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Marine integrated pest management (MIPM) approach for sustainable seagriculture

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ABSTRACT

Seaweed farming, or seagriculture, is expected to provide sustainable biomass enabling the development of marine bioeconomy through the blue growth. Epiphytism is a common phenomenon in seaweed farming that impacts the biomass yield. Epiphytes may be other non-wanted algal species, viruses, bacteria, and fungi. Epiphytes can attract grazers such as crabs, lobsters, shrimp, crayfish, fish, and turtles, which have both positive (enriched biodiversity throughout the food chain, ecosystem services, etc.) and negative (yield loss, etc.) impacts on seaweed farming. A critical challenge for the future seagriculture is how to address the pest problem. Although well developed for terrestrial agriculture, pest management frameworks for seaweed farming have yet to be set up. In this regard, we propose a framework for marine integrated pest management in seaweed farming. Based on several cases-studied: indoor and offshore seaweed farming in Israel and traditional seaweed farming in India, pest prevention, pest control, pest mitigation strategies and their implementations are discussed.

1. Introduction

Macroalgae, generally known as seaweeds, play a significant role in bioeconomy and low carbon societies, providing food ingredients, chemicals, and biofuel [1,2]. Their high biomass productivity [3,4]and unique constituents [5], make them an interesting feedstock for the biorefineries. Seaweed-based biorefineries cover various sectors such as platform chemicals, biofuels, pharmaceutical and cosmetic ingredients, biofertilizers, animal feed, food, and food additives, demand for which is growing worldwide.

Nowadays, seaweeds are already cultivated at commercial scale for direct human consumption [6], production of high-value products [7] and for extraction of unique polysaccharides [1] such as agar, carrageenan, and alginate [8,9]. In the last decades, the increasing demand for seaweed resulted in the increase of the cultivation area: the seaweed production (27.3 million tons) in 2014 represented ~49% of the total mariculture [10].

Our previous global productivity assessment showed that seaweed farming in the near-future technologically and economically deployable areas, associated with up to 100 m water installation depth, and 400 km distance from the shore, can provide for 10^9 dry weight (DW) ton·year^{-1}, which is equivalent to ~18EJ [1]. Processing of this biomass could potentially displace 20% of fossil fuels in the transportation sector in 2050, or provide for 100% of the predicted demand for ethanol, acetone, and butanol, and 5–24% of the demand for plant proteins in 2054 [1]. This production, however, will require significant expansion of the cultivation areas [11]. Additionally, any expansion of cultivation area can lead tonew problems such as ecological disturbance, diseases outbreaks, non-indigenous pests, as observed in the terrestrial agriculture [1,10]. Therefore, further understanding of the marine environment changes associated with large-scale farming is needed.

Though occurrence of epiphytes and fauna are inevitable in the marine environment of seagriculture [12], increase in their abundance can negatively impact seaweed crop yields. For example, decreases in biomass production and product quality generated from seaweed cultivated in Malaysian and Filipino seawater were linked to epiphytic outbreaks [13]. In the Philippines, 2011 to 2013, the 'ice-ice' disease in *Kappaphycus alvarezii*, caused by bacteria infection [14,15], led to a heavy economic loss of almost $310 million [10]. However, in contrast to the terrestrial agriculture, the control and management of marine pests have been neglected and there is a gap in the methods addressing and managing marine pests. With these data on crop losses from the current largest world producers, it is necessary to consider the problem caused by pests and develop an appropriate risk management process for seagriculture. One approach to tackle these problems is to understand the macroalgae interactions with associated epibiotic species. Because of the extreme sensitivity of marine ecosystems to chemical treatment, the only ecosystem-based pest management strategy, with a focus on the biological control that is friendly to the local ecosystem,

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would be applicable.

The integrated pest management (IPM), developed for terrestrial agriculture, is the decision-based process used to optimize the control of all types of pests in an economical and ecological way [16]. In terrestrial agriculture, IPM strategy not only shows effective management of pests and diseases but also reduction of production costs to farmers [17]. IPM integrates multidisciplinary methodologies for the development of agri-ecosystem management strategies while reducing negative impacts on public health and environment [18].

In this study, we focus on potential pests in seagriculture by reviewing the damages to seaweed crop due to the different types of organisms associated with seaweeds. We propose a categorization of pests in a seagriculture system using IPM framework and suggest risk management strategies to address the pest problem. We support this analysis with a field visit in India and controlled indoors and offshore case studies of cultivation of the green macroalgae *Ulva* sp. in Israel.

2. Materials and methods

2.1. Methodology for pest classification

The overview of the interaction of seaweed with its epibiota was based on literature. Special focus was made on interactions that could damage seaweed or seaweed derived products. Based on the definition of pests in terrestrial agriculture, we defined pests for seagriculture. The classification was done according to the nature of the pests, as well as their potential damage to seaweed crops.

2.2. Interview with seaweed farmers in India

The information related to pest problems that seaweed farmers are facing was collected from a field visit to commercial cultivation site in South India in August 2016 by interviewing the farmers or people involved in seaweed cultivation. In India, the exploitation of seaweed was traditionally carried out in the southern part, which is famous for the production of seaweed for agar and alginate [19].

2.3. Indoor macroalgae cultivation in the plastic photobioreactor

Two species of marine green macroalgae were cultivated for 2 months building integrated macroalgae photobioreactor described in ref. [20]. The selected species were *Cladophora* sp. collected from the Mikhmoret beach in Israel, and *Ulva rigida*, collected from Haifa, Israel. The biomass was manually sorted and then cultivated in custom made 40 L, 200 μm polyethylene sleeves (Politiv, Israel, length 100 m, thickness 200 μm, width 0.4 m) with embedded anti-UV protection. The cultivation was done in nutrient-enriched seawater under natural illumination from July to August 2016. Cultivation was continuously circulated with the exchange rates of 40–80 L h^{-1}. Mixing was done using an air column at 2–4 L min^{-1} air flow rate. Depending on specific sleeve location, illumination varied between reactors in the range of 238–348 μmol photons $m^{-2} s^{-1}$. Nutrients were supplied by adding ammonium nitrate (NH_4NO_3, Haifa Chemicals Ltd., IS) and phosphoric acid (H_3PO_4, Haifa Chemicals Ltd., IS) to maintain 6.4 g m^{-3} of nitrogen and 0.97 g m^{-3} of phosphorus in the cultivation media. Epiphytes were monitored daily and recorded by digital photography. Sleeves were manually cleaned with soap and bleach to remove the contaminating epiphytes from the system prior to cultivation.

2.4. Offshore macroalgae cultivation in net-cages

The cultivation was performed in the marine basin of the Tel Aviv Reading power station from December 2015 to February 2016 as described in ref. [21]. Biomass (40 g wet weight per reactor) was cultivated in thin layers (2 cm layer), separated by nets (TENAX Tubular nets for Mussel Breeding & Packaging Shellfish Polypropylene, mesh configuration – rhomboidal, 32 G 223 neutral. 74 N 140 green, Gallo Plastik, Italy).The cage (0.15 m × 0.3 m, total illuminated area 0.045 m^2) was built from polyethylene (PE) (D = 32 mm) and high density polyethylene (HDPE, D = 16 mm) pipes and a TENAX net (Gallo Plastik, Italy) to allow for full illumination while preventing access to grazers. The reactors were connected to ropes and kept at 5–20 m from the shore. Three cultivation reactors were used in this study. Daily growth rate (DGR) was calculated as in Eq. (1).

$$DGR = \frac{1}{N} \cdot \frac{m_{out} - m_{in}}{m_{in}} \cdot 100\% \tag{1}$$

N is the number of days between measurements, m_{out} are the WW (gr) measured at the end of each growth period, and m_{in} is the WW (gr) of the inoculum.

3. Results and discussion

3.1. Interaction of seaweed with its ecosystem and possible risk factors to seaweed crops

In this nutrient competitive marine ecosystem, seaweed with a solid surface, provides anchoring surface, carbon source, nitrogen, secondary metabolites and other beneficial additives to microorganisms [22,23] and other epibionts [24]. In addition, seaweeds provide habitat resource for seaweed-dependent multicellular organisms; as well as protecting them from environmental stresses and predators.

In nature, seaweeds are holobiomes [25]. Indeed, seaweed can host various microorganisms such as protista, fungi, bacteria, and viruses [26]. Additional epiphytes associated with seaweed can be microalgae and other seaweed species, which cover the seaweed surface resulting in its cloudy, thick and clustered appearance. Epibiota or epifaunal communities on seaweed also referred as 'phytal', are generally vertebrates, small to large grazers and other animals [27]. Majority of these species are not harmful to seaweed directly as it provides them food and shelter [27]; however, some of them can damage seaweed crop in industrial cultivation [28]. In this study, we are using the word epifauna to refer to certain animals that are important components of seaweed ecosystem and interact with seaweed directly or indirectly. In the following sections, we will provide an analysis of various interactions of seaweeds with organisms living in their environment.

