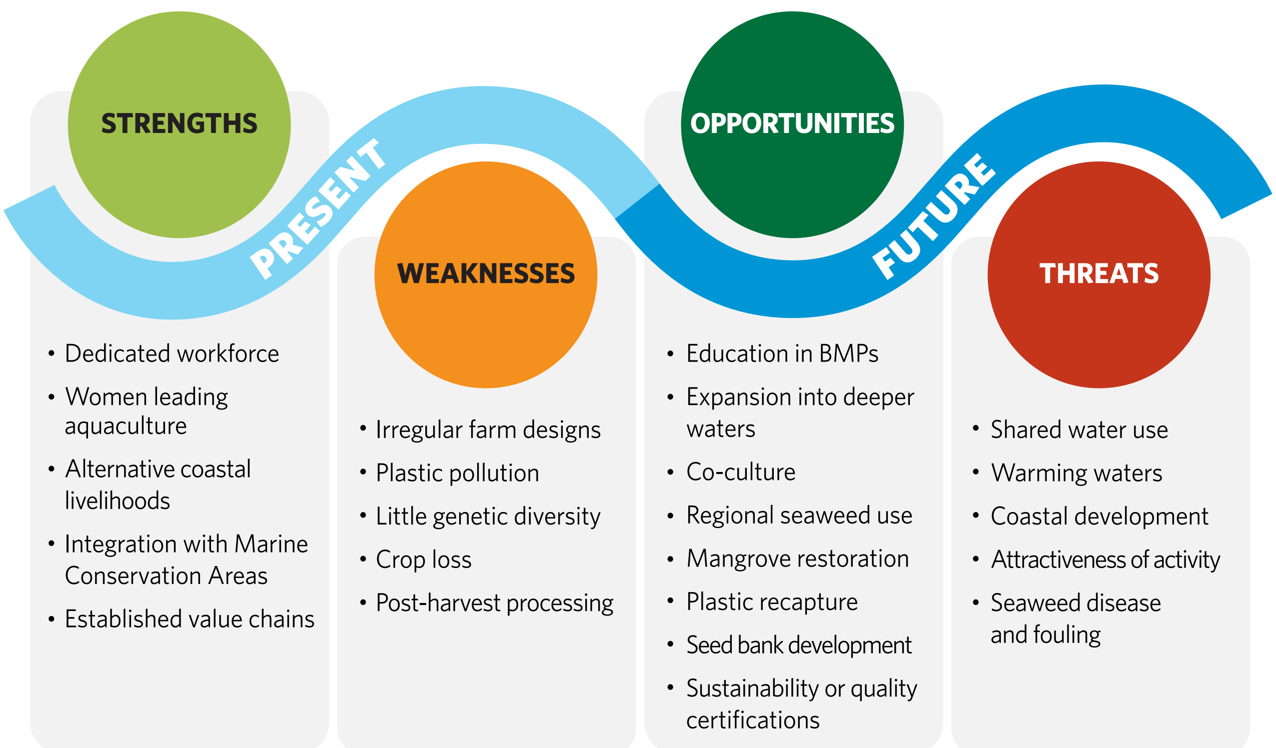
# Summary

Seaweed farming is an activity employing approximately 25,000 people in Tanzania; 80 – 90% of which are women. Most of the seaweed farming activity in Tanzania revolves around two red seaweed species: *Kappaphycus alvarezii* (cottonii) and *Eucheuma denticulatum* (spinosum), which were originally brought to Tanzania from Asia, but are now naturalized. Cultivation of both species is currently conducted through vegetative propagation which means the propagules are genetic clones of their parent. Farmers outplant the propagules on suspended lines in shallow coastal waters to grow and harvest the biomass 30 - 45 days later.

Seaweed farming activities in Tanzania share space with many other water users and marine organisms. The health and abundance of the cultivated seaweed is reliant on good ambient water quality, ecosystem services like water exchange and nutrient provision, and frequent attention from the farmer. Seaweed crop loss can occur from diseases, epiphytes, grazing, breakage, and poor drying conditions. In recent years, an increased incidence of disease, namely ice-ice, has been observed on many Tanzanian seaweed farms.

The environmental sustainability of Tanzanian seaweed farming can be improved with better siting practices away from corals and mangroves, proper disposal of used cultivation lines, and avoidance of mangrove materials. Additionally, farmers can improve seaweed yields by using a standardized farm design, attaching larger, healthy propagules to grow out lines with Double Made Loops, and conducting timely and attentive farm maintenance. Establishing seedbanks and breeding programs for more climate resilient seed, and even possibly siting seaweed farms in deeper waters, may increase the resiliency of Tanzanian seaweed farming in a changing global climate.

In 2020, approximately 106,091 wet tonnes of Eucheumatoid seaweed were produced in Tanzania. Most of this seaweed was dried and exported to Asia,



Europe, or the United States where it is processed into refined or semi-refined carrageenan. Many processed food, animal feeds, cosmetics, nutraceuticals, and household products use this carrageenan as a thickener and stabilizer. Only a small portion of the seaweed produced in Tanzania consumed regionally as food or used in artisanal production of body products.

In recent years the Tanzanian seaweed supply chain has experienced price stagnation due to the commoditization of carrageenan and the availability of alternatives. This situation is perpetuated through the delivery of low-quality dried product, either unintentionally due to lack of proper instructions or through the addition of water or sand to increase the seaweed weight, and thus earnings. Furthermore, there is a dearth of financing mechanisms available to farmers or local entrepreneurs wishing to expand their cultivation or post-harvest processing.

The livelihood benefits to Tanzanian seaweed farmers can be increased by encouraging the application of better farming practices, minimizing conflict with other water users, enabling financing mechanisms to support the purchase of seaweed farming and processing equipment, and potentially the additional development of value-added products for sale locally and regionally. Seaweed buyers and manufacturers can improve their bottom-line by pursuing and incentivizing increased traceability and sustainability of the seaweed they purchase.

TNC's work in Tanzania is motivated by a vision of a sustainable seaweed aquaculture industry that provides ecosystem benefits for Tanzania's coastline and supplemental or alternative income for Tanzanian coastal communities. We believe that coastal aquaculture, when practiced in a socially and environmentally sustainable way, can be a powerful tool for conservation, uplifting marginalized communities, and supporting the resilience of coastal ecosystems.

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