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UPDATED REVIEW OF THE SEAWEED FARMING INITIATIVES IN THE COLOMBIAN CARIBBEAN FOR ITS SUSTAINABLE DEVELOPMENT CONSIDERING REGIONAL AND NATIONAL CONTEXTS

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Abstract

An updated review of the contexts of seaweed farming in the Great Caribbean and Colombia was analyzed. Fifteen countries made trials with native species getting limited results. Eleven countries introduced the non-native species *Kappaphicus alvarezii* to get better performance and quality products in the Caribbean and Brazil. 619 native macroalgae species are reported so far in the Colombian Caribbean (CC), and seaweed farming were at experimental trials so far. Most viable hypothesis is that *K. alvarezii* was possibly introduced in 1991 in Colombia for seaweed farming. Environmental considerations showed several species aggregated with seaweed farming with no significant effects in the environment; aquaculture considerations show challenges with weather conditions, epiphytism, herbivorism, among others, but still easy and inexpensive. Legal considerations are still complicated for the marine aquaculture, but social considerations showed a great potential as an alternative for vulnerable ethnic coastal communities. An analysis of *K. alvarezii* as an invasive species revealed that the species did not show any invasive behavior in the CC after several years of being introduced, despite several weather events that washed up cultivation trials and may allowed the species to be expanded in the whole area. No technical evidence was confirmed to declare the species as an invasive species in Colombia, despite being declared noninvasive in other Caribbean countries.

Keywords: Introduced species, native species, seaweed farming, sustainable development

Introduction

Global cultivation of algae (seaweed) grew by half a million tons in 2020, up by 1.4 % from 34.6 million tons in 2019, generating socio-economic benefits for tens of thousands of households, mainly in coastal communities, contributing to human health, environmental benefits, and ecosystem services (FAO, 2022). Seaweed is one of the sustainable opportunities that can contribute to global food security, either as food or as feed including for aquaculture, in a context of a growing world population and environmental challenges as restorative aquaculture in the frame of a blue transformation of aquatic food systems providing ecosystem services (Cai et al., 2021; TNC, 2021; Jones, 2021; FAO, 2022). The seaweed trade increased from USD 65 million in 1976 to USD 1.1 billion in 2020; China, Indonesia and South Korea are the major exporters, while China, Japan, and the United States lead imports (FAO, 2022), being used in human consumption, animal feed, cosmetics, medicines, chemical, cosmetic, fertilizers, and energy industries, among others (Zhang et al., 2022; Arias-Echeverry et al., 2022), including production of phycocolloids or marine gums used as stabilizers and thickeners in the food industry.

The main macroalgae species cultivated throughout the world are the Japanese kelp *Laminaria japonica* (35.5%), Eucheuma seaweeds *Eucheuma* spp. (23.2%), Gracilaria seaweeds *Gracilaria* spp. (14.8%), Wakame *Undaria pinnatifida* (6.8%), Nori *Porphyra* spp. (6.3%) and Elkhorn seamoss, *Kappaphycus alvarezii* (4.6%) (FAO, 2022). Verdegem et al. (2023) reported main global production in *L. japonica* with 39%, *Eucheuma* spp. and *Gracilaria* spp. with 28% and 10%, respectively. *Laminaria*, *Saccharina Gracilaria*, *Porphyra*, and *Undaria* are used for human consumption, while tropical algae *K. alvarezii* and *Eucheuma* spp. were mostly used for carrageenan extraction (Zhang et al., 2022).

In Latin America (LA), Chile leads the seaweed farming, followed by Mexico, Peru, and Brazil; species of *Kappaphycus* and *Eucheuma* have been the main carrageenophytes cultivated in Latin America and globally, and seven countries (Brazil, Colombia, Cuba, Ecuador, Mexico, Panama and Venezuela) attempted to introduce and establish commercial seaweed farming (Hayashi et al., 2017), but according to Espi et al. (2019), none of them has been especially successful. However, there were governmental and private initiatives that promoted the sea farming of *K. alvarezii* in the region and as a sustainable development strategy for coastal communities (Smith & Rincones, 2006; Robledo et al., 1997; Hayashi et al., 2010; Rincones, 2016).

