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662

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Understanding diseases and control in seaweed farming in Zanzibar

***Cover photographs*:**
Seaweed farmers in Zanzibar, Tanzania (©A. Menezes).

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662

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Preparation of this document

In view of all the production and productivity problems the aquaculture sector has been facing, during the final validation and handover meeting of the Food and Agriculture Organization of the United Nations (FAO) Technical Cooperation Programme "Support to the Aquaculture Subsector of Zanzibar" (TCP/URT/3401), seaweed stakeholders in Zanzibar recommended biological and economic research on seaweed as a relevant pillar of the Aquaculture Development Strategy Plan. The severe cases of seaweed die-off in the Zanzibar archipelago led to the formulation of a small emergency research project.

This document was prepared within the framework of the FAO-funded Technical Cooperation Programme "Support to Seaweed Diseases and Die-off Understanding and Eradication in Zanzibar" (TCP/URT/3601/C1). Moreover, as part of its continued efforts to reduce food insecurity, improve the livelihoods, economic growth and balance of trade in developing countries, recognizing the importance of seaweed farming in Zanzibar, which provides a steady income to seaweed farmers, 90 percent of whom are women, and support the International Year of Plant Health 2020, the Fisheries and Aquaculture Division supported the review and publication of this technical report.

The assessment is mainly based on site visits to seaweed farms in Unguja and Pemba Islands and laboratory analysis of collected seaweed samples conducted by the authors between February and June 2017. The findings were cross-checked with literature on the topic and presented during the stakeholders' meetings on both islands.

Abstract

Since 2011, seaweed farmers and traders have experienced serious decreased production and income. This study identifies some causes of the seaweed die-off of *Eucheuma denticulatum* (commonly known as spinosum) and *Kappaphycus striatum* and *K. alvarezii* (both commonly known as cottonii) observed in the farming areas of Unguja and Pemba (Zanzibar archipelago). It also makes short- and long-term recommendations to protect the farming ecosystem environment, control (prevention and mitigation) of *ice-ice* disease and epiphyte infestation, and boost the seaweed industry in the island.

Die-offs are mainly caused by a severe case of epiphyte infestation coupled with a high incidence of *ice-ice* disease, which has long been observed by farmers to intensify during the hot-dry season and diminish during the wet season. High temperature in the farming sites (29.5–35.5 °C) is determined as one of the main triggers of the *ice-ice* occurrence as well as the bloom of epiphyte infestation. Another factor is high light intensity/irradiance. As seaweed farming in Zanzibar is mainly done in shallow intertidal lagoons, seaweeds are almost in direct contact with the bottom substrate during low tides and hence exposed to higher levels of temperature and light intensity. This combination predisposes seaweed to opportunistic pathogens, manifesting the thalli whitening popularly called *ice-ice* disease. Bacterial infection leads to softening of the thalli and to their eventual fragmentation.

These infestations and diseases are a continuing threat to the commercially farmed eucheumoids and makes seaweed production in Zanzibar to be highly season dependent from what used to be a continuous year-round of plant-harvest-plant cycle done every 30–45 days, providing a steady income to seaweed farmers who are 90 percent women. The study recommends short-term measures and long-term strategies that include: (i) implementing strict quarantine procedures; (ii) transferring the farming of *E. denticulatum* and *K. striatum* to deeper waters (2–5 m) using longlines or raft method where practical; (iii) using a "freshwater shock" or a commercially available anti-fouling agent to eliminate epiphytes if lagoon farming is continued during the hot-dry season; (iv) promoting the farming of a variety of *E. denticulatum* called *million-million*; (v) improving the genetic stock with alternative local strains; (vi) promoting income-generating activities for farmers, such as value addition using harvested seaweed; (vii) developing multitrophic sustainable aquaculture by integrating seaweed aquaculture with other high-value species; and (viii) creating livelihood opportunities other than farming by exploring the potential of harvesting/farming other seaweeds with other uses that are abundant in Zanzibar.

Contents

TABLES

FIGURES

ANNEXES

Acknowledgements

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Thanks are given to all the seaweed farmers in Unguja and Pemba, namely, the members of the Zanzibar Seaweed Cluster Initiative farmers in Unguja (Kidoti, Paje, Matemwe, Kiwengwa and Bweleo (entrepreneur farmers), and the farmers in Pemba (Fundo, Makangale, Chokocho, Tumbe and Mjini Kiuyu), who were gracious, welcomed us into their villages and provided us with crucial information.

A word of appreciation also goes to the staff and management of the Institute of Marine Sciences, University of Dar es Salaam, for the use of its facilities and assistance in the laboratory with the seaweed sample analyses, especially Idd Khamis Ramadhan and Mtumwa Mwadini. Thanks are also due to the staff of the Ministry of Agriculture, Natural Resources, Livestock and Fisheries in Unguja (Buriyan Mussa Hassan and Hamisuu Yusuf Marzouk) and Pemba (Hidaya Khamis Hamad and Juma Khamis Jaffar).

Executive summary

Since 2011, the die-offs of *Eucheuma denticulatum (*commonly known as *spinosum)* and *Kappaphycus striatum* and *K. alvarezii* (both commonly known as *cottonii*) in the farming areas of Unguja and Pemba, the two largest islands of the Zanzibar archipelago, have caused production to decline. Die-offs are mainly caused by a severe case of epiphyte infestation coupled with a high incidence of *ice-ice* disease, which has long been observed by farmers to intensify during the hot-dry season and diminish during the wet season. This, in effect, makes seaweed production in Zanzibar highly season-dependent, as opposed to the former continuous year-round plant harvest. Production-harvest cycles are realized every 30–45 days, providing a steady income to seaweed farmers, 90 percent of whom are women.

Based on microscopic examinations, the epiphyte has been identified as a species of the filamentous red alga *Polysiphonia-Neosiphonia* complex (Family Rhodomelaceae, Order Ceramiales). During the hot-dry season, this epiphyte attains an average density on *E. denticulatum* of 20 individuals per cm (range of 0–85) in Unguja farms and 7 individuals per cm (range of 0–40) in Pemba farms. On the other hand, epiphytes on *K. striatum* reached an average of 57 individuals per cm (range of 0–78) in Paje. In the recent past, the seaweed was commercially farmed in Pemba, where epiphyte density was observed at an average of 1.4 individuals per cm (range of 0–18). The effect of *Polysiphonia-Neosiphonia* is exacerbated by the occurrence of other epiphytic filamentous algae, notably the brown alga *Ectocarpus* sp. and the cyanobacterium *Oscillatoria* sp., which were found to be quite prolific in farms in Matemwe and Bweleo, respectively. These epiphytes are a continuing threat to the commercially farmed eucheumoids, identified as having low genetic variability, even when they were first introduced to Zanzibar from the Philippines in the early 1980s.

Ice-ice disease, on the other hand, is caused by extreme, prolonged conditions of elevated water temperature of up to 35 °C, coupled with high light intensity; this destructive combination especially is true for farmed eucheumoids that, although tied to monolines, are directly touching the ground during low tides. The exposure to extreme conditions of water temperature and light intensity was observed to extend the entire day during spring tides. Unique to Zanzibar, this method of farming is in contrast to the traditional "off-bottom monoline culture method" done in the Philippines, where the eucheumoids are at least 0.5 m above the ground. Aside from facilitating uptake of nutrients from the water column, off-the-bottom hanging of seaweeds is also meant to avoid herbivore grazings and infection caused by disease-causing organisms dwelling on the ground. Bare white sand that reflects more light into the farmed algae exacerbates stress on crops already exposed to extreme levels of water temperature – a perfect combination that predisposes them to opportunistic pathogens, manifesting the thalli whitening popularly called "*ice-ice*" disease. Bacterial infection leads to softening of the thalli and to their eventual fragmentation, although crop loss is not an issue as fragments can still be easily recovered as long as they remain in the lagoon.

To prevent more die-offs in the future, the following short- and long-term mitigation measures are recommended. Short-term solutions are: (i) implement a strict quarantine procedure on introduced seaweeds to Zanzibar; (ii) move the farming of *E. denticulatum* and *K. striatum* to deeper waters (2–5 m) using longlines or raft method, especially during hot-dry periods; (iii) inform farmers of the use of a "freshwater shock" or of a commercially available anti-fouling agent such as AMPEP to eliminate epiphytes if lagoon farming is continued during the hot-dry season; and (iv) promote the farming of a variety of *E. denticulatum* called *million-million* recently introduced to Jambiani, which demonstrates resistance to epiphytes when grown above seagrass beds; this appears to occur as a "shadow effect" of seagrasses to seaweeds due to high direct solar radiation.

The long-term solution to die-offs of seaweeds that have been already compromised by epiphytes and *ice-ice* diseases is to find alternative local strains that will have a wider and stronger genetic base (being able to reproduce sexually), with desirable carrageenan quality, and that are more resistant to diseases, epiphytes and other pests. These can then be mass propagated through micropropagules and tissue culture. Eventually, the local strains will replace the clonally propagated strains of *Eucheuma* and *Kappaphycus*, introduced from the Philippines.

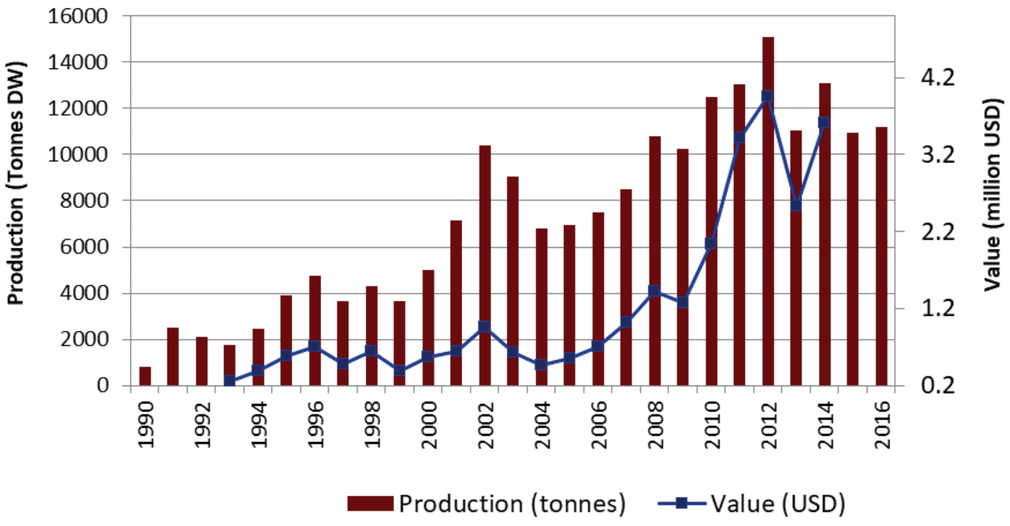
In addition, to mitigate die-offs caused by epiphytes and *ice-ice* disease, the following actions are recommended during the "off-season" of *Eucheuma* and *Kappaphycus* farming: (i) promote income-generating activities for farmers, such as value addition using nature harvested seaweed (e.g. household cleaning and hygienic products, as already initiated by the Seaweed Cluster Initiative in Zanzibar); (ii) develop multitrophic sustainable aquaculture by integrating seaweed aquaculture with other high-value species (e.g. sea cucumber and milkfish) to increase farm productivity and higher incomes for farmers; and (iii) create livelihood opportunities other than farming by exploring the potentials of harvesting other seaweeds with other uses that are abundant in Zanzibar. Note that the brown seaweed *Sargassum* grows on rocky areas and is washed ashore during peak season. Also, in addition to its use as direct human food, the agar-producing *Gracilaria* was recently found, after analysis, to possess agar quality (based on viscosity and gel strength) that is sufficient for other applications.

Finally, on the issue of health and safety, it is important that farmers are warned of the dangers of certain marine organisms (such as hydroids, sponges, corals and jellyfishes) that release microscopic "stinging cells" or "fire cells" (nematocysts) into the water, and certain cyanobacteria (such as *Lyngbya*) that, upon contact, cause skin itchiness that could lead to serious cases of skin infection during the hot season.

1. Background and history of seaweed farming in Zanzibar

Seaweed production in the United Republic of Tanzania started back in 1989 with three main cultivated species, *Kappaphycus striatum, K. alvarezii* and *Eucheuma denticulatum*; the sector currently employs 23 654 seaweed farmers, of which 13 393 (90 percent) are women. Both *K. alvarezii* and *K. striatum* are commercially known as "*cottonii*", while *E. denticulatum* is known as "*spinosum*". According to the Department of Fisheries and Marine Resources database (2012), 63 percent of farmers are in Pemba and 37 percent in Unguja, the two largest islands in the Zanzibar archipelago. Production capacity of dry seaweed reached its peak at 15 000 tonnes in 2012 (Department of Fisheries and Marine Resources, 2016), but in 2014 it fell to 13 000 tonnes, worth USD 3.9 million. In 2016, it further reduced to 11 000 tonnes (Figure 1). The fluctuation in production is likely due to the fact that the market is controlled by multinational companies abroad and, to some extent, the occurrence of *ice-ice* disease and epiphyte infestation. Most affected are the farming areas of Unguja Island, which produces 25 percent of total *cottonii* and *spinosum* seaweeds in Zanzibar.

FIGURE 1
Seaweed production in Zanzibar, 1990–2016



Source: Department of Marine Resources, Zanzibar.
Note: DW = dry weight.

Seaweed farming in Tanzania was more or less inspired by the success of the seaweed industry in the Philippines, whose origin can be traced back to the late 1960s when the red alga *Chondrus crispus*, then the original main source of carrageenan, became overharvested and alternative sources had to be identified. Commissioned by the largest carrageenan company Marine Colloids Corporation (United States of America), Maxwell Doty, professor at the University of Hawaii, came to the Philippines, subsequently identified *Eucheuma* as a source of high-quality carrageenan, and promoted it for farming. Later, Doty's student Keto Mshigeni, attempting to elevate the economic status of his native Tanzania, introduced *Eucheuma* farming into his country. Ultimately, Mshigeni's action became a success story in itself, empowering 90 percent of women who engaged in seaweed farming to earn a higher income than their husbands.

Eucheuma farming using clonal propagation through the monoline method has never changed over the years. Not only is it a very simple method to follow, but it is also cost-efficient, involving only the attachment of seaweed fragments to nylon lines, connected at opposite ends to wooden stakes, which are usually made of mangrove wood or other materials. Although it was the most effective method of mass producing the seaweeds over several decades, the vegetative clonal propagation of *Kappaphycus* and *Eucheuma* may have allowed the deterioration in the growth rate of *Kappaphycus* in the Philippines due to a lack of genetic variability (Hurtado *et al*., 2014), hence the weakness of the plants to changes in environmental factors. Professor Mshigeni fell into the same error by bringing the same clonal stock to Tanzania from Bohol, the Philippines, although the seaweeds failed to grow in the initial attempt. Finally, the planting material brought to Tanzania by the staff of CP Kelco Philippines successfully propagated the seaweeds in Zanzibar, then to the rest of Tanzania (Tirso Lirasan of CP Kelco Philippines, currently acquired by Marcel Trading Corporation, personal communication) and to other African countries, such as Madagascar, Mozambique and Kenya. Until today, these three species remain the only cultivated seaweeds in Zanzibar, adapting the same monoline technique of farming.

Upon the request of the Zanzibar Government, the Food and Agriculture Organization of the United Nations in Tanzania (FAO-TZ) has engaged the services of the authors to look into the problem of die-offs caused by *ice-ice* disease and epiphyte infestation experienced in the seaweed farms of Zanzibar, especially in *Kappaphycus* spp., which have seen a persistent decline in production since 2011 (Msuya *et al*., 2014; FAO, 2014). This gloomy trend threatening the future of the seaweed farming industry in Zanzibar and the rest of Tanzania makes any available solution a welcome development in a region whose income from seaweed production is second to tourism and clove production.

