VINGNANAM Journal of Science

Journal homepage: https://journal.jfn.ac.lk/vingnanam/

Seaweed Farming in the Indian Ocean: A Comprehensive Regional Review

N.M.I. Anjalie[1]*, J. Santos[2] and S. Kuganathan[1]

[1]Department of Fisheries, Faculty of Science, University of Jaffna, Jaffna 40000, Sri Lanka.

[2]Norwegian College of Fishery Science, UiT Arctic University of Norway, Tromso, Norway.

11 June 2025; 22 August 2025; 15 September 2025

ABSTRACT

Seaweed farming in the Indian Ocean has gained prominence as a sustainable livelihood and an environmentally beneficial industry. However, its regional status and potential have not been investigated. This paper reviews the current state of seaweed farming in the region, examining species diversity, farming techniques, production methods, and socio-economic impacts. The study synthesizes 32 articles, selected among 149 articles, published between 2009 and 2023, gathered from the Web of Science database, to assess trends in both commercial and experimental seaweed species cultivations. Dominant farmed species such as *Kappaphycus alvarezii*, *Gracilaria tenuistipitata*, and *Eucheuma denticulatum* are highlighted, emphasizing their ecological roles and economic value. The review identifies key farming methods, including off-bottom, rope culture, and floating raft systems, which have been employed to optimize yields and minimize environmental impacts. The production of seaweeds in the Indian Ocean region is concentrated in countries like Indonesia, Malaysia, and the Maldives, with a growing interest in other nations such as Kenya, Mauritius, and Seychelles. Seaweed farming has delivered significant benefits, including income generation, promotion of gender equity advancement in coastal zone management, and potential contributions to climate change mitigation, particularly through carbon sequestration and habitat restoration. However, it faces challenges such as diseases, market price fluctuations, and limited infrastructure. This review highlights the importance of integrated management approaches for the sustainable growth of seaweed farming in the Indian Ocean, addressing both ecological and socio-economic challenges and opportunities.

Keywords: Economic Impact, Indian Ocean, Seaweed Farming, Species Diversity, Sustainable Aquaculture

1. INTRODUCTION

Seaweeds, commonly referred to as benthic marine algae, are plant-like organisms that inhabit both marine and freshwater ecosystems. Like higher plants, they contain pigments that enable them to carry out photosynthesis, using sunlight and dissolved nutrients to generate energy and organic matter [12].Unlike terrestrial plants, however, seaweeds do not possess true roots, stems, or leaves. Instead, their body comprises a simple structure called a thallus, which typically includes three parts: the holdfast, stipe, and blade [12; 5].

Seaweeds are broadly categorized into three main groups based on the types of pigments present in their thallus. These include brown algae (Phaeophyceae), green algae (Chlorophyta), and red algae (Rhodophyta) [22]. Seaweeds typically inhabit coastal areas ranging from the intertidal zone, between high and low tides to subtidal regions where light availability is reduced to as little as 0.01% of surface photosynthetic light [12]. Their distribution is influenced by a variety of physical, chemical, and biological factors. Physical factors include water temperature, type of substrate, light intensity and quality, turbidity, wave and tidal action, wind conditions, and depth [44]. Chemical factors involve the presence of dissolved gases such as carbon dioxide and oxygen, salinity, pH levels,

* Corresponding author: ishara4190@gmail.com

availability of nutrients, and the presence of pollutants [10]. Biological factors affecting seaweed distribution include herbivory, disease prevalence, microbial interactions, epiphytic growth, and parasitic organisms [6].

Seaweeds are harvested globally, either from natural habitats or through aquaculture practices. They serve a wide range of purposes, including human consumption, and are also valued as sources of hydrocolloids, such as agar and carrageenan, used in food additives, animal feed, fertilizers, biofuels, cosmetics, and pharmaceuticals [27; 29; 31; 44; 47; 48; 49]. Over the past two decades, rising commercial demand for agar and carrageenan has significantly driven the expansion of seaweed farming worldwide [25]. The primary species cultivated for carrageenan production are *Kappaphycus* and *Eucheuma*, while *Gracilaria* is the main source of agar [27; 29]. In 2018 alone, global seaweed production exceeded three million tons of fresh biomass [21,44;47;48]. Despite estimates suggesting that approximately 48 million km² across 132 countries are suitable for seaweed cultivation, only 37 to 44 countries are currently engaged in active farming, utilizing just 0.001% of this potential area [5; 21]. Seaweed aquaculture is recognized as an environmentally sustainable and economically valuable practice, offering numerous ecosystem services [7; 47; 2]. At present, around 27 seaweed species are commercially farmed worldwide [5].

The Indian Ocean spans from approximately 25°N to 40°S latitude and from 45°E to 115°E longitude [45]. Encompassing an area of about 75 million square kilometers, it accounts for roughly 30% of the total global ocean surface. With an average depth of 3,873 meters, the Indian Ocean is known for its rich marine biodiversity. Its extensive marine resources play a vital role in supporting the economies of many surrounding nations [53].

The objective of this study is to provide a comprehensive and systematic review of seaweed farming in the Indian Ocean region. It focuses on the current state of the industry, highlighting species diversity and production, existing cultivation practices, socio-economic significance, ecosystem services, and potential opportunities for future development. The purpose of examining seaweed farming is to offer a general understanding of its role in biodiversity, cultivation techniques, economic value, environmental impact, and its contribution to sustainable development in selected countries within the region.

2. MATERIALS AND METHODS

2.1 Search Criteria

A literature review was conducted using the Web of Science database, covering publications from 2009 to 2023, based on two central themes: seaweed farming and the Indian Ocean. To enhance the search, the names of 22 countries (members of the Indian Ocean Rim Association as of 2020) were included. Research articles were selected based on the relevant terms in the title, abstract, and author keywords, and only English-language publications were considered. The following search string was used to retrieve relevant literature on September 23, 2023: (seaweed farming AND (Australia OR Bangladesh OR Comoros OR India OR Indonesia OR Iran OR Kenya OR Madagascar OR Malaysia OR Maldives OR Mauritius OR Mozambique OR Oman OR Seychelles OR Singapore OR Somalia OR South Africa OR Sir Lanka OR Tanzania OR Thailand OR United Arab Emirates OR Yemen)). This search yielded a total of 148 articles, which formed the primary dataset for the review. An additional publication was found through other sources. All identified records were exported to Microsoft Excel for further analysis.