3.1.1. Seaweed interaction with viruses

Viruses were shown to infect algal hosts with large double-stranded DNA. For example, marine brown macroalgae viruses latently occur in their host cells and are induced to multiply in response to a variety of external stimuli such as a change in light and temperature [28]. Recent genome research of *Ectocarpus siliculosus* showed that up to 50% of the natural algal population are infected by viruses [29]. This suggests that viruses have a potential to strongly influence seaweed lifestyle [30]. Further studies are needed to detect potential viral infections in commercial seaweed farming.

3.1.2. Seaweed interaction with fungi

Although there is very little reliable documentation of fungi associated with seaweeds (as far as we know), the majority of fungi associated with algae belong to the *Ascomycota* division or phylum of fungi and only a few conidial fungi are known [31,32]. As symbiotic bacteria, some fungi may play important role in seaweed biology [33], but fungi-algal interaction is generally complex and predominately shows pathogenicity or parasitism [32].

3.1.3. Seaweed interaction with bacteria

Probably the most investigated interactions so far are seaweed-bacteria interactions. As a favorable place for existence and reproduction [34], various biochemical and physical properties of seaweed surface play important role in bacterial communities by providing oxygen, nutrients, and habitat to grow on. For example, seaweed cell wall consists of various carbon-rich elements, which are a possible source of nutrients for bacterial species. This symbiosis of seaweeds and bacteria is possible probably because of the mutual benefits of these species in the competition for nutrients marine environment. Bacteria need seaweeds and seaweeds need bacteria.

Some bacterial species are essential for seaweed growth. These bacteria produce protective chemicals with antifungal activity [35], antiprotozoal [36], anti-settlement [37], antibiotic activity [38], and photosynthesis functions [39]. For example, epiphytic bacteria produce indole-3-acetic acid which acts as a growth hormone in seaweed [40,41]. In addition, epiphytic bacteria can provide many essential nutrients, vitamins such as vitamin B12 [42,43] to seaweed. Moreover, bacteria help in the settlement of seaweed spores [44,45], spore germination, and morphogenesis. For example, thallusin-producing [46] bacteria play a critical role in Ulva development [46,47]. Other bacteria produce Acyl Homoserine Lactones (ASL's), which are essential for Ulva's zoospore accumulation, and improve zoospore germination [48]. Additional examples include seaweeds that regulate associate bacteria activity by producing quorum-sensing inhibitors [49]. For example, seaweed bladderwrack, *Fucus vesiculosus*, produces fucoxanthin pigments which in high concentration show antifouling properties [50]. These natural capabilities of seaweed to regulate their epibiota [51] could be used in the future to develop strategies to protect seaweeds crops from bacterial infections.

Except for the bifacial role that bacteria plays in seaweed lifestyle, the bacteria play an important role in many seaweed diseases [22]. For example, the algal diseases could happen due to bacterial digestive enzymes that degrade the algal cell wall [22]. In addition, bacteria can produce toxins [52] and inhibitors of seaweed development [53]. During the disease, the number of bacteria increases dramatically, leading to the rapid collapse of the seaweed crop culture [54].

Additional problems with bacteria arise from biofilms. Bacterial biofilms start the colonization process by creating a microenvironment that is more favorable for biofouling species as it enhances the attachment of fouling organisms that may be pest or parasites [55]. Biofilms also cause reduction of the light transmission to the seaweed [56] and reduction of gaseous exchange [57,58], which are responsible for the death or adverse impact on crop's yield.

3.1.4. Seaweed crop interaction with epiphytic algae

Besides bacteria, fungi, and viruses, other epiphytic organisms in seaweed culture are algal species that include marine microalgae, filamentous algae, and other seaweed species. Although microalgae, phytoplankton, are not directly responsible for any known harm to seaweed, in high density they can compete for the nutrients [59]. The filamentous algae are one of the most preferred food in marine environment [60], so it can easily attract grazers if present with the seaweed crop. However, few filamentous algal species are responsible for the diseases in the seaweed [13].

The interaction of seaweed crops with other seaweed species is primarily for the use the surface of the host seaweed for the attachment and growth as shown in (Fig. 1A, B, and D). However, this attachment can be harmful to host seaweed directly or indirectly in many ways. If epiphyte problem outbreaks frequently, it can reduce the quantity of seaweed in production with drop down seaweed product quality and increase the possibility of disease [13]. The direct injuries to the host plant due to penetration of anchor of an epiphytic seaweed can result in diseases to or death of the host. In addition, almost all epiphytes attract many grazers that feed on them and on the host leading to additional yield reduction.

3.1.5. Seaweed interaction with animals

Physical and biological factors such as temperature, predation pressure, competition, availability of epiphytes, and productivity impact epifauna activity [61]. The morphological complexity of seaweed, the presence of specific epiphytes are the preferable places for few faunal species because it provides them habitat and protection [62]. Although many of the epifaunal organisms feed on decaying matter or other fauna, few species directly feed on seaweed crops and must be controlled [63].

These epifaunal species includes diverse kinds of invertebrates, a small crustacean, fish, turtles, and birds, which get benefits from seaweed and its epiphytes. As seaweeds are primary producers in this ecosystem, many marine herbivores dependent on them either on them directly or on the epiphytes present on the body of seaweed. Although few amphipods reduce epiphytic biomass from the seaweed *Sargassum filipendula* [64], many species of crustaceans reduce the seaweed biomass itself [65].

The examples of various epibiota on the seaweed are summarized in Fig. 1. It is included the epiphytes found the places on the same species (Fig. 1A) and different species (Fig. 1B) and the impact of epiphytic bacteria on the seaweed (Fig. 1C and E).

3.2. Herbivorous fishes damaging the commercial Kappaphycus alvarezii farming in India

In last few decades, the commercial seaweed farming of *Kappaphycus alvarezii* has started in the coastal part of southern India. Although several methods are available for *Kappaphycus alvarezii* cultivation, bamboo raft method is most commonly used in India [66] shallow water farming for its low initial capital investment (Fig. 2A). It is constructed from locally available materials such as bamboos, ropes and is efficient for multiple cultivation cycles. However, coral reefs, warmer water, lack of shadow and lack of other food, such as seagrass or non-crop seaweeds, attracts grazers, mostly fish, to the farming area. Although the farmers use nets on the bottom of the rafts, these nets protect the crop only from the large fish. Smaller herbivore fish (Fig. 2B), such rabbitfish, are the main grazers in the cultivation area, which are responsible for the heavy loss of crop (Fig. 2C). The fingerlings of herbivore fish found in August–September after the breeding season, graze in droves and easily pass through the net and graze the crop (Fig. 2D).

3.3. Example of protection strategy and damages from herbivorous fishes in offshore Ulva sp. cultivation in Israel

During one month of *Ulva* sp. cultivation in cages (Fig. 3A–C) with no protection, the average DGR was negative at $-2.5 \pm 1.9\%$. Fig. 3D [21] shows the digital images of *Siganus rivulatus*, species known to include *Ulva* sp. in its diet in Eastern Mediterranean [67], found in the cultivation cage. To avoid grazing by fish, the double net structure of the cultivation cage was used (Fig. 3E, F). The addition of the protecting net led to the DGR of $8.1 \pm 6.1\%$.

3.4. Seaweed inoculation density used to protect from epiphytes in closed indoor cultivation systems inside plastic photobioreactor

The method for reduction epiphytes growth by cultivation at high densities of seaweed crop outdoors was proposed in 1979 [68]. In the closed recirculated system tested in this work, low density of inoculums (m_{in}11.5 g) with seaweed collected from the sea, the reactors were contaminated with epiphytes (Fig. 4B). At these contaminated reactors, we found another seaweed (Fig. 1D, F), nematodes (Fig. 1G), copepods (Fig. 1H, I) and bacteria (Fig. 1J). Under these conditions, the culture collapsed. The high density of inoculums (m_{in}179–264 g), (Fig. 4A) led to the DGR of up to 15%; no significant epiphytes were detected in those reactors.