2. Farming areas and species of cultivated seaweeds in Zanzibar

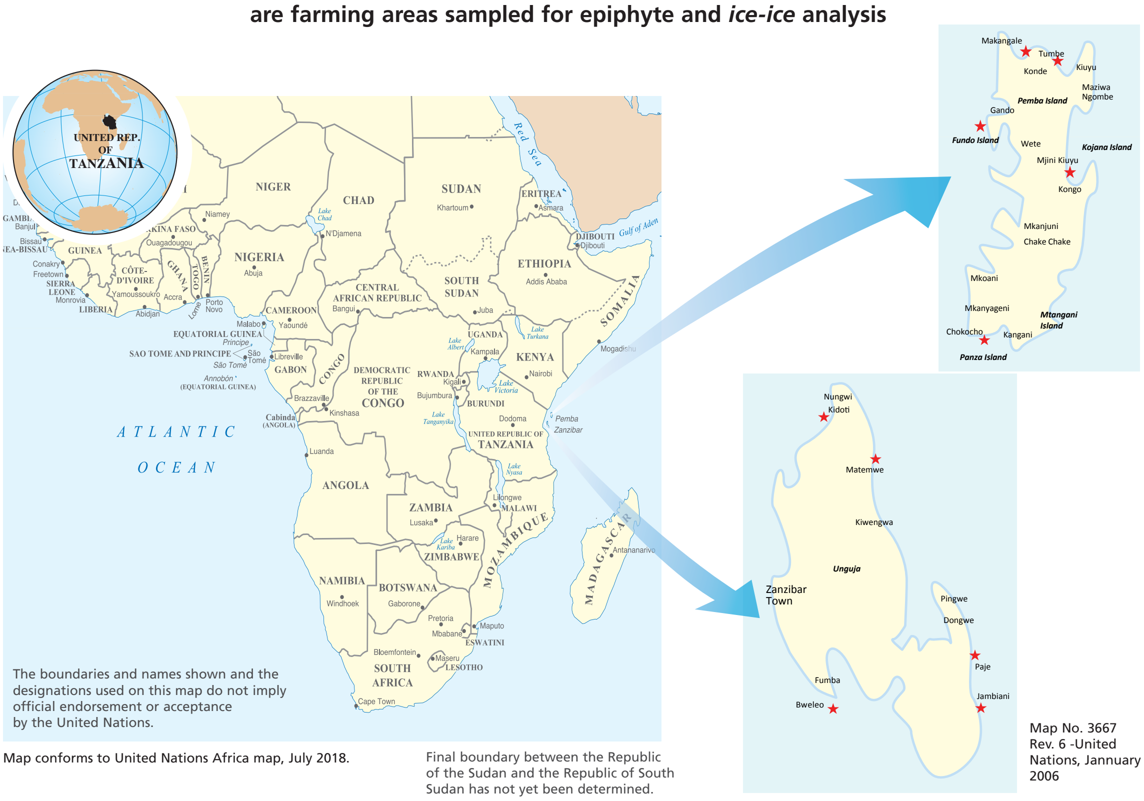
Zanzibar is composed of two main islands – Zanzibar (or Unguja) Island and Pemba Island (Figure 2). In addition to mainland Tanzania, which produced 800 tonnes of seaweed in 2017, Zanzibar is a major seaweed production area and is the third-largest carrageenan-seaweed producing area in the world, next only to Indonesia and the Philippines. There are three main species of seaweeds being cultivated in the whole of Zanzibar: *Kappaphycus striatum*, *K. alvarezii* (both are commonly known as *cottonii*) and *Eucheuma denticulatum* (known as *spinosum*). These last two species were originally brought from Bohol, the Philippines, in the 2000s, after local strains used in seaweed farming failed (Tirso Lirasan, CP Kelco Philippines, personal communication). Today, of the three species that began cultivation in the late 1980s, only *K. striatum* (the "sacol variety" brought from the Philippines) and *E. denticulatum* remain as the major seaweeds being farmed in Zanzibar.

Some of the cultivation areas in Zanzibar/Unguja are in Paje, Jambiani, Kidoti, Matemwe and Bweleo, which have experienced the worst seaweed die-offs in recent years, while in Pemba, the main cultivation sites are in Fundo, Makangale, Chokocho, Tumbe and Mjini Kiuyu (Figure 2).

Seaweed farming in Zanzibar is mainly done in shallow waters that, during low tides, form lagoons of just a few centimetres deep and enable women to be engaged in the farming. Parts of some farms extend near the deeper areas, but are not more than waist deep at low spring tide.

FIGURE 2

Map of Africa showing Zanzibar and its two main islands – Unguja (Zanzibar) and Pemba. Red stars are farming areas sampled for epiphyte and *ice-ice* analysis



Map conforms to United Nations Africa map, July 2018.

Final boundary between the Republic of the Sudan and the Republic of South Sudan has not yet been determined.

3. Assessment methodology

FIELD

Farming sites of *Eucheuma* and *Kappaphycus* in Unguja and Pemba Islands were sampled during the hot-dry (February–March 2017) and wet (April–June 2017) seasons (Table 1). The sampled seaweeds, although farmed in the same sites (vast farming areas), were not cultivated on the same line or next to each other. Two sets of samples were collected in each season in Unguja and one set in each season in Pemba (Table 1). The last two sampling periods (31 March–9 April and 28 May–1 June) were just at the onset of the northeast monsoon season. All collected samples were preserved in 5–10 percent formalin/seawater solution, while some were simply air-dried prior to microscopic examination; samples collected in March–April were directly analysed as wet material. Up to 30 samples of *E. denticulatum* were collected at random in each farm from ten different sites, for a total of 300 samples for the entire farming sites of Zanzibar. In sites where *cottonii* (mostly *K. striatum*) was also farmed, such as Paje in Unguja and Fundo, Chokocho and Makangale in Pemba, only 10 samples were obtained per site.

TABLE 1
Field sampling in the farming sites of Unguja and Pemba Islands representing hot-dry and wet seasons, 2017

	Seaweed farming sites	Sampling dates (2017)	Tidal height during sampling (metres)	Weather condition
Unguja	Paje, Bweleo, Kidoti, Matemwe and Kiwengwa	10 February – 15 February	0.08 – 0.42	Hot-dry season
		27 February – 10 March	0.03 – 1.4	Hot-dry season
		31 March – 9 April	0.08 – 1.37	Wet season
		28 May – 1 June	0.09 – 0.89	Wet season
Pemba	Makangale, Fundo, Chokocho, Mjini Kiuyu, and Tumbe	28 February – 4 March	0.03 – 1.4	Hot-dry season
		28 May – 1 June	0.09 – 0.89	Wet season

The farming sites were selected based on local authorities and farmers' report of severe cases of *ice-ice* and epiphytism experienced by farmers. Water temperature and salinity were measured using an alcohol-filled thermometer and an Atago handheld refractometer, respectively, except in February–March when such instruments were not yet available. Measurements were made across a gradient from the landward edge of the seaweed farm to the edge of the farm where the water level is about knee-deep at low tide. The substrate type (whether pure sand, sandy-muddy or muddy), the colour of the cultivars and the exposure of the cultivars to air or submergence in residual water in lagoons were noted and photo documented, as well as some flora and fauna that were attached to the farmed eucheumoids.

Group interviews with seaweed farmers

During the March–April visit in Kidoti and Paje in Unguja, the team arranged a group interview with the seaweed farmers in the area (all of them women) to discuss issues and problems they were experiencing with their farmed seaweeds. (Note: these were the same groups that were visited in February 2017, hence sampling was consistent.) Each group was facilitated by a leader, together with government fisheries officers who were available at the time of the visit. Aside from farming, the groups in Kidoti and

Paje, who are also engaged in value addition of their seaweeds such as soap-making, are members of the Zanzibar Seaweed Cluster Initiative. At these meetings, the farmers shared with the authors first-hand experiences on the seasonal occurrence of *ice-ice* disease and epiphyte infestation.

LABORATORY

Samples of seaweeds from the farms were brought to the laboratory at the Institute of Marine Science of the University of Dar es Salaam in Zanzibar for microscopic analysis. Epiphytes were directly observed under a stereo-microscope (Meiji Techno Co., Inc., Tokyo, Japan) from mostly unsectioned samples; otherwise, thin sections from the surface tissue of the host seaweed underwent higher power observations of the epiphytes under a light microscope (Olympus CH 2, Olympus Optical Co., Ltd., Japan). All photographs of specimens were made using a Canon SLR camera.

The degree of epiphyte infestation based on *Polysiphonia-Neosiphonia* density counts in all areas in Unguja and Pemba were compared between sampling dates, coinciding with periods of hot-dry (December–February) and rainy months (March–May). Where other epiphytes were present and appeared dominant in certain cultivars, these were also counted and photo documented. Based on the samples of *E. denticulatum* and *K. striatum* obtained from the ten sites in Unguja and Pemba, 1-cm pieces were randomly cut into transverse sections and, using a manual counter, the number of epiphytic filamentous algae (EFA) per cm of thallus was counted at their point of attachment on both sides of the thallus under x40 magnification. The average density per site was computed by dividing the total number of epiphytes per site by 30 (for *E. denticulatum*) or by 10 (for *K. striatum*). Similarly, the percentage of *ice-ic*e occurrence was estimated from the same number of samples for *E. denticulatum* and *K. striatum*.

4. Results and discussion

4.1 NATURE OF EPIPHYTES AFFECTING THE FARMED *EUCHEUMA* AND *KAPPAPHYCUS* IN ZANZIBAR

The epiphyte mostly observed in all samples examined from Unguja and Pemba farms was a small filamentous red alga resembling *Polysiphonia-Neosiphonia* complex (Figure 3A, B, C, D, E; Figure 5A, B, C, D, E, F) belonging to the Family Rhodomelaceae, Order Ceramiales, Division Rhodophyta. This EFA has been previously reported by several authors as seriously affecting production in the seaweed farms in Asia (Hurtado *et al*., 2006; Vairappan, 2008 *et al*.; Pang *et al*., 2011). For lack of more detailed taxonomic analysis of this species in this current study, the name "*Polysiphonia-Neosiphonia* complex" is temporarily assigned based mainly on the alga's diagnostic characters to the genus level, such as "having a corticated axial filament which cut off at least four pericentral cells producing indeterminate branches" (Kim and Lee, 1999, and its cited literature). While Largo (2002) and Hurtado *et al*. (2006) used the name *Polysiphonia* in their papers, Charles Vairappan of Malaysia has identified these epiphytes, including those from Tanzania, as *Neosiphonia savatieri* (Vairappan *et al*., 2008). A recent study of this alga using a molecular tool reassigned this species as a synonym of *Melanothamnus savatieri* (Hariot) Díaz-Tapia and Maggs (Díaz-Tapia *et al*., 2017). Not only is this EFA destroying the eucheumoid seaweeds farmed in Zanzibar, but at least two other EFA species have been identified on the sites: the brown filamentous alga *Ectocarpus* sp. (Figure 3G, H) and cyanobacterium *Oscillatoria* sp. (Figure 3I, J, K). While the first two EFAs make the host seaweed appear hairy, especially when submerged (Figure 3I, J, K), *Oscillatoria* makes the seaweed surface appear black, possessing tumour-like clumps (Figure 3I, earlier mistaken in the field as sea squirts).

Of the three epiphyte species mentioned, historically, only the *Polysiphonia-Neosiphonia* has generated so much attention since its first documentation in the seaweed farms of Calaguas Islands (the Philippines) in 2001, causing abandonment of farms (Largo, 2002). It is highly possible that the epiphytes on the seaweed strains introduced to Zanzibar may have also come from their country of origin since no quarantine procedures seem to exist yet in Zanzibar, unlike those implemented in the Pacific Islands of Fiji, as described by Sulu et al. (2004). While this epiphyte remains the most persistent, being present in the majority of the cultivars in all sites in Zanzibar (Table 2), the presence of *Ectocarpus* in a few cultivars in Matemwe and *Oscillatoria* in both Matemwe and Paje is a signal for their potential to become major pests given certain, although still unknown, growing conditions. It is possible that these two species were present in all other areas, but settling this question would have required more extensive assessments.

Aside from these epiphytes already mentioned, there were also other species recorded, including the common filamentous cyanobacterium *Lyngbya majuscula* that is loosely attached to cultivars in Paje and Kidoti (Figure 6E), some macro-epiphytes, namely, the green algae *Cladophora* sp. (Figure 3K), *Chaetomorpha crassa*, *Ulva* (=*Enteromorpha*) *clathrata* (Figure 4A, B), foliose *Ulva* spp., and the red algae *Gracilaria edulis* (Figure 5E) and *Acanthophora spicifera* that were loosely attached. Epibionts, including sponges (Figure 5B), shelled molluscs (Figure 5D), sea anemones (Figure 5D) and the hydroid *Hydrallmania* (Figure 4D), were also noted, many on wooden pegs of monolines but also attached to seaweeds. These are common fouling organisms, especially on older seaweeds that were left unattended. The women farmers complained of itchiness on their skin during epiphyte season, which may have been caused by the presence of *Lyngbya majuscula* and nematocyst-bearing hydroids and other animals such as corals and jellyfishes.

FIGURE 3

Epiphyte-infested cultivars of *E. denticulatum* in Zanzibar seaweed farms. A, Hairy appearance of *E. denticulatum* infested with *Polysiphonia-Neosiphonia* epiphyte. B, A tip of *E. denticulatum* attached with a bunch of epiphytes penetrating its surface forming craterlike holes (arrows). C, Mid-branch of *E. denticulatum* showing the same epiphytes in bushy appearance. D, Closer view of *Polysiphonia-Neosiphonia* filaments showing tetrasporangia (arrows). E, *Polysiphonia-Neosiphonia* filaments showing "fruits" (cystocarps) (arrows) from which new individuals are produced. F, *E. denticulatum* with load of silt trapped by the epiphytes. G, *E. denticulatum* with *Ectocarpus* appearing like a "pompom". H, Close-up of *Ectocarpus* filaments showing a reproductive organ (plurilocular sporangium) (arrow, inset). I, *E. denticulatum* with filamentous cyanobacterium *Oscillatoria* appearing like tumours. J, A mid-close-up view *Oscillatoria* on *E. denticulatum* surface. K, A more magnified view of *Oscillatoria* with a mix of *Cladophora* filaments (black arrow) and *Polysiphonia* (red arrows). Scale bars = 1 cm; micrographs (D, E, I) are magnified x80

