Belize Seaweed Industry Technical Guide

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The Nature Conservancy

BELIZE FISHERIES DEPARTMENT

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Contributors

Dr. Juli-Anne Russo, Caribbean Aquaculture Education and Innovation Hub

Dr. Cait Murray-Green, Strategic Scientific Consulting

Dr. Riccardo Morris, Envi Services

Karlotta Rieve, Hatch Blue

Maekba Felix

Seleem Chan, The Nature Conservancy – Belize

Megan Considine, The Nature Conservancy – Global Aquaculture

Tiffany Waters, The Nature Conservancy – Global Aquaculture

James Foley, The Nature Conservancy – Belize

Hannah St. Luce-Martinez, The Nature Conservancy – Belize

Jane Salazar Mcloughlin, The Nature Conservancy – Belize

Julie Robinson, The Nature Conservancy – Belize

Felicia Cruz, Ministry of Blue Economy & Disaster Risk Management – Belize

Virginia Burns-Perez, Turneffe Atoll Sustainability Association - Belize

Trina Palacio, Ministry of Blue Economy & Disaster Risk Management – Belize

Wilbur Dubon, The Placencia Producers Cooperative Society Ltd. – Belize

Shakera Arnold, Belize Fisheries Department

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Photo and Illustration Credits

Cover: A snorkeler tends to a sustainable seaweed farm in Belize, which provides economic opportunity and creates a habitat for marine species. Photo credit: Jennifer Adler.

Section masthead: A closeup of *Eucheumatopsis isiformis*. Photo credit: Sarah Aly.

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Introduction

This guide provides details on the four considerations of sustainable seaweed cultivation (see Figure 1 and the upcoming sections), as well as details on the technical aspects of seaweed cultivation using the submersible method.

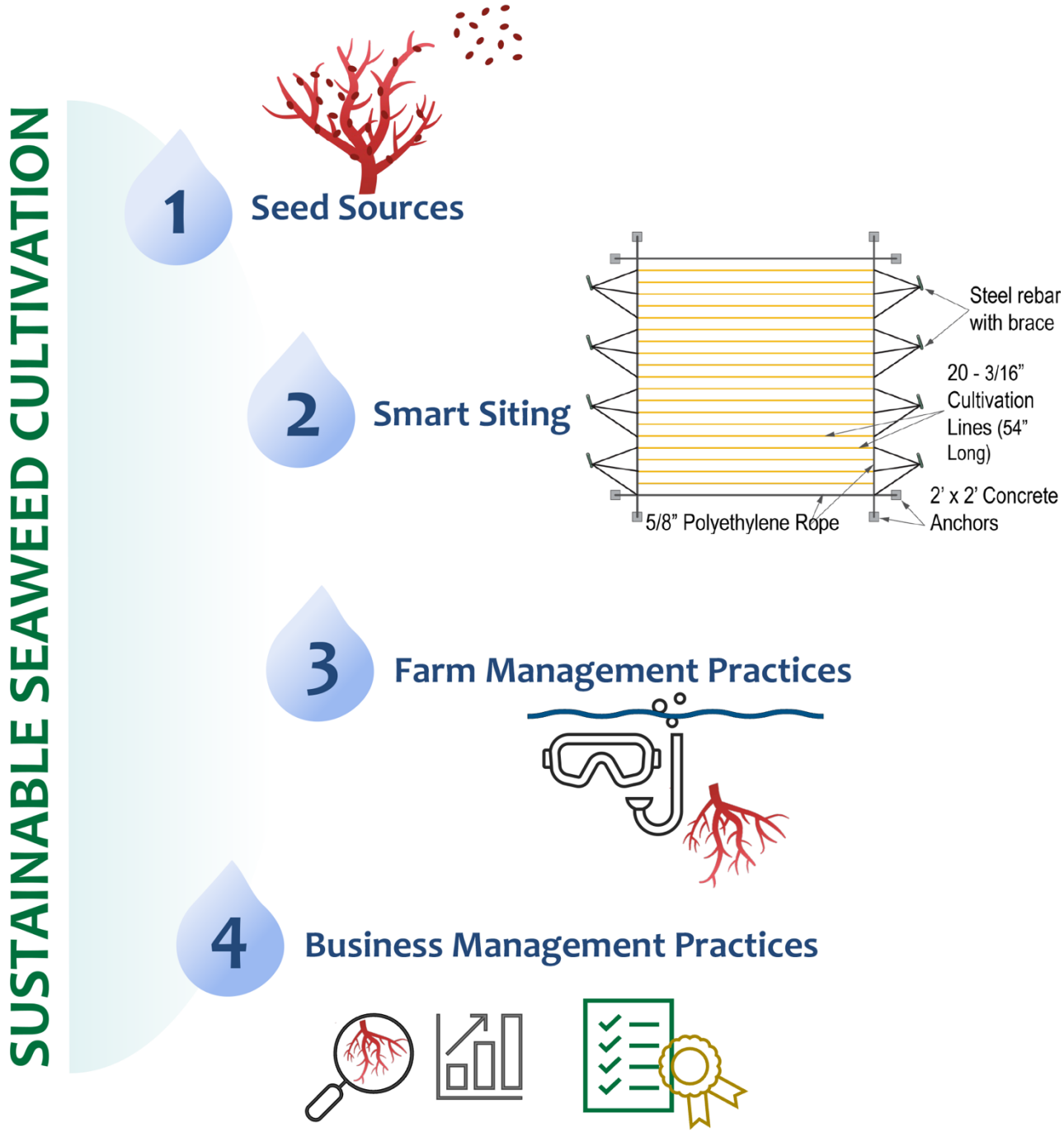


Figure 1. The four considerations of sustainable seaweed cultivation. Image credit: Seaweeds and site design diagram by Jim Kopp.

CONSIDERATION 1
Sources of Seeds

Fishers have been wild-harvesting seaweeds for decades in Belize, passing on the skills from generation to generation. Consuming food items made from wild-harvested seaweed is rooted in the culture of coastal communities. Wild-harvested seaweeds are also used to seed seaweed mariculture farms. However, to date, a comprehensive stock assessment study has yet to be done to determine the size and location of natural populations. Hence, the following recommendations are based on international recommendations and anecdotal evidence of stock size. Some considerations for the sustainable management of wild seaweed populations include the following:

Proper permitting and authorization

Before any seaweed is harvested from the wild, especially in marine protected areas (MPAs), proper authorization must be obtained from the relevant authorities, whether the harvesting is to supply the local market or to seed farms. This authorization ensures compliance with relevant fisheries regulations.