In Colombia, Acevedo (1968) compiled old reports of marine algae since 1799 to 1965 from different sources in both Colombian Pacific and Caribbean Ocean. He reported by that time 173 species and around 70 subspecies. Experimental trials of seaweed cultivation in Colombia started in 1983 with Professor G. Bula- Meyer (Bula-Meyer & Newball, 1983; Bula-Meyer, 1988, 1989a, 1989b). Álvarez-León et al. (2007) made a review of the potential use of seaweeds in the Colombian Caribbean (CC) and Pacific identifying studies and initiatives. Arias-Echeverry et al. (2022) made a review of seaweed reports and cultivation initiatives and their application in Colombia.

This review pretends to update the seaweed farming context by identifying initiatives at national and regional levels (Gulf of Mexico, Great Caribbean, and Brazil), including a comprehensive analysis of socioeconomic, environmental, legal, and aquaculture of both native and introduced species for seaweed farming to establish alternatives for its sustainable development. It analyzed the of situation of *K. alvarezii* as an introduced species in the CC, and its current invasive status in the country.

Updated Context of Seaweed Use and Farming in the western tropical Atlantic

A review of the regional is presented to show the context of both native and introduced seaweed species farming, showing how seaweed has been part of marine products consumption in several Caribbean countries.

- **Native species farming**

Local and indigenous people had been using native marine macroalgae as food or for drinks for a long time, and seaweed farming experimental trials started in the late 60s and 70s in this region. First studies showed that 20 native species of the Chlorophyta were useful for nutritional flours, 20 species of seven genera of Phaeophyta were useful sources of alginates, and about 28 species of 12 genera of Rhodophyta were useful as sources of agar or carrageenan, recommending regulation of wild harvests and the development of the cultivation of economic species (Díaz-Piferrer, 1969; Smith & Rincones, 2006). Smith & Rincones (2006) made a review of the main native macroalgae with potential use in the Caribbean (Figure 1); an updated review of native macroalgae use and trials is showed in Table 1.