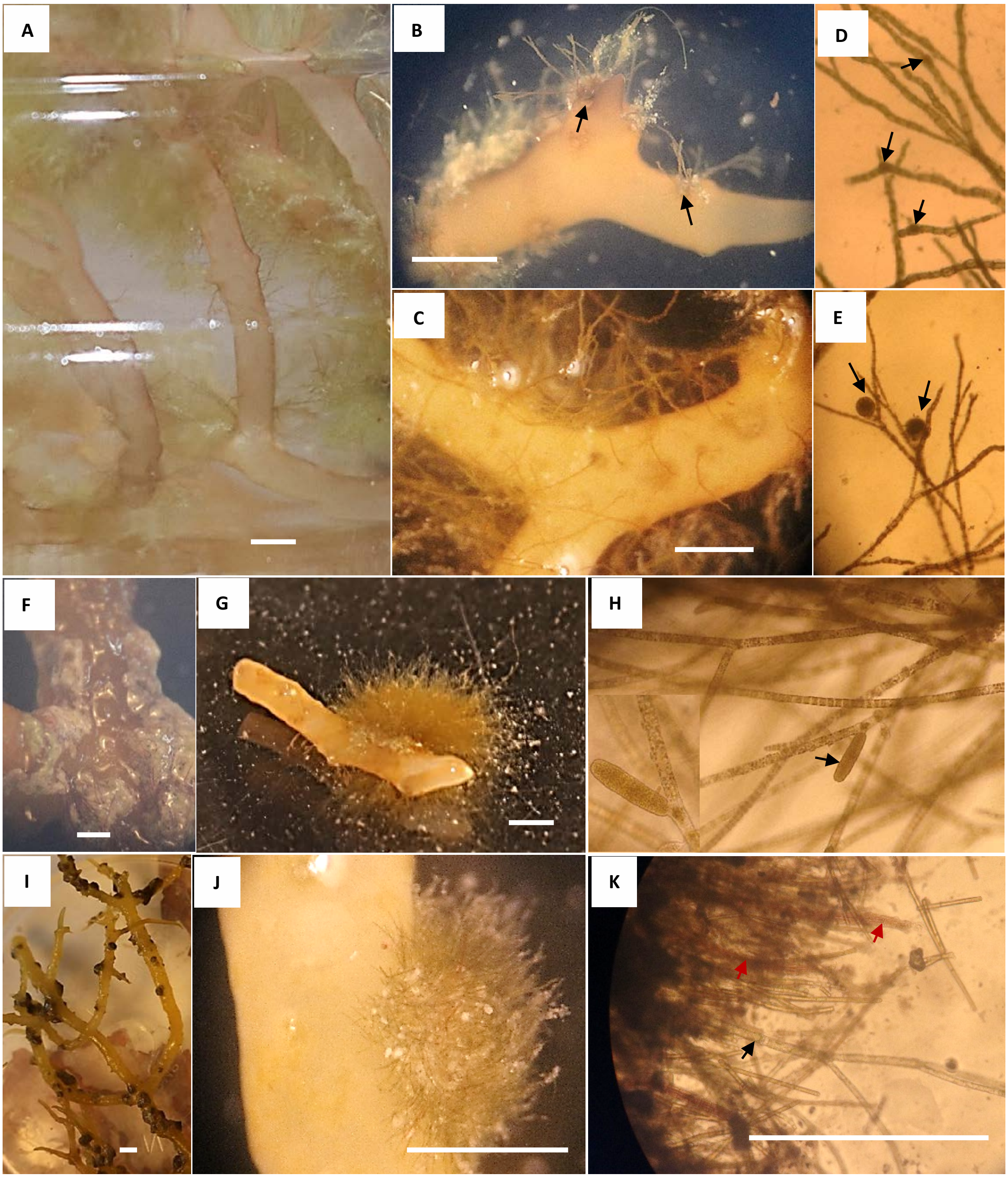


TABLE 2
List of epiphytes and fouling organisms observed on the farmed seaweeds in Unguja in late March to early April during the hot-dry season in Zanzibar

Epiphyte	Mode of association	Unguja Island				
		Paje	Jambiani	Kidoti	Matemwe	Bweleo
A. Small filamentous algae						
1. *Poly-Neosiphonia* complex	Penetrates the cortex	xxx	xxx	x	xxx	
2. *Ectocarpus* sp.	Superficially attached on surface				xx	
3. *Oscillatoria* sp.	Superficially attached on surface	xx			x	
4. *Lyngbya majuscula*	Loosely entangled	x				x
B. Larger macroalgae						
5. *Chaetomorpha crassa*	Loosely entangled		x			x
6. *Ulva (=Enteromorpha) clathrata*	Loosely entangled		x			
7. *Cladophora* sp.	Loosely entangled		x	x	x	x
8. *Ulva* spp.	Loosely entangled		x			x
9. *Gracilaria* spp.	Attached by holdfast	x	x	x	x	xxx
10. *Acanthophora* sp.	Attached by holdfast	x		x	x	
11. *Laurencia* spp.		x	x		x	x
12. *Hypnea* sp.	Attached by holdfast	x	x		x	
13. *Gelidium* sp.	Attached by holdfast on ropes			x		
14. *Sargassum* spp.	Loosely entangled			x		x
C. Biofouling animals						
15. Sea squirts	Attached	x		x		
16. Hydroids						
16.1 *Hydrallmania*	Attached	x		x		
17. Oysters	Attached			x		
18. Sponges	Attached			x		

Note: x = present to a less extent; xx = present to a moderate extent; xxx = present to a great extent.

4.2 IMPACT OF EPIPHYTE INFESTATION ON THE FARMED SEAWEEDS IN ZANZIBAR

During the hot-dry season in Zanzibar, in 2017, the thalli of *E. denticulatum* appeared to be thinner and longer than they originally were from their parent plants in the Philippines (they can be easily mistaken as some species of *Gracilaria*). They also appeared lighter in colour than their original reddish brown or dark-green colour. These changes are speculated to be due mainly to their exposure to too much sunlight especially during spring low tides, the seaweeds being planted very close to, if not touching the ground (not exactly off-bottom). Lewis (1964, as cited by Franklin and Forster, 1997) suspected that the timing of low water spring tides may influence the zonation of the shade-acclimated algae of the lower shore, or subtidal fringe. Also, a more extreme solar radiation stress occurs in those regions where algae are immersed close to the solar noon by low water spring tides. Consequently, long exposure to intense heat from the sun have obvious consequences to seaweed health, leading to the development of *ice-ice* conditions. High light intensity, probably coupled with nourishment from land-based nutrients, trigger blooms of the epiphytes. Except for Paje in Unguja and in some farms in Pemba Island (namely, Fundo, Makangale, Chokocho and Mjini Kiuyu), there are fewer farms now using *cottonii* as a consequence of

FIGURE 4

Cultivars of *E. denticulatum* with other forms of epiphytes. A, With green alga *Ulva* (=*Enteromorpha*) *clathrata* in Paje. B, A line of cultivars colonized by *Ulva clathrata* in Jambiani. C, Cultivars colonized with the cyanobac-teria *Oscillatoria* (arrows) in Paje. D, Hydroids (arrow) on a peg and monoline in Paje. E, A loose line of *E. denticulatum* in Kidoti. F, An epiphyte-infested *E. denticulatum* cultivar in Kidoti showing intact branches (arrows) that may still have the chance to recover during the rainy period

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die-offs, especially in the past five years; of the *E. denticulatum* crop that has remained, the majority of them have been intensely colonized by epiphytes during hot-dry months (Figure 5). In selected villages such as Jambiani, Matemwe, Fundo and Chokocho, only a few lines planted with *cottonii* (*K. striatum*) remained during the hot-dry season, in 2017, but these were also full of macro-epiphytes composed of the more ephemeral green algae *Chaetomorpha* and *Ulva*. This was an indication that no active maintenance had been done by farmers in this area; some farmers stopped farming altogether during the hot season. Many areas seemed to have been neglected during March–April, hence no farm maintenance had been done for the previous couple of weeks or months. In Kidoti, the *E. denticulatum* were not only covered by filamentous epiphytes but were also in an advanced stage, covered by silt and fouling organisms.

In Bweleo in Unguja, seaweed cultivars have been overtaken by a large biomass of *Gracilaria edulis* (identified as *Sarconema* by Msuya, 2013), another red alga that thrives well in quite silty bottom conditions, a characteristic of the Bweleo intertidal area. In addition to seaweed farming, farmers in the area have been organized to become entrepreneurs in soap-making during lean months in order to establish an alternate livelihood. Farmers hoped that the rain would help their crops recover from epiphyte infestation. Although rain did come in May to April (2017), it was not continuous as previously observed in the same time during previous years, according to a group discussion with the women farmers in Kidoti and Paje. In areas where the rain had yet to come, the *E. denticulatum*, although appearing weak, was still surviving despite the appearance of epiphytes in most of the cultivars. The farmers were also optimistic that the coming rain would revive their crop in due time. Finally, the rain

FIGURE 5

Seaweed cultivars with macro-epiphytes or biofouling organisms. A, With sea squirts in Paje. B, A sponge-covered *E. denticulatum* in Matemwe. C, *E. denticulatum* colonized with a mix of algae and silt in Kidoti. D, *E. denticulatum* entirely covered by a mix of algae, sponge, sea anemone and shelled mollusc (arrows) in Kidoti. E, *Gracilaria edulis* partly burying *Eucheuma* cultivars (with arrow) on the monoline in Bweleo

did come and was continuously heavy in April, followed by a short break during May, and then again a heavy daily rain. In June, showers came only intermittently, tempered by cold winds from the southeast.

Currently, an effort is underway by the private seaweed company Zanzibar East Africa Seaweed (ZANEA) company to introduce a new strain of *E. denticulatum* from the Philippines. This strain, called *million-million*, has appeared to be more resistant to epiphyte attacks when test-planted over seagrass beds (Figure 13) (see section 4.5 for more discussion). Thus, ZANEA is optimistic that *million-million* will perform well in Zanzibar.

4.3 EPIPHYTE DENSITY

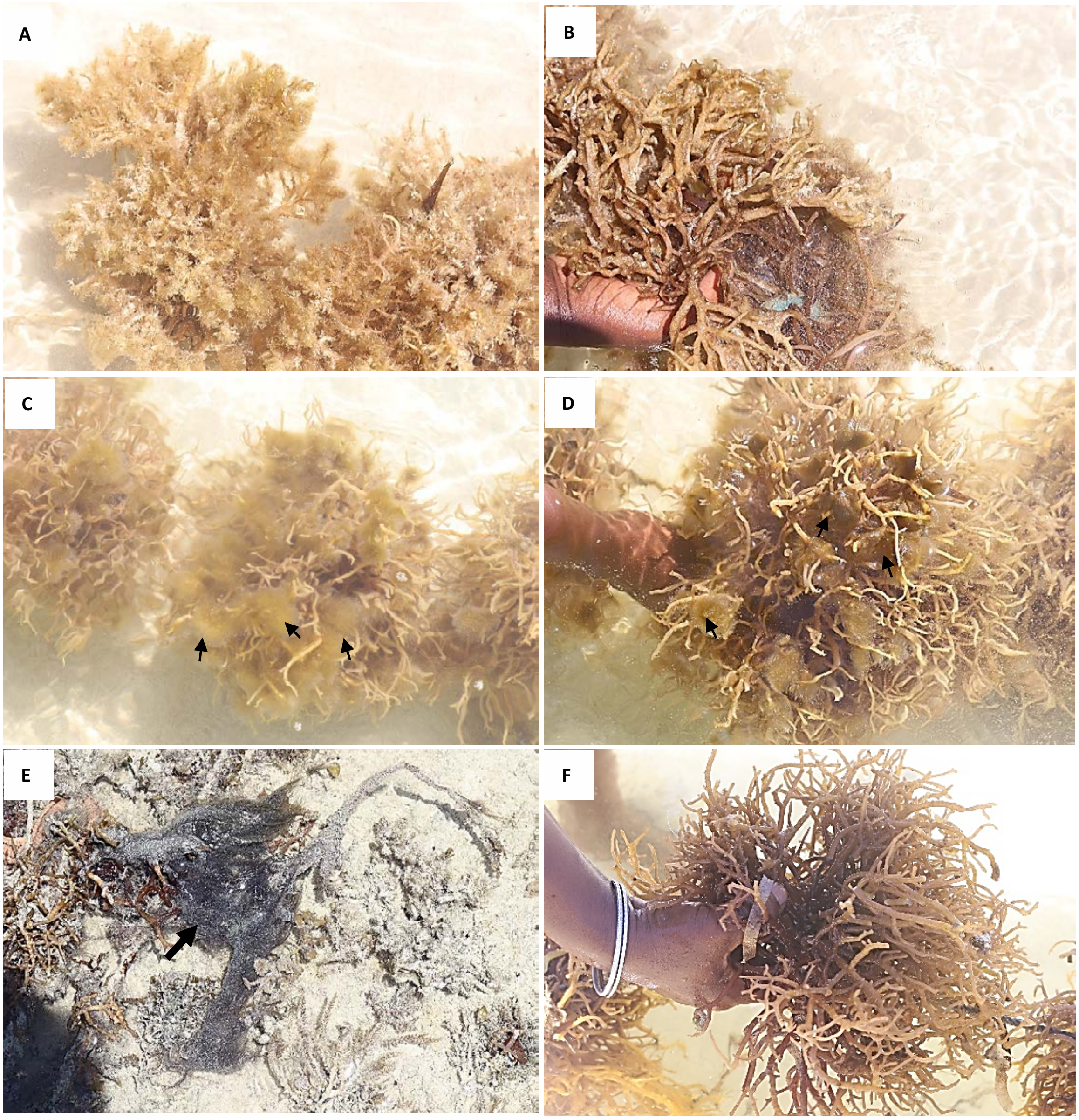
The samples of mostly *E. denticulatum*, and occasionally of *K. striatum*, subjected to epiphyte counting, showed that Unguja farms were more infested with epiphytes than Pemba farms. These samples were collected in early 2017, from late February to early March, which was still the peak of the hot-dry season in this region. In addition to the EFA, macro-epiphytes were also noticeably affecting the farmed seaweeds. In Kidoti (Unguja Island), for instance, the filamentous epiphytes were replaced by mostly fouling animals, such as shelled molluscs, sponges and sea anemones (Figure 5D indicates the impossibility of performing a count), which also affect the growth of seaweeds. Table 3 shows the epiphyte density range among farms in Unguja and Pemba Islands based on samples that were collected in the hot-dry season (February–March) and preserved by both formalin fixation and drying, and samples collected in late March to early April that were observed fresh one day after being collected. Except for Matemwe, epiphyte density in *spinosum* was higher in samples collected during the hot-dry season in all farming sites compared to samples collected during the wet season, although this could be due to the limited number of samples analysed, thus being insufficiently represented. Based on formalin fixed and dried samples of *E. denticulatum*, the highest epiphyte infestation was observed in Kidoti, with an average density of 19.9 ± 18.6 (range of 0–85) epiphytes per cm, followed by Matemwe with an average density of 17.7 (range of 0–63) epiphytes per cm. *K. striatum* (also a *cottonii*), which was collected in Paje, had a density range of 39–78 epiphytes per cm based on fresh samples collected in late March, but these were based on empty pores appearing on the surface (a few of these pores were still occupied by single filaments of *Polysiphonia-Neosiphonia*) (Figure 7). *Oscillatoria*, in a few cultivars in Paje, had a density range of 0–21 ind. per cm of thallus. Epiphyte densities during the hot-dry season were generally higher in Unguja farms than in Pemba farms (Figure 8), regardless of whether the samples were fixed in formalin or simply dried, although there was about a 40 percent reduction observed in the counts from formalin-fixed samples in Unguja. The counts from Pemba were almost similar between the two preservation methods.

During the wet season, average epiphyte densities were almost the same in both islands, regardless of the preservation method, and were drastically reduced by 90 percent from those of the hot-dry season in both islands. No attempt was made to compare the data here with the data of Vairappan *et al*. (2008) in their studies in Sabah, Malaysia, and of Tsiresy *et al*. (2016) in Madagascar because of the slightly different approach in the estimation of density between this study and those in Malaysia and Madagascar. In this survey, thalli were cut into 1 cm pieces and the number counted in the entire piece instead of using square centimetre areas, as done in Vairappan *et al*. (2008).