2.2 Exclusion and inclusion criteria

The selection of studies was guided by the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analysis) framework to analyze the articles extracted from the Web of Science database. Only studies that focused on the Indian Ocean region, including the coastal zones of its bordering nations, were considered. The inclusion criteria also required that the studies directly address the research objectives of the systematic review. Priority was given to studies that offered full-text availability and covered a broad range of outcomes, such as the chemical properties of seaweeds, pest and disease management, environmental impacts of invasive seaweeds, practical applications, socio-economic factors, and species diversity. At last, 32 articles met these criteria and were selected for inclusion in the review.

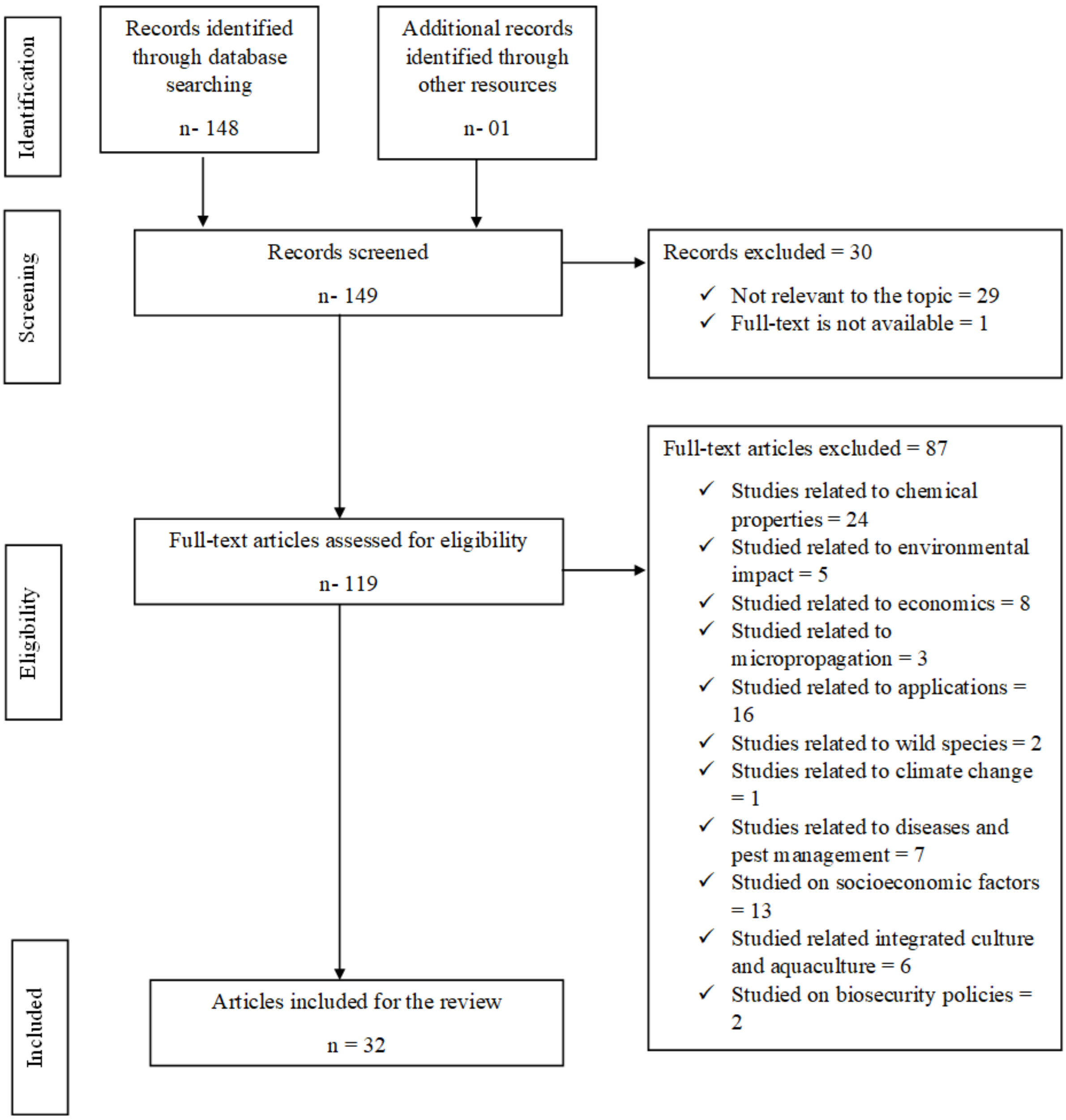

Figure 1. PRISMA flowchart illustrating the study selection process. Adapted from Anjalie, (2023, Unpublished data

2.3 Data selection

The qualitative data extracted from the 32 selected articles included the title, year of publication, country of study, seaweed species, biomass production, seasonal variations, cultivation methods, post-harvest processes, strengths of seaweed farming, challenges faced, environmental impacts, the role of women, and socio-economic implications. The articles were then categorized into groups based on the outcomes of their findings.

3. RESULTS AND DISCUSSION

3.1 Spatial Distribution and Diversity of Seaweed Farming Across the Indian Ocean

Seaweed species in the Indian Ocean can be divided into two main categories based on their usage: commercial species, which are either cultivated or harvested from the wild for economic gain, and experimental species, which are currently under research and development. Analysing the commercial species highlights a landscape influenced by market demand, economic feasibility, and established industry practices. Table 1 displays the diversity of seaweed farming across various countries in the Indian Ocean, while Figure 2 presents a map showing the distribution of seaweed farming in the region based on the reviewed publications.

Seaweed farming in the Indian Ocean has primarily focused on the cultivation of carrageenophytic red algae, particularly *Kappaphycus* and *Eucheuma* species. However, recent research in the region has shifted towards agarophyte species. This change in focus is driven by increased interest in cultivating algae genus such as *Gracilaria* and *Gelidium*, which are valued for their unique properties and diverse potential applications in various industries.