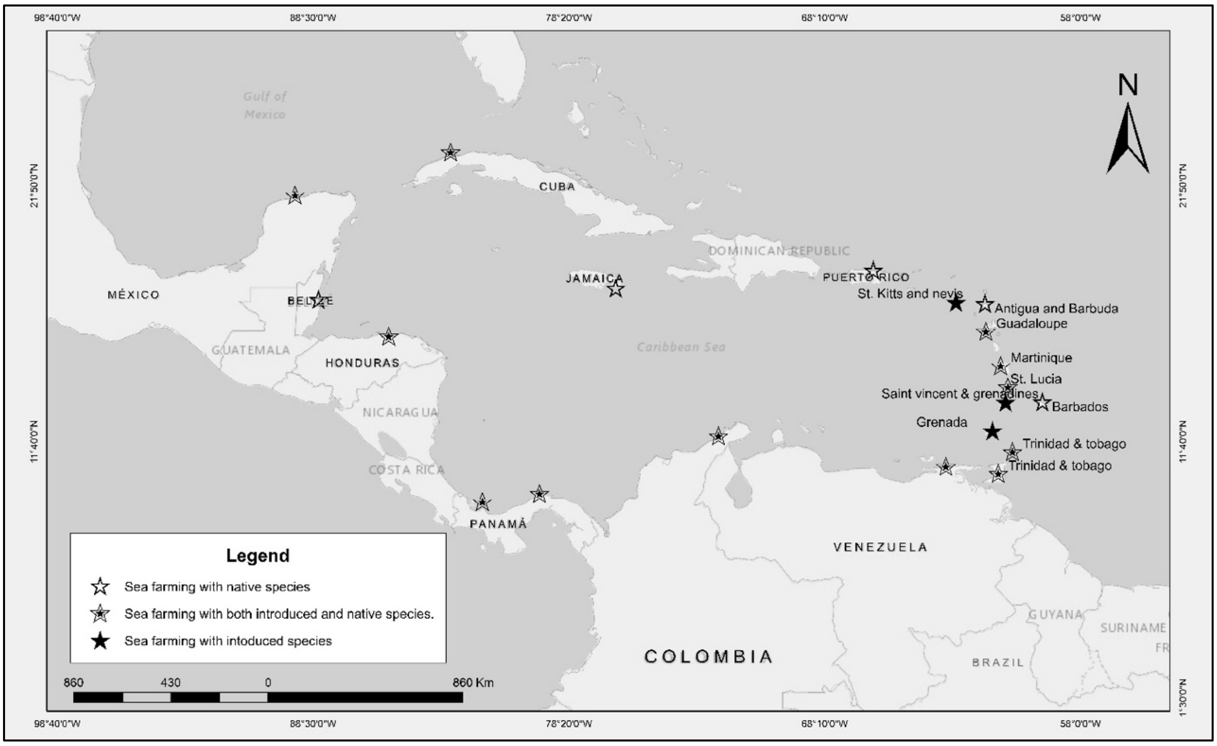

Figure 1. Caribbean Sea places where native and introduced species have been reported for seaweed farming purposes.

Fifteen countries have seaweed farming trials with native species with limited results, with few exceptions (Table 1). The Caribbean Natural Resources Institute (CANARI) published the first guideline for the Seamoss cultivation in the West Indies (Smith, 1997).

- **Introduced species farming**

On the other hand, several countries started to introduce other macroalgae species due to its better performance and quality of their products (Figure 1). An updated context of seaweed farming with introduced species in the Caribbean is shown in table 2.

The introduction of *K. alvarezii* in Honduras has a non- confirmed report in 1978, but there is no further information about it. (I. C. Neish, Pers. Com.). Introduced alga in the French Antilles (Martinique and Guadeloupe islands) got promising results but commercial implementation was unfeasible due to the low price for the carrageenan industry and the high costs of living in those places (Barbaroux et al., 1984).

The three introduced algae in Cuba were positive, but the lack of adequate legislation and a proper economic model for community participation made its commercial implementation difficult (Areces & Céspedes, 1992).

Table 1. Updated main reports of studies and main uses of native marine macroalgae in the Caribbean (Based on Smith & Rincones, 2006)

Country	Reports	Source
Barbados	A study of five species showed that only *Hydropuntia cornea* (as *G. debilis)* formed a firm gel without treatment with alkali, like weaker gels required by the food industry.	Duckworth et al., 1971; Smith & Renard, 2002
Puerto Rico	15 *Gracilaria* species having potential for commercial explotaition. Bronw algae species of Sargassum were evaluated as sources of alginic acid.	Ortiz Sotomayor & Almodóvar, 1982; Aponte de Otaola et al., 1983
Cuba	A number of agarophytes were identified as having commercial potential, especially *Bryothamnion triquetrum* which was tested as a potential source of industrial agar. The economic potential of *Hypnea musciformis*, which produces kappa carrageenan, was investigated. The extract yield and quality were suitable for biomedical applications. Sargassum and Turbinaria brown algae species were investigated.	Sosa, 1983; Estévez et al., 1985; Areces, 1990; Areces, 1995
Martinique & Guadaloupe	*Eucheuma isiforme* and *E. spinosum* were attempted to be cultivated.	Barbaroux et al., 1984
St. Lucia	*Graciliaria* seamoss was attempted to be cultivated. Alkali-treated extracts from *G. mammillaris* contained high-quality agarose that was suitable for industrial and biotechnological applications. *G. domingensis* and an unidentified terete verrucosoid type referred to as GT, which grows fast that was cultivated in the mid-90s. Seamoss farmers established a processing and bottling facility aimed at both local and export markets. *Graciliaria* farms started and by 2000 *E. isiforme* replaced *Graciliaria* spp. as main crop. Focus on propagation and cultivation of H. cornea in Laborie Bay.	Smith et al., 1984 Lahaye et al., 1988 Smith & Renard, 1992 Brown, 1999; Smith & Rincones, 2006
Venezuela	The economic potential of *Hypnea musciformis,* was investigated. *Hydropuntia cornea (*as *G. debilis)* was cultivated and showed a firm gel without treatment with alkali*; G. serrulatum*	Muñoz et al., 1986 Rincones, 1990 Lemus et al., 1991 Smith & Renard, 1992