A comparison among the different farms in Zanzibar showed Kidoti and Paje in Unguja, and Fundo in Pemba, as having a mean epiphyte density in *E. denticulatum* of more than 10 ind. per cm during the hot-dry season. That of Kidoti reached the highest infestation in this eucheumoid species of a little over 30 ind. per cm, while that of Fundo, which had the highest epiphyte occurrence in Pemba, reached up to

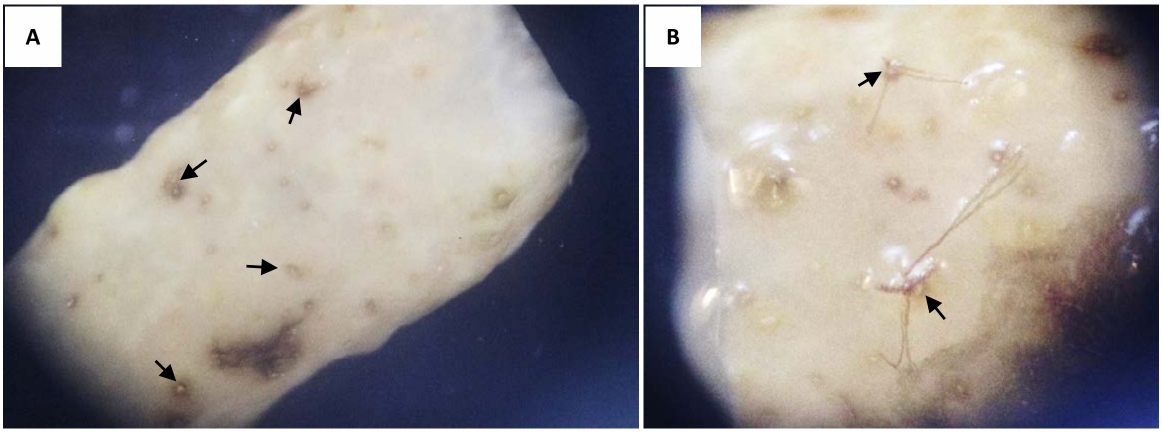
FIGURE 6

Epiphyte-infested cultivars of *E. denticulatum* in Zanzibar seaweed farms. A, Most common filamentous epiphyte in *E. denticulatum* identified as a species of *Polysiphonia-Neosiphonia* complex, which makes the seaweed appear hairy all throughout the thallus. B, The same as A, but lifted up to show the thallus' appearance when emerged from water. C, The filamentous brown alga *Ectocarpus* found to also colonize the *E. denticulatum* cultivars appearing like "pompoms" when submerged (arrows). D, The same as in C, but lifted up to show the attachment of the epiphytes to the thallus (arrows). E, Filamentous cyanobacteria *Lyngbya majuscula* (arrow) in Kidoti, which is known as causing "swimmers itch" in Hawaii. F, A healthy cultivar of *E. denticulatum*



16 ind. per cm (Figure 9). During the wet season, epiphyte densities were significantly reduced in all farms except Mjini Kiuyu. The increase in Mjini Kiuyu could be due to the factors that stimulate growth, mainly the nutrient availability that could be brought by rain as surface run-off, despite the tempering effect of rainy and cold periods as shown in other sites. While epiphyte and host eucheumoid both respond to availability of nutrients, the epiphyte's high surface-to-volume ratio enables it to respond much faster than the host. Worm and Sommer (2000) have found that epiphytes on *Fucus vesiculosus* have a comparative advantage in taking up nutrients than does their host;

FIGURE 7
1-cm section of *K. striatum* showing empty tiny spores (A, arrows) as remnants of the epiphyte *Polysiphonia-Neosiphonia* complex and spores still occupied with filaments (B, arrows)



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this especially evidences if nutrients are available in a pulse rate in a duration of a few hours, as in the case of Zanzibar where rainy periods occur intermittently.

For *K. striatum*, most of the samples in Pemba where the species is farmed, albeit with higher production than Unguja, had a lesser epiphyte load (Figure 10) but evidenced high occurrence of *ice-ice* disease (see section 4.4). The sample in Fundo, which had the highest epiphyte content among sites in Pemba during the hot-dry season, had only 10 epiphyte ind. per cm of thallus. In stark contrast to Pemba Island, the only sampled farm in Unguja with existing *K. striatum* was Paje, where the mean epiphyte density was highest at 56.5 ind. per cm of thallus during the hot-dry season, based on freshly collected samples (Figure 10).

Where more epiphytes occurred, seaweed production was always reduced, as is the case in Unguja, which has the lowest seaweed production since epiphyte infestation began in the early 1990s (Davis, 2011). Although Figure 1 shows that seaweed production increased in Zanzibar until 2012 (based on data from the Department of Fisheries and Marine Resources, 2016), this could be due to seaweed farming areas being expanded or to an increase in the number of farmers taking up the activity (Msuya *et al*., 2014). Similarly, after a decade or two of successful farming of *Eucheuma* and *Kappaphycus* in the Philippines and in countries where they were introduced, such as China, Indonesia, Madagascar and Malaysia, the problem of epiphytism began to appear and took a toll on farmed seaweeds, reducing the production in these countries. Had it not been for the expansion of production areas in, for example, Indonesia, which has been the world's main producer of eucheumoids since 2008 (Hurtado, Montaño and Martinez-Goss, 2013), global production would have been lower. As mentioned above, it is highly possible that the epiphytes also arrived with the eucheumoids, all the way from the Philippines; the problem was first documented in Calaguas Island in Camarines Sur, where entire farms were abandoned because of epiphyte blooms (Largo, 2002).

Molecular study has yet to establish whether the *Polysiphonia-Neosiphonia* epiphytes existing in the Philippines are identical to those in countries where the seaweeds have been introduced. Should this be true, strict quarantine procedures will be required in the future for introducing exotic species into Zanzibar. The impact of epiphytes on seaweeds can be explained by the study of Pang *et al.* (2011) where the same filamentous red alga they identified later as *Neosiphonia savatieri* (Pang *et al*., 2015) was shown to inhibit photosynthesis of *K. alvarezii* farmed in Lian Bay, China. Overcrowding (as in the intensive farming in shallow water areas in Zanzibar) resulted in shading and stunted growth of the seaweed host which eventually led to its early senescence. South of Zanzibar, in nearby Madagascar, epiphytes continue to affect the

TABLE 3

Epiphyte density counts in samples from farming areas in Unguja and Pemba Islands. The samples were collected during two different periods in 2017, consisting of hot-dry months (February–March) and the onset of rainy months with intermittent hot days (April–May). Counting was made on three sets of samples, preserved in 10 percent formalin, dried or fresh

Sampled area	Farm designation	Seaweed species	Epiphyte	Epiphyte Density (ind. per cm)		
				Late February – early March		Late March – early April
				In 10% formalin	Dried	Fresh
Unguja Island						
Paje	Farm 1	*E. denticulatum*	*Poly-Neosiphonia*	4 – 72	2 – 47	No data
			Oscillatoria sp.			1 – 21
		K. striatum	*Poly-Neosiphonia*			39-78
	Farm 2	*E. denticulatum*	*Poly-Neosiphonia*	6 – 25	7 – 37	
	Farm 3	*E. denticulatum*	*Poly-Neosiphonia*	11 – 54	1 – 58	
Bweleo	Farm 1	*E. denticulatum*	*Poly-Neosiphonia*	0 – 1	0 – 1	0
	Farm 2	*E. denticulatum*	*Poly-Neosiphonia*	0 – 3	0	
Kidoti	Farm 1	*E. denticulatum*	*Poly-Neosiphonia*	5 – 37	13 – 30	Fouling organisms – too crowded to count
	Farm 2	*E. denticulatum*	*Poly-Neosiphonia*	0 – 85	18 – 78	
	Farm 3	*E. denticulatum*	*Poly-Neosiphonia*	6 – 41	11 – 85	
Matemwe	Farm 1	*E. denticulatum*	*Poly-Neosiphonia*	23 – 50	11 – 42	13 – 52
	Farm 2	*E. denticulatum*	*Poly-Neosiphonia*	5 – 36	0 – 63	
	Farm 3	*E. denticulatum*	*Poly-Neosiphonia*	0	0 – 5	
Kiwengwa	Farm 1	*E. denticulatum*	*Poly-Neosiphonia*	0	0 – 12	No samples collected
	Farm 2	*E. denticulatum*	*Poly-Neosiphonia*	0	0 – 40	
	Farm 3	*K. striatus*	*Poly-Neosiphonia*	0	0	
Pemba Island						
Makangale	Farm 1	*E. denticulatum*	*Poly-Neosiphonia*	9 – 23	0 – 39	No samples collected
		K. striatum	*Poly-Neosiphonia*	0	No sample available	
	Farm 2	*E. denticulatum*	*Poly-Neosiphonia*	0 – 4	0 – 16	
	Farm 3	*E. denticulatum*	*Poly-Neosiphonia*	0 – 16	0 – 31	
Fundo	Farm 1	*E. denticulatum*	*Poly-Neosiphonia*	8 – 22	0 – 18	
		K. striatum	*Poly-Neosiphonia*	6 – 18	No sample available	
	Farm 2	*E. denticulatum*	*Poly-Neosiphonia*	0 – 17	0 – 30	
	Farm 3	*E. denticulatum*	*Poly-Neosiphonia*	6 – 39	3 – 39	
Tumbe	Farm 1	*E. denticulatum*	*Poly-Neosiphonia*	0 – 16	0 – 30	
	Farm 2	*E. denticulatum*	*Poly-Neosiphonia*	0 – 1	0 – 1	
	Farm 3	*E. denticulatum*	*Poly-Neosiphonia*	0 – 1	0	
Chokocho	Farm 1	*E. denticulatum*	*Poly-Neosiphonia*	0 – 77	0 – 19	
		K. striatum	*Poly-Neosiphonia*	0 – 3	No data	
	Farm 2	*E. denticulatum*	*Poly-Neosiphonia*	0 – 4	0 – 31	
	Farm 3	*E. denticulatum*	*Poly-Neosiphonia*	0	0 – 16	
Mjini Kiuyu	Farm 1	*E. denticulatum*	*Poly-Neosiphonia*	0	0 – 40	
		K. striatum	*Poly-Neosiphonia*	0 – 1	No sample available	
	Farm 2	*E. denticulatum*	*Poly-Neosiphonia*	0 – 3	0 – 1	
	Farm 3	*E. denticulatum*	*Poly-Neosiphonia*	0 – 2	0 – 9	

island's farmed seaweeds, which had also been brought there in 1989 from Zanzibar by private seaweed growers (Msuya *et al.*, 2014). During these epiphyte infestation episodes, farmers have been severely affected economically.

FIGURE 8

Comparison in average epiphyte density on *E. denticulatum* between hot-dry and wet seasons in Unguja and Pemba on samples preserved by air-drying and by 5–10 percent formalin. Vertical lines are standard deviation (n = 280); legend applies to both panels

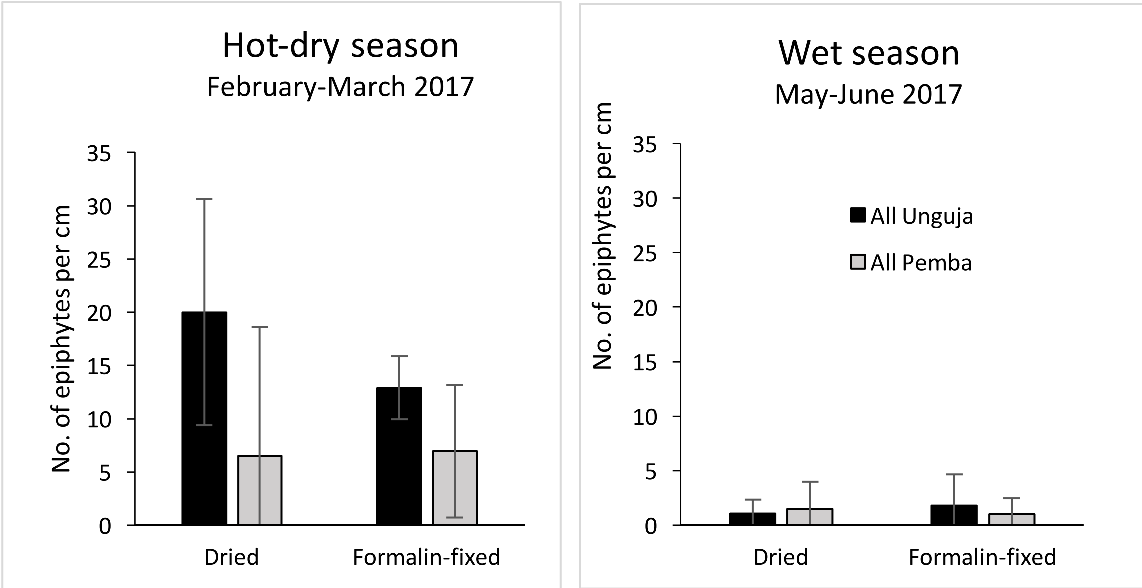
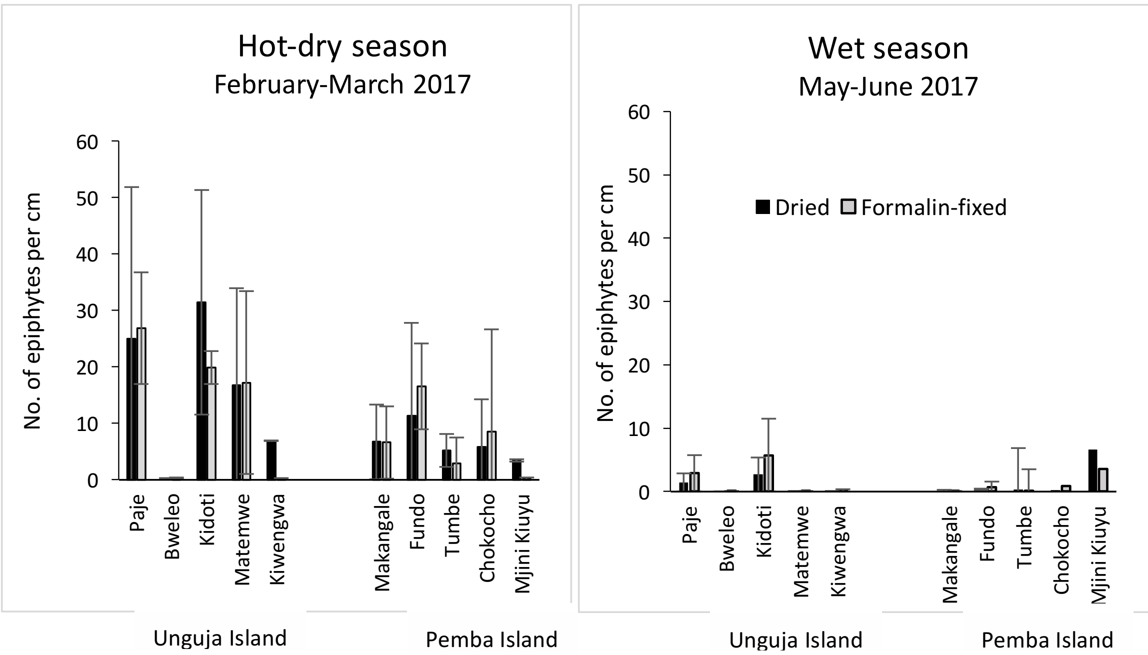


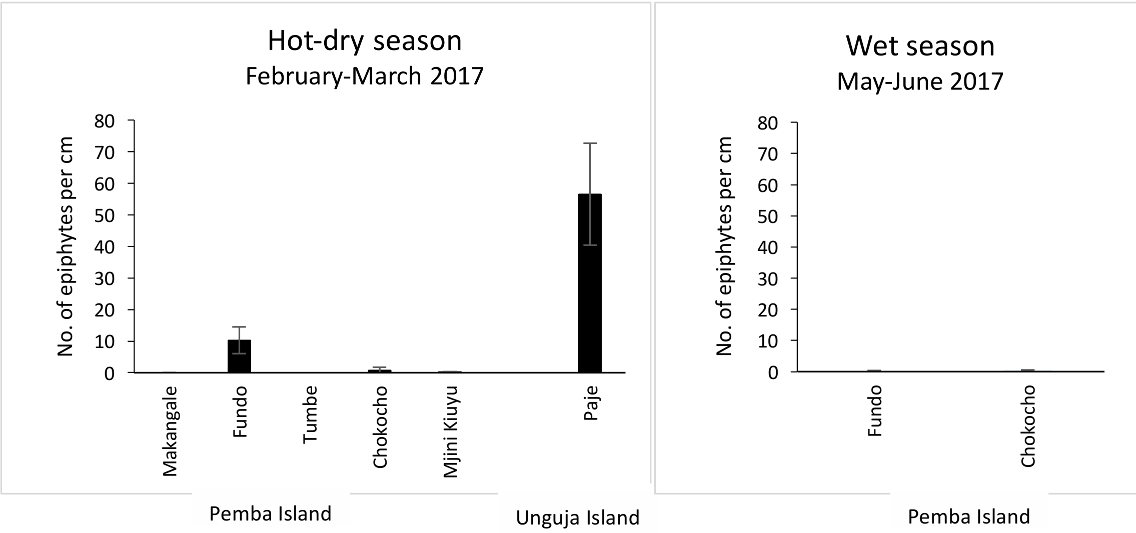
FIGURE 9

Comparison of epiphyte density in *E. denticulatum* between hot-dry (February–March 2017) and wet seasons (May–June 2017) in different farms of Unguja and Pemba on samples preserved by air-drying and 5–10 percent formalin. Vertical lines are standard deviation (n = 30); legend applies to both panels



During this study, farmers expressed hope that rain could "remove" the epiphyte problems. The farmers in Paje and Kidoti said with confidence that the rainy season is a blessing to them, as the rain could surely remove epiphytes from their seaweed host.