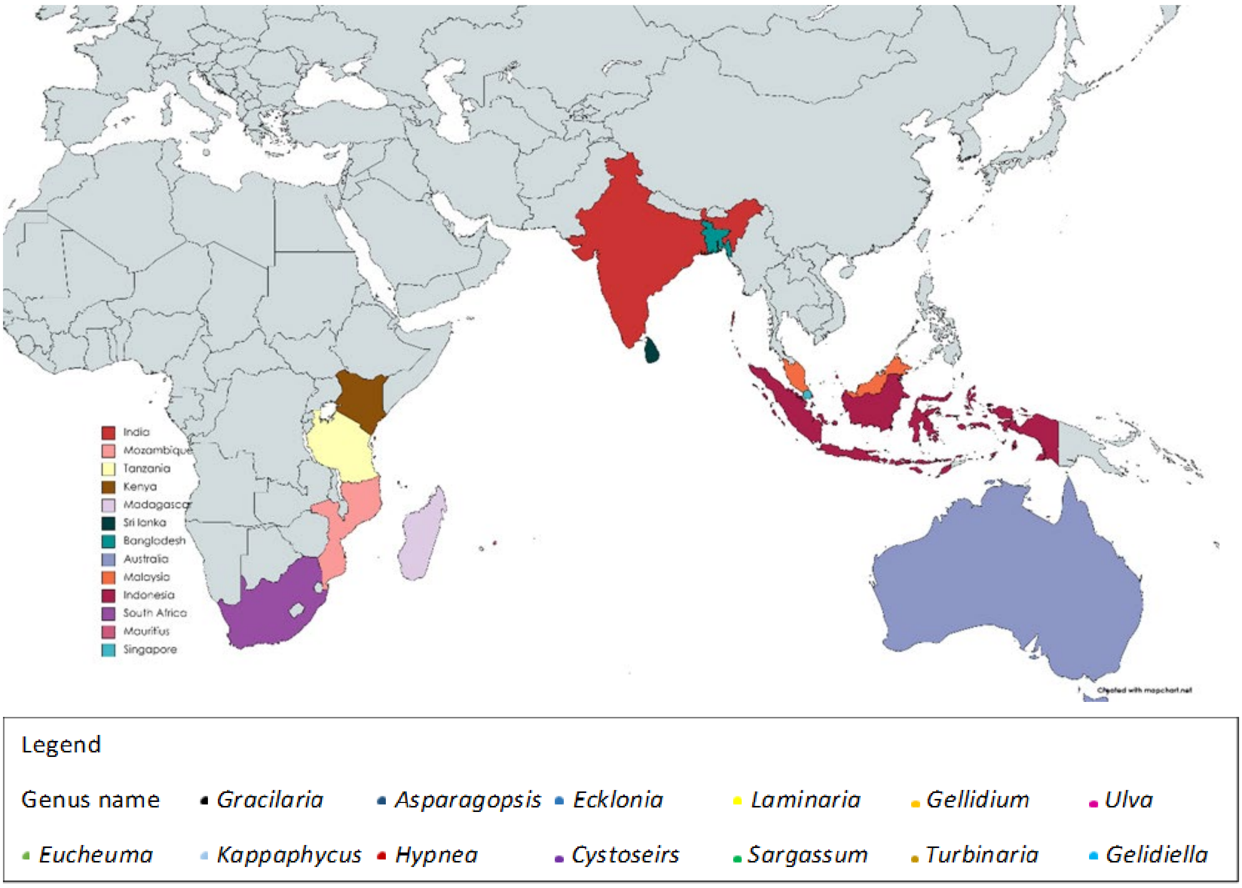

Figure 2. Distribution of Commercial Seaweed Farming Across the Indian Ocean. Adapted from Anjalie (2023, Unpublished data).

Table 1. Diversity of seaweed farming in different countries in the Indian Ocean (both Wild harvesting and farming). Adapted from Anjalie, (2023, Unpublished data).

Country	Commercial species	Source	Experimental species	Source
Australia			*Pterocladia lucida, Gelidium austral, Solieria robusta, Plocamium angustum, Ecklonia radiate, Scytothalia dorycarpa, Cystophora subfarcinata, Sargassum linearifolium*	54
Bangladesh	*Gracilaria tenuistipitata*	5; 44; 48	*Gracilariopsis longissimi*	47
	Ulva intestinalis, Ulva lactuca, Hypnea musciformis	21	*Gellidium* spp., *Enteromorpha* spp., *Halimeda* spp., *Padina* spp., *Dictyota* spp., *Caulerpa racemose*, *K. alvarezii*, *Porphyra* spp., and *Sargassum* spp	5
India	*Gelidiella acerosa*, *Gracilaria edulis*	50	*Gracilaria verrucosa*	16
	Gracilaria salicornia	16	*Gracilaria dura*	50; 51
	Kappaphycus alvarezii	31; 8	*Gracilaria debilis*	52
			Gracilaria verrucosa	41
	Genus *Sargassum*, *Turbinaria*, *Cystoseira*	30	*Hypnea musciformis*	29
			S. cinctum, *S. vulgare* , *S. wghtii*	30
Indonesia	*Kappaphycus alvarezii* (Doty), *Kappaphycus striatum, Eucheuma denticulatum* (*cottonii*), *Gracilaria*, *Gracilariopsis*	20	*Gelidium amansii, Pterocladia*, *Ptilophora*	20
Kenya	*Kappaphycus* sp., *Eucheuma* sp., *Hypnea* sp, *Gracilaria* sp., *Gelidium, Sargassum* sp., *Cystoseirs* sp., *Turbinaria* sp.	36		
Madagascar	*Gelidium madagascariense*, *K. striatus*, *E. denticulatum,* Gracilaria sp. *Ulva* sp.	36		
	K. alvarezii	3; 37		
Malaysia	*Kappaphycus alvarezii*, *E. denticulatum*, *Kappaphycus striatum*	19; 20; 39; 42	*Gelidium amansii*	20
	Gracilaria, *Gracilariopsis*	20	*Gracilaria edulis*, *Gracilaria tenuistipitata* var *liui*	55
Mauritius	*E. denticulatum*, *K. alvarezii*, *K. striatum. Gracilaria Salicornia,*	37	*G. Salicornia*	36
Mozambique	*Eucheuma* sp., *Kappaphycus* sp.	36	*Gracilaria* sp.	36
Singapore			*Hydropuntia edulis*	18
South Africa	*Gracilaria gracilis, Ulva* sp., *Asparagopsis armata, Ecklonia maxima*, *Laminaria pallida, Gelidium pristoides*	36		
Sri Lanka	*K. alvarezii*	46		
Tanzania	*E. denticulatum*, *K. alvarezii*, *K. striatum*	14; 37; 49	*Gracilaria Salicornia, Hypnea musciformis*, *Hypnea pannosa*	37