This phenomenon could be explained by light umbrella theory [68], as follows:

"*a multi-layered seaweed community is guarded against epiphytes by*

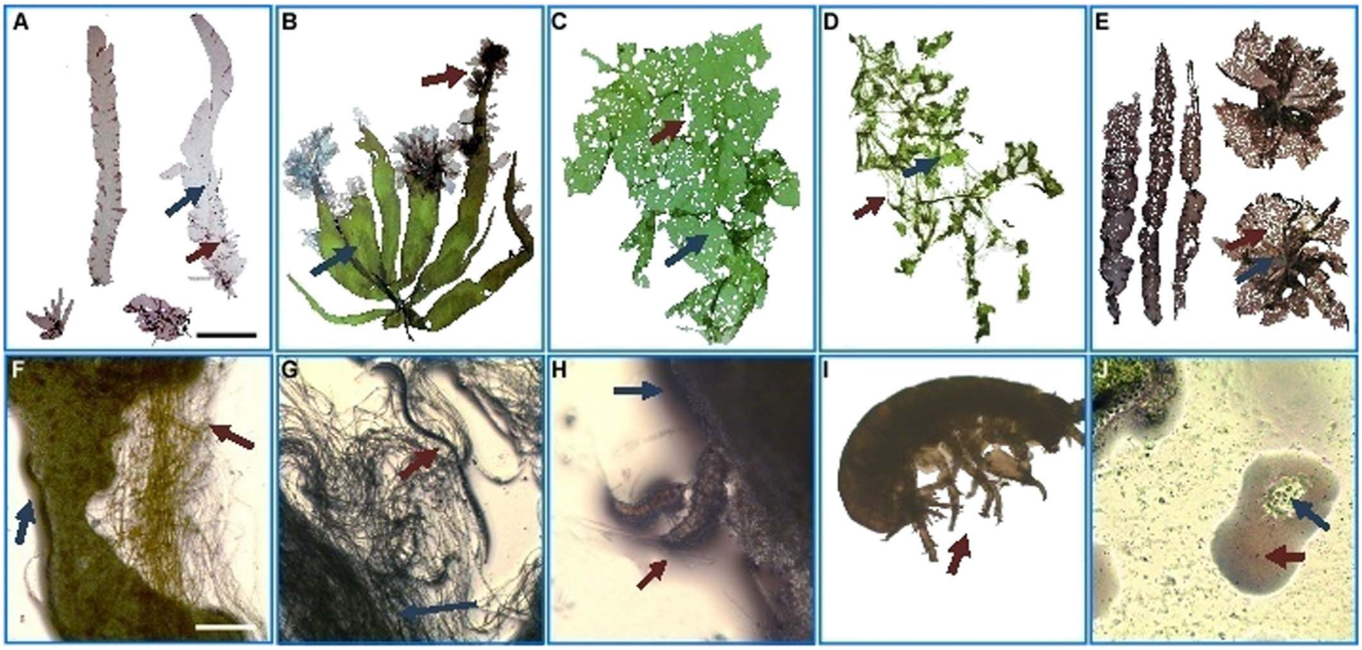

Fig. 1. Epibiota associated with seaweed. Blue arrows - host seaweed. Red arrows - epibiotic organism. A. **Host** - *Porphyra* sp. from Taiwan, fromtank cultivation. **Epiphyte** - young *Porphyra* of the same species, scale bar: 45 mm. B. **Host** - *Spatoglossum salieri*, from Rosh-Hanikra reef, Israel. **Epiphyte** - *Porphyra linearis*. Scale bar: 43 mm. C. **Host** - *Ulva* sp., tank cultivation, destruction of thalli after a sharp warming. **Epiphyte** - bacterial destruction. Scale bar: 26 mm. D. **Host** - *Ulva rigida* from Haifa, Israel, grown in the offshore system in a net cage. **Epiphyte** - *Ulva compressa*. Scale bar: 362.5 mm. E. **Host** - *Porphyra linearis*, **Epiphyte** - the bacterial destruction of thalli at the end of the cultivation season (due to water warming), scale bar: 41 mm. F. Magnification of host and epiphyte same as in D, scale bar: 0.59 mm. G, H, I. **Host** - sameas in photo D. **Epifauna** - Nematode and Copepods. Scale bar: 0.62 mm, 0.22 mm and 71 μm respectively. J. **Host** - *Ulva rigida*. **Epiphyte** - *Alteromonas* sp. grown on agar petri dish, around of the cut *Ulva* sp. fragment. Scale bar: 40 μm. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

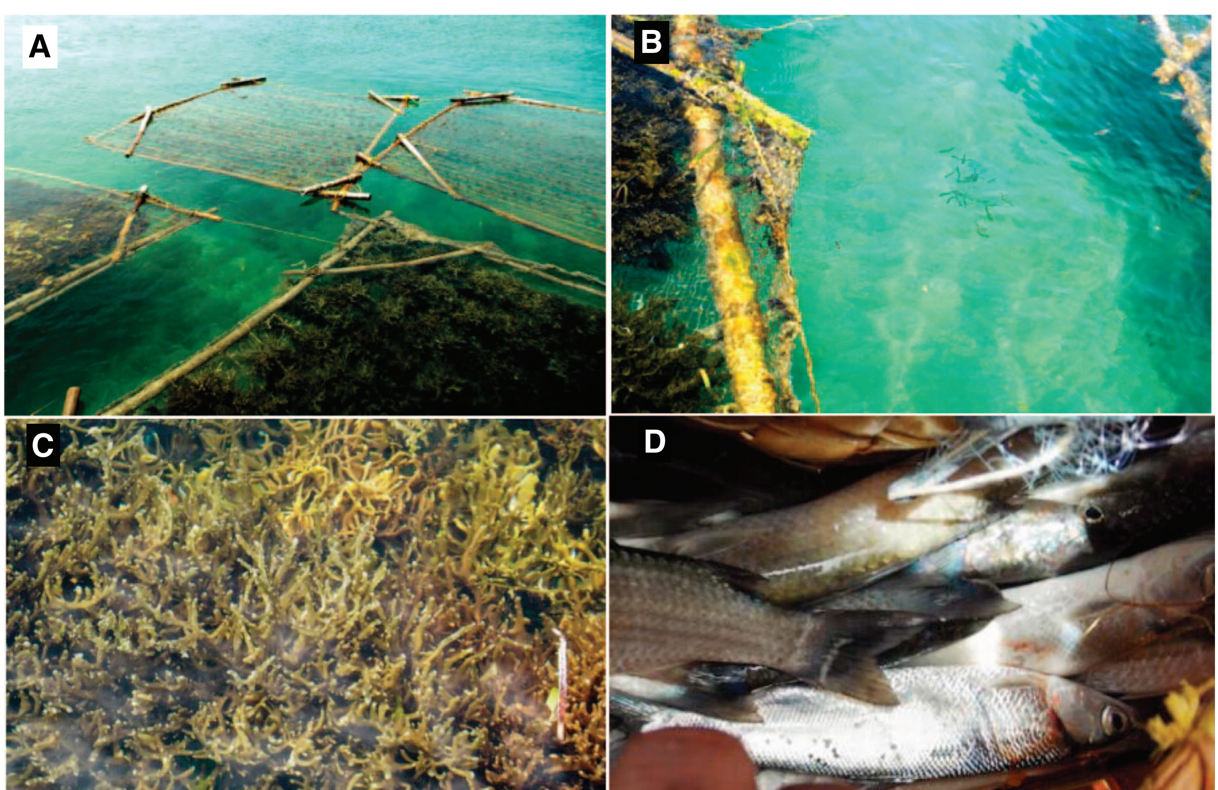

Fig. 2. The impact of grazers in the cultivation of Indian seawater. A. The bamboo raft used for the seaweed cultivation in which net is used in each raft for protection from grazing. B. Fingerlings of herbivores fish can easily move through the net of the rafts. C. *K. alvarezii* seaweed after grazed by fingerlings. D. Herbivore fishes.