FIGURE 10
Comparison of epiphyte density in *K. striatum* between hot-dry (February–March 2017) and wet seasons (May–June 2017) in different farms in Pemba and Unguja (Paje only, May–June 2017) using samples fixed in 5–10 percent formalin. Farms not mentioned have no cultivars of *K. striatum* to sample with. Vertical lines are standard deviation (n = 10)



As proof of this post-rain "removal" were the empty cavities or pores observed on the surfaces of the eucheumoids while the latter regained health (Figure 7). This was validated in our quantitative analysis of samples collected during the wet season when epiphyte density was significantly reduced. Indeed, in Kidoti, even the fouled or highly epiphytized cultivars showed parts that were emerging and that were partly devoid of epiphytes (Figure 4F) following a few days of intermittent rains, causing the revival of seaweed health. Such natural reinvigoration can indicate what strategy to implement to remedy the epiphyte bloom. For example, briefly dipping the seaweeds for a few minutes in a bath of freshwater could possibly reduce, if not, remove the epiphytes during their peak season. Adding lime juice (citric acid, as practiced in Japan) could possibly enhance the removal of epiphytes. Although these two remedies may sound laborious, they might be worth trying, if only to improve the condition of the cultivars during the hot-dry season. In the case of macro-epiphytes and fouling animals, they can only be eliminated by removing them manually during low tide, as part of a regular maintenance activity by farmers.

In Kidoti, all plants/cultivars were in an advanced stage of fouling during the hot season (Figure 5D). As in Paje, the farmers expected the rainy season to reduce, if not, eliminate the epiphytes. In this place, most of the farming lines seemingly were in need of replacement after a period of dormancy; the same occurred in both Unguja and Pemba where affected farming lines were seen scattered all over the areas. In Bweleo, where lines appeared to be abandoned, the observed competitors were not the EFAs but another red macroalga – *Gracilaria*. The growth of this alga in the area was so abundant that the *Eucheuma* seaweeds attached to monolines were literally buried beneath the thick *Gracilaria* biomass (Figure 5E). Surprisingly, the *Eucheuma* seaweeds underneath the thick biomass of *Gracilaria* remained generally healthy except for a few cultivars that had the *ice-ice* condition. There were also negligible epiphytes detected in the Bweleo farms (see Table 2). An opportunity exists to utilize these "undesirable seaweeds" as food for human consumption, despite the surprising reluctance of farmers to use seaweeds for food purposes or for the extraction of agar, which some *Gracilaria* species are known for. Finding alternative livelihoods for the women seaweed farmers would be a welcome opportunity (discussed in more detail in section 4.8 below). The *Gracilaria* competition with *Eucheuma* farms in Bweleo was reported as a form of algal bloom by Msuya (2013), who identified it as a species of *Sarconema*.

As mentioned above, epiphyte infestation is not unique to Zanzibar, as it has also occurred and spread to many farming areas where *E. denticulatum* and *K. alvarezii* have been introduced. More recent literature shows that, in nearby Madagascar, similar epiphytes have been reported to be deteriorating the farms there; hence, the seaweed production in that country south of Zanzibar (Ateweberhan, Rougier and Rakotomahazo, 2014; Tsiresy *et al*., 2016) has suffered a decline. Likewise, Brazil, which has also introduced the seaweed originally from the Philippines, began to have problems with epiphytism in the early 2000s, although of a different epiphyte species identified as *Colaconema infestans* (Araújo *et al*., 2014).

4.4 *ICE-ICE* DISEASE AND ITS CONTRIBUTION TO SEAWEED DETERIORATION

As in epiphyte infestation, the occurrence of *ice-ice* disease on *E. denticulatum* in Zanzibar was very high during the hot-dry season (February–March), but this declined during the wet season in May–June by an average of up to 99 percent (Figure 11). For instance, Bweleo in Unguja with 36 percent *ice-ice* and Makangale in Pemba with 72 percent *ice-ice* during the hot-dry season had only 0.38 percent and 1.4 percent *ice-ice* in the wet season, respectively. *Ice-ice* incidence was comparatively higher in the farms of Pemba Island during the hot-dry season than those in Unguja Island, with an average of 45.7 percent compared to Unguja's 23.5 percent during this period. Although drastically reduced during the wet season, Pemba remained higher in *ice-ice* incidence than Unguja. Except for Tumbe, which had only 22 percent *ice-ice* incidence, all farms in Pemba had *ice-ice* incidence ranging from 49–98 percent during the hot-dry season. The high standard deviation of *ice-ice* in all *E. denticulatum* means some seaweeds were devoid of *ice-ice* at all, while some had very high *ice-ice* incidence. During the wet season, the percentage of *ice-ice* incidence ranged only from 1.4 percent in Makangale to 11.4 percent in Tumbe. In Unguja, during the hot-dry season, the seaweed farms in Bweleo and Paje were the most affected, where both farming areas had about 35 percent *ice-ice* incidence rate compared to Matemwe, Kidoti and Kiwengwa with only less than 18 percent. During the wet season, all farms in Unguja had *ice-ice* incidence of less than 3 percent, except Kiwengwa with 17 percent, i.e. a reduction of 80–99 percent. Again, the standard deviation of these percentages is also high, i.e. the seaweeds are in various states of health. Nevertheless, the condition is still present even to cultivars that appeared to be relatively devoid of epiphytes. The *ice-ice* mainly affects the older parts of thalli (Figure 12), which Largo *et al*. (1995) and Largo, Fukami and Nishijima (1995) attributed to the extreme conditions of environmental factors, such as high temperature and light intensity that predispose the seaweeds to opportunistic pathogens; however, it could also be a result of a secondary infection after epiphytes leave behind openings on the algal cortex that weaken the alga, paving the way for microbes to invade (Largo, 2002; Vairappan *et al.*, 2008).

In most farms, the seaweeds had *ice-ice* patches, which were in different positions on the thallus. Sometimes the *ice-ice* would be near the tie-tie where the seaweed was attached to the line, and sometimes it would be in the middle of the plant (Figure 12B, C, D). In most cases, the seaweed with *ice-ice* would bleach where it was affected, then rot and disintegrate. However, in Chokocho (Pemba), *ice-ice* had a different type of effect. The seaweed broke off at the point where there was *ice-ice* (in this case, at the attaching point, Figure 12E, F, G), and whole branches of the seaweed would fall onto the sediment. Even though the rest of the plant surface remained intact, the whole plant became colourless (Figure 12 H-I).

Opportunistic pathogens are normally occurring microbes in seawater or residents on healthy seaweeds that, under normal conditions, do not cause any disease. Seaweeds under stress of high water temperature due to intense heat during low tides, coupled with high light intensity, could trigger these opportunistic pathogens to impose their ability to hydrolyze cellular parts, such as cell wall and metabolic products like carrageenan using their degrading enzymes (Largo, Fukami and Nishijima, 1995; Largo *et al*., 1997). Samples coming from both Unguja and Pemba analysed for epiphyte infestation also included thalli parts with *ice-ice* conditions, but the incidence rates

FIGURE 11

Percentage of *ice-ice* incidence in the different farms during hot-dry (left panels) and wet seasons (right panels) presented per island (Unguja – top panels; Pemba – middle panels), and the whole of Unguja and Pemba comprising the region of Zanzibar (bottom panels). Note the decline in incidence of *ice-ice* by up to 99, 98 and 86 percent, respectively. Vertical lines are standard deviation

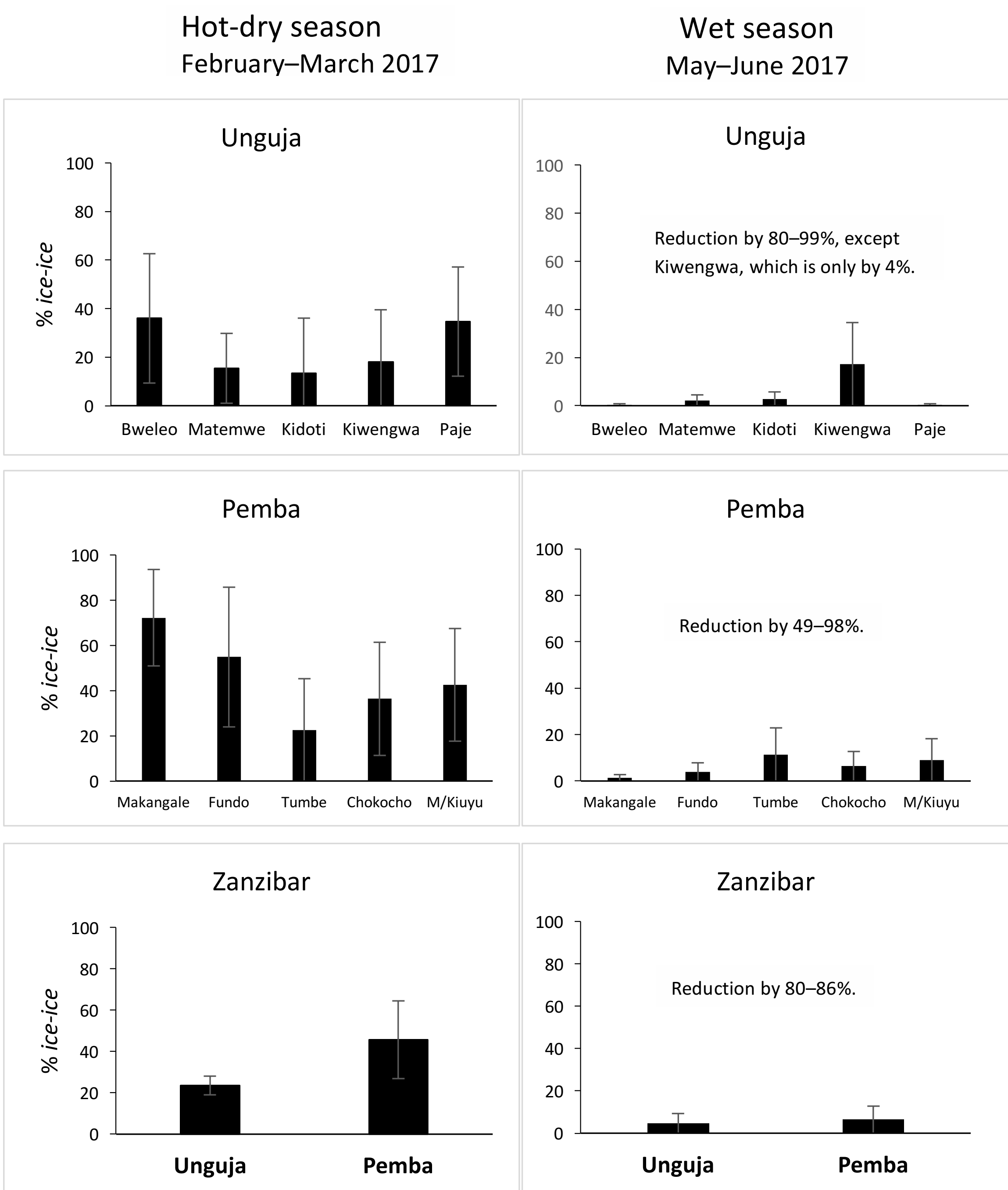


FIGURE 12

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

cannot be determined at present based on the samples collected from these sites. It is highly probable that *ice-ice* disease as a result of high temperatures and high light intensity plays only a secondary role in the deterioration of the seaweed farms in both places in Zanzibar compared to the widespread negative impact of epiphytes.

4.5 POSSIBLE ROLE OF SEAGRASSES IN THE SEAWEED FARMS FOR BETTER SEAWEED HEALTH MANAGEMENT: A CASE OF A NEW STRAIN OF *EUCHEUMA DENTICULATUM* TO REPLACE EPIPHYTE VULNERABLE STRAINS

The assessment of farming conditions in Zanzibar will have to be dealt with on a case-by-case basis depending on the site. A visit to Paje and Jambiani on 31 March 2017 compared the two sites in terms of substrate type. While Paje has an almost pure white sand, that of Jambiani, especially near the shore, has a transition of a muddy bottom starting from the beach to a sandy bottom towards the sea and patches of seagrass beds characterized the muddy intertidal flat. The staff of a private company made an interesting observation. Test cultivars of a strain of *E. denticulatum* from the Philippines called *million-million*, which the company introduced into Zanzibar in early 2017, attached to a line above the seagrass bed were almost devoid of epiphytes compared to the cultivars that were hanging over bare sand where abundant epiphytes covered all branches of the cultivars (Figure 13). It appeared that the presence of seagrasses has afforded some form of protection to the *E. denticulatum* strain against epiphytes, which tends to support the study by Mtolera (2003). The study, comparing two sites in Unguja with differing seagrass cover, one with low cover (Paje) and the other with high cover (Uroa), found that fortifying the seaweeds (*E. denticulatum* and *K. alvarezii*) with metal, either manganese, copper, iron or zinc, in addition to Provasoli-enriched medium that already contained the nutrients nitrogen and phosphorus, conferred resistance of the seaweeds to physical stress which otherwise made them susceptible to epiphytism or microbial infection responsible for the *ice-ice* disease. Mtolera held that seagrasses might concentrate these metals in their tissues, which would be released to adjacent seaweed farms, thus giving them better growth when seagrasses were present. The reason why the seaweeds in Paje were prone to epiphytes and *ice-ice* disease compared to Uroa, or Jambiani (observed during the visit on 30 March 2017), could be due to its low seagrass cover. The healthy appearance of *E. denticulatum million-million* strain when grown over seagrass beds could be proof of this metal-boosted resistance. Although the study of Msuya and Salum (2012) showed no effect of seagrasses on *K. alvarezii* planted over it, it seemed to affirm the observations of Mtolera *et al*. (1995) that growth of *E. denticulatum* is reduced on seagrass beds, which the latter explained to be due to its lack of the enzyme carbon anhydrase that enables seaweeds to utilize HCO_3 – one of the seaweeds' source of inorganic carbon. A study by Collén *et al*. (1995) showed poor growth of *E. denticulatum* when planted on seagrass beds, which the authors attributed to the interference that seagrass has on CO_2 uptake by *E. denticulatum*. The tendency of this species to produce hydrogen peroxide is in response to stress caused by high light intensity, elevated pH, and competition with other species (Mtolera *et al*., 1995). But, as is widely known, this eucheumoid species is still prone to epiphytism by *Polysiphonia-Neosiphonia*.

Another reason for the robust condition of *million-million* when grown over seagrasses can simply be explained by the "shadow effect" it provides to seaweed, by lowering both water temperature (down to 28–29 °C) and light intensity, which otherwise could predispose the seaweed to more epiphytes and *ice-ice* disease under extremely high levels. High light intensity could bring about photoinhibition in *K. alvarezii* during midday in Zanzibar, which Terada *et al.* (2015) also observed in Viet Nam, where incident irradiance on the frond under a fine clear sky could be too strong for effective photosynthesis to take place, and hence a potential physical stress to the farmed seaweed.