3.2 Seaweed output

Asia is the dominant region in global seaweed production, accounting for approximately 3.5 billion tons annually [40]. Within the Indian Ocean, Indonesia is the primary producer. After Asia, seaweed production is spread across the Americas, Europe, Africa, and

Oceania. In Africa, where the total production reaches 0.15 million tons, key contributors from the Indian Ocean region include Tanzania, South Africa, and Madagascar. Table 2 presents the seaweed production figures for the leading countries in the Indian Ocean.

Table 2. Seaweed production in different countries in the Indian Ocean [9].

Country	Total production (tons) (wet weight)	Share of world production (%)	Aquaculture contribution (%)
Indonesia	9 962 800	27.81	99.55
Malaysia	188 110	0.53	100.00
Tanzania	106 069	0.30	100.00
South Africa	11 155	0.03	19.32
Madagascar	9 665	0.03	91.72
Australia	1 923	0.01	0.00
Kenya	400	0.00	100
Sri Lanka	247	0.00	100

3.3 The process of seaweed farming

Seaweed farming involves several stages: site preparation, planting, maintenance, harvesting, and post-harvest activities such as drying, cleaning, sorting, and packing. The farming method depends on the location and species cultivated. Seedlings are typically sourced from previous harvests, neighboring farmers, or export companies [36]. The average growth period is 45 days, with seaweeds typically reaching 10 times their original size within 6-8 weeks [27]. The timing of harvesting is determined by the growth rate and peak economic value of the seaweed [47]. Cultivation and collection are primarily carried out by women, although men also participate at various stages [30; 36]. After harvesting, a portion of the seaweed is kept for future planting, while the rest is dried for sale. Drying typically occurs in the open air and sunlight for 2 days, reducing the moisture content to 30-38% [14]. Some seaweed is treated with chemicals like sodium tetraborate or formalin to preserve quality before being packed in sacks and distributed for market sale or value addition [30; 14].

3.4 Seaweed Farming Techniques in the Indian Ocean

Various seaweed farming techniques are used in the Indian Ocean, including the off-bottom method (peg and line) [5; 36], rope/floating-raft culture [36], long-line or mono-line method [29], tube net method [29] polypropylene net method [50], net bag method [50], hanging rope technique [50], and net pouch method [50]. Each method is adapted to different environmental conditions and farming needs, such as wave action and water depth.

3.4 Seaweed farming techniques in different countries

Seaweed farming practices across the Indian Ocean region vary significantly based on local environmental conditions, species cultivated, and levels of technological development.

3.5 Countries adopt both common and trial-based methods to optimize seaweed yield and sustainability

Table 3 summarizes the key cultivation techniques employed in selected countries, distinguishing between commonly used and experimental methods.

Table 3. Seaweed farming techniques in different countries within the Indian Ocean. Adapted from Anjalie, (2023, Unpublished data)

Country	Common methods	Experimental methods
Bangladesh	Off-bottom long-line method Off-bottom net method Floating raft method Line and post method	Floating long-line method Semi-floating single-line method Square net method
India	Floating raft method	Bottom net method Net bag method Net pouch method Nylon rope method(coir) Single rope floating raft method Tube net method Coral stone method Stone method Concrete block method Hanging rode technique Pond culture
Indonesia	Floating line method Fixed off-bottom method Hanging long-line method Single raft long-line method	
Kenya	Off-bottom mono-line method	Floating raft method Broadcasting method Net method
Madagascar	Off-bottom method Long-line system method Tubular net method	
Malaysia	Fixed off-bottom method Hanging long-line method Hanging basket method	
Mauritius		Floating raft method
Mozambique	Off-bottom method	
Sri Lanka	Floating bamboo raft method Off-bottom mono-line method	
Tanzania	Off-bottom method Floating line method Bamboo raft method Net bags method Tubular method	