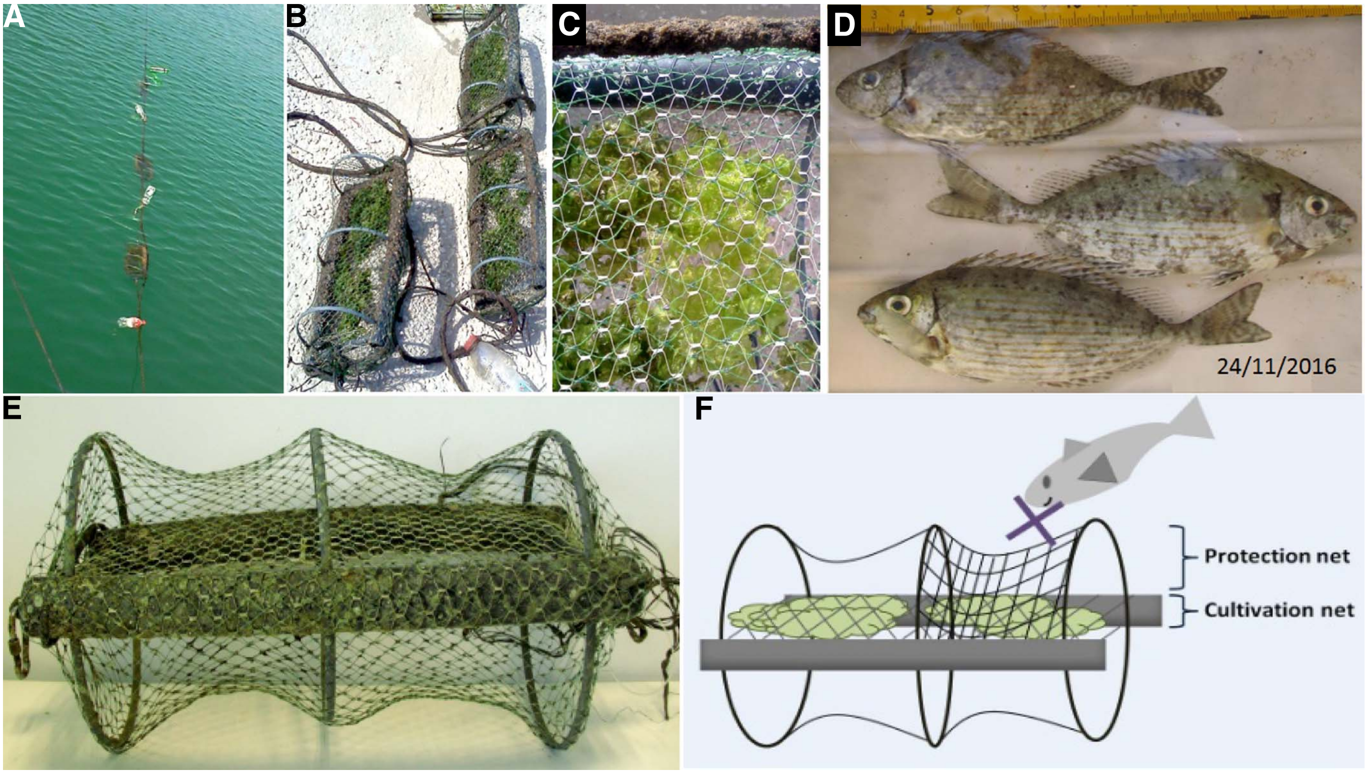

Fig. 3. *Ulva* sp. cultivation at Tel Aviv, Israel. Grazers and protection systems. A. Offshore cultivation system for *Ulva* sp. cultivation. Three cages, designed with two layers of net. B·*Ulva* sp. harvested from the seain the three cages. C. Special net design to prevent the crop runoff. D. Digital images of fish found in the cultivation riding cages. E. One cage included two nets system, internal net pore sizes 15 mm x15mm, external net pore sizes 13 mm × 13 mm. The cage sizes: (40 cm × 20 cm, Ø = 18 cm). Addition of the external net provided to prevent the biomass loss. Without the second net, the fish grazed the biomass. F. Illustration of the two net cages, one net is for seaweed runoff prevention, the second net is for protection from fish.

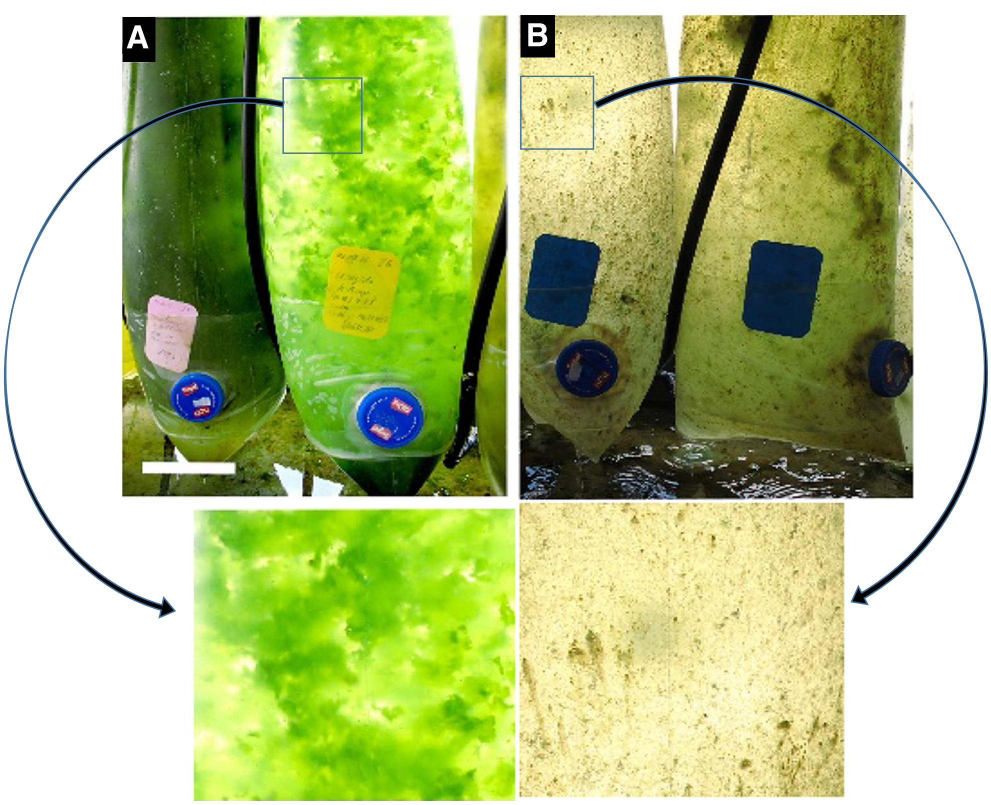

Fig. 4. Seaweed crop protection from epiphytes by inoculum density. A. Two 40 L reactors include non-contaminated seaweed. The left reactor was inoculated with 179.3 g (WW) of *Cladophora* sp. Right reactor was inoculated with 264.77 g. (WW) of *Ulva rigida*. B. Two 40 L reactors with contaminated seaweed. The left reactor was inoculated with 11.5 g. of *Cladophora* sp. Right reactor-was inoculated with 11.5 g. (WW) of *Ulva rigida*. Scale bar for A and B: 95.2 cm and magnification in boxes showing with scale bar 40.5 mm.

high-density cultures, which act as a _light umbrella_. In natural populations, these plants are shielded from excess irradiance often by larger algae, e.g., by the kelp canopy. The method of reducing the growth of epiphytes by cultivation at high densities was first developed by Ryther et al. (1979)" [68].

This literature background and field studies clearly show that there is a need for the strategy to manage epiphytes and epifauna in the seagriculture. In the following section, we propose a strategy for marine pest management.

3.5. Proposed marine integrated pest management (MIPM) framework

3.5.1. The definition of 'pests'

According to the International Plant Protection Convention (IPPC), the term *pest* means 'any species, strain or biotype of plant, animal, or pathogenic agent, injurious to plants or plant products' [69]. As seagriculture is mostly done in rural areas by low-income farmers, the problem of pests in this industry is not widely addressed. According to the IPPC definition, the pathogenic bacteria, fungal infection, epiphyte types that penetrate into the tissues of host seaweed, seaweed grazers, can be considered as a pest in seagriculture.

We suggest to define the term '*pests*' in seagriculture as, 'any species, strain or biotype of plant, animal, or pathogenic agent, potentially harmful or injurious directly or indirectly to cultivated seaweed or its products'. Here the word 'harmful' refers to responsible for any adverse impact on the growth rate, quality and quantity of seaweed crop, and the word 'injurious' means any physical damage to seaweed plant, which gets injured by the pests. The word 'directly or indirectly' referred, whether the seaweed is the target of certain pests directly or not. In Fig. 5 we mapped the potential pests in seagriculture according to the suggested definition.

The possible examples of pests in seagriculture are shown in Table 1.

3.5.2. Framework for the risk assessment and risk management criteria

To address the problem of pest management in seagricultre, we propose the following marine integrated pest management (MIPM). The proposed framework is divided into six sections as shown in Fig. 6. The continuous monitoring is expected at every stage of the proposed MIPM cycle. The establishment of a knowledge base (Section 1) is the primary task in the field of MIPM, followed by an inspection and risk assessment primarily to the cultivation (Section 2), followed by prevention (Section 3), control (Section 4), intervention and mitigation (Section 5), evaluation and record keeping (Section 6).

3.5.2.1. Section 1 - knowledgebase. The establishment of a knowledge base is a crucial task that includes the knowledge of the seaweed crop, the seasonal production, favorable conditions, possible environmental risks, and possible pests available in the cultivation area. It should also include the information and knowledge about the natural enemies of the pests, their availability and abundance, crop life cycle and lifespan, all known risks to the cultivated crop, including the market and possible environmental impacts due to the cultivation.

To establish a knowledge base, it is necessary to get the following information for each cultivation site:

- The selection of suitable species. The species should be resistant to the seasonal changes and known diseases.
- The life cycle of a specific crop, its genetic sequences, methods of cultivation, possible association with other species, and general practices those are in use to minimize the pests and possible diseases.