Responsible harvesting levels

To ensure the resilience of wild populations, it is recommended that harvesting from wild stocks not exceed more than 25% of the standing stock per area per annum. Wild populations are subject to damage by inclement weather, natural die-offs, diseases, and more. Hence, overharvesting severely decreases their resilience and may lead to population collapse. Having quotas on the quantity harvested annually will theoretically allow wild populations to recover from natural and anthropogenic factors.

Seedling quality and translocation

In cases where seaweed seedlings will be harvested and transported to other areas for seaweed cultivation, it is recommended that only healthy seedlings are harvested. Healthy seedlings have many thalli, show signs of new growth, and have no disease or pests. Transporting unhealthy seedlings from one site to another may unacceptably spread diseases and pests, potentially causing population collapse. Given that the species cultivated and harvested locally are native, the risks of the seaweed being invasive are very low.

Fishers in southern Belize have noted that the populations of *Gracilaria crassissima* near Placencia and Harvest Caye have been affected by anthropogenic activities to the point of no recovery. This situation should be avoided for all populations of wild-harvested seaweeds.

Figure 2. The Belize Barrier Reef. Photo credit: Aurore Shirley, TNC Photo Contest 2022.

CONSIDERATION 2
Smart Siting

Site selection must be considered carefully for high-quality seaweed production. The water quality, including all physicochemical parameters, can negatively or positively affect the quality and quantity of seaweed produced each cycle. Also, farm locations should be outside ecologically sensitive areas to avoid negative impacts.

Site selection is critical to ensuring minimal negative impacts on not only the farms and seaweed but also the fragile ecosystems in which they are placed — and to ensuring no user conflicts in the area. For Belize, the following criteria are suggested when considering farm site selection:

Uncontaminated water away from coastal communities and runoff

Contamination can be both chemical and biological. For example, coastlines may experience runoff from large agricultural industries such as the banana or citrus industry. Additionally, biological contaminants, such as E. coli, various fungi, and viruses, can wreak havoc on the health of the seaweed and on the individuals who consume the product. To avoid these risks and ensure only high-quality edible seaweed is produced, it is recommended that farms be sited in uncontaminated areas; this may require initial water quality testing.

Sheltered waters by beaches and/or behind reefs, away from heavy wave action

Placing farms near sheltered beaches or other sheltered sites prevents direct damage from strong water currents, wave action, and possibly debris. Additionally, in the case of Belize and the broader Caribbean, positioning the raft is key to ensuring minimal entanglement with drifting nuisance macroalgae, such as sargassum. However, growout sites should still have relatively good current flow, as this is vital for ensuring access to sufficient nutrients to support growth and health.

Benthic marine flora

For juvenile aquatic organism recruitment to the seaweed farm and subsequent settlement to the reef ecosystem, it is recommended that farms be placed in areas with sufficient marine flora, such as seagrass. The possible damage to this important habitat should also be considered. The flora is thought to provide shelter for the organisms when they are migrating from the seaweed farms to the reef. However, the following should be noted:

In Belizean waters, it is not uncommon to discover that the dominant species of seagrass found in these areas is *Thalassia testudinum* (turtle grass). The blades of *T. testudinum* can grow very long over time, with the canopy height in the Turneffe Atoll Marine Reserve seaweed cultivation site reaching between 35 and 40 cm. Other aquatic plants, such as *Syringodium filiforme* (manatee grass), *Halimeda spp*. (green microalgae), and *Penicillus spp*. (green macroalgae), are also found in these areas. These regions have high densities of detrital material, as well, mainly mangrove forest litter. To avoid compromising the integrity of such benthic habitats, the following recommendations are made:

Figure 3. A snorkeler above a farm sited about 5 ft below the water's surface. Clear water allows light to reach the seaweed. Photo credit: Seleem Chan.

- Shallow canoes should be used when tending to farms.
- Wild-harvesting should be avoided.
- Seaweed should be cultivated at low to medium densities to avoid shading. Excessive shading can result in seagrass mortality, thereby affecting organisms living in or on benthic substrate.
- No benthic clearance should be done, especially of seagrasses.
- Anchors should be properly pegged to the seabed to avoid unwanted movement and the disturbance of benthic habitats.
- Farmers and harvesters should avoid polluting the area with debris such as old, discarded ropes, buoys, plastics, wood, and the like. They should also avoid any chemical or biological pollution.

Water depth

In areas with no seagrass, farms should be placed in water depths between 4 and 8 ft (1.2 and 2.4 m; e.g., Figure 3). Farms should be placed in waters that will allow sufficient light penetration for photosynthesis and deep enough to ensure they are submerged during low tides. To avoid damaging the benthic habitat, especially seagrass beds, it is recommended that shallow canoes be used where possible. This practice allows farmers to traverse the farm and conduct maintenance activities with ease, only requiring them to enter the water when necessary.

Salinity

Salinity can be a limiting factor, particularly if it decreases drastically and rapidly. Ideal saline conditions for *Eucheumatopsis isiformis* (syn. *Eucheuma isiforme*) are between 30 and 35 PSU (full-strength seawater). For *G. crassissima*, it is possible to successfully cultivate in lower salinities around 20-25 PSU, like the water in lagoon and bay areas such as Corozal Bay. While *G. crassissima* has a greater tolerance for salinity fluctuations, drastic fluctuations during floods and other weather events may still result in mass mortality due to shock. *E. isiformis* will also suffer mortality if the salinity drastically fluctuates over a short period.

Salinity is a crucial factor to consider when sourcing seedlings from different areas of the country, as the seedlings may die if the salinity differs drastically between sites. Hence, the farm's location and water depth play key roles. Greater water depth allows for greater mixing and minimal salinity decreases; shallow waters are prone to drastic decreases in salinity.

Water temperature

Water temperature can be a limiting factor and should ideally be at 25-30 °C. Sudden tempera-

ture changes can negatively affect seaweed growth and, in extreme cases, can cause mass mortality. Both shallow waters and stagnant water bodies are prone to gradually increasing water temperatures, making such areas unsuitable for seaweed cultivation.

Low densities of grazers

Grazers, such as sea urchins, sea cucumbers, various parrotfishes, jellyfish, and even sea anemones, are known to consume both seaweed species cultivated in Belize. While preliminary growth trials have not shown any significant level of grazing, it does occur, and farmers should be mindful. Farmers should avoid placing farms in areas known to harbor high densities of grazers. Additionally, farmers should avoid killing grazers, as they play important roles on coral reefs; thus, the best option is to relocate the grazers when possible.