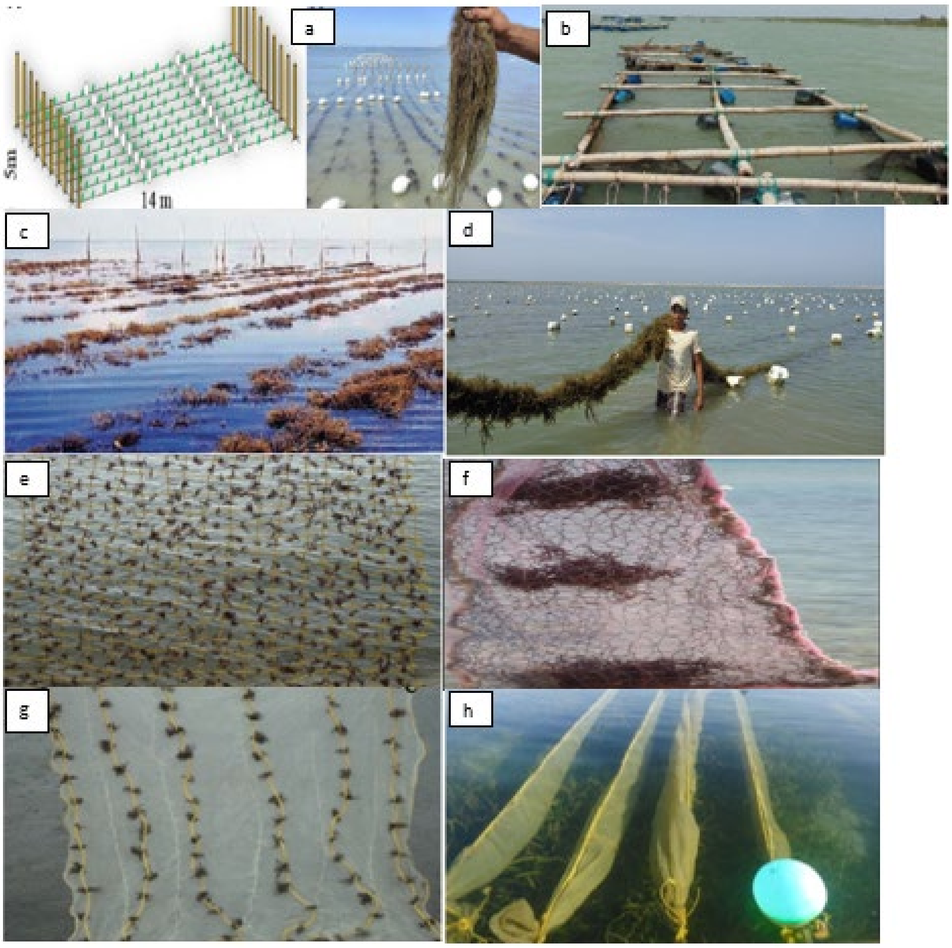

Figure 3. a-Off-bottom method [5], b- Floating bamboo raft culture [47], c- Long-line or mono-line method [29], d- Tube net method [29], e- Polypropylene net method [50], f- Net bag method [50], g- Hanging rope technique [50], h- Net pouch method [50].

3.6 Factors affecting the growth rate of seaweeds

Seaweed distribution and production in the Indian Ocean are influenced by several water quality factors like depth, salinity, nitrate (NO_3^-) levels, sea surface temperature, and current speed [3; 13; 34; 44]. High suspended matter in the water reduces light penetration, limiting photosynthesis [44] and thereby seaweed potential. Salinity plays a key role in growth as, seaweeds normally tolerate as low salinity as 17–22 ppt. But very low salinity can cause death, and high salinity slows growth [32]. Availability of nitrate is important for growth as this nutrient makes up to 5–10% of the tissue content [44].

Depth also affects the growth of seaweeds, with very shallow waters (<2 m) and deep waters (>15 m) being less than ideal [44]. Moderate currents are positive for nutrient uptake, but strong currents can disturb attachment. The best temperature for seaweed growth is 18–27 °C. Outside this range, growth is impaired in countries like Bangladesh [44]. Farming methods affect quality and yield. Floating culture produces cleaner and more colorful *Gracilaria* with higher growth and biomass [5]. Square net culture gives better results than the long-line method for *G. longissima* [47]. Seeding intensity also matters—100 seedlings/m² gives better growth and production than 50 or 150 seeds/m² [47].

Seasonal changes impact growth. The growth of *Gracilaria* exhibits a slowdown in October, increases in November, peaks in December–January, and declines after April [5]. Growth can also be limited by the presence of herbivorous fish, epiphytes, disease, and sedimentation [3].

3.7 Ecological and Socioeconomic Value of Seaweeds

Seaweeds have growing commercial importance across various industries, including human food, animal feed, organic fertilizers, biofuel, cosmetics, and pharmaceuticals [21; 42; 1]. According to Hossain *et al*. (2021), seaweed farming in Bangladesh contributes to eight Sustainable Development Goals by promoting carbon capture, healthy ecosystems, shoreline protection, food and nutrition security, and alternative livelihoods for coastal communities [33]. Seaweed habitats also support marine biodiversity by serving as breeding, nursery, feeding, and shelter grounds.

Commercial seaweed farming offers a wide range of ecosystem services, generally categorized into four types: regulating, supporting, provisioning, and cultural. Regulatory services include nutrient removal, heavy metal uptake, and improving soil quality. Supporting services involve providing habitat, aiding in biogeochemical cycles, and offering nursery grounds. Provisioning services refer to tangible products such as food, fuels, hydrocolloids, and ingredients for cosmetics and medicines [21; 42]. Cultural services include non-material benefits such as tourism, cultural identity, and recreation. Seaweeds also help mitigate climate change by acting as carbon sinks—absorbing over 4 million tons of CO_2 in 2009 alone—and by filtering excess nutrients like phosphate and nitrate, which helps prevent eutrophication [7].

Moreover, seaweed farming is seen as a practical tool for community-based resource management [29; 37]. It plays a vital role in improving the socio-economic status of coastal populations [35; 41; 17; 24]. Thanks to its short production cycle—typically around 45 days—seaweed farming provides a steady income with relatively low risk compared to other aquaculture or land-based farming. It also supports gender equity by involving women in key farming activities like seed tying, harvesting, drying, and sorting. As noted by Mantri *et al*. (2017), earnings from seaweed farming often go toward household needs, including children's education, housing, and family expenses, ultimately contributing to improved community well-being.

3.8 SWOT Analysis for Commercial Seaweed Farming Strengths

Seaweed farming is low-cost and easy to set up, using basic methods with minimal inputs [36]. Labor is readily available in coastal communities, and it offers an extra source of income for fishing families [11]. There's growing demand for seaweed in local markets for use as animal feed and fertilizer. It also provides important ecological benefits [29]. With a short growth cycle of around six weeks and good prices, it's a profitable activity [49].

3.9 Weaknesses

Most seaweed farming still relies on traditional, labor-intensive methods, with limited access to modern technology and expertise. There are no effective treatments for seaweed diseases, and many countries lack clear policies and biosecurity measures [29; 36]. Health risks for farmers include long hours in the sun and heavy lifting, along with poor infrastructure [14]. Predation and storm damage are also concerns [49].

3.11 Opportunities

Seaweed farming offers alternative livelihood opportunities, particularly in coastal regions where employment options are limited. Beyond providing income, it contributes to social security [43], carbon sequestration [7], and environmental benefits such as reducing carbon emissions and improving marine habitats [21, 15]. Moreover, it can empower rural communities, especially women, by creating jobs and enabling participation in seaweed processing and value-added product development [36; 43]. Integrated Multi-Trophic Aquaculture (IMTA), where seaweed is cultivated alongside fish and shellfish, further enhances these benefits by aligning environmental restoration with economic growth [29; 7].