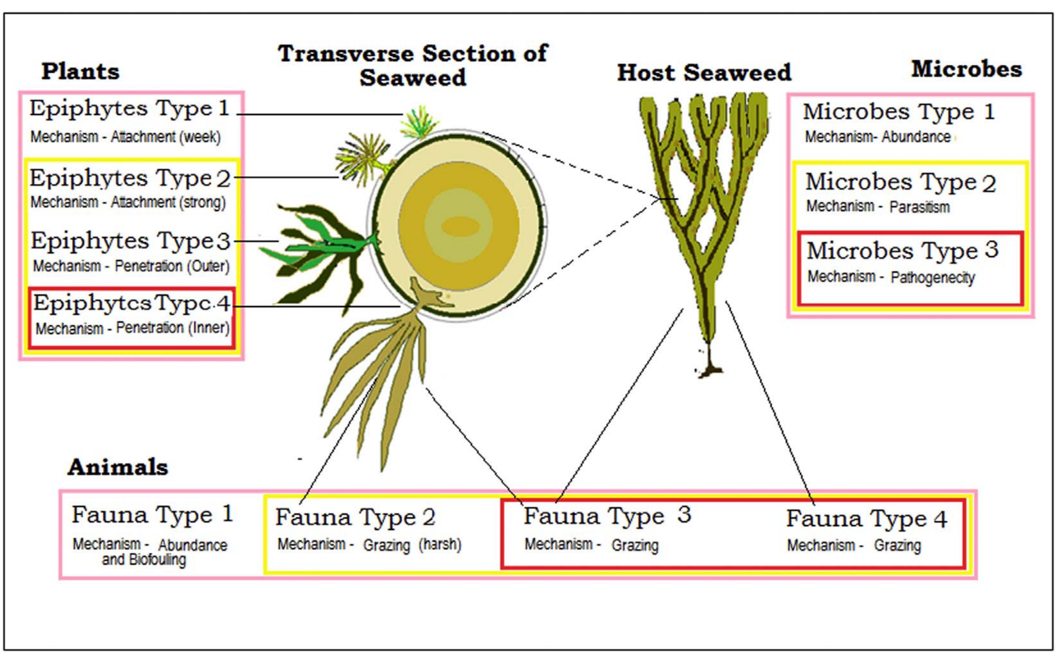

Fig. 5. Categorization of pests in seagriculture. Red boxes show the types of epibiota, which can be responsible for the direct damage to seaweeds. These can be considered as pests as per IPPC's definition. The yellow boxes show the possible pests after modification in the IPPC definition by adding the word 'directly or indirectly'. Finally, the pink brackets show the possible pests after the modification of the word 'injurious' to 'potentially harmful or injurious' in the IPPC definition of pest. Microbes type 1 - responsible for the adverse impacts on the growth of seaweed by competition for light. Microbes type 2 - shows parasitism with seaweed and become responsible for harm to seaweed. Microbes type 3 – shows pathogenicity to seaweed and can be responsible for injuries and diseases in seaweed. Fauna type 1 – shows no direct harmful mechanism such as surface grazing or biofouling or abundance in the seaweed ecosystem and may responsible for the possible harm indirectly. Fauna type 2 – shows harsh grazing of epiphytes may be responsible for the indirect injuries to seaweed. Fauna type 3 - shows grazing of epiphytes and seaweed crop both and responsible for direct injuries to the seaweed. Fauna type 4 - shows grazing of seaweed crop. The cross-section of host seaweed is showing the level of epiphytes penetration in the tissues of the host plant. Epiphyte type 1 - attaches weakly to the surface of host plant but do not show any injury but can be harmful indirectly. Epiphyte type 2 - attaches strongly to the surface of host and can be responsible for the indirect harms and injuries to the host plant. Epiphyte type 3 - bleaches the deck-lamella and penetrating the outer layer of the host's cell wall, surely responsible for injuries to host indirectly. Epiphyte type 4 - penetrates deck-lamella and an outer layer of the host's cell wall with a direct injury. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Table 1
Potential damages to seaweed crops from pests.

Type of pest	Mechanism of pest	Seaweed	Pests	Type of damage	Study area	Study year	Ref.
Microbes type 1	*Abundance*	*General seaweeds*	Epiphytic diatoms	Cover the seaweeds	Iceland	2005	[70]
Microbes type 2	*Parasitism*	*Kappaphycus alvarezii*	Filamentous red algae, *Alteromonas* sp., *Flavobacterium* sp. and *Vibrio* sp.	Goose-bump like structure, formation of pit, infection can lead to disease	Philippines, Indonesia, Malaysia, Tanzania	2005–2006	[13]
Microbes type 3	*Pathogenecity*	*Kappaphycus alvarezii* and *K. striatum*	*Aspergillus ochraceous, A. terreus*	Potential for the ice-ice disease	Philippines	2007	[71]
Epiphytes type 1	*Week attachment*	*Laminaria hyperborea* (*Gunn.*) *Fosl.*	*Palmaria palmata, Ptilota plumosa, Membrano ptera alata, Phycodrys Rubens*	Covers the seaweed totally	United Kingdom	1968–1969	[72]
Epiphytes type 2	*Strong attachment*	*Gracilaria gracilis*	*Chaetomorpha* sp., *Antithamnion densum, Acrochaetium* sp.	Strongly attached epiphytes	Argentina	2006–2008	[73]
Epiphytes type 3	*Outer penetration*	*Acrochaete heteroclada*	*Choundruscriospus*	Penetrates the host but not harmful directly	Canada	1990	[74]
Epiphytes type 4	*Inner penetration*	*Gracilaria tikvahiae*	*Ulva lactuca*	Penetrates in the cortex and harm to cortical tissues	United States	2000	[75]
Fauna type 1	*Grazing (surface)*	*Laminaria species*	Sea-snail *Lacuna vincta*, sea urchin *Strongylocentrotus droebachiensis*	Surface grazing, not specific harm but attract to another animal	Canada	1985	[76]
Fauna type 2	*Grazing of epiphytes (harsh)*	*Macrocystis pyrifera*	*Oxyjulis californica*	Damage to blades of seaweed due to harsh grazing	United States	1979	[77]
Fauna types 3	*Grazing (epiphytes and seaweed)*	*Ulva* sp.	*Gammarus*	In low nutrients condition, Gammarus sp. prefer to feed on *Ulva* sp.	Netherlands	1995	[78]
Fauna type 4	*Grazing (seaweed)*	*Chondrus crispus*	*Gammarus oceanicus, Idotea baltica, Lacuna vincta*	Damage to tissue	Canada	1981	[63]

- The current ecosystem in that area, dominant species of epiphytes and grazers.
- The accepted level of pests, and their impacts on cultivation and environment.
- Target and non-target species, their life cycles, dependency on each other, possible links to diseases.
- Possibility of pests and disease forecasting techniques, the use of non-chemical methods and management practices.
- Possible risk identification to crops from environmental factors and from crops to the environment.

3.5.2.2. Section 2 - inspection and assessment

Inspection is the primary step of assessment of any new set up for the cultivation of seaweed in which the possible pests risk should be characterized by its potential and frequency. The basic level of this step is to set the goals and find the management options to tackle the pest problem. The general information required about the questions at this stage is shown in the Supplementary Table 1. An inspecting team, a monitoring team, and an assessment team should know the best environment required for seaweed, actual environment of the site and suggest the required actions. Assessment of possible pest problem should be characterized performed after the inspection. It should consist of observed types, nature, availability, and distribution of pests. It should also include the length of the crops exposure to pests, crop doze response to the pest and end-point effect. The success of this step depends on the availability of data, resources invested to complete the assessment, and accuracy of the risk analysis.

3.5.2.3. Section 3 - prevention. Importantly, the successful removal or reduction of epiphytes during nursery stage can prevent further growth and large-scale infection at the cultivation site. It is found that the in case of lacking fresh seawater and ammonium sources, in tank culture of *Gracilaria conferta*, the epiphytic biomass decreases [79].

The selection of cultivation sites, suitable seaweed species, inspecting and monitoring seawater quality, and seasonal changes can prevent pests. Cleaning and removal of debris from the bottom of cultivation site mechanically can limit the number and diversity of epiphytic species. The use of healthy seedling for the cultivation and their maintenance in clean tanks can reduce the epiphytic outbreaks [13].

Crop rotation, fallow, availability of a trap crop, intermediate crop are all the possible strategies generally used in IPM of terrestrial agriculture that can be effective in seagriculture to reduce pests without harm to the ecosystem. The trap crops are the plants which are cultivated with the main crops to attract the pests toward them from the main crop [80]. For example, in terrestrial agriculture, marigold or cucumber is cultivated as a trap crop in the tomato farming [81]. Although dense cultivation of seaweed can minimize the risk of epiphytes, it can create a shadow to the large areas of the sea and adverse environmental impacts. However, a contradictory effect is very relevant in large-scale cultivation, while dense cultivation can higher the risk of a disease outbreak [26]. In a dens cultivation, the disease could spread faster. Also, the common practice of using ropes on the surface of seawater to which the seaweed is attached is favorable for epiphytes to grow and for many animals to move freely in the cultivation area.