Adequate and self-replenishing nutrient levels of the water

It is vital to ensure the site selected has adequate and self-replenishing nutrient levels. Two of the most important nutrients for seaweed growth are nitrates and phosphates. These nutrients should be in the ranges of 1-3 ppm and 0.01-0.021 ppm, respectively. The seaweed's survival, growth, and health will indicate the water's suitability for cultivation.

Proximity to supporting infrastructure

The distance of the farm from the coast will affect farmers' accessibility. Farms located in closer proximity to infrastructure — such as villages, towns, cities, or, in the case of Turneffe Atoll, fishing camps — may allow for frequent monitoring and maintenance while simultaneously dissuading piracy.

A proper storage site is also necessary to maintain the integrity of the product. It is important to keep the area dry to prevent rehydrating the seaweed, which may cause liquefaction or mold growth. Finally, the storage area must prevent rodent and other pest infestations due to the numerous health risks associated with contaminated products.

Proximity to coral reefs and other hard substrates

While no study has specifically examined the appropriate distance of seaweed farms from coral reefs and other hard substrates, as a precaution, it is recommended that farms be placed no less than 100 ft (30 m) away. Siting farms away from reefs may mitigate damage to these important ecosystems.

Availability of fresh water

For the local market, the availability of fresh water is important for cleaning and soaking the seaweed post-harvesting. In the case of the campsite at Turneffe Atoll Marine Reserve and other similar areas, large water-storage containers should be used to store rainwater or fresh water from wells when possible. Using brackish or salt water to clean the seaweed will result in a high salt content after drying is complete. While this salt content may be acceptable for the international market, the local market requires unsalted and fresh seaweed.

Consideration of existing and future uses

Site selection should also consider the current and future uses of the areas, including MPAs, replenishment zones, commercial development zones, and others. Planning can avoid the high cost of relocating. Choosing farm sites at random may result in unwanted territorial overlap with other users. Social conflicts should be avoided when considering seaweed mariculture and other similar activities.

CONSIDERATION 3
Farm Management Practices

Designs for a submerged structure

Instructions for designing a submerged-structure farm can be found in this guide's appendix. A submerged-structure farm is an important consideration due to warming sea temperatures. The submerged structure allows you to cultivate seaweeds lower within the water column, where the temperature is much cooler.

Establishment and management of seaweed nurseries

Establishing and managing seaweed nurseries represents a crucial milestone for the industry's development. While no stock assessment studies have been conducted to determine the location, size, and health of wild seaweed stocks, anecdotal evidence suggests that the wild populations are very small and may be unable to continually sustain harvesting activities. This means that the supply to the market would be limited, as would the supply to nurseries.

Farm maintenance

It is recommended that farmers perform maintenance (e.g., Figure 4) at least 10 days each month to ensure minimal pest and disease damage and maximal seaweed production. Farmers should do the following:

1. First, ensure no animals or debris are entangled in the raft. If they are, carefully remove them. For debris, place it in the boat and discard it properly after maintenance is done.
2. Next, remove all unwanted algae and other smaller marine debris that may have accumulated on the raft and seaweed. Shake the ropes or manually dislodge them. To avoid hand injuries, it is recommended that a marine glove be used during maintenance.
3. After removing all unwanted debris, replace all broken raffia with new raffia or broken connecting eyes with new eyes.
4. Then, replace or remove all diseased or affected seaweed with new, healthy seedlings. Be sure to completely remove diseased seaweeds from the site and discard them on land to prevent spreading the disease.
5. Fragments of seaweed dislodged from the raft and collected in net bags can be used to replace the affected seaweed, provided that the fragments are healthy. Excess fragments can also be harvested, dried, and used for personal consumption.

Figure 4. Seaweed farmer conducting maintenance on a bamboo raft for *E. isiformis*. Photo credit: Wilbur Dubon.

Disease, pest, and piracy management

Table 1 details the common seaweed diseases, pests, and piracy; their impacts on seaweed; and potential remedies.

Table 1. Description of diseases, pests, and problems and their relevant mitigation.

Pest / disease	Description and impacts	Potential remedies
Epiphytes	Organisms that grow on the surface of a plant and derive their moisture and nutrients from the air, rain, water, or debris accumulating around them. Both macro- and micro-epiphytes exist.	• Select areas with minimal naturally occurring epiphytes. • Select areas with a suitable current. • Regularly maintain seaweed and remove epiphytes. • Properly discard affected seaweed.
Grazing fishes	Organisms that feed on the seaweed, including various species of parrotfish. They indiscriminately consume seaweed and may lead to the mortality of the seaweed plant.	• Carefully relocate grazers (if possible) to a distant site but one with a similar ecosystem structure. • Increase plant density (functions as a buffer and allows for a reasonable final seaweed productivity level). • If grazing is too frequent and intensive, relocate the farm to a new site and perhaps to deeper waters. • Properly discard affected seaweed.
Echinoderms and jellyfish	Organisms that feed on the seaweed, including sea urchins, sea cucumbers, and upside-down jellyfish, among others. They consume smaller quantities than grazing fishes but may also lead to seaweed mortality.	• Carefully relocate said organisms where possible. • If grazing is too frequent and intensive, relocate the farm to a new site and perhaps to deeper waters. • Properly discard affected seaweed.
Grazing turtles	Large marine turtles that consume seaweed. While not prevalent in Belize, various species of sea turtles consume seaweed and may lead to seaweed mortality. Entanglement with seaweed farm structures may also lead to turtle mortality.	• While not prevalent in Belize, when encountered, turtles should be relocated. • It is illegal to capture, kill, or consume marine turtles; hence, should entanglement with the farm occur, contact the Belize Fisheries Department or other relevant authorities.
Freshwater intrusion	A heavy downpour of fresh water during rain events. They reduce growth and farm production, and they cause mortality in very severe cases.	• Place the farm away from runoff areas or areas that are too shallow. • Place the farm in an area with suitable current flow. • Add weight to seaweed lines to partially submerge the seaweed.
Air exposure	While short-term exposure to air may not cause seaweed mortality, long-term exposure will cause bleaching and plant mortality.	• Place the farm in deeper areas. • Add weight to seaweed lines to partially submerge the seaweed and prevent overexposure to air.