	produced an extract of high quality. Water extracts showed gel strengths >300g/cm2, increasing to >1000/cm2 with alkaline treatment. Alkali-treated extracts from cultivated *Gracilariopsis lemaneiformis* showed gel strengths around 1000g/cm2, probably one of the highest for a Caribbean gracilarioid with commercial scale cultivation. Extracts reported that *Gracilaria mammillaris* agar was of poor quality, while *Gelidiella acerosa* was a potential source of high-quality agar. Growth of *Euchema isiforme* in suspended systems were assessed in Cubagua Island	Racca et al., 1993; Murano et al., 1996; Montoya et al., 2020
Trinidad & Tobago	At least six species of *Gracilaria* are harvested for local consumption. *Gelidium serrulatum* is harvested in Trinidad for commercial processing of seamoss drinks.	Chu Cheong, 1990 Smith & Renard, 1992
Mexico	*E. isiforme* and *Gracilaria cornea* showed high levels of soluble carbohydrates and crude protein content of >12% and >5% of dry matter, respectively.	Robledo & Freile Pelegrín, 1997
Honduras	Macroalgae used to prepare drinks and desserts, introduced by west Indian migrants.	Espinoza- Avalos, 1994
Panama	Macroalgae used to prepare drinks and desserts, introduced by west indian migrants. Experimental seaweeds farms utilized by the ethnic population around the district of Colon were established in 1995	Espinoza- Avalos, 1994 Batista et al., 2004
Belize	*Eucheuma isiforme* was harvested commercially; approximately 800kg (air-dry weight) were exported annually to the USA for use in health-food applications in the 90s. There is no current exports but harvesting continues for local consumption. Cultivation trials were performed remaining free of silt and epiphytes and maintaining a doubling time of 10-12days. UNDP implemented a GEF small grant to introduced fishers and tour guides to sustainable seaweed production in Placencia, Gladden Spit and Silk Cayes Marine Reserve. NGOs are supporting seaweed aquaculture for coastal restoration in the country as nature-based solutions.	Smith & Renard, 2002 Smith & Rincones, 2006; The GEF Small Grants Programme, 2016 The Nature Conservancy (Website)
Jamaica	*Gracilaria terete*, a verrucosoid alga type was cultivated as a result of training and extension. The country is trying to turn washing up sargassum into something useful.	Smith & Renard, 2002; Deer, 2024

Antigua and Barbuda	*Eucheuma isiforme* was also harvested commercially in Antigua and Barbuda until the 80s, primarily from the Codrington Lagoon on Barbuda.Used locally and exported for traditional food in the region. Ceased due to severe over-harvesting.	Smith & Rincones, 2006
West Indies	Various red algae for the preparation of locally important drinks and desserts, especially in english-speaking islands.	Smith & Renard, 2002 Smith & Rincones, 2006
Brazil	Several native macroalgae species are reported to be cultivated in the country such as *Gayralia oxysperma, Monostroma* sp., *Ulva clathrata*, *U. ramulosa, Graciliaria birdiae* and other *Graciliaria* species.	Espi et al., 2019

Table 2. Countries and territories where species and varieties of introduced seaweed in the Caribbean.