3.12 Threats

Environmental changes, invasive species, and declining nutrients in water can harm seaweed growth [5; 44; 4]. Diseases like ice-ice condition and pests threaten farm productivity, especially in species like *Kappaphycus* [3]. Fast-growing algae (e.g., genus *Ulva* and *Padina*) can attach to farmed seaweeds and reduce yield [16]. Further, the high cost of initial setup and the need for advanced farming technologies pose significant barriers to entry, particularly for small-scale farmers, threatening the long-term growth and inclusivity of commercial seaweed farming [49; 23]. In Zanzibar, declining productivity of high-quality seaweed species has led to fewer women participating in farming, and increased competition for coastal resources has sparked conflicts between small-scale mariculture and traditional users [34].

This review outlines the current status of seaweed farming in the Indian Ocean, emphasizing species diversity, farming practices, ecosystem services, socio-economic impacts, and emerging challenges and opportunities. Commercial farming is largely dominated by genus *Kappaphycus* and *Eucheuma* species, though interest in cultivating wild species like *Gracilaria*, *Hypnea*, and *Gelidium* is increasing due to their economic potential [36]. Indonesia leads global production, followed by Malaysia and Tanzania, while countries like Australia, Kenya, Sri Lanka, and Mozambique show promising but still limited output [27]. Some regions, such as Somalia, offer favourable conditions but remain untapped [36].

Farming methods vary across regions, with intertidal off-bottom cultivation being the most common. This is a very simple and cheap method, but it has its drawbacks, such as overexposure to sunlight [44]. Alternatives like floating rafts, deep-sea farming, and experimental techniques (e.g., hanging rope and concrete block methods) are emerging, showing promise in productivity and sustainability [29]. Ecosystem services such as carbon sequestration, nutrient cycling, and marine biodiversity enhancement are well-recognized [24]. However, environmental concerns, such as habitat disruption, invasive species, and nutrient imbalance, remain challenges, especially in crowded coastal zones [5; 29; 26].

Socio-economically, seaweed farming provides alternative livelihood [38], income diversification, and women empowerment, notably in regions like Zanzibar [14]. Still, barriers such as seaweed diseases, market fluctuations, and regulatory gaps need attention. Opportunities lie in exploring new species like *Gracilaria* dura through carpospore culture [31], and scaling up sustainable propagation methods, including spore culture to avoid degeneration from repeated stock use [55; 41]. Advancements in genomics, bioengineering, and molecular breeding can further enhance yield, disease resistance, and adaptation, although such technologies require institutional and international support for implementation [42].

Throughout this work, the absence of prior reviews on this topic was notable. This systematic effort aims to bridge that gap, despite limitations such as time constraints, selective reporting, and publication bias over the 15-year search period. The review remains a valuable contribution toward understanding the seaweed farming landscape in the Indian Ocean and guiding future research and development efforts.

4. CONCLUSION

This systematic review emphasizes the role of seaweed farming in supporting progress toward multiple Sustainable Development Goals (SDGs) in the Indian Ocean region. Seaweed farming in the Indian Ocean is shaped by pronounced regional differences in species diversity, farming practices, and production scale. Countries such as Indonesia, India, and Tanzania dominate overall output, yet their farming landscapes differ markedly. Eastern regions, including Indonesia and India, cultivate a wide range of species encompassing carrageenophytes, agarophytes, and green seaweeds through varied methods such as fixed off-bottom lines, floating rafts, and integrated systems. In contrast, western regions such as Tanzania and Madagascar focus primarily on carrageenophytes, using low-cost, small-scale techniques that have become vital livelihood sources for coastal communities, particularly women. These differences reflect a complex interplay of ecological conditions, market access, historical development, and government or donor support.

While the sector demonstrates substantial potential for economic growth, climate change-related stressors, seasonal productivity fluctuations, pest and disease outbreaks, and inconsistent quality control remain critical threats. In some areas, weak market infrastructure and limited access to technology constrain farmers' capacity to expand or diversify. Nevertheless, opportunities exist to strengthen resilience through selective breeding, improved farming technology, species diversification, and the integration of seaweed into multi-trophic aquaculture systems. Expanding value-added processing, fostering equitable market participation, and embedding seaweed farming in national blue economy strategies could enhance its role in supporting food security, poverty alleviation, and multiple Sustainable Development Goals. In doing so, seaweed farming can evolve from a primarily subsistence or semi-commercial activity into a robust, climate-resilient industry capable of delivering lasting environmental, social, and economic benefits across the Indian Ocean region.

Acknowledgement

This work was carried out during my research stay at UiT – The Arctic University of Norway. I gratefully acknowledge the support and resources provided by the university, which significantly contributed to the development of this study.

REFERENCES

1. Ali, M.K.M., and Mohd. Noor, N., Seaweed farming in Malaysia: a historical perspective, current status and future prospects. *Aquaculture Reports*, 2021. 20: 100747.
2. Almonte, T.L., Hurtado, A.Q., Naguit, M.R.A., and Critchley, A.T., Exploring appropriate farming practices for Kappaphycus and Eucheuma in Calaguas Islands, Philippines. *Journal of Applied Phycology*, 2012. 24(6): p. 1121–1129.
3. Ateweberhan, M., Rougier, A., and Rakotomahazo, C., Influence of environmental factors and farming technique on growth and health of farmed Kappaphycus alvarezii (cottonii) in south-west Madagascar. *Journal of Applied Phycology*, 2015. 27(4): p. 923–934.
4. Azanza, R.V., and Ask, E.I., Seaweed industry in the Philippines: status, challenges and opportunities. *Journal of Applied Phycology,* 2023. 35(1): p. 97–109.
5. Banik, U., Mohiuddin, M., Wahab, M.A., Rahman, M.M., Nahiduzzaman, M., Sarker, S., Wong, L., and Asaduzzaman, M., Comparative performances of different farming systems and associated influence of ecological factors on Gracilaria sp. seaweed at the south-east coast of the Bay of Bengal, Bangladesh. *Aquaculture*, 2023. 574: p. 739675.
6. Baweja, P., Kumar, S., Sahoo, D., and Levine, I., Biology of seaweeds. In *Seaweed in health and disease prevention* (pp. 41–106). Academic Press, 2016.
7. Bhushan, S., Veeragurunathan, V., Kavale, M.G., Jaiswar, S., and Mantri, V.A., Regulatory ecosystem services through large-scale commercial farming of Kappaphycus alvarezii: Pan-India potential estimates. *Journal of Applied Phycology*, 2023. pp. 1–12.
8. Bindu, M.S., and Levine, I.A., The commercial red seaweed Kappaphycus alvarezii—an overview on farming and environment. *Journal of Applied Phycology,* 2011. 23(6): p. 789–796.
9. Cai, J., Lovatelli, A., Aguilar-Manjarrez, J., Cornish, L., Dabbadie, L., Desrochers, A., Diffey, S., Garrido Gamarro, E., Geehan, J., Hurtado, A., and Lucente, D., Seaweeds and microalgae: an overview for unlocking their potential in global aquaculture development. *FAO Fisheries and Aquaculture Circular*, 2021. 1229.
10. Chapman, A.S., and Chapman, D.J., *Seaweed ecology and physiology*. Cambridge University Press, Cambridge, UK, 1980.
11. Critchley, A.T., Ohno, M., and Largo, D.B., World markets and trade in Kappaphycus and Eucheuma seaweeds: exploiting their