FIGURE 13

***Million-million* strain of *E. denticulatum* from the Philippines introduced to Jambiani showing resistance to epiphytes of cultivars grown over seagrass beds (right panels), in contrast to those which happened to be over bare sandy substrate (left panels). Topmost panel shows a culture line with the new strain, one part on bare sand with high epiphyte load and the other part on seagrass bed with less epiphyte load. Middle and bottommost panels are magnified views of the same cultivars**

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Whether the absence of epiphytes on the new strain cultivated on top of seagrasses will be sustainable until the harvest period requires long-term observation; if the pilot experiment in Jambiani is successful, it could be worth promoting it to the rest of Zanzibar. Making a choice of expanding *E. denticulatum* production, although commanding a lower market price, can be made on the basis of the new strain's (*million-million*) better resistance to epiphytes when grown on seagrass beds. Promoting this strain will therefore require areas with barren sand to be transplanted with seagrasses (e.g. *Cymodocea* or *Thalassia*). The method of seagrass transplantation is abundant in the literature (e.g. Van Katwijk *et al*., 2009; Bastyan and Cambridge, 2008; Van Keulen, Paling and Walker, 2003). Although having fewer epiphytes is expected to cause better growth performance, the strain *million-million* on seagrasses needs to be accompanied with a scientific assessment of its growth performance against cultivars grown on bare sand. Therefore, having seagrasses below *E. denticulatum million-million* strain can be a good approach to ensuring better seaweed health management of this strain in Zanzibar. Empirical data will also be needed to draw a better conclusion. This observation has to be considered when culturing strains of *K. alvarezii* or *K. striatum* and *E. denticulatum*, which, in the case of *million-million*, can be implemented while waiting for the empirical data to be available. *Million-million* can be better propagated on seagrass beds, as Jambiani has more of this vegetation than Paje. In the case of Paje, seagrasses can be transplanted using available methods and this could be one approach that should be considered to complement deep-water farming, which otherwise may not be feasible for women farmers since some are unable to swim, especially older members. Also to be considered is the trade-off between having seagrass beds and epiphyte-free cultivars and the vegetation's tendency to attract grazing organisms that take shelter and feed on the vegetation including the farmed seaweeds. On the other hand, seagrasses, aside from performing ecosystem services such as acting as natural filters that reduce the effects of coastal pollution, eutrophication and sedimentation, protection of coastlines from erosion and acting as a buffer against extreme weather events (Nelleman, Corcoran and Duarte, 2009, as cited by Geere, 2014), also provide habitat and spawning and nursing grounds for myriads of marine organisms, including important fishery resources (e.g. blue crabs, shellfish) that could be an additional source of income for seaweed farmers.

4.6 WATER TEMPERATURE, IRRADIANCE, SALINITY, WATER MOVEMENT, EPIPHYTE BLOOMS AND RELATIONSHIP WITH *ICE-ICE* DISEASE OCCURRENCE

Surface water temperature measured across lagoons in the farm sites of Unguja during low tide ranged between 27.5 and 35.5 °C depending on the part of the lagoon, time of the day and cloud cover, with higher temperatures in the more exposed portions of the lagoon (Table 4). While these values cannot be directly linked to global warming in the absence of long-term empirical data, Msuya and Porter (2014) reported abnormally high water temperature values of above 33 °C in 18 sites of Songo Songo Island, south of Tanzania. Measurements made in Zanzibar fall within the same months when Msuya and Porter (2014) conducted their study in Songo Songo Island. The same authors cited Mmochi, Shaghude and Msuya (2005) and Msuya *et al.* (2012) to have measured surface water temperature above 34 °C in other parts of Tanzania. The optimal temperature for growth of *Eucheuma* and *Kappaphycus* is between 24 and 30 °C, and when the seaweed is placed experimentally at a high temperature of between 33 and 35 °C *ice-ice* develops (Largo *et al.*, 1995). Based on previous and present data (this study) on water temperature within the waters of Tanzania (western Indian Ocean), it would be safe to say that high incidence of *ice ice* disease during the hot and dry months in Zanzibar is directly linked to the extremely high water temperature prevailing during these months, especially in shallow waters. While it is normal for the water temperature to increase during dry months, a long observation period is required in a specific site like

Zanzibar to link high water temperature to global warming, although Levitus *et al.* (2000) observed global water temperature to have already increased by close to 1 °C in the last half century (based on objective analyses of the running five-year composites of all historical oceanographic temperatures for the period 1948–1996 at standard depth levels from the surface to 3 000 metres). If indeed there is such a link, this could be devastating to farmed seaweeds, which continue to be grown too close to the bottom, especially during low tides where residual waters could heat up to an extremely high level in both water and substrate. Uniquely, seaweed farming in Zanzibar is being done in very shallow intertidal lagoons. Consequently, in addition to temperature, the seaweeds are more exposed to extreme conditions of light intensity and salinity that mainly occur in residual waters during low tides, lowering their resistance and making them more susceptible to pathogens (Largo, Fukami and Nishijima, 1995). A mitigating measure that local researchers in Zanzibar resort to (Msuya, 2006; Msuya *et al.*, 2007; Msuya 2015, 2017) is bringing seaweed farming into deeper water areas where water temperature and salinity are more stable and regulated by the deep Indian Ocean circulation that keeps farming conditions to within optimal range. However, without proper training and support, this kind of operation may add on the costs for logistics and render deep-water farming difficult, especially for women who are the main workforce of Zanzibar's seaweed farming activities.

While high water temperature has been the main cause of the *ice-ice* disease, salinity appears to work both ways in Zanzibar – either in favour of or against the farmed eucheumoids. Measurements of salinity across the lagoon area and during a spring low tide, on 31 March 2017, indicated that after heavy rains, salinity could be reduced to below 30 practical salinity units (psu) in the upper intertidal area (observed in Paje), while it maintains within the normal range (34–35 psu) in the subtidal area towards the open sea (observed in Jambiani and Kidoti) (Table 4). It is possible that a lower salinity level during heavy rains could be directly responsible for the reduction in epiphyte growth, as reported by seaweed farmers; although, it has been observed that drops in temperature and light intensity associated with weather change from sunny to rainy are factors that also reduce epiphyte occurrence. Whether excessive rainfall has a negative impact on the growth performance of the seaweeds remains to be determined through weekly biomass measurements. Excessive, continuous rain may reduce salinity to the extent that farmed seaweeds become stressed, predisposing them to *ice-ice* disease and resulting in low growth rates. This was observed in neighbouring Kenya for both *E. denticulatum* (brown strain) and *K. alvarezii* (brown strain) (Wakibia *et al.*, 2006). In addition, rainy periods affect the farmers' ability to dry their produce, resulting in high moisture content, and a harvest of low-quality seaweeds that bring lower prices.

Epiphyte infestation has also been associated with warm water temperature in Zanzibar and seems to be mitigated when the rainy season arrives, an observation made by farmers since cultivation began in 1989. They also noted that warm waters caused *ice-ice* disease, which decimates farms all over Zanzibar during the months of January to March, resulting in dramatic declines in seaweed production since 2011 (Msuya 2011a; Msuya *et al.*, 2014). During field visits in the farms of Unguja between 31 March and 9 April 2017, water temperature ranged from 27.5 to 35.5 °C , though a temperature reading as high as 38 °C was noted in the tide pools in Kidoti. In Matemwe, a very intense solar heat in the afternoons caused the large intertidal lagoon to heat up, increasing the temperature level up to 34 °C and the salinity up to 36 psu (measurements made on 1 April 2017). In this area, while the seaweed appears healthy from a distance, a closer look at the thalli showed intense occurrence of epiphytes covering entire cultivars (Figure 3, Figure 6A–D).

Although no measurement of light intensity or irradiance was undertaken during the study, light intensity has been established in several studies as a major factor that, at extreme levels, promotes the growth of epiphytes and the development of *ice-ice* disease at the expense of the host seaweeds' growth. Borlongan *et al*. (2016) experimentally showed that epiphyte-infested *K. alvarezii* exposed to high irradiance had lower photosynthetic rates that compromised its growth.

Ice-ice disease was not observed during the wet season visits in Zanzibar as being as widespread as epiphytes, probably because when the rainy period arrived the water temperature as well as the light intensity dropped, which relieved the cultivars from stressful conditions occurring during the hot, sunny season.

TABLE 4
Temperature and salinity readings across the lagoons in five farming sites of Unguja between 31 March and 9 April 2017

	Station[1]	Temperature[2] (°C)	Salinity[3] (psu)	Remarks
Paje (31 March)	1	30.0	ND	Overcast (cloudy)
	2	29.5	34	
	3	29.5	35	
	4	29.5	35	
	5	29.5	35	
Jambiani (31 March)	1	30.1	28	About 30% cloud cover changing to open sky in the late afternoon, with sun appearing
	2	30.1	33	
	3	30.0	33	
	4	30.0	33	
	5	29.5	35	
Kidoti (1 April)	1	33.5*	35	Very sunny, after a heavy downpour
	2	33.5*	35	
	3	33.5*	33	
	4	34.0*	35	
	5	35.5*	35	
Matemwe (1 April)	1	33.5*	36 (!)	Very sunny
	2	34.0*	36 (!)	
	3	33.4*	36 (!)	
	4	33.0*	36 (!)	
	5	34.0*	36 (!)	
Bweleo (9 April)	1	27.8	34	Cloudy (50% overcast)
	2	27.5	34	
	3	27.5	34	
	4	27.5	34	
	5	27.5	34	

[1] 1 nearest to shore, ca. 20 meters away; 5 - farthest the shore, approx. 300 meters away; 2, 3, 4 are in-between 1 and 5, roughly at 100-m interval.
[2] Measured using an alcohol-filled thermometer.
[3] Measured using an Atago refractometer.
Notes: * = considered extreme for eucheumoids; ND = no data; PSU = practical salinity unit.

In addition to increases in water temperature, light intensity and salinity during the hot-dry months, the Zanzibar area is affected by two monsoon systems that either dampen or increase the speed of the East African Coastal Current (EACC). These water movements have implications upon the effects of the above-mentioned factors. The water current during the southeast monsoon (April–October) pushes and accelerates the northbound EACC, while during the northeast monsoon (November–March), the northerly wind retards the EACC (Ngusaru, 2000). The seasonal and tidal dynamics around Zanzibar, particularly those in the Zanzibar Channel, were studied by

Zavala-Garay *et al.* (2015) to complement earlier studies, such as those of Shaghude, Wannas and Mahongo (2002), Mahongo and Francis (2010) and Muzuka *et al.* (2010). During the northeast monsoon season around the seaweed farms, the slow water movement could exacerbate the impacts of the above-mentioned factors on the seaweeds during the extremely hot-dry months of January to March (as was shown by Msuya, 2011b, in Pemba). Local, low water movement also decreases the uptake rate for nutrients in seaweeds, which are already stressed from high temperature, light intensity and salinity. It is no surprise that the period of high susceptibility to epiphyte infestation and *ice-ice* disease also occurred during these months in Zanzibar. The environmental impact on the seaweeds is significantly reduced during the rainy-cool season from April to October when the southeast monsoon occurs.

4.7 FARMERS' RESPONSE TO FARMING SEAWEEDS IN DEEPER WATER

In deeper water locations, seaweed farming is expected to achieve more favourable results. This is because deep water has more stable water temperature and salinity together with a well-circulated water column due to the EACC that upwells cool and nutrient-rich water from the deep Indian Ocean and contains fewer bottom grazers that are abundant in the intertidal area. These conditions being optimal and stable are also not conducive for epiphytes to bloom and *ice-ice* to develop. Economically, one of the deep-water methods, namely the floating lines, proved to be better than the off-bottom method (Msuya *et al*., 2007; Valderramma *et al.*, 2015). The floating method has also been recommended by Bindu and Levine (2010) as a better option to cultivate *K. alvarezii* in Africa, which is more susceptible to die-offs caused by epiphytes and *ice-ice* disease when planted in much shallower waters.

In Zanzibar, "deep-sea cultivation" has been proposed by Msuya *et al.* (2014) to address the problem of die-offs, especially for *K. striatum*. Until now, the idea has been received with little enthusiasm, especially for women farmers who are used to farming in the shallow lagoon and lack the ability to swim. While the meaning of "deep sea" is not comparable to deep sea cultivation as used in the Philippines, where the seaweeds are placed on rafts or on longlines with floaters over depths of more than 5 m or so, the "deep sea" as applied in Zanzibar is only a matter of 2–3 m deep at low tide. However, even if the depth was only 2–3 m, farming still requires swimming and use of boats during farming operations as the distance between the shore and the reef's edge is more than a kilometre. Asked during the interview if they would be willing to implement "deep-water farming", farmers appeared reluctant to pursue this option and would only consider it if there is no other choice available, and if they are also provided with appropriate training and boats; this is an investment that only the government and private companies may have the capacity to undertake.

4.8 OPPORTUNITIES FOR SEAWEEDS

The Zanzibar Aquaculture Development Strategy, prepared under the FAO-funded Technical Cooperation Programme "Support to the Aquaculture Subsector of Zanzibar" (TCP/URT/3401), strongly advocates for seaweed value addition. Seaweeds made into soap, lotion, shampoo, drink/juice (Figure 14) are just some of the products that seaweed farmers in Zanzibar have developed, not only when the seaweed harvest is low, but also throughout the year as additional income. The Zanzibar Seaweed Cluster Initiative promotes seaweeds by adding value and bringing these products into the market. Unfortunately, the market in Zanzibar is very small, addressing only to basic needs, and therefore requires active promotion and advertisement for wider consumption of higher value products. The seaweed farmers are highly focused on the eucheumoids, even though other economically important seaweed species exist outside the farms, their potential uses and value not yet explored. For instance, in Bweleo, in the town of Fumba, the bloom of the red macroalgal species tentatively identified as *Gracilaria edulis* has been exceptionally high. Although known as a source of agar, they are not well known in Zanzibar as such. Considered as "pests" to *Eucheuma* farming, competing with the latter's growth and contributing to the decline in the latter's production, *Gracilaria* simply is recognized as an "undesirable" seaweed.

However, the use of *Gracilaria* as a biofilter and the extraction of the agar gel have already been experimented with and recommended as an alternative farming species in Zanzibar and Tanzania in general (Msuya and Neori, 2002; Buriyo and Kivaisi, 2003; Msuya *et al*., 2014).

FIGURE 14
Some seaweed-based products from the Zanzibar Seaweed Cluster Initiative, shown by a successful seaweed entrepreneur participant from Bweleo

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The *Gracilaria* in Bweleo has a good potential as food and as a source of agar with desirable quality. Samples collected on 9 April 2017 and sent to the Southeast Asian Fisheries Development Center (SEAFDEC, Iloilo, Philippines) for agar analysis showed viscosity and gel strength in values that could qualify it as a food additive and as a soft gelling agent for various applications in food and beverages, pharmaceuticals and in personal care products (Table 5).

TABLE 5
Viscosity and gel strength of agar from *Gracilaria edulis* collected from a seaweed farm of Bweleo, Unguja, on 9 April 2017, based on analysis conducted at the Southeast Asian Fisheries Development Center (SEAFDEC) in Iloilo, the Philippines. Values have been shown as fit for food additive and for soft gelling agent

<table>
<tr><th></th><th>Viscosity (cP)</th><th>Remark</th><th>Gel strength (g/cm²)</th><th>Remark</th></tr>
<tr><td>Sub-sample 1</td><td>23.5</td><td rowspan="3">Good as food additive</td><td>210.58</td><td rowspan="2">Good for soft gelling agar</td></tr>
<tr><td>Sub-sample 2</td><td>26.0</td><td>230.73</td></tr>
<tr><td>Sub-sample 3</td><td>23.0</td><td>–</td><td>–</td></tr>
</table>

Based on this initial result, *Gracilaria edulis* from Bweleo should be promoted as a source of nutrition and extra income for the seaweed farmers in this area. During the April visit, seaweed farmers were taught how to prepare *Gracilaria* salad and other food recipes. Although those recipes were well received by them, it remains to be seen how this introduction of a seaweed recipe from *Gracilaria* will find its way into the households' regular table menu. Since farmers were already using *Eucheuma* and *Kappaphycus* as food (e.g. salad, jam, juice), there is a big possibility that they will also use *Gracilaria*. Seaweeds, including both *Gracilaria* and *Eucheuma*, are rich in essential amino acids, vitamins and minerals. The utilization of *Gracilaria* as food is, therefore, an option for seaweed farmers and all other community members. However, as *Gracilaria* is a bloom-forming alga whose trigger is not known and is a fouling seaweed in Bweleo since 2012, there is a need to analyse its safety for continuous human consumption, e.g. analysing for heavy metals and toxins.

Exploring other seaweeds in Zanzibar for greater opportunities is indispensable if the seaweed industry is to flourish in the islands. *Gracilaria* farming must be explored further if only to provide an alternative seaweed to the deteriorating eucheumoid farming industry in Zanzibar. For now, a deeper understanding of some environmental rehabilitative measures is required for the existing strains to survive.