Pest / disease	Description and impacts	Potential remedies
Silt	Areas such as lagoons and open sea may have heavy siltation during rain events. Silt settles and covers the seaweed, preventing nutrient uptake and photosynthesis.	• Relocate the farm to deeper areas with suitable current flow. • Conduct regular maintenance to remove the silt.
Ice-ice	Under stressful conditions, the tips of the seaweed turn white with red blotches.	• Relocate the farm to cleaner waters with suitable current flow. • Properly remove affected seaweed. • Replant areas with missing seaweed.
Piracy	Unattended seaweed may fall victim to piracy from seafaring individuals, especially farms that are located far offshore.	• Ensure a proper base camp is available, not just for security and monitoring but for easier farm maintenance. • Ensure that piracy, if definitively identified, is reported to the relevant authorities.

Harvest and postharvest handling of farmed seaweed

The seaweed's harvest (e.g., Figure 5) time depends on the species being cultivated and the initial size and weight of the seedlings used. Typically, *G. crassissima* can be harvested after 8 weeks of cultivation due to its high growth rate. *E. isiformis,* on the other hand, requires a minimum of 10 weeks to grow to maturity and is most often harvested in Belize at around 12 weeks of cultivation.

Regardless of the cultivation duration, the following things should be considered when harvesting seaweed from farms:

Standing stock/biomass

Only mature plants should be harvested. Farmers should not remove more than 25% of the standing stock/biomass at one time. Removing more than 25% may contribute to the stock's depletion because, in addition to harvesting by fishers, wild stocks are under pressure from diseases, pests, and other environmental conditions. While measuring exactly 25% of the biomass may be impractical, a visual estimation may be sufficient. Limiting each harvest will ensure sufficient healthy seedlings remain, contributing to the stock's resilience.

Quantity harvested

It is standard practice to harvest no more than 75% of the standing stock of seaweed, whether from wild stocks or from cultivated stocks. The harvested seaweed can be transplanted to new rafts, which will more than double in size and function as seedlings for nursery or farm expansion. A partial harvest can be done to meet market demands for dried seaweed.

- During harvesting, all debris and critters should be removed before exiting the water. This practice allows recruited juveniles to dislodge from the seaweed and find safety elsewhere. It also ensures that the final product is clean of such items.
- Healthy seaweeds that have broken off from the farm can be collected and used to reseed farms.

Figure 5. Farmers returning from harvesting a small batch of *E. isiformis* from Hatchet Caye seaweed farm. Photo credit: Leonel Tucker.

Rinsing and drying for the local market

After harvesting, the rinsing and drying process for the local market (e.g., Figure 6) should follow the steps in Figure 7:

Figure 6. In-specting seaweed on a drying rack. Photo credit: TNC.

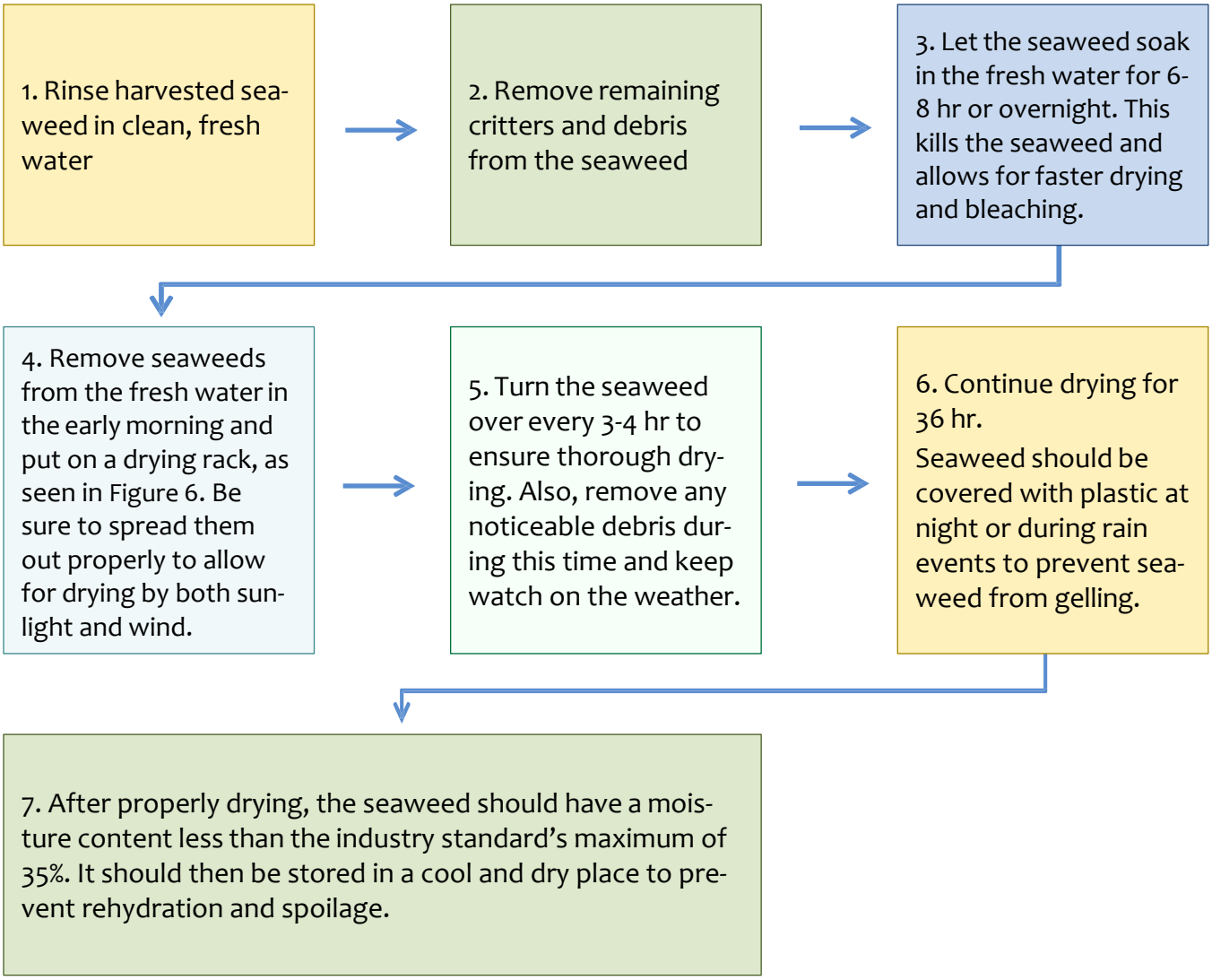


Figure 7. Postharvest process for rinsing and drying seaweed for the local market.