Country	Current status	Source
Honduras	Seaweed expert comment on *K. alvarezii* introduction in 1978. No results known	I.C. Neish (Pers. Comm.)
French West Antilles (Martinique and Guadaloupe)	*E. denticulatum* was introduced from the Philippines for experimental purposes in 1978. Abandoned.	Barbaroux et al., 1984
Cuba	*K. alvarezii*, *K. striatum,* and *E. denticulatum* were introduced for experimental purposes in 1991 from Luzón (Philippines). FAO technical cooperation project. Abandoned.	Areces & Céspedes, 1991
Brazil	*Kappaphycus* spp. and *Euchema* spp. were first introduced in Brazil for commercial purposes in 1995. A brief review of the studies related to *K. alvarezii* cultivation in southern and southeastern Brazil, and discoveries concerning pharmacological studies with this species were carried out. A cultivation system was established for *K. alvarezii* in Santa Catarina State and Sao Pablo. Satellite images were used to generate an analysis for suitable cultivation in Grande Island and Sepetiba bays.	Paula et al., 2002; Hayashi & Reis, 2012; Santos & Hayashi, 2022; Mesquita & Schwahofer, 2023
Venezuela	*K. alvarezii* var. tambalang and *E. denticulatum* were introduced from the Bohol Sea (Philippines) for commercial purposes in 1996.	Rincones & Rubio, 1999; Rincones, 2000

Mexico	*K. alvarezii* was introduced in the Yucatan Peninsula from Venezuela and Brazil in 1999.	Muñoz et al., 2004
Panama	*K. alvarezii* was introduced in the province of Colon.	Batista et al., 2004; Batista et al., 2006; Batista, 2014; Sellers et al., 2015
Saint Vincent & Grenadines	5 Kg of *K. alvarezii* were introduced from Venezuela with experimental and commercial purposes on Union Island.	Rincones, 2011
St. Lucia	*K. alvarezii* was introduced as part of a Mariculture program	Rincones, 2011
Grenada	*K. alvarezii* was introduced for small-scale trials	Rincones, 2011
St. Kitts and Nevis	Small grant of the Liamunga Seamoss group to supply high quality seamos (*K. alvarezii)* products	CANARI, 2019
Trinidad & Tobago	Seamoss (*K. alvarezii*) was introduced in 2009 and small grants were used to improve cultivation and new products.	Pierre, 2019

In Brazil, after a first introduction in 1995, other implants were brought from Japan which came from commercial farms in Luzon, Philippines (Paula et al., 2002; Bulboa & Paula, 2005; Reis et al., 2007). In 2008, the Brazilian Environmental Institute IBAMA issued authorization for the commercial cultivation of *K. alvarezii* in the open sea in a coastal area of Rio de Janeiro and Sao Paulo. In Venezuela, introduced algae showed around 150 tons exported after two years (1999-2001) from marine farms in the Araya peninsula and Isla de Coche to processing plants in Denmark, France, and Chile (Rincones & Rubio, 1999; Rincones, 2000; Smith & Rincones 2006).

In Mexico, specimens of *K. alvarezii* were introduced for experimental purposes as part of a project for the diversification of mariculture and development of coastal communities of the Center for Research and Advanced Studies (CINVESTAV) (Muñoz et al., 2004). Although Sellers et al. (2015) stated that is not clear how *K. alvarezii* was first introduced in the Panamanian Caribbean, Batista et al. (2002) reported the first farm with this species in 2000, whose original implants were imported from Venezuela (Batista et al., 2006). The material harvested in the marine farms located in the province of Colón has been exported to Europe since 2002 (https://gracilarias.org/quienes-somos/presentacion-institucional/).

In Saint Vincent & the Grenadines, St. Kitts and Nevis, and Trinidad and Tobago, the introduction programs was supported by the UNDP Small Grants Program and the Global Environment Facility (GEF) aiming to enhance knowledge about innovations and best practices that can be applied to support conservation, restoration and sustainable use of coastal and marine resources n marine protected areas (MPAs) and marine managed areas (MMAs) where the seaweed farming became a new source of income (Rincones, 2011; Pierre, 2019). In St. Lucia, a cooperative manages a crop plot for local consumption as a drink. The introduction of

K. alvarezii had a view to reinforcing and improving the algae cultures that had been carried out with local species of *Gracilaria* spp. and *E. isiforme*. (Rincones, 2011).

Given the increasing demand for sustainable livelihoods for coastal people in developing countries, and the need to ensure sustainable commercial production of native and introduced species as raw material for different purposes, these results show *K. alvarezii* as the main species to be introduced in several countries in the Caribbean for cultivation purpose.