3.5.2.4. Section 4 - control. There is a lack of commercially available pesticides that can be used in the seaweed cultivation, particularly near shore or offshore environment [82]. Although multiple environmental limitations must be taken into consideration, some chemicals such as copper in low level can be applied for the onshore cultivation or nursery level [83] for control of certain epiphytes [82].

Pest control in early colony forming stage at the nursery is the most important control step, as without it contamination can be propagated to the large-scale. Indeed, nurseries can serve as the collection units or species banks. For example, pollution prevention is suggested for *polyphonic* epiphytes and bacterial infections to *Kappaphycus* sp.

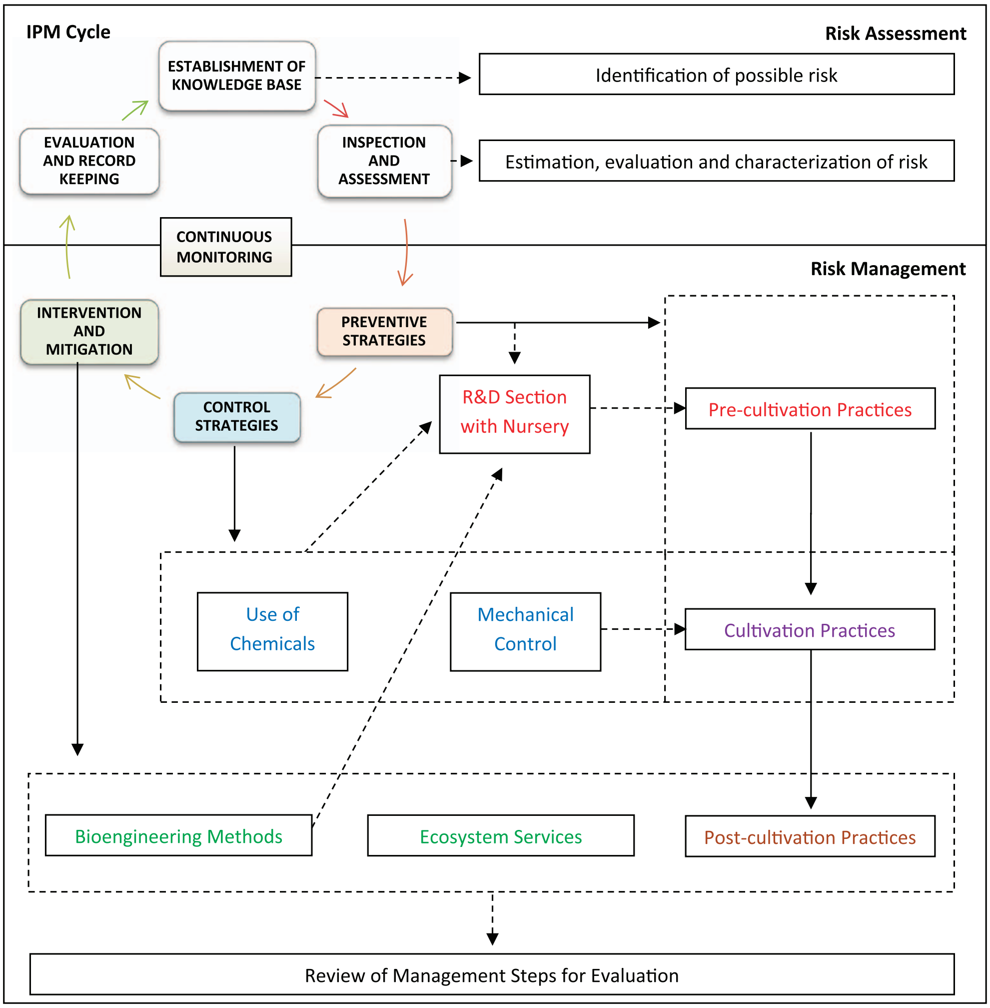

Fig. 6. Marine integrated pest management (MIPM) framework for the seagriculture.

cultivation [84].

Cultivation method also impacts the quality of seaweed product and increases its growth rate, limiting the potential damage from pests. For example, vegetative fragmentation and tissue culture methods were compared [85] for growth rate and quality of agar of Gelidiella. In the cultivation of Gracilaria, it is found that the cultivation period [86] and spore culture method [87] are most important factors to control its epiphytes.

Mechanical control is simple but is labor intensive that is effective to control large pests. There are few reports related to mechanical control of pests in seagriculture in tanks such as intensive water filtration and multiple water exchange [83]. Nutrient control, for example, nitrogen limitation [79], is another strategy to prevent pests but it also found that the one of the dominant grazers '*Gammarus*' shows higher grazing on epiphytes of *Ulva* sp. under the high nutrient condition [78]. In addition, avoiding farming at the dominant grazer breeding season can prevent large-scale damages to the seaweed crops.

3.5.2.5. Section 5 - intervention and mitigation. The overall objective of intervention and mitigation step is to nullify 1) the impacts of seaweed farming on the environment and 2) pest impact on seaweed. This could be achieved by a development of supporting ecosystem services. This step should provide the knowledge for better management, conservation, and rehabilitation of the ecosystem, with mitigating the resource degradation. For example, the dominant epiphytes can be managed with amphipods and grazers, which feed on them [64]. In an additional example, the development of associated bacteria with symbiotic relation with seaweed could enable better growth and development [47]. The use of such bacteria in the nursery level of seaweed can improve the quality of the crop.

The collaboration with local fishermen and fishing agencies will be helpful to get the knowledge if any initial outbreaks of epiphytes. This can encourage the monitoring team and save the further loss in yield.

There should be a special arrangement for monitoring the weather forecast to mitigate possible damage due to any sudden environmental risk such as hurricane, cyclone, high-tide, hailstorm etc.

3.5.2.6. Section 6 - evaluation and record keeping. The review of all steps followed in the risk management is the primary step of evaluation and record keeping. The evaluation process should include the success and failure of each step of MIPM and all management practices to tackle the pest problem with definite objectives. For example, while evaluating the term of 'site selection' for cultivation in 'pre-cultivation practices', the success and failure of the selected site should be discussed with the objective of establishing the 'criteria for the site selection'.

There are few possibilities to convert the records after evaluation into the knowledge base.

- Establishment of discussion forum to share the research updates and latest knowledge in this area by the researchers, research institutes, governmental bodies working in this area.
- Establishment of network or website to share the ideas, views, suggestions, prevention-control and mitigation measures into all farmers and all people that are related to this field. We are here suggesting developing webpages on social media devoted to this work can be utilized as a platform to share the knowledge in this

area. The sharing of records will get information about the behavior of a specific type of pest in specific seaweed cultivation in specific season and environmental conditions.

- The industries that use seaweeds as a raw material can take efforts in the implementation of MIPM by creating awareness in the farmers through regular visits, seminars, and workshops. This can promote the sustainability, consistency, quality, and quantity of the raw material.
- Establishment of large-scale cultivation facilities, including the seedlings preparation in a large case, development of seaweed breeding program, seaweed genebank can be useful techniques in case of failure.

4. Conclusions

Although the annual production of seaweed biomass doubled in the last decade, very little attention has been paid to the pest management issues of seagriculture. Because of the fragility of the marine environment, it is almost impossible to use pest control chemical methods as done today in commercial agriculture. Besides few separate studies, there has been no attempt to provide a universal framework for pest management in seagcriculture. To address this problem, in this work, we proposed the expansion of the IPM approach to the marine environment - the framework we coin MIPM. MIPM provides a framework to increase seaweed crops yields with reduced environmental impact. Therefore, MIPM framework could provide a tool for seaweed farmers, industry and policy-makers for sustainable seagriculture in the coming years.

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KNI developed the approach, conducted a field visit, analyzed the data and drafted the paper, MP analyzed the data and drafted the paper, AC analyzed the data and drafted the paper, AG analyzed the data and drafted the paper.Conflict of interest statement

All authors declare no conflict of interest.Statement of informed consent, human/animal rights

No conflicts, informed consent, human or animal rights applicable.