Packaging and storage for the local market

For seaweed that will be sold on the local market, the typical packaging requirement is basic heat-sealed or vacuum-sealed plastic packaging (e.g., Figure 8). Farmers should do the following:

- Ensure the plastic packaging material is free of all foreign material and does not have any extra holes that would prevent proper sealing or allow for contamination.
- Properly weigh the seaweed as per market requirements.

Figure 8. Packaged *E. isiformis* seaweed being bulk-transported using a net bag. Photo credit: Wilbur Dubon.

- Properly seal the plastic packaging using a heat sealer, vacuum sealer, or other similar sealing tools.
- If necessary, use a proper packaging label.
- Package all strains separately.

Drying, packaging, and storage for the international market

The drying, packaging, and storage process for the international market is shown in Figure 9 and is shorter than the process for the local market.

The storage area for the seaweed should be a cool, dry place with no sign of rodents or other potential sources of biological or chemical contaminants. Any contaminated seaweed, packaging material, or related materials should be properly discarded, and the storage area should be properly sanitized and sealed.

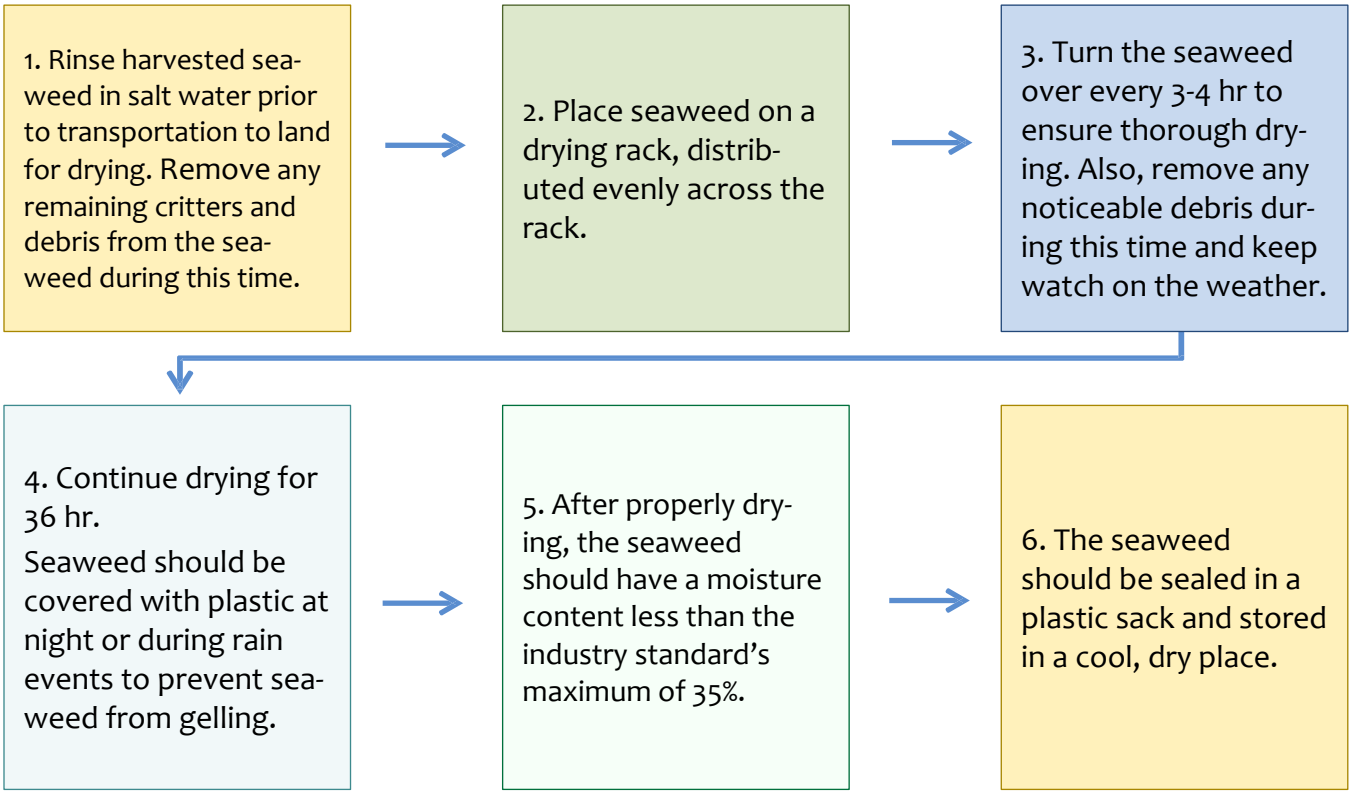


Figure 9. Postharvest process for drying, packaging, and storing seaweed for the international market.

CONSIDERATION 4

Business Management Practices

Successful business management depends heavily on having both an adequate operational framework and a competent, happy team of individuals on all levels. These are the key ingredients in ensuring social, financial, and ecological sustainability. What follows are some things to consider when working toward effective operational management:

Legislative considerations

Marine research permit (MRP)

It must be noted that the current process of site selection must be approved by the Belize Fisheries Department. Before establishing any new farm sites, farmers (groups) must apply for and be granted an MRP from the Belize Fisheries Department. Failure to obtain a proper permit will result in the removal of the farms.

In cases where there is a long-term memorandum of understanding (MOU) with the department and co-managers of MPAs, farmers must abide by the rules listed within the MOU. Failure to do so will also result in the removal of the farms.

These are the general considerations of an MRP or MOU:

- Farmers should be in full compliance with all relevant laws and regulations governing seaweed cultivation, including the clear demarcation of seaweed farm boundaries (must not be in shipping or transportation areas).
- There should also be no extractive activities other than seaweed.
- There should be adequate oversight/security of the farm to prevent piracy.
- Samples should only be taken with prior written permission from the Fisheries Department, and if it is necessary to send a sample out of the country for testing, additional permitting will be required.

The above points are merely examples; each permit will have its own conditions attached, and farmers must adhere to those conditions.

