Traditional Seaweed Farming Methods

Subjects: Engineering, Marine

Contributor: Robert Maxwell Tullberg, Huu Phu Nguyen, Chien Ming Wang

The imperative to substantially expand the world's seaweed aquaculture supply is well established in published literature and has the strong backing of virtually all global non-government organizations (NGOs). The expansion of seaweed farming is recognised as one of the best approaches to realising many of the sustainable development goals of the United Nations.

Keywords: seaweed ; infrastructure ; longline ; offshore wind

1. Introduction

The demand for seaweed products in a low-carbon world is extensive and growing [1][2]. Seaweed as a traditional food source (used in salads, soups, sushi wraps, etc.) provides for a low-calorie diet that supplies vitamins A, B, C, and E, dietary fibre, omega-3 fatty acids, essential amino acids, and has been shown to improve digestive health, reduce the risk of colorectal cancer, and reduce obesity [3]. Seaweed-derived hydrocolloids are used in many food products, such as salad dressings, ice cream, and beverages, and account for about 40% of the global hydrocolloids market [4]. Other uses include fertilisers, cosmetics, nutraceuticals, pharmaceuticals, and the emerging markets for bio-plastics, fabrics, bio-fuels, bio-char, and potentially carbon sequestration. Seaweed also plays an important role in the aquatic ecosystem, providing eutrophication mitigation, shoreline protection, and habitat for aquatic organisms as nursery grounds [1].

In response to concerns about greenhouse gas emissions the beef cattle market is being challenged by changing dietary patterns and the growth of lab-grown meat and vegan substitutes. The inclusion of small quantities of specific seaweed species as feed additives has been shown to substantially reduce enteric methane production in beef and dairy cattle. For example, the inclusion of the red seaweed *Asparagopsis Taxiformis* at a dietary dry matter level of just 0.2% yielded a methane reduction of 98% relative to a controlled beef steer group [5]. In another study, the inclusion of a closely related species *Asparagopsis Armata* in Holstein dairy cattle at a rate of 1% dry matter yielded a methane reduction of 67.2% [6]. Notably, these and other studies on seaweed feed supplementation reported simultaneous improvements in feed efficiency for beef cattle and milk production [7][8].

The overwhelming majority of current seaweed farming production is in nearshore-sheltered and intertidal shallow waters where simple systems combine with low labour costs for their feasibility. However, existing nearshore-sheltered farming practice is facing a number of challenges to its continued growth. Many nearshore-sheltered coastal sites are in direct competition with other uses in marine spatial planning—namely tourism, shipping, and fishing [9]. In many places, particularly in tropical and lower latitudes, rising upper pelagic ocean temperatures are limiting the productivity of seaweed farming [10]. There are also a number of environmental risks in nearshore-sheltered farming including the slowing of water flows in protected areas, and the spread of disease and parasites under some circumstances. Farming offshore or in exposed coastal waters would avoid the trampling and shading of natural macroalgal beds and seagrasses, reduce the incidence of herbivorous fish grazing, fouling, and epiphytic growth, and help to reduce ocean acidification [1][11][12][13].

2. Traditional Farming Methods

2.1. Background and Seaweed Species Classification

As with any form of aquaculture the infrastructure and cultivation methods used are highly dependent on the seaweed species and their ideal growing environment. The most commonly farmed species and their uses and basic infrastructure are summarised in **Table 1**. The simplest systems can often provide inspiration for further development. Examples of bamboo rafts and twine-growing frames, tube nets, simple monolines, buoy-supported longline systems, and staked rope bottom culture are illustrated in **Figure 1**. The most basic and labour intense systems, such as the bamboo rafts, and staked rope bottom cultures (typically used in the tropics in small-scale farming of red seaweed) rely on manual fragmentation and seedling propagule attachment to seeding ropes [14][15]. Simple tube-net systems are used to give improved resistance to nearshore wave damage.

Figure 1. Simple seaweed systems—raft, monoline, tube nets-images from https://www.slideshare.net/zoysa89/sea-weed-farmingsouth-east-asia (accessed on 22 September 2022), floating longlines (*bottom left*) [16], staked rope bottom culture (*bottom right*) [16].

Table 1. Seaweed species use and infrastructure.

Species Group	Seaweed Colour	Biomass Load per Metre (Scale 1–3)	Tonnes (Wet) Annual Cultivation [1]	% World Market [1]	Buoyancy	Region	Applications	Cultivation Method(s)	Hydrodynamic Suitability (Scale 1–3)
Laminaria/Saccharina	Brown	2—Moderate	12,273,748	35.4%	Neutral/slightly negative	Temperate	Human consumption; Raw material for alginate, mannitol, iodine, Abalone feed	Longlines	2—Moderate, grows in exposed water
Undaria (wakame)	Brown	2—Moderate	2,563,582	7.4%	Negative	Temperate	Sea mustard, Abalone Feed	Longlines	1–2—Low–moderate, grows in exposed waters
Macrocystis pyrifera	Brown	3—High	2	0.0%	Positive	Temperate	Food and Cosmetic Products, Animal Feed	Longlines	2—Moderate, grows in exposed waters
Sargassum	Brown	3—High	304,000	0.9%	Positive	Tropical	Food and Cosmetic Products, Animal Feed	Longlines	2—Moderate, grows in exposed waters
Alaria esculenta	Brown		105	0.0%		Temperate	Animal feed	Longlines	2—Moderate, grows in exposed waters