The greatest commercial activity is around *Kappaphycus* and *Eucheuma*, with successful experiences that have been generating positive social and economic transformations (e.g., Venezuela and Brazil) but also considering environmental sustainability.

Updated context of Seaweed Farming in the Colombian Caribbean

The most updated list of the macroalgae present in the CC was made by Rincon-Diaz & Gavio (2020) with 619 species belonging to three kingdoms, four phyla, eight classes, 39 orders, 86 families, and 230 genera. By phylum, there are 34 species of Cyanobacteria, 72 of Ochrophyta, 164 of Chlorophyta, and 349 of Rhodophyta.

Peña & Alvarez-León (2006) and Alvarez-León et al. (2007) compiled a review of experiences in the experimental macroalgae mariculture in the CC and Pacific coasts, suggesting that marine macroalgae have a potential for promissory future use. Regarding the macroalgae mariculture, Bula-Meyer (1988, 1989a, 1989b) established the relevance of algae as an economic potential resource and began the first experiments for its cultivation, with the species *Grateloupia filicina* in Santa Marta, Magdalena (Bula-Meyer and Newball, 1983).

The most recent review of seaweed cultivation in Colombia was made by Arias-Echeverry et al. (2022) compiling several studies mainly with native species. Although they mentioned *K. alvarezii* in their analyses, the alga was not included in their list with cultivation results, dispite having two studies in the CC.

It is not clear when *K. alvarezii* was introduced in Colombia. The most acceptable version (but not strictly confirmed) is that it was introduced from Venezuela with Cuban seedlings in 1991 through a FAO funded Project (Rincones, 2006; Hurtado et al., 2015); seedlings were quarantined, acclimatized, and kept in floating enclosures at the Center for Research, Education, and Recreation (CEINER as for its acronym in Spanish) at Pajarales Island (Rosario and San Bernardo Archipelago, off Cartagena de Indias) but there is no confirmation yet. In 1999, seedlings were transferred to the Mundo Marino Aquarium of the Jorge Tadeo Lozano University in El Rodadero, Santa Marta for experimental purposes. García & Pardo (2002) observed its adaptation and growth rate in a confined environment, showing a decrease in growth in comparison to previous growth rates reported, high hermivorism by juvenile parrot fishes, other fishes and shrimps, manipulation and high variation of physical-chemical parameters that induced the “ice-ice” disease.

FAO, together with the Alexander von Humboldt Research Institute of Biological Resources (AvHRI), the Regional Environmental Authority for the Guajira Department - CORPOGUAJIRA- (Guajira as a province or state in other countries), other institutions, and the Wayuú ethnic communities (around 45 families) carried out the FAO project TCP/COL/2901 (FAO & AvHRI, 2006) called the Jimoula Initiative (Jimoula stands for seaweed in Wayuú ethnic language) (Rincones, 2006). Around two (2) Kg of *K. alvarezii* implants were collected in Bahía Portete and Puerto Estrella (Colombia) between August and September of 2003 and transferred to Cabo de La Vela (Guajira) where cultivation trials began, using polypropylene ropes and wooden stakes in shallow areas of 0.5 m on sandy-muddy bottoms (Figure 2).

Results on growth and productivity rates showed daily growth rates (DGR) between 5.1 and 6.5%, and an estimated production around 40-50 metric tons/year (dry weight), which can be comparable to the levels registered in the Philippines and Indonesia (Gallo & Rincones, 2003; Rincones & Gallo, 2004; Cuartas, 2004; Smith & Rincones, 2006; Rincones, 2006; Peña & Álvarez, 2006).

The project was suspended due to a requirement for an Environmental Impact Assessment (EIA) to get clearance from CORPOGUAJIRA, although this institution was participating in the project, and even developed a training course of algae cultivation (Cuartas, 2004). A seaweed cultivation area zoning, an environmental management plan, and a HACCP plan were suggested to avoid invasive species dispersion (Palacios & Peña, 2004; Peña & Palacios, 2011).