References

[1] Y. Lehahn, K.N. Ingle, A. Golberg, Global potential of offshore and shallow waters macroalgal biorefineries to provide for food, chemicals, and energy: feasibility and sustainability, Algal Res. 17 (2016) 150–160.
[2] R. Jiang, K.N. Ingle, A. Golberg, Macroalgae (seaweed) for liquid transportation biofuel production: what is next? Algal Res. 14 (2016) 48–57.
[3] D.J. McHugh, A guide to the seaweed industry, FAO Fish. Tech. Pap. (2003) 105.
[4] S. Kraan, Mass-cultivation of carbohydrate rich macroalgae, a possible solution for sustainable biofuel production, Mitig. Adapt. Strateg. Glob. Chang. 18 (2013) 27–46.
[5] A.D. Hughes, M.S. Kelly, K.D. Black, M.S. Stanley, Biogas from macroalgae: is it time to revisit the idea? Biotechnol. Biofuels 5 (2012) 86.
[6] N. Wei, J. Quarterman, Y.-S.S. Jin, Marine macroalgae: an untapped resource for producing fuels and chemicals, Trends Biotechnol. 31 (2013) 70–77.
[7] A.J. Smit, Medicinal and pharmaceutical uses of seaweed natural products: a review, J. Appl. Phycol. 16 (2004) 245–262.
[8] M.S. Kelly, Dworjanyn, The Potential for Marine Biomass for Anaerobic Biogas Production, The Crown Estate, 2008.
[9] A.H. Buschmann, et al., Seaweed production: an overview of the global state of exploitation, farming, and emerging research activity, Eur. J. Phycol. 52 (2017) 391–406.
[10] E.J. Cottier-Cook, et al., Safeguarding the Future of the Global Seaweed Aquaculture Industry, (2016), p. 12 (doi:ISBN 978-92-808-6080-1).
[11] F. Fernand, et al., Offshore macroalgae biomass for bioenergy production: environmental aspects, technological achievements, and challenges, Renew. Sust. Energ. Rev. (2016), http://dx.doi.org/10.1016/j.rser.2016.10.046.
[12] K. Yamamoto, H. Endo, S. Yoshikawa, K. Ohki, M. Kamiya, Various defense ability of four sargassacean algae against the red algal epiphyte Neosiphonia harveyi in Wakasa Bay, Japan, Aquat. Bot. 105 (2013) 11–17.
[13] C. Vairappan, et al., Distribution and symptoms of epiphyte infection in major carrageenophyte-producing farms, J. Appl. Phycol. (2007), http://dx.doi.org/10.1007/978-1-4020-9619-8.
[14] A.Q. Hurtado, A.T. Critchley, A. Trespoey, G. Bleicher Lhonneur, Occurrence of polysiphonia epiphytes in Kappaphycus farms at Calaguas Is., Camarines Norte, Philippines, J. Appl. Phycol. 18 (2006) 301–306.
[15] D.B. Largo, K. Fukami, T. Nishijima, M. Ohno, Laboratory-induced development of the ice-ice disease of the farmed red algae *Kappaphycus alvarezii* and *Eucheuma denticulatum* (Solieriaceae, Gigartinales, Rhodophyta), J. Appl. Phycol. 7 (1995) 539–543.
[16] L. Ehler, Integrated pest management (IPM): definition, historical development and implementation, and the other IPM, Pest Manag. Sci. 62 (2006) 787–789.
[17] D.B. Ahuja, U.R. Ahuja, S.K. Singh, N. Singh, Comparison of integrated Pest management approaches and conventional (non-IPM) practices in late-winter-season cauliflower in Northern India, Crop Prot. 78 (2015) 232–238.
[18] R.F. Smith, J.L. Apple, D.G. Bottrell, The origins of integrated pest management concepts for agricultural crops, Integrated Pest Management, 1976, pp. 1–16.
[19] K. Ingle, et al., Macroalgae biorefinery from *Kappaphycus alvarezii*: conversion modeling and performance prediction for India and Philippines as examples, Bioenergy Res. (2017), http://dx.doi.org/10.1007/s12155-017-9874-z.
[20] A. Chemodanov, A. Robin, A. Golberg, Design of marine macroalgae photobioreactor integrated into building to support seagriculture for biorefinery and bioeconomy, Bioresour. Technol. 241 (2017) 1084–1093.
[21] A. Chemodanov, et al., Net primary productivity, biofuel production and CO_2 emissions reduction potential of *Ulva* sp. (Chlorophyta) biomass in a coastal area of the Eastern Mediterranean, Energy Convers. Manag. 148 (2017) 1497–1507.
[22] F. Goecke, Labes, J. Wiese, J. Imhoff, Chemical interactions between marine macroalgae and bacteria, Mar. Ecol. Prog. Ser. 409 (2010) 267–299.
[23] F. Goecke, V. Thiel, J. Wiese, A. Labes, J.F. Imhoff, Algae as an important environment for bacteria-phylogenetic relationships among new bacterial species isolated from algae, Phycologia 52 (2013) 14–24.
[24] M. Wahl, Marine epibiosis. I. Fouling and antifouling: some basic aspects, Mar. Ecol. Prog. Ser. 58 (1989) 175–189.
[25] S.M. Dittami, D. Eveillard, T. Tonon, A metabolic approach to study algal-bacterial interactions in changing environments, Mol. Ecol. 23 (2014) 1656–1660.
[26] C.M.M. Gachon, T. Sime-Ngando, M. Strittmatter, A. Chambouvet, G.H. Kim, Algal diseases: spotlight on a black box, Trends Plant Sci. 15 (2010) 633–640.
[27] N.A.N.U.V. Anitchanant, Variation in Epifauna Community and Epiphyte Cover Among Marine Algae, (2013).
[28] M. Kapp, Viruses infecting marine brown algae, Virus Genes 16 (1998) 111–117.
[29] J.M. Cock, et al., The *Ectocarpus* genome and the independent evolution of multicellularity in brown algae, Nature 465 (2010) 617–621.
[30] S. Egan, et al., The seaweed holobiont: understanding seaweed–bacteria interactions, FEMS Microbiol. Rev. 37 (2013) 462–476.
[31] C.P. Loque, et al., Fungal community associated with marine macroalgae from Antarctica, Polar Biol. 33 (2010) 641–648.
[32] A. Zuccaro, et al., Detection and identification of fungi intimately associated with the brown seaweed *Fucus serratus*, Appl. Environ. Microbiol. 74 (2008) 931–941.
[33] C. Raghukumar, Algal-fungal interactions in the marine ecosystem: symbiosis to parasitism, Recent Adv. Appl. Asp. Indian Mar. Algae With Ref. to Glob. Scenar, 1 2006, pp. 366–385.
[34] E.T. Englebert, C. McDermott, G.T. Kleinheinz, Effects of the nuisance algae, Cladophora, on *Escherichia coli* at recreational beaches in Wisconsin, Sci. Total Environ. 404 (2008) 10–17.
[35] A. Franks, et al., Inhibition of fungal colonization by *Pseudoalteromonas tunicata* provides a competitive advantage during surface colonization, Appl. Environ. Microbiol. 72 (2006) 6079–6087.
[36] C. Matz, et al., Marine biofilm bacteria evade eukaryotic predation by targeted chemical defense, PLoS One 3 (2008) e2744.
[37] S. Egan, S. James, C. Holmström, S. Kjelleberg, Inhibition of algal spore germination by the marine bacterium Pseudoalteromonas tunicata, FEMS Microbiol. Ecol. 35 (2001) 67–73.
[38] M.L. Lemos, A.E. Toranzo, J.L. Barja, Antibiotic activity of epiphytic bacteria isolated from intertidal seaweeds, Microb. Ecol. 11 (1985) 149–163.
[39] L. Delbridge, J. Coulburn, W. Fagerberg, L.S. Tisa, Community profiles of bacterial endosymbionts in four species of Caulerpa, Symbiosis 37 (2004) 335–344.
[40] R.P. Singh, A.J. Bijo, R.S. Baghel, C.R.K. Reddy, B. Jha, Role of bacterial isolates in enhancing the bud induction in the industrially important red alga Gracilaria dura, FEMS Microbiol. Ecol. 76 (2011) 381–392.
[41] R.P.R. Singh, V.A. Mantri, C.R.K. Reddy, B. Jha, Isolation of seaweed-associated bacteria and their morphogenesis-inducing capability in axenic cultures of the green alga Ulva fasciata, Aquat. Biol. 12 (2011) 13–21.
[42] M.T. Croft, M.J. Warren, A.G. Smith, Algae need their vitamins, Eukaryot. Cell 5 (2006) 1175–1183.
[43] M.T. Croft, A.D. Lawrence, E. Raux-Deery, M.J. Warren, A.G. Smith, Algae acquire vitamin B12 through a symbiotic relationship with bacteria, Nature 438 (2005) 90–93.
[44] K. Tait, et al., Disruption of quorum sensing in seawater abolishes attraction of zoospores of the green alga Ulva to bacterial biofilms, Environ. Microbiol. 7 (2005) 229–240.