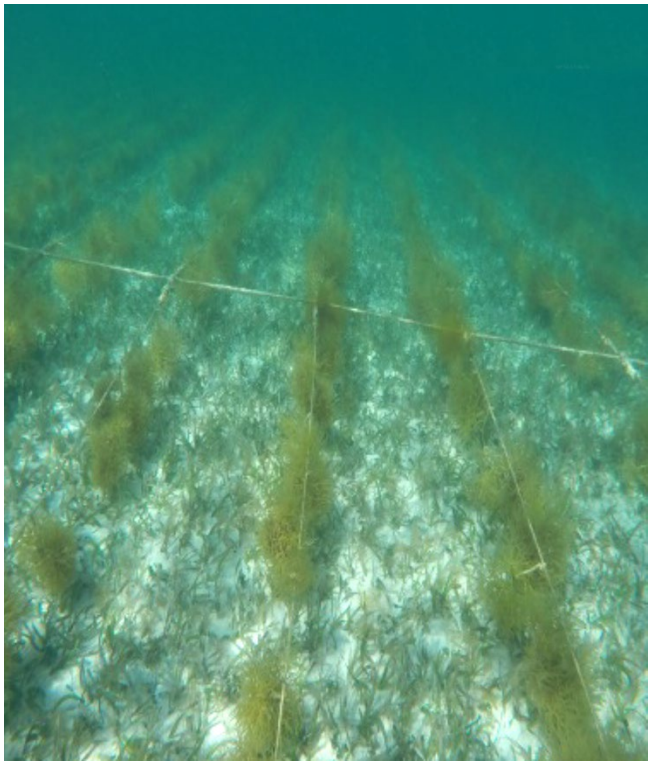


Figure 10. A cultivation design for a submerged seaweed farm. Photo credit: Seleem Chan, TNC.

Permit for using the seabed

The Physical Planning Section of the Department of Natural Resources, under the Ministry

of Natural Resources, requires that proper permits be attained before any and all uses of the seabed. (e.g., Figure 10) A proposal, along with a completed application form for the use of the seabed, must be submitted to the Physical Planning Section, which will then proceed with the revision process and either grant or reject the application. If granted, permits for up to 3 years can be given by the department. Hence, all prospective farm owners must attain not only an MRP but also a permit for using the seabed.

Labor force

Where seaweed cultivation is conducted using an employed labor force, employers must abide by the laws and regulations set out by the Belize Labour Act, Chapter 297, Revised Edition 2000. In summary, employers must ensure the following:

- No underage or illegal people are employed.
- Fair remuneration must be given to everyone employed.
- Employees are aware of dangers, as well as relevant safety procedures; occupational health and safety are extremely important. Common dangers include strong currents, floating and submerged debris, and large marine animals, such as sharks, rays, and crocodiles.
- Employees should not be forced to work during times of inclement weather, as it may result in injury, sickness, or in extreme cases, death by drowning.
- Like farm owners, employees should receive proper training in sustainable seaweed cultivation.

Although not required, gender equity should always be considered by any employer.

Operational considerations

Business plan

Depending on the scale of the activities, a basic business plan is necessary to guide the operations to a profitable level. The plan's components are highly dependent on the goals and objectives of the business but normally include the following:

- **Executive summary.**
- **Company/business description** – It describes who you are, how you operate, and what your goals are.
- **Products and services** – In this case, the main product will be raw dried seaweed. Certain cases may include seaweed cultivation or ecotourism.
- **Market analysis** – This component can be for local, regional, or international markets and for specific products.
- **Strategy and implementation** – It details the sales and marketing strategy, which will be implemented using the operational plan explained in the next subsection.
- **Organization and management team** – This component is used in the case of larger businesses and is not necessarily applicable to individuals.
- **Financial plan and projections** – It is important to produce realistic financial forecasting. Income generation is critical for ensuring not only the longevity of the business but also its improvement and advancement.

Operational plan or framework

While not mandatory, successful farming and harvesting operations follow either written or unwritten operational plans. Such plans ensure good organization, allowing for effective and efficient seaweed production. This plan typically covers the who, what, where, when, and why questions. It focuses on achieving short-term

goals and may include but is not limited to the following:

- Frequency of planting, maintenance, harvesting, and processing
- Human and other resources needed to conduct the relevant activities

General preparedness

To further ensure the safety of the ecosystem and the resource users, each farm should have its own emergency plan. It does not have to be a written plan but should include the following and should be understood by all individuals:

- Exit routes from the base camp in case of storms or human injury.
- Basic first aid equipment, which should always be onboard any vessel or at any campsite. Basic cardiopulmonary resuscitation (CPR) or first aid training is also recommended.

Storm preparedness

It is very important for seaweed farmers and nursery or seed-bank owners to consider the very real threat of storms. For context, between 1954 and 2013, 29 cyclones affected Belize, of which 12 were tropical storms and 17 were hurricanes, with five of them reaching Category 3 or higher intensities (source cited in Figure 11). These storms can cause mass damage to the agriculture, aquaculture, and mariculture industries, as seen with Hurricane Earl in 2016.

Storm damage is not restricted to only one area of the country. As seen in Figure 11, storms have impacted the north, central, and southern regions of Belize.

The following recommendations are for pre- and post-storm farming continuation:

Pre-storm preparedness

Having executed proper site selection, one of the next important factors for a farmer is understanding basic weather patterns in the region. Severe and sometimes unpredictable weather conditions have the potential to affect not only the farm but the farmer and their equipment. One of the most common and detrimental weather conditions is a squall. Not only do squalls cause product loss, but strong winds can also dislodge the raft and cause entanglement in other rafts, mangroves, and even