4.9 LOW GENETIC VARIABILITY OF FARMED SEAWEEDS: A HINDRANCE TO INCREASED COMMERCIAL PRODUCTION

Seaweed production in Zanzibar started strongly in its early years of introduction due to favourable conditions in Zanzibar, then declined after a decade of successful annual production due to widespread occurrence of *ice-ice* disease and epiphyte infestation, which shows a symptomatic seaweed's inability for long-term adaptation to changing environmental conditions and is possibly a reflection of their low genetic variability. That farmed seaweeds are deteriorating in genetic diversity due to clonal propagation is an observation that has been pointed out by several authors, including Collén *et al*. (1995), Hurtado and Cheney (2003), Salvador and Serrano (2005), Luhan and Sollesta (2010) and Hurtado, Neish and Critchley (2015). Because of this finding, Halling *et al*. (2013) conducted research on the genetic variability between farmed and wild *Eucheuma* and *Kappaphycus* in Zanzibar to encourage the search for a local strain with a strong genetic base, good growth and carrageenan properties that will sustain the industry in this island. Apparently, the introduced strains from the Philippines have become compromised due to the occurrence of these maladies. This Technical Cooperation Programme (TCP) research team, while recommending some mitigating measures in addressing these maladies, is less optimistic regarding the seaweeds' fate in future years unless new strains, desirably local ones, are identified as having the qualities necessary to survive the farming and support the seaweed farming sectors in Zanzibar. Halling *et al*. (2013) also recommended a search for wild strains of eucheumoids that are able to reproduce sexually in their natural habitats and will eventually replace the introduced strains.

The identification of important commercial strains of *Kappaphycus* and *Eucheum*a, at national and regional scale, has been done by Tan, Lim and Phang (2013) and Lim *et al*. (2014) in Malaysia, and Araújo *et al.* (2014) in Brazil. Their studies focused not only on the production and productivity but also on the potential for invasiveness of the seaweed, and in the comparison of strains from the main carrageenan producing countries in Southeast Asia (Indonesia, Malaysia, the Philippines and Viet Nam).

In view of all production and productivity problems the sector has been facing, as well as the very monopolistic market, the FAO-funded Technical Cooperation Programme "Support to the Aquaculture Subsector of Zanzibar" (TCP/URT/3401) recognized and recommended the Biological and Economic Research on Seaweed as a very relevant pillar of the Aquaculture Development Strategy Plan.

4.10 IMPACT OF GLOBAL WARMING TO FARMED SEAWEEDS

Global warming is an issue that has been and continues to be discussed on many fronts, including its impact on global biodiversity. In particular, the impact of global warming on cultivated seaweeds, particularly *Eucheuma* and *Kappaphycus*, has been reviewed recently by Largo *et al.* (2017), since the rise in water temperatures could have deleterious effects on the farmed seaweeds, including the increasing occurrence of *ice-ice* disease and epiphyte infestations. An abrupt increase of seawater temperature especially during El Niño events could trigger the disease. Readings of water temperature in most sites visited in Unguja were quite high, especially during low tides. In Paje and Jambiani, water temperatures ranged from 29.5 to 31 °C, and between 33.5 and 35.5 °C in Kidoti and Matemwe, which are considered extremely high for seaweed production. Clearly, high temperature in all Zanzibar sites was the main factor that triggered the *ice-ice* occurrence in both Unguja and Pemba Islands. The bloom of epiphytic algae during warm months, on the other hand, could also be a response of the epiphytes to the rise in temperature as observed in Malaysia (Vairappan, 2008) as between 27 and 31 °C (and salinity increase from 28 to 34 psu) occurring between the months of March and June. Contributory factors in favour of epiphyte growth also include high light intensity/irradiance where the host seaweeds, serving as substrate for attachment, provide a favourable habitat to maintain this growth.

5. Conclusions

Based on the present assessment made on seaweed die-offs in Zanzibar and stakeholders meetings, the following are conclusions that will further derive the recommendations of this TCP in what are regarded as short-, medium- and long-term mitigation options.

i) Die-offs of *Eucheuma denticulatum* (*spinosum*), *Kappaphycus alvarezii* and *K. striatum* (both known as *cottonii*) in the seaweed farms of Zanzibar have been confirmed as primarily being caused by the occurrence of epiphytic filamentous algae (EFA) and *ice-ice* disease, with Unguja Island as being more affected by epiphytes than Pemba Island. The opposite is true for *ice-ice*, which is more widespread in Pemba than in Unguja. The spread of epiphyte infestations is facilitated by the fact that seaweed farming in Zanzibar is mainly done in shallow intertidal lagoons where the seaweeds are almost, if not, directly in contact with the bottom substrate during low tides, which exposes them to higher levels of temperature and light intensity (exacerbated by the reflective ability of the white sand background) than when they are off the ground. The presence of seagrasses under the seaweed cultivars appeared to minimize the impact of high temperature and high light intensity providing a "shadow effect" to the cultivars, at least as one newly introduced strain has demonstrated in Jambiani, in Unguja Island.

ii) Epiphyte density, particularly belonging to *Polysiphonia-Neosiphonia* complex, varies among farm sites where samples were randomly collected. For the most widely farmed *E. denticulatum* during the hot-dry season in Unguja, epiphytes reached up to an average of 20 epiphytes per cm of thallus (with a range of 0–85) across the five villages visited, while in Pemba farms the average was 7 epiphytes per cm (with a range of 0–40). During the wet season, all farms across Unguja and Pemba, except for Mjini Kiuyu, had epiphytes reduced to almost nil (0.1–0.3 epiphytes per cm); Mjini Kiuyu may have other factors such as nutrients promoting epiphyte growth during this period. In Paje, the remaining site in Unguja where *K. striatum* is still farmed albeit in less quantity, epiphytes on that species reached an average density of 57 epiphytes per cm (with a range of 0–78), whereas in Pemba the average was only 10 epiphytes per cm (range of 0–18 epiphytes per cm). In contrast, during the wet season, epiphyte densities went down drastically to almost nil (0.1–0.3 epiphytes per cm) in Pemba where *K. striatum* remained to be farmed in a number of sites. Epiphyte density, regardless of season and species, was therefore always higher in Unguja than in Pemba farms.

iii) The epiphytic filamentous alga *Polysiphonia-Neosiphonia* complex, belonging to the Family Rhodomelaceae, Order Ceramiales, Division Rhodophyta (red algae), identified through microscopic examination, was the most common epiphytic organism in all of the seaweed farms in both Unguja and Pemba Islands. Other epiphytes were also present – such as the filamentous brown alga *Ectocarpus*, the cyanobacterium *Oscillatoria* and large fouling organisms consisting of macroalgae (e.g. *Cladophora* sp., *Ulva* spp., *Gracilaria* spp., *Laurencia* sp., *Acanthophora* sp.), hydroids (e.g. *Hydrallmania* sp., *Bugula turrita*), molluscs, sponges and sea squirts – and could have played a secondary role in the overall deterioration of the seaweeds, especially in the late stage of cultivation.

iv) During the hot-dry season in February, the percent incidence of *ice-ice* was high (average of 24 percent in Unguja, 46 percent in Pemba), but this was significantly reduced to just around 5 percent in both islands during the wet months of May to June, concurring with other studies that water temperature is the major factor affecting the seaweed production in Zanzibar.
v) The temperature in the lagoons during the hot season at midday at low tide ranged between 30 and 35.5 °C, with higher values in Kidoti and Matemwe; salinity in the same area was in the normal range except in Matemwe, which reached 36 psu in the lagoons because of the intense solar heat. High temperatures beyond 30 °C coupled with high light intensity appear to be the extreme condition that predisposed the farmed seaweeds to both *ice ice* disease and epiphyte infestation, although both problems have been observed by farmers as controllable during the rainy and relatively cold season.
vi) The rainy season is considered by seaweed farmers as a signal for seaweeds to recover after a season of hot-dry, sunny days in Zanzibar. This was verified by epiphyte density counts, which showed a significantly reduced density in samples taken during the wet season in both Unguja and Pemba. However, rainy periods, according to farmers, have affected their ability to dry their produce prompting to its poor quality with consequently diminished market value. Ironically, low-quality harvests can also be due to improper drying practices observed in Pemba.
vii) A promising, newly introduced strain of *E. denticulatum* from the Philippines (called *million-million*) appeared to be epiphyte resistant when grown over seagrass beds as opposed to grown on bare sand, which was full of epiphyte load. This strain needs further evaluation.

6. Recommendations

Based on the present assessment involving field samplings and microscopic analyses, stakeholder interviews and group discussions, backed with published literature, the research team propose the following recommendations. These are short-, medium- and long term measures to address the die-off problem, and proposed innovations and interventions as measures for mitigation and alternative livelihoods.

6.1 MITIGATING MEASURES (SHORT, MEDIUM AND LONG TERM)

i) Improve the genetic stock of farmed seaweeds in Zanzibar by introducing more local strains of eucheumoid algae into the farms, which have a wider and stronger genetic base. This can be done through mass propagation using micropropagules and tissue culture techniques. Eventually, these local strains will replace the introduced, epiphyte- and disease-compromised strains of *Eucheuma* and *Kappaphycus* in Zanzibar.

ii) The Government of Zanzibar should implement a strict quarantine procedure for introduced species of seaweeds (perhaps including other exotic species of fauna and flora). A good example for this quarantine procedure has been undertaken by the Government of Fiji in the South Pacific (Sulu *et al.*, 2004), which is intended to prevent the unnecessary introduction of pest organisms, including epiphytes that are carried by the seaweeds from the country of origin.

iii) Encourage farmers to change the usual 30–45 days of the harvesting of *Eucheuma/ Kappaphycus* to a longer period (e.g. 60 days) to increase carrageenan yield, thus commanding a higher price from buyers. Msuya *et al.* (2012) have demonstrated that increasing the cultivation period from six to eight weeks increased the yield and quality of carrageenan. The higher price for the product, however, needs to be discussed and agreed with by buyers.

iv) Considering the seasonality of *ice-ice* and epiphyte infestation in Zanzibar, seaweed farming in the shallow lagoons can be made into a seasonal activity, with "off-season" during hot months when outbreaks of the *ice-ice* disease and epiphytes occur, and "open season" during wet and cold months when diseases and epiphytes are reduced, if not, gone. Although farming in deeper waters may be done continuously during the hot season using raft or longlines, water turbulence due to monsoon winds may limit the farming period in these areas. This can be done, however, on a case-by-case basis, as some areas can be more protected from monsoon winds than others due to the presence, for instance, of a barrier reef or a land mass on the opposite side.

v) Like any other agriculture activity, maintenance activity should be made part of the regular work of farmers. The saying that goes, "The best nutrient in the farm is the shadow of the farmer," makes a lot of sense even in seaweed farming since seaweeds need to be cleaned and freed from competing organisms to allow the crop to photosynthesize. Shaking the cultivars, which not only removes spores of epiphytes that proliferate the pest but also removes the silt on the thallus surface that attracts more fouling organisms to attach, must be done to improve photosynthetic capacity of seaweeds, thereby increasing the productivity of the farm.

vi) Planting of seaweeds over seagrass beds has shown promising results in a pilot farm for a new strain of *E. denticulatum* (*million-million*) in Jambiani. The suspicion that seagrasses serve to provide a "shadow effect" over which the seaweeds are tied on a line could do the trick of avoiding epiphytes from proliferating during high temperature and high light intensity months. Seagrasses can be introduced through transplantation in barren sandy grounds to serve the purpose of the "shadow effect." On the other hand, whether seagrasses also serve as a shield against microbial attack because of their antimicrobial properties remains to be assessed.

vii) Teaching traditional farmers to become farmer-scientists would minimize the impact of diseases and epiphytes. For instance, they can be taught to look for changes in water conditions through the use of simple and inexpensive tools, such as a thermometer to monitor water temperature, and to estimate water movement to anticipate when *ice-ice* disease and epiphytes would start to bloom. When these types of conditions are known, then a decision to stop or to continue farming can be made by the farmers themselves.

viii) A new breed of young seaweed farmers who are able to swim (or willing to learn how to swim) could receive training in deep-water seaweed farming and offered further swimming lessons. The same would apply for current farmers opened to this type of farming.

ix) In what are regarded as health risks experienced by the farmers during the hot season, sign boards with pictures of dangerous marine organisms, including those that could cause skin to itch, should be placed in farming villages to warn seaweed farmers against getting into contact with these organisms (e.g. hydroids, corals, jellyfish and cyanobacterium *Lyngbya*). Skin itchiness, when the skin is intensively scratched, could lead to lesions, which can lead to serious cases of skin infection by some microorganisms, including bacteria that are present in ambient waters, especially in tide pools at high temperature.

6.2 INNOVATIONS AND INTERVENTIONS THAT COULD HELP IMPROVE PRODUCTIVITY AND PROVIDE OPPORTUNITY FOR ADDITIONAL INCOME

i) Promote integrated multitrophic aquaculture (IMTA) – an ecosystem-based concept – in Zanzibar as an environmentally responsible and sustainable form of aquaculture. This is done by integrating fed species (e.g. milkfish, pompano) with some extractive species, such as seaweed species known for their biofiltration efficiency for inorganic wastes (e.g. *Gracilaria*, *Eucheuma*/*Kappaphycus*, *Ulva*, *Sargassum*), and bottom and filter-feeding invertebrates, such as sea cucumbers (e.g. *Holothuria scabra*), sea urchins (e.g. *Tripneustes gratilla*), mussels (e.g. *Mytilus mytilus*) and oysters (*Pinctada*), that remove suspended organic wastes. Ideally, IMTA should integrate high-value species, such as the ones mentioned, to recover the cost of investments and to earn more income for farmers. Sandfish (*H. scabra*), for instance, can be introduced in existing shallow lagoon seaweed farms, as has been done experimentally in Unguja by Beltran-Gutierrez *et al.* (2014) with *K. striatum* and Namukose *et al*. (2016) with *E. denticulatum*, who both found better growth performance in seaweeds grown over sea cucumbers at low density. In deeper waters, fed species (e.g. milkfish) can be farmed in floating cages, together with seaweeds and sea cucumber or other bottom feeders. This concept addresses not only the problem of pollution associated with fed aquaculture, but also creates opportunities for farmers since the species involved must be high-value crops that can be harvested for additional income. Synergies using the hatchery project in Zanzibar dedicated to the production of sea cucumber and milkfish would only be beneficial to all farmers and the island at large.

ii) **Milkfish culture**

Milkfish farming in the open sea is becoming a trend in many Asian countries, where the first induced spawning of milkfish for the pond farming system was developed. The supply of fingerlings and feed is crucial to the success of milkfish farming; therefore, hatcheries/nurseries that are operated initially by the government provides an inexpensive source of fingerlings to farmers. Eventually, the private sector will also have to play an important role in a partnership with the government to operate these hatcheries for profit. In addition, feeds that need to be supplied to grow the fish from young to harvestable size can be sourced commercially and can be produced using local raw materials, which include the farmed *E. denticulatum* and *K. striatum* and the green seaweed *Ulva* (Mmochi *et al*., 2001). More research in government and academic institutions to find alternative feed, including locally available plant-based materials (e.g. soya), that could lead to the development of low-cost, high-protein feed for milkfish should be given priority. This recommendation applies not only to Zanzibar but to mainland Tanzania as well.