potential value through germplasm improvement and sustainability initiatives. *World Seaweed Resources: An Authoritative Reference System*, 2006. p. 323–335.

12. Dhargalkar, V.K., and Kavlekar, D., *Seaweeds—A Field Manual. 1st Edition*, National Institute of Oceanography, Dona Paula, Goa, 2004.
13. Eggertsen, M., Tano, S.A., Chacin, D.H., Eklöf, J.S., Larsson, J., Berkström, C., Buriyo, A.S., and Halling, C., Different environmental variables predict distribution and cover of the introduced red seaweed Eucheuma denticulatum in two geographical locations. *Biological Invasions,* 2021. 23(3): p. 1049–1067.
14. Fröcklin, S., de la Torre-Castro, M., Lindström, L., Jiddawi, N.S., and Msuya, F.E., Seaweed mariculture as a development project in Zanzibar, East Africa: A price too high to pay?. *Aquaculture*, 2012. 356: p. 30–39.
15. Gam, H.A., Peña, L., Neish, I.C., and Hurtado, A.Q., Seaweed mariculture and climate change: Adaptation and mitigation potential in Asia. *Marine Pollution Bulletin*, 2023. 187(114602).
16. Ganesan, M., Eswaran, K., and Reddy, C.R.K., Farming of agarophytes in India—a long-time sustainability for the industry and preserving wild stocks. *Journal of Applied Phycology*, 2017. 29(5): p. 2239–2248.
17. Hanif, N., and Tesfamichael, D., Seaweed farming in Zanzibar: an ecological and socioeconomic analysis. *Western Indian Ocean Journal of Marine Science,* 2020. 19(2): p. 37–51.
18. Heery, E.C., Lian, K.Y., Loke, L.H., Tan, H.T., and Todd, P.A., Evaluating seaweed farming as an eco-engineering strategy for 'blue' shoreline infrastructure. *Ecological Engineering*, 2020. 152(105857).
19. Hurtado, A.Q., and Critchley, A.T., Cultivation of Kappaphycus and Eucheuma: looking back, looking ahead. *Journal of Applied Phycology*, 2018. 30(1): p. 1–4.
20. Hurtado, A.Q., Gerung, G.S., Yasir, S., and Critchley, A.T., Cultivation of tropical red seaweeds in the BIMP-EAGA region. *Journal of Applied Phycology*, 2014. 26(2): p. 707–718.
21. Hossain, M.S., Sharifuzzaman, S.M., Nobi, M.N., Chowdhury, M.S.N., Sarker, S., Alamgir, M., Uddin, S.A., Chowdhury, S.R., Rahman, M.M., Rahman, M.S., and Sobhan, F., Seaweeds farming for sustainable development goals and blue economy in Bangladesh. *Marine Policy*, 2021. 128(104469).
22. Jayasankar, R., *Classification of algae with special reference to seaweed*, 2022.
23. Kim, J.K., Yarish, C., Hwang, E.K., Park, M., and Kim, Y., Seaweed aquaculture: cultivation technologies, challenges and its ecosystem services. *Algae*, 2017. 32(1): p. 1–13.
24. Krishnan, M., and Narayanakumar, R., Socio-economic impact of seaweed farming in India. *Journal of the Indian Ocean Region*, 2013. 9(1): p. 47–59.
25. Kumar, V., Sahoo, D., and Levine, I., *Seaweed farming: a perspective for food security and sustainable livelihood*. In D. Sahoo and J. Seckbach (Eds.), *The Algae World: Seaweeds and Microalgae,* 2020. p. 415–428.
26. Largo, D.B., Fukami, K., Nishijima, T., and Ohno, M., Occurrence of an ice-ice like disease of the farmed red alga Kappaphycus alvarezii in the Philippines. *Japanese Journal of Phycology*, 1995. 43(2): p. 97–105.
27. Liu, C., Gao, J., Jiang, H., Sun, J., Gao, X., and Mao, X., Value-added utilization technologies for seaweed processing waste in a circular economy: Developing a sustainable modern seaweed industry. *Comprehensive Reviews in Food Science and Food Safety*, 2024. 23(6).
28. Louime, C., Fortune, J., and Gervais, G., The economic impact of seaweed farming on the Caribbean region: are we ready for the emerging industry?. *Journal of Food Distribution Research*, 2006. 37(1): p. 130–134.
29. Mantri, V.A., Eswaran, K., Shanmugam, M., Ganesan, M., Veeragurunathan, V., Thiruppathi, S., Reddy, C.R.K., and Seth, A., An appraisal on commercial farming of Kappaphycus alvarezii in India: success in

diversification of livelihood and prospects. *Journal of Applied Phycology*, 2017. 29(1): p. 335–357.