Figure 2. Seaweed farming carried out in La Guajira Peninsula between Carrizal and Cabo de la Vela. Source: Rincones & Moreno (2011).

Cultivation trials in Bahia Portete (Delgadillo & Newark, 2008) were carried out by the Marine and Coastal Research Institute “Jose Benito Vives de Andreis” -INVEMAR- and CORPOGUAJIRA, with the financial support of CERREJÓN Co. (a pit coal mining company) between July 2005 and June 2006 as productive alternatives for the coastal communities. A total of 114 kg of trial species were cultivated from vegetative implants inserted in polypropylene ropes and cylindrical meshes with DGR reported, but no quality nor composition of the phycocolloids was assessed for economic feasibility.

Between September 2009 and August 2010, experimental cultivation of native macroalgae was carried out with the support of Terrazul Foundation and the National Learning Service (SENA for its acronym in Spanish) in the townships of Carrizal and Cabo de La Vela (Uribia Municipality, Guajira Department) which included the main socioeconomic, cultural and environmental aspects of the target community (Rincones & Moreno, 2011). Cultivation results were discrete for DGR and production.

Camacho & Montaña (2012) made cultivation trials with *H. musciformis* between February and June of 2006 in the coastal area of Taganga and Puerto Luz, near Santa Marta city (Magdalena). Results showed low biomass with the cultivation system used (bags suspended in a line at 0.5 m depth), DGR at 2.66% and carrageenan content of 44-48% (dry weight).

Cultivation trials were carried out in Fray Domingo Bay, Punta de Piedra Beach (Atlántico) with *G. longissima* (before *G. verrucosa*) between June and November of 2004, using a handmade structure whose main rope with plastic perforated sleeves served as support for the algae (Molina-Vargas & Álvarez-León, 2012). Results showed no invasive attacks, high epiphytism on ropes, irregular growth with an average growth rate of 1.08/day in 120 days trial, and the presence of associated fauna such as juveniles of crabs, shrimps, and lobsters. Table 3 shows a chronological updated review of on seaweed farming in the CC including native and introduced species.

Table 3. Updated seaweed species (native and exotic) cultivated in the Colombian Caribbean

Species	Region	Reference
Grateloupia filicina	Santa Marta, Magdalena	Bula-Meyer & Newball, 1983 Bula-Meyer, 1989
Kappaphycus alvarezii *	Santa Marta, Magdalena	Garcia & Pardo, 2002
Kappaphycus alvarezii *	Northern Guajira Peninsula	Gallo & Rincones, 2003 Rincones & Gallo, 2004 Cuartas, 2004 Rincones, 2006 Peña & Álvarez-León, 2006 Peña &Palacios, 2011
Hydropuntia cornea (today *Crassiphycus corneus*) *Eucheuma isiforme* (today *Eucheumatopsis isiformis*)	Northern Guajira Peninsula	Diaz-Pulido & Diaz-Ruiz, 2004
Gracilaria cervicornis (today *G. longissima*), *Hydropuntia cornea* (today *Crassiphycus corneus*), *Hypnea musciformis*, *Grateloupia* sp.	Bahia Portete, Guajira Peninsula	Delgadillo & Newmark, 2008
Gracilariopsis tenuifrons, *Eucheuma isiforme (today Eucheumatopsis isiformi)*	Northern Guajira Peninsula	Rincones & Moreno, 2011
Hypnea musciformis	Santa Marta, Magdalena	Camacho & Montaña, 2012

*Gracilaria verrucosa (*today as *Gracilaropsis longissima)*	Magdalena	Molina-Vargas & Álvarez-León, 2014

*introduced species

Information about cultivation trials in the open sea for the CC showed no information or low growth rates and productivity for native species (Arias Echeverry et al. 2022; this study). These results are below the average required for a species under a cultivation system to be considered economically viable. This study shows that for *K. alvarezii*, the adaptation and growth in aquariums showed no good results but experiments with the same species in open sea showed very good DGR (over 4%/day), which were like those in other countries with commercial cultivation systems (e.g., Venezuela; Rincones & Rubio 1999, Rincones 2000).