6.3 ADDITIONAL INCOME FROM SEAWEED OTHER THAN FARMING TO ENHANCE LIVELIHOOD OPPORTUNITIES FOR SEAWEED FARMERS

The following are recommended:

i) Promote the Zanzibar Seaweed Cluster Initiative to support income-generating activities of farmers: the branding of products to be more attractive to the market, linking farmers to markets; and Pemba-based seaweed farmers to train on how to make soaps, lotion, shampoos and other products made from seaweeds.

ii) Harvesting in Bweleo of *Gracilaria*, which is considered a pest, to be used as food for human consumption, as demonstrated to farmers in Bweleo. *Gracilaria* is also a source of agar, which was found, based on an analysis by SEAFDEC, to have a viscosity and gel strength that are desirable enough as a food additive and as a soft gelling agent for many applications in food (e.g. coating for canned meat to extend shelf life), beverages (e.g. juices) and personal care products, such as lotions, shampoos and toothpaste. Research on this aspect needs to be intensified to exploit the species to the maximum for the benefit of the community. Since *Gracilaria* is a bloom-forming seaweed in Bweleo, more analyses should be done to analyse for heavy metals, pesticides and toxins, etc., especially for scaling up its use as direct human food.

iii) Explore the use of other seaweed species found in Zanzibar that have industry potential. For instance, the brown seaweed *Sargassum*, which in tropical regions is the equivalent of the cold-water kelp, can be a potential source of material for producing animal feed supplements (for the malnourished cattle observed in Kidoti and Tumbe, Figure A6.1B, Annex 6), as organic fertilizer for agricultural crops (e.g. rice, potato, spices), as raw materials for extracting chemicals used as ingredients for insecticides (insect repellents) and antimicrobial agents, and for extracting hydrocolloid alginate, which has food, nutraceutical, pharmaceutical and cosmetic applications.

6.4 SEAWEED DRYING FACILITIES

Investment in seaweed dryers, which are important facilities for drying seaweed, needs to occur. Having these facilities in Zanzibar's farming sites are extremely useful, especially during rainy periods when buyers prefer to have the seaweed harvest dried to a moisture content of about 30 percent. Solar dryers are also useful for drying seaweed. They are the most preferred among several types of plant dryers, but cost-effective ones should be developed locally or imported from elsewhere. Meeting this requirement plus a contaminant-free harvest can lead to seaweed improvements and obviously to a better market price.

6.5 ADVANCED TRAINING ON SEAWEED FARMING TECHNOLOGY AND RESEARCH FOR GOVERNMENT PERSONNEL

Key government personnel to serve as trainers need to receive advanced training on seaweed farming technology and research (e.g. Seaweeds Unit of the Department of Fisheries Development) to learn best practices in seaweed farming and post-harvest value addition from countries with advanced production and research in seaweed, such as the Philippines, for instance. This training can be done at the Southeast Asian Fisheries Development Center (SEAFDEC) in Tigbauan, Iloilo, the Philippines (seafdec.org.ph). Trained personnel could then serve as trainers of local seaweed farmers in Zanzibar. Under this and previous projects, FAO has trained farmers and other stakeholders on best management and business projects on supporting the subsector of Zanzibar, but further training is necessary to enrich the already existing knowledge.

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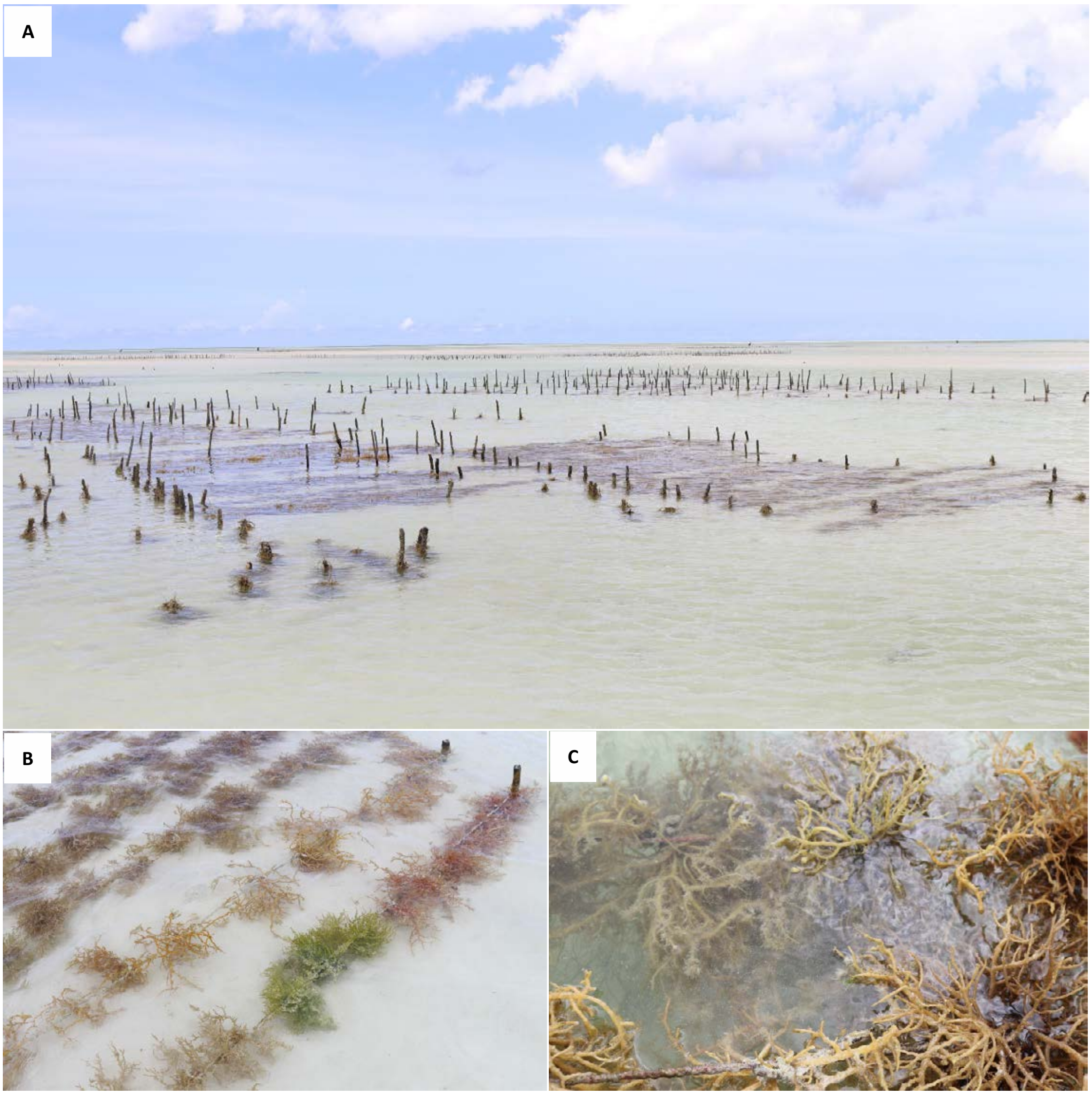
Annex 1

FIGURE A1

A seaweed farm in the lagoons of Paje during low tide (A). Cultivating two strains of *Eucheuma denticulatum* – brown and green (B). All cultivars in this area are highly epiphytized (C)



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Annex 2

FIGURE A2
Seaweed farm in Jambiani where cultivars are highly exposed to intense solar heat during spring low tide (A). Cultivation here is done over seagrass beds (B) and sandy beds (C)

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Annex 3

FIGURE A3

Seaweed farm in Kidoti with a very exposed rocky tidal area during spring low tide (A). Seaweeds on ropes lying on the ground are in an advanced stage of biofouling, indicating that no active maintenance is being implemented in the farm (B). A close-up of cultivars show biofouling contributing to the seaweeds' deterioration (C)

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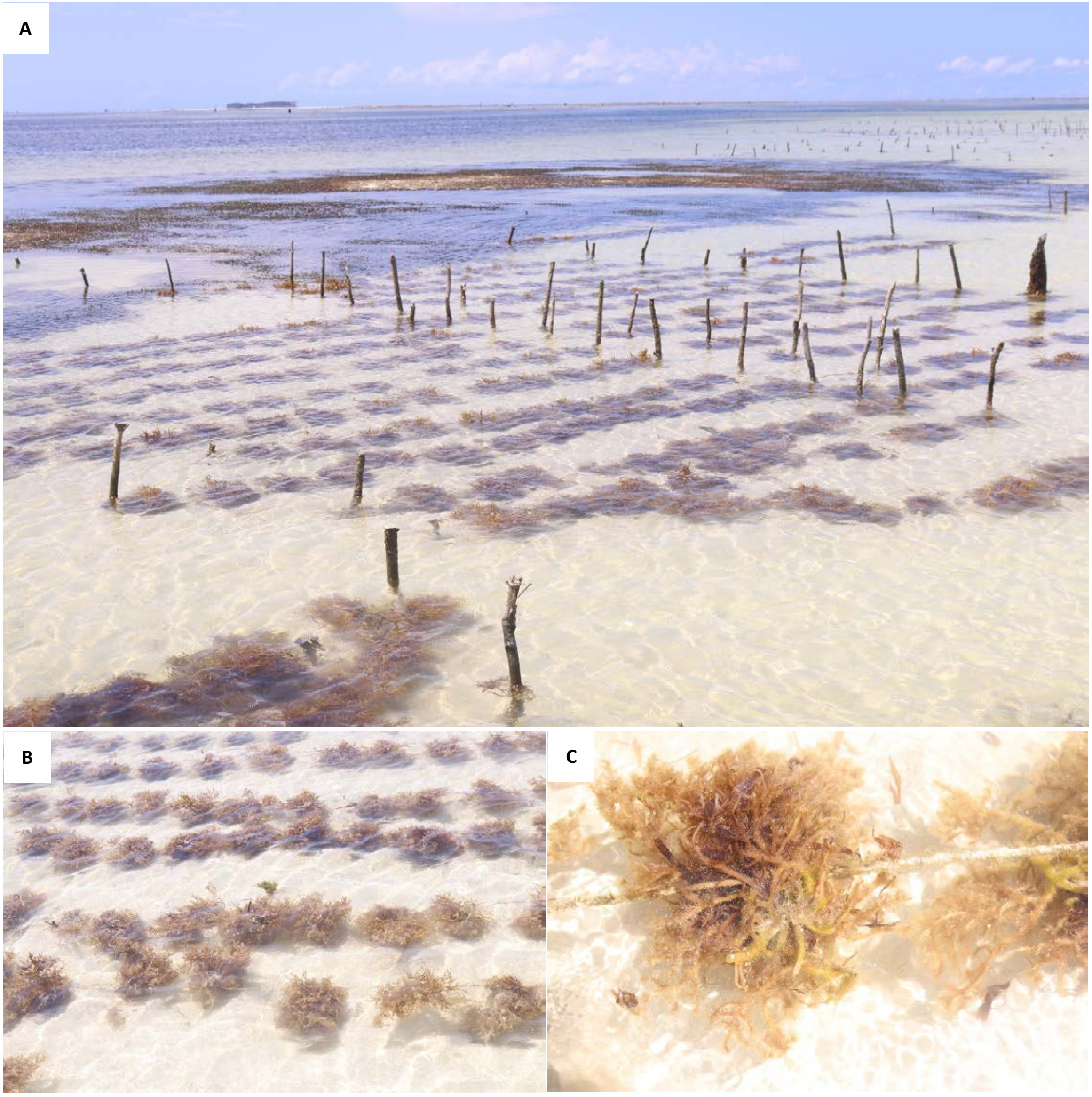
Annex 4

FIGURE A4

Seaweed farm in Matemwe lagoon during spring low tide at midday (A) where water temperature was measured to reach up to 34 °C. Rope cultivation over bare sand (B) appear to predispose the seaweeds to epiphyte infestation (C) due to high temperature

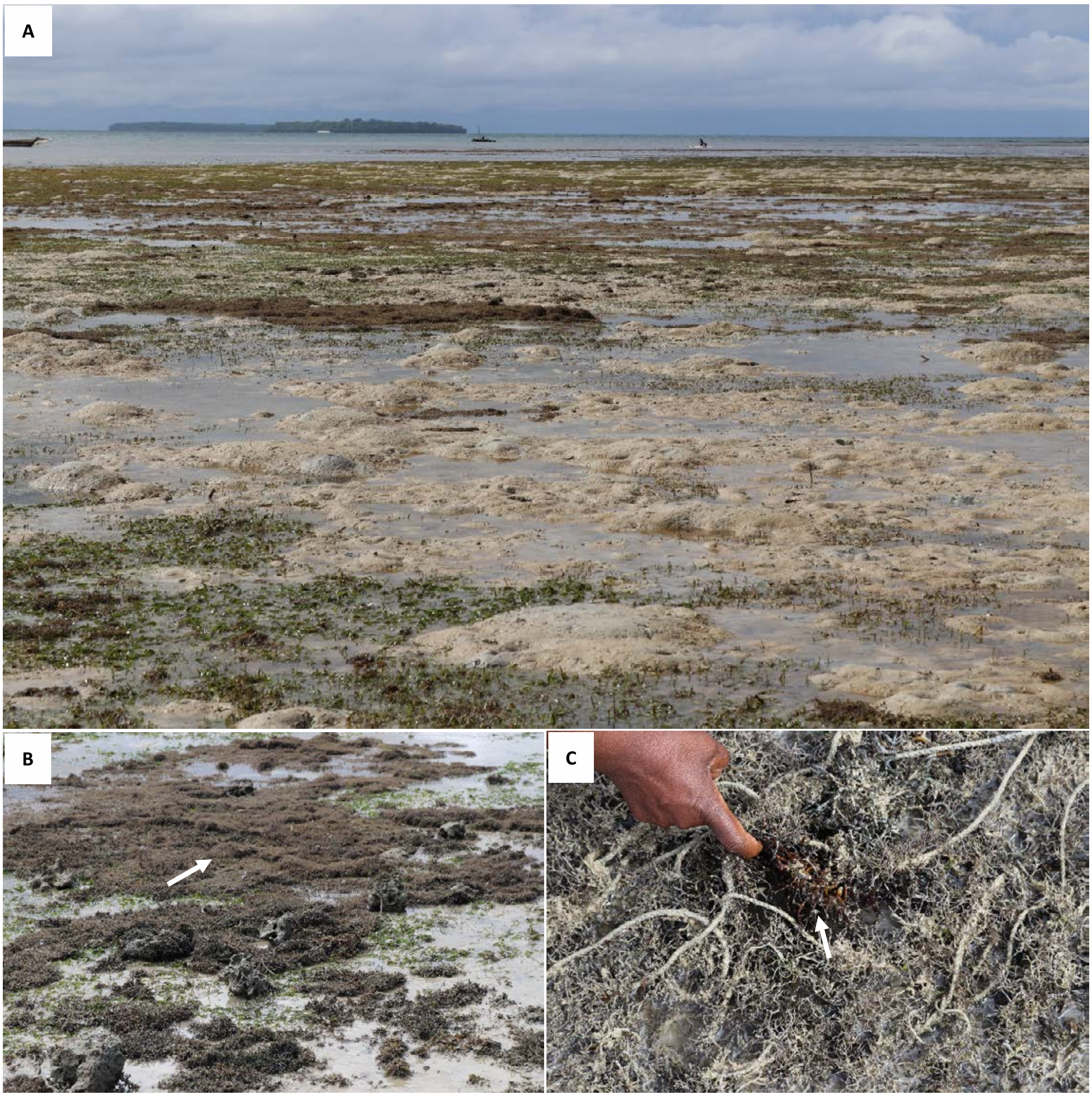


PHOTOS: ©FAO/D. B. LARGO AND A. MENEZES

Annex 5

FIGURE A5

The intertidal area in Bweleo with a generally muddy substrate (A) and dominance of agarophyte genus *Gracilaria* (with arrow) (B) whose biomass has overtaken the farmed *Eucheuma* (C, with arrow). *Gracilaria* can be exploited as edible food for humans and as a source of raw materials for agar extraction



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Annex 6

FIGURE A6

Seaweed drying practices in Tumbe, Pemba Island, the largest seaweed-producing area in the whole of Zanzibar. A–B, Drying seaweeds on bare soily-sandy and grassy grounds; note the animals in the fore- and background whose waste could contaminate the seaweeds

A

B

Biological and economic research on seaweed farming has been recognized and recommended as a relevant pillar for aquaculture development in Zanzibar. Seaweed farming has experienced serious challenges in terms of production and productivity with significant reduction of seaweed trade, household income and livelihoods in general. FAO supported this technical report, which covers an initial analysis of the epiphyte infestation and *ice-ice* disease in seaweed farms in Zanzibar and offers management strategies, including short- and long-term prevention and mitigation measures for farmers, traders and policy-makers.

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