30. Mantri, V.A., Ganesan, M., Kavale, M.G., and Gajaria, T.K., Status, exploitation and resource management of alginophytes in India: an account and way forward. *Journal of Applied Phycology*, 2020. 32(6): p. 4423–4441.
31. Mantri, V.A., Kavale, M.G., and Kazi, M.A., Seaweed biodiversity of India: reviewing current knowledge to identify gaps, challenges, and opportunities. *Diversity,* 2019. 12(1): p. 13.
32. Msuya, F.E., Effects of rising seawater temperature and salinity on growth and survival of farmed seaweeds Eucheuma denticulatum and Kappaphycus alvarezii in Tanzania. *Tanzania Journal of Natural and Applied Sciences*, 2013. 4(1): p. 590–602.
33. Msuya, F.E., and Hurtado, A.Q., The role of women in seaweed aquaculture in the Western Indian Ocean and South-East Asia. *European Journal of Phycology*, 2017. 52(4): p. 482–494.
34. Msuya, F.E., and Porter, M., Impact of environmental changes on farmed seaweed and farmers: the case of Songo Songo Island, Tanzania. *Journal of Applied Phycology*, 2014. 26(5): p. 2135–2141.
35. Msuya, F.E., and White, M., Resilience and vulnerability of seaweed farmers to climate change in the Western Indian Ocean region. *Marine Policy*, 2022. 140.
36. Msuya, F.E., Bolton, J., Pascal, F., Narrain, K., Nyonje, B., and Cottier-Cook, E.J., Seaweed farming in Africa: current status and future potential**.** *Journal of Applied Phycology*, 2022. 34(2): p. 985–1005.
37. Msuya, F.E., Buriyo, A., Omar, I., Pascal, B., Narrain, K., Ravina, J.J., Mrabu, E., and Wakibia, J.G., Cultivation and utilisation of red seaweeds in the Western Indian Ocean (WIO) Region. *Journal of Applied Phycology*, 2014. 26(3): p. 699–705.
38. Neish, I.C., and Msuya, F.E., Seaweed farming: an alternative livelihood for small-scale fishers?. *ICES Journal of Marine Science*, 2015. 72(3): p. 887–896.
39. Nor, A.M., Gray, T.S., Caldwell, G.S., and Stead, S.M., A value chain analysis of Malaysia's seaweed industry. *Journal of Applied Phycology*, 2020. 32(5): p. 2161–2171.
40. Oliviera, E.C., Qi, Y., and Yarish, C., Seaweed cultivation and marine ranching. *FAO Fisheries Technical Paper*, 2000. 429: p. 1–48.
41. Padhi, S., Swain, P.K., Behura, S.K., Baidya, S., Behera, S.K., and Panigrahy, M.R., Cultivation of Gracilaria verrucosa (Huds) Papenfuss in Chilika Lake for livelihood generation in coastal areas of Orissa State. *Journal of Applied Phycology*, 2011. 23(2): p. 151–155.
42. Phang, S.M., Development of phycology in Malaysia. *Journal of Applied Phycology,* 2018. 30(6): pp. 2967–2979.
43. Rajasuriya, A., and Narayanasamy, R., Seaweed farming: prospects for sustainable livelihoods and blue economy in Sri Lanka. *Aquatic Ecosystem Health & Management,* 2021. 24(3): p. 69–75.
44. Sarker, S., Siddique, M.A.B., Bithi, U.H., Rahman, M.M., Rahman, M.S., and Akter, M., Diseases, metals and bioactive compounds in seaweeds of Bangladesh. *Regional Studies in Marine Science*, 2021. 48.
45. Sengupta, R., and Qasim, S.Z., *The Indian Ocean—An environmental overview*, 1995.
46. Shanmugam, M., Sivaram, K., Rajeev, E., Pahalawattaarachchi, V., Chandraratne, P.N., Asoka, J.M., and Seth, A., Successful establishment of commercial farming of carrageenophyte Kappaphycus alvarezii Doty (Doty) in Sri Lanka: Economics of farming and quality of dry seaweed. *Journal of Applied Phycology*, 2017. 29(6): p. 3015–3027.
47. Sobuj, M.K.A., Rahman, S., and Ali, M.Z., A review on commercially important seaweed resources from the Bangladesh coast. *Food Chemistry Advances*, 2024. 4: p. 100655.
48. Ullah, M.R., Akhter, M., Khan, A.B.S., Yasmin, F., Hasan, M.M., Bosu, A., Haque, M.A., Islam, M.M., Islam, M.A., and

Mahmud, Y., Comparative estimation of nutritionally important chemical constituents of red seaweed, Gracilariopsis longissima, affected by different drying methods. *Journal of Food Quality,* 2023. 2023(1): p. 6623247.

49. Valderrama, D., Cai, J., Hishamunda, N., Ridler, N., Neish, I.C., Hurtado, A.Q., Msuya, F.E., Krishnan, M., Narayanakumar, R., Kronen, M., and Robledo, D., The economics of Kappaphycus seaweed cultivation in developing countries: a comparative analysis of farming systems. *Aquaculture Economics & Management*, 2015. 19(2): p. 251–277.
50. Veeragurunathan, V., Eswaran, K., Malarvizhi, J., and Gobalakrishnan, M., Cultivation of Gracilaria dura in the open sea along the southeast coast of India. *Journal of Applied Phycology*, 2015. 27(6): p. 2353–2365.
51. Veeragurunathan, V., Eswaran, K., Saminathan, K.R., Mantri, V.A., Ajay, G., and Jha, B., Feasibility of Gracilaria dura cultivation in the open sea on the Southeastern coast of India. *Aquaculture*, 2015. 438: p. 68–74.
52. Veeragurunathan, V., Prasad, K., Malar Vizhi, J., Singh, N., Meena, R., and Mantri, V.A., Gracilaria debilis cultivation, agar characterization and economics: bringing new species in the ambit of commercial farming in India. *Journal of Applied Phycology*, 2019. 31(4): p. 2609–2621.
53. Wafar, M., Venkataraman, K., Ingole, B., Ajmal Khan, S., and LokaBharathi, P., State of knowledge of coastal and marine biodiversity of Indian Ocean countries. *PLoS One*, 2011. 6(1): p. e14613.
54. Wiltshire, K.H., and Tanner, J.E., Comparing maximum entropy modelling methods to inform aquaculture site selection for novel seaweed species. *Ecological Modelling*, 2020. 429: p. 109071.
55. Yu, C.H., Lim, P.E., and Phang, S.M., Effects of irradiance and salinity on the growth of carpospore-derived tetrasporophytes of Gracilaria edulis and Gracilaria tenuistipitata var. liui (Rhodophyta). *Journal of Applied Phycology,* 2013. 25(3): p. 787–794.