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Eckolonia, Lessonia	Brown	2—Moderate	-	-	Negative	Temperate	Human consumption, fertiliser, animal feed (e.g., livestock, aquaculture), nutraceuticals, and biopolymers and bioplastics	Longlines	2—Moderate, grows in exposed water
Durvillaea	Brown	3—High	-	-	Negative	Temperate	Alginate industry, fertiliser	Longlines	3—High, grows in very exposed waters
Kappaphycus/Eucheuma	Red	2—Moderate	11,622,213	33.5%	Negative	Tropical	For carrageenan extraction	Longlines/nets	1–2—Low–moderate, grows in open water
Gracilaria	Red	1—Low	3,639,833	10.5%	Negative	Tropical	Feed for abalone; For agar extraction; Bioremediation	Longlines/nets	1–2—Low–moderate, grows in exposed water
Porphyra	Red	1—Low	2,984,123	8.6%	-	Temperate	Food wrap	Nets	1—Low–delicate
Asparagopsis	Red	1—Low	-	-	-	Tropical/warm temperate	Animal feed	Longlines, net tubes	1—Low–delicate, unsuitable for open waters
All Green	Green	1—Low	14,019	0.0%		Tropical/temperate	Human consumption	Land-based facilities	1—Low–delicate
TOTAL			34,679,134						

With a few notable exceptions, such as free-floating *Sargassum* spp., almost all wild-found and farmed seaweed rely on seaweed attaching to some structure through their root-like “holdfast” organ. Given adequate sunlight for photosynthesis, nutrient availability, salinity, temperature range, oxygen, and carbon dioxide, seaweed propagules can grow regardless of how deep the sea beneath is.

Depending on the fragility of the species, the water speed, through wave action, currents, or tides, needs to be kept within upper bounds to avoid damage and lower bounds for optimal nutrient uptake and growth [14][17][18].

It has been shown that increased tension in sub-surface culture lines increases water flow and, hence, the growth of some kelp species in low current and surface wave conditions [17][18]. However, in moderate to higher energy environments though, this increased tension reduces the ability of the culture line to dampen wave and current energy risking seaweed holdfast detachment and higher mooring loads. A further consideration for system design is the buoyancy of different species. Positively buoyant species such as *Macrocystis* spp. that develop pneumatocysts (air-sacs) grow up from their holdfast, whereas most other species are typically slightly negatively buoyant. This variation in species buoyancy, size, and drag inevitably means that infrastructure systems need to be customised and adapted into solutions to suit different groups sharing similar characteristics.

2.2. Cultivation Systems

Larger operators in more temperate regions typically automate the seeding of longlines in laboratory based hatcheries [19]. By adjusting light and temperature conditions in spawning tanks seaweed spores are induced, settled, and grafted onto coiled longlines. These are subsequently deployed at a suitable depth by using float buoys and concrete moorings in the grow-out phase. Depending on the species, these longlines are either harvested completely and replaced with new freshly seeded longlines or trimmed every few weeks and allowed to regrow multiple times throughout a growing season or for several years in some cases—a technique known as multiple partial harvesting. An alternate variation uses fine strings to seed spores, which are then in turn bound to a larger culture rope, as shown in **Figure 2** [17]. Depending on the species and its buoyancy, line systems must be devised that control the average depth of the seaweed for growth optimisation, minimise damage to due wave and current action, and allow for efficient harvesting. The major variations of traditional culture line systems used for most neutral or negatively buoyant species are categorised as horizontal longlines, vertical lines, or garland lines are shown in **Figure 3** [20].

Figure 2. Typical cultivation lifecycle in the northern hemisphere of *Saccharina latissimi* using seeded strings. *Reproduced with Permission* [17].

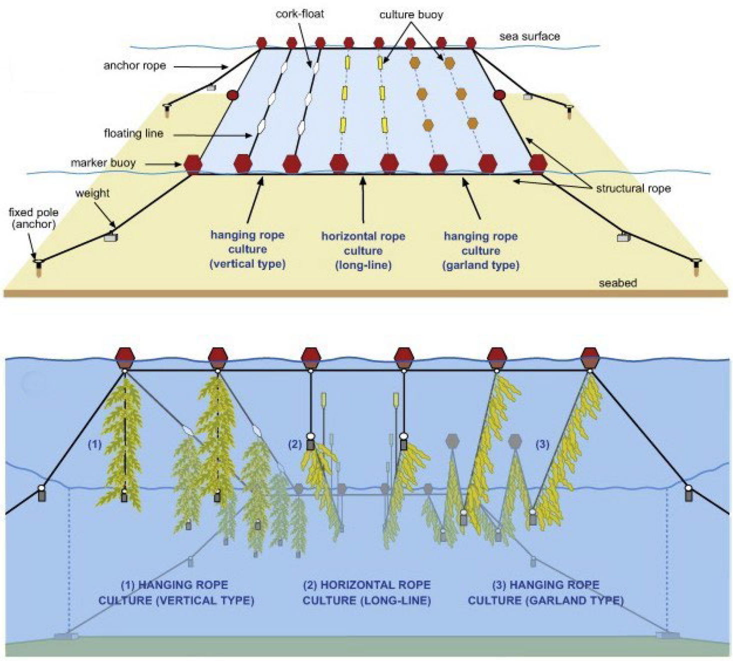

Figure 3. Variations on traditional culture rope systems. *Reproduced with Permission* [17].

For some species, such as many of the green seaweeds, their weak resistance to waves and currents makes them unsuitable for farming in open waters. These are typically grown in tank-based land facilities where water temperature and water biochemistry can be easily controlled. However, the higher costs inherent in these systems restrict this market to high-value (food uses) applications. Examples of land-based seaweed farming are shown in **Figure 4**.

Figure 4. (**a**) Farming Ulva and Gracilaria in Israel (https://seakura.co.il/en/ (accessed on 22 September 2022)), (**b**) farming Umbibudo sea grapes in Vietnam (http://www.dtvietnam.com/# (accessed on 22 September 2022)).

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