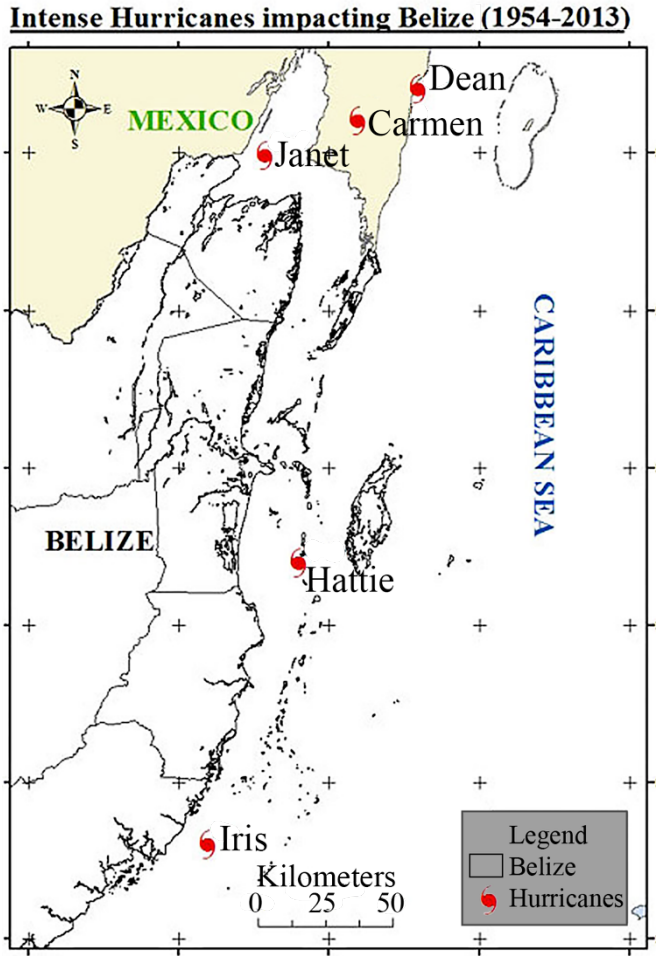


Figure 11. Intense hurricanes impacting Belize, 1954-2013. Source: AmbergrisCaye.com Forum, 2015, "Analyzing 60 Years of Belize Hurricane History," https://ambergriscaye.com/forum/ubbthreads.php/topics/504270/analyzing-60-years-of-belize-hurricane-history.html.

sensitive coral reefs. They can also cause small marine vessels to capsize, posing great danger to individuals onboard.

To ensure minimal impacts from such conditions, farmers should take the following precautions:

- Ensure all ropes, anchors, seedlings, and bamboos are properly tied.
    - Farmers should identify the most appropriate method of storing seedlings for post-storm recovery and cultivation. In some instances, the best solution may be to store seaweed in net bags submerged in deeper waters. A lengthy rope with a buoy can be used to keep track of where the seaweed was placed. A concrete anchor can also be pre-deployed to serve as the anchor point.
- Ensure each raft has sufficient anchors and the anchors are pegged to the ground or are unable to move easily.
- Ensure all dislodged items are removed from the farm area and stored or disposed of appropriately.
- Ensure no maintenance or harvesting is done during inclement weather.
- Ensure marine vessels are secured firmly to an anchor point.
- Ensure all other equipment and materials are secured.
- In cases where fishers may be subjected to such conditions, sufficient nonperishable food items, first aid kits, and spare equipment and materials are readily available.
- Farmers should always have access to communication equipment, whether cell phones, handheld transceivers, VHF radios, or others. A regular radio to listen to the weather forecast is a must-have for any farmer.

In case of major storms such as tropical storms and hurricanes, farmers should maintain great caution. In addition to ensuring the previously listed actions are taken, farmers should evacuate and seek shelter until the storm passes. While the weather bureau will provide relatively accurate information on the most probable path, wind speeds, and other parameters, storms often change. ***It is important to remember that the well-being of the individuals takes priority over the farms and materials***.

Seasonal calendar

It is important to plan activities ahead of time and to have a backup plan should the situation change. It is common knowledge that working during the cooler months is inherently more difficult due to the lower water temperature and rain. In March and April, strong wind gusts not only prevent farmers with smaller boats from traveling to the farms but also make the conditions at the farms too dangerous to work in. During such times, it may be best to conduct only basic maintenance of farm materials.

Post-storm recovery

For smaller weather events such as a squall or a thunderstorm, individuals may assess the damage to the farms 12-24 hr after the storm has passed. This interval provides sufficient time for debris and other matter to settle or pass by. For larger storms, such as tropical storms and hurricanes, it may be impossible to conduct a damage assessment until 3 to 5 days

after the storm. When assessing the damage, farmers should ensure the following:

- Conduct a damage assessment with a partner for safety purposes.
- Use life vests and proper snorkeling gear during the assessment and ensure the marine vessel is properly anchored nearby.
- Ensure that a knife is readily available for emergency purposes, such as cases when a farmer becomes entangled in the ropes of the raft or when entangled marine animals need to be released immediately to avoid mortality.
    - The knife can also be used to remove the raft from reef or mangrove areas, depending on the severity and urgency of the matter.

Debris removal

After assessing the damage, it is imperative that farmers proceed with removing debris from the surroundings. Such debris should be completely removed and recycled when possible. Should the farmer decide to cease farming due to significant losses, the farmer is still responsible for ensuring no abandoned rafts or debris from the rafts pose significant risks to other humans, marine animals, the coral reef, or other sensitive ecosystem components.

If necessary, farmers can request assistance from other farmers, the Belize Fisheries Department, MPA co-managers, the Department of the Environment, or other entities with capabilities for removing the damaged raft and/or equipment and materials.

Figure 12. A fishing camp dock in Turneffe Atoll Marine Reserve, Belize. Photo credit: Randy Olson.

Conclusion

The Belize seaweed industry is in its infancy and lacks the structure of well-developed seaweed industries in countries like Indonesia, the Philippines, China, and Chile. However, this early stage can have its advantages. It allows for the creation and institutionalization of Best Management Practices, regulations, policies, and other standards to properly guide the industry's development from the outset. These early-stage tools are very important given that economies of scale prohibit Belize from competing with large producers who market their products at significantly lower prices.

This document focuses on sustainable seaweed cultivation to provide sufficient guidance to current and future farmers and law enforcement officials. This guide is intended to be used in conjunction with the seaweed cultivation training program from the Placencia Producers Cooperative (training curriculum, manual, video, theory, and practical sessions). Also, conservation managers can use this document as a tool for marine conservation and, at the same time, promote seaweed mariculture as a viable alternative livelihood for fishers and other marine resource users.

Figure 13. Cultivation lines prepared for a Eucheuma farm. Photo credit: Sarah Aly.

Appendix: Instructions for Designing a Submerged-Structure Farm

Items needed

Table A-1. Quantities and materials for the items needed for a submerged-structure farm.