[45] I. Joint, M.E. Callow, J.A. Callow, K.R. Clarke, The Attachment of Enteromorpha Zoospores to a Bacterial Biofilm Assemblage, (2000).
[46] Y. Matsuo, H. Imagawa, M. Nishizawa, Y. Shizuri, Isolation of an algal morphogenesis inducer from a marine bacterium, Science 307 (2005) 1598.
[47] T. Wichard, et al., The green seaweed Ulva: a model system to study morphogenesis, Front. Plant Sci. 6 (2015) 72.
[48] I. Joint, K. Tait, G. Wheeler, Cross-kingdom signalling: exploitation of bacterial quorum sensing molecules by the green seaweed Ulva, Philos. Trans. R. Soc. Lond. Ser. B Biol. Sci. 362 (2007) 1223–1233.
[49] M. Manefield, et al., Halogenated furanones inhibit quorum sensing through accelerated LuxR turnover, Microbiology 148 (2002) 1119–1127.
[50] M. Saha, M. Rempt, K. Grosser, G. Pohnert, F. Weinberger, Surface-associated fucoxanthin mediates settlement of bacterial epiphytes on the rockweed *Fucus vesiculosus*, Biofouling 27 (2011) 423–433.
[51] A. Othmani, J.-F. Briand, M. Ayé, M. Molmeret, G. Culioli, Surface metabolites of the brown alga Taonia atomaria have the ability to regulate epibiosis, Biofouling 32 (2016) 801–813.
[52] B.R. Berland, D.J. Bonin, S.Y. Maestrini, Are some bacteria toxic for marine algae? Mar. Biol. 12 (1972) 189–193.
[53] P. Patel, M.E. Callow, I. Joint, J.A. Callow, Specificity in the settlement–modifying response of bacterial biofilms towards zoospores of the marine alga Enteromorpha, Environ. Microbiol. 5 (2003) 338–349.
[54] F. Weinberger, M. Friedlander, W. Gunkel, A bacterial facultative parasite of *Gracilaria conferta*, Dis. Aquat. Org. 18 (1994) 135–141.
[55] M.J. Huggett, J.E. Williamson, R. de Nys, S. Kjelleberg, P.D. Steinberg, Larval settlement of the common Australian sea urchin Heliocidaris erythrogramma in response to bacteria from the surface of coralline algae, Oecologia 149 (2006) 604–619.
[56] M. Wahl, et al., Ecology of antifouling resistance in the bladder wrack *Fucus vesiculosus*: patterns of microfouling and antimicrobial protection, Mar. Ecol. Prog. Ser. 411 (2010) 33–48.
[57] A. Terada, T. Yamamoto, S. Tsuneda, A. Hirata, Sequencing batch membrane biofilm reactor for simultaneous nitrogen and phosphorus removal: novel application of membrane-aerated biofilm, Biotechnol. Bioeng. 94 (2006) 730–739.
[58] M. Wahl, F. Goecke, A. Labes, S. Dobretsov, F. Weinberger, The second skin: ecological role of epibiotic biofilms on marine organisms, Front. Microbiol. 3 (2012) 292.
[59] Q. Xing, et al., World's largest macroalgal blooms altered phytoplankton biomass in summer in the Yellow Sea: satellite observations, Remote Sens. 7 (2015) 12297–12313.
[60] N.A. Paul, R. De Nys, P.D. Steinberg, Seaweed-herbivore interactions at a small scale: direct tests of feeding deterrence by filamentous algae, Mar. Ecol. Prog. Ser. 323 (2006) 1–9.
[61] E. Jones, C.S. Thornber, Effects of Habitat-modifying Invasive Macroalgae on Epiphytic Algal Communities, 400 (2010), pp. 87–100.
[62] E. Cacabelos, C. Olabarria, M. Incera, J.S. Troncoso, Estuarine, coastal and shelf science effects of habitat structure and tidal height on epifaunal assemblages associated with macroalgae, Estuar. Coast. Shelf Sci. 89 (2010) 43–52.
[63] P. Shacklock, G.B. Croft, Effect of grazers on Chonder crispus in culture, Aquaculture 22 (1981) 331–342.
[64] J.E. Duffy, Oecologia Amphipods on Seaweeds: Partners or Pests? (1990), pp. 267–276.
[65] O. Geertz-Hansen, K. Sand-Jensen, D.F. Hansen, A. Christiansen, Growth and grazing control of abundance of the marine macroalga, *Ulva lactuca* L. in a eutrophic Danish estuary, Aquat. Bot. 46 (1993) 101–109.
[66] V.A. Mantri, K. Eswaran, M. Shanmugam, M. Ganesan, An appraisal on commercial farming of *Kappaphycus alvarezii* in India: success in diversification of livelihood and prospects, J. Appl. Phycol. 29 (2017) 335–357.
[67] M. Bariche, Diet of the Lessepsian fishes, *Siganus rivulatus* and *S. luridus* (Siganidae) in the eastern Mediterranean: a bibliographic analysis, Cybium Int. J. Ichthyol. 30 (2006) 41–49.
[68] K. Lüning, S. Pang, Mass cultivation of seaweeds: current aspects and approaches, J. Appl. Phycol. 15 (2003) 115–119.
[69] FAO, Risk Analysis for Quarantine Pests, Including Analysis of Environmental Risks and Living Modified Organisms, (2004), p. 11.
[70] C. Totti, Æ.M. Poulin, Æ.T. Romagnoli, Epiphytic Diatom Communities on Intertidal Seaweeds From Iceland, (2009), pp. 1681–1691, http://dx.doi.org/10.1007/s00300-009-0668-4.
[71] M.J.L. Solis, S. Draeger, E.T.E. dela Cruz, Marine-derived fungi from *Kappaphycus alvarezii* and *K. striatum* as potential causative agents of ice-ice disease in farmed seaweeds, Bot. Mar. (2010) 587–594, http://dx.doi.org/10.1515/bot.2010.071.
[72] A. Whittick, Spatial and temporal distributions of dominant epiphytes on the stripes of Lamznarza hyperborea (gum.) Fosl. (Phaeophyta: Laminabiales) in S. E. Scotland, J. Exp. Mar. Biol. Ecol. 13 (1983).
[73] L.A. Martín, A.L.B. De Zaixso, P.I. Leonardi, Epiphytism in a Subtidal Natural Bed of Gracilaria gracilis of Southwestern Atlantic Coast (Chubut, Argentina), 2003 (2013), pp. 1319–1329.
[74] J. Correa, Pigmented Algal Endophytes of Chondrus Cripus Stackhouse: Host Specificity, Fine Structure and Effects on Host Performance in Infections by Acrochaete Operculata Correa & Nielsen and A. Heteroclada Correa & Nielsen, (1991).
[75] C.J. Dawes, B.W. Teasdale, M. Friedlander, Cell Wall Structure of the Agarophytes Gracilaria tikvahiae and G. cornea (Rhodophyta) and Penetration by the Epiphyte *Ulva lactuca* (Chlorophyta), (2000), pp. 567–575.
[76] C.R. Johnson, K.H. Mann, The importance of plant defense abilities to the structure of subtidal seaweed communities: the kelp Longzcrurzs De La Pylaie survives grazing by the snail *Lacuna vincta* (montagu) at high population densities, J. Exp. Mar. Biol. Ecol. 91 (1986) 231–267.
[77] B. Bernstein, N. Jung, Selective pressures and coevolution in a kelp canopy community in Southern California, Ecol. Monogr. 49 (1979) 335–355.
[78] P. Kamermans, et al., Effect of grazing by isopods and amphipods on growth of *Ulva* spp. (Chlorophyta), Aquat. Ecol. 36 (2002) 425–433.
[79] M. Friedlander, A. Ben-amotz, The Effect of Outdoor Culture Conditions on Growth and Epiphytes of *Gracilaria conferta*, 39 (1991), pp. 315–333.
[80] A.M. Shelton, F.R. Badenes-Perez, Concepts and applications of trap cropping in Pest management, Annu. Rev. Entomol. 51 (2006) 285–308.
[81] D.N. Kambrekar, S.B. Jagginavar, N.D. Sunitha, A. Entomology, Role of trap crops in integrated pest management, The Hindu, 2008, pp. 1–5.
[82] R.L. Fletcher, Epiphytism and fouling in Gracilaria cultivation: an overview, J. Appl. Phycol. 7 (1995) 325–333.
[83] R. Ugarte, B. Santelices, Experimental tank cultivation of Gracilaria chihsis in central Chile, 101 (1992), pp. 7–16.
[84] H. Anicia, C. Alan, Occurrence of polysiphonia epiphytes in Kappaphycus farms at Calagas Is., Camarines Norte, Philippines, J. Appl. Phycol. (2006), http://dx.doi.org/10.1007/978-1-4020-5670-3.
[85] M. Ganesan, C.R.K. Reddy, B. Jha, Impact of cultivation on growth rate and agar content of Gelidiella acerosa (Gelidiales, Rhodophyta), Algal Res. 12 (2015) 398–404.
[86] B. Alejandro, G. Patricio, Interaction mechanisms between Gracilaria chilensis (Rhodophyta) and, Hydrobiologia 260 (1993) 345–351.
[87] K. Alveal, H. Romo, C. Werlinger, E. Oliveira, Mass cultivation of the agar-producing alga Gracilaria chilensis (Rhodophyta) from spores, Aquaculture 148 (1997) 77–83.