	Quantity	Item	Material to make the item	Total amount of materials (in feet and meters except where noted)	
				ft	m
	2	headropes, each 54 ft long	5/8-inch polyethylene rope	108	32.9
	20	cultivation lines, each 54 ft long	3/16-inch polyethylene rope	1080	329.2
	40	double-eye spliced ropes, each 2 ft long	5/8-inch polyethylene rope, with the eyes created by splicing both ends of each rope	80	24.4
	1400	raffia strings, each 1 ft long	1/8-inch or 3/16-inch braided nylon rope, sold on spools	1400	426.7
	8	one-eye anchor ropes, each 10 ft long (i.e., the rope tying the structure to the anchors)	5/8-inch polyethylene rope, with the eyes created by splicing one end of each rope	80	24.4
	10	headrope strings, each 5 ft long	3/16-inch polyethylene rope	50	15.2
	8	cement anchors, each 2 ft x 2 ft x 4 inches high and each with two handles	cement	(see Step 9 in Table A-3)	
			3/8-inch steel handles	16 handles	
	8	pins for cement anchors, each 5 ft in length	5/8-inch steel rebar	40	12.2
	10	headrope pins, each 5 ft in length	5/8-inch steel rebar	50	15.2
	6	flotation buoys	made commercially	6 buoys	

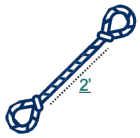
Table A-2. Total amounts of each material to produce all items.

Material	**Amount** (in feet and meters except where noted)	
	ft	**m**
5/8-inch polyethylene rope	268	81.7
3/16-inch polyethylene rope	1130	344.4
1/8-inch or 3/16-inch braided nylon rope	1400	426.7
3/8-inch steel handles	16 handles	
5/8-inch steel rebar	90	27.4
commercially-made buoys	6 buoys	

Instructions

Rope and pin preparation

Table A-3. Steps for preparing the ropes and pins for a submerged-structure farm.

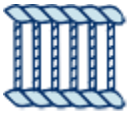
Step		Description
	1	Ensure you have purchased all the equipment needed to construct your farm design, per the materials in the previous list and the tools required for the steps in this list (e.g., a sharp knife).
	2	Using a sharp knife, cut two headropes for your structure using 5/8-inch polyethylene rope. Each should be 54 ft long. Be sure to burn both ends of each headrope to avoid unraveling.
	3	Again, using a sharp knife, cut 20 cultivation lines using 3/16-inch polyethylene rope. Each should be 54 ft long. Be sure to burn both ends of each line to avoid unraveling.
	4	Cut 40 lengths of 5/8-inch polyethylene rope, each 2 ft long, to prepare 40 double-eye spliced ropes. Create an eye on both ends of each 2-ft-long rope by splicing the rope into itself. These double-eye spliced ropes will later be tied to your headropes.
	5	Make your raffia using braided nylon. Cut 1400 lengths of braided nylon, each 1 ft long. Remember to burn both ends of each length to prevent unraveling. A total of 70 raffia strings will be tied onto each cultivation line. You will use the raffia to secure your seaweed seeds to your cultivation lines.
	6	Cut eight anchor ropes using 5/8-inch polyethylene rope. Each should be 10 ft long. Remember to burn those ends of the ropes that will not be spliced. Create an eye on one end of each 10-ft-long anchor rope by splicing a loop into itself. You will use these one-eye anchor ropes to secure your structure to the cement anchors.

	Step	Description
	7	You are almost finished preparing the ropes. The next step is cutting your headrope strings. Cut 10 headrope strings using 3/16-inch polyethylene ropes. Each should be 5 ft long. Again, be sure to burn all the ends. You will use these headrope strings to tighten your cultivation lines after constructing your structure.
	8	Cut 18 pins using 5/8-inch steel rebar. Each should be 5 ft long. You will use eight of the 18 pins to secure your cement anchors to the seafloor. You will use the remaining 10 of the 18 as headrope pins to elevate your cultivation lines within your structure.
	9	Create a form for each anchor and pour cement to create them: • Construct eight form boxes measuring 2 ft x 2 ft x 4 inches high using ¼-inch plywood and 1 inch x 4 inch pine lumber. • Place four evenly spaced 5/8-inch steel rebars at mid-box height to serve as reinforcement. Two inner bars should measure 2 ft long, while two outer bars should be 3 ft long to accommodate the making of the handles. • Place a 4-inch-long ¾-inch PVC pipe vertically at the center of the form to allow for pegging the anchor to the seafloor later on. • Mix the concrete. Generally, you will use a mixture of one bag of marine-grade cement for eight 5-gallon buckets of sand and gravel. Add water and mix per the cement bag's instructions. Pour it into the form boxes. Let cure for 7 days.

Structure assembly

Table A-4. Steps for assembling a submerged-structure farm.

	Step	Description
	10	Locate a nice open lawn, one big enough to construct a 50 ft x 50 ft square.
	11	Locate both your headropes and the 40 double-eye spliced ropes you prepared. Evenly distribute 20 of your double-eye spliced ropes along the length of one headrope. Ensure you leave a 2-ft space on both ends of the headrope; the double-eye spliced ropes should be spaced approximately 2.5 ft apart. Twist your headrope and then feed the double-eye spliced rope into the headrope and secure with a double knot. Repeat this process with the other headrope and the remaining 20 double-eye spliced ropes.

	Step	Description
	12	Locate your 20 cultivation lines and the 1400 braided nylon strings (raffia strings). Place 70 raffia strings on one of your 20 cultivation lines, spacing them evenly. Ensure you leave a 2-ft space on both ends of the cultivation line; the raffia strings should be spaced approximately 5 or 6 inches apart. Similar to the step above, twist the cultivation line and then feed the raffia into the cultivation line, securing with a single knot and allowing the full length of the raffia to hang from the cultivation line. Repeat this process with the other 19 cultivation lines.
	13	Lay out your entire structure on dry land to get a real-life visual of what you will be constructing underwater. This will also give you an opportunity to ensure your double-eye spliced ropes are evenly spaced along the headropes.
	14	With your two headropes on the ground, tie the 20 cultivation lines to the 40 double-eye spliced ropes. (In a previous step, you already tied the double-eye ropes to your headropes.) This should be done on both ends, creating a 50 ft x 50 ft square.
	15	It is unlikely that you will need to place your anchors at the corners of your 50 ft by 50 ft square during this dry-land setup. However, go right ahead if you want to. By doing so, you can ensure you have all the rebar pins needed, as well as anchor ropes and headrope strings.

Structure installation

You are now ready to construct your first submerged-structure seaweed farm by installing it in the water. Remember the following points when setting up your farm:

Ensure you have all necessary equipment on the boat when traveling to your farm site, including the items listed in Table A-1 and any tools you require. Avoid the inconvenience of leaving something important behind.

Place your cultivation lines parallel to the water's current.

You will need approximately 300 lb of wet seaweed seeds per plot.

Each seed should be no less than 100 g in weight.

The Nature Conservancy – Belize
Mountain View Boulevard,
14B Garden City Plaza
Belmopan, Belize
Phone: +501-822-0274
Email: belize@tnc.org