Considerations for Seaweed Farming in the Colombian Caribbean

The regional context of macroalgae cultivation projects in the great Caribbean and the initiatives taken to cultivate macroalgae in the CC allow to analyze considerations from different perspectives that may clarify facts and real possibilities for seaweed farming in the country.

- **Environmental considerations**

From the environmental point of view, the cultivation of marine macroalgae serves as a substrate and refuge for many species of fish and invertebrates that fulfill part of their life cycle. Experiences in the Caribbean have shown that algal cultures are substrate and refuge for several species of fish, invertebrates, and other algae species (Hay et al., 1987; Holmlund et al., 1990, Schneider & Mann, 1991). Experimental trials with *K. alvarezii* in Cuba reported juveniles of the spiny lobster *Panulirus argus* in larger implants (Serpa-Madrigal & Areces, 1997). In Venezuela, a significant number of species were reported associated to seaweed in the frame of a *K. alverezii* environmental assessment (32 fishes, 26 mollusks, 13 crustaceans, seven echinoderms, and 24 macroalgae), which showed that the macroalga culture may act as a bottom stabilizer (Salazar, 2000).

In the CC, Delgadillo & Newmark (2008) reported small shrimps, amphipods and poliqueates as host of the macroalgae implants, bivalves (*Pteria colymbus*), other algae (*H. musciformis, G. cervicornis, Soliera* sp. and *Sargassum* sp.) and fishes associated (*Sparisoma rubripinne*, *Gerres cinereus*, *Archosargus rhomboidalis*, *Acanthurus chirurgus* and others of the Haemulidae and Lutjanidae family), but also epiphytes, cirripeds, hydroids, ascidians, among others. Molina & Alvarez (2012) reported associated fauna in trials with *G. longissima*. A report of the Jimoula Initiative (2004-2006) showed the presence of juveniles and larval stages of *P. argus,* other decapod crustaceans, and fish species (*Lutjanus* spp., *Epinephelus* spp., *Eugerres* spp. and *Lachnolaimus maximus*) associated with culture implants. Seaweed farming may contribute with ecosystem services (Bermejo et al., 2022) and habitat provisioning or a range of associated organisms that need to be quantified in and around macroalgal cultivation (Corrigan et al., 2022).

Seaweed farming is an environmentally clean activity. The macroalgae grow naturally not needing any additional feeding or exhaustive attention (https://www.globalseafood.org/blog/seaweed-aquaculture-benefits/). The development of seaweed farming can contribute to removing nitrogen, and byproducts of marine macroalgae may be used for their phosphorous content (Yarish et al., 2016; Zollman et al., 2021). It also offers an opportunity to mitigate and adapt to climate change sinking CO_2 that causes ocean acidification, used for biofuel production, improving soil quality by substituting synthetic fertilizers, reducing the emissions from agriculture, helping to damp wave energy and protecting shorelines (Duarte et al., 2017; Zheng et al., 2019; Alleway, 2023) or being part of the diet in Fish aquaculture (Naiel et al., 2021). Seaweed farming offers a versatile, nature-based solution for climate change mitigation and adaptation and for counteracting eutrophication and biodiversity crisis (Duarte et al., 2022), and may work to mitigate the coastal erosion present in the CC (Posada & Henao, 2008).

Seaweed farming can contribute to fisheries and environmental tradeoffs in the CC. Lobster fishery (traps) are demanding more product that is overexploited (Barreto et al., 2022) and still traded as “baby” or “super-baby” lobster in the main cities of the region. There are nesting and feeding sea turtle areas and reported as fishery target and trade, especially in La Guajira Peninsula (Minambiente & INVEMAR, 2002; Ceballos-Fonseca, 2004; FAO & AvHRI, 2006; Martinez, 2011; Puentes et al., 2014).

The Saiwaru Integrated Management District (Agreement 019 of 2018; Agreement 026 of 2018- CORPOGUAJIRA) is an IUCN category VI protected area (Dudley, 2008) that allows sustainable use of natural resources; it was established in previous areas where seaweed farming was carried out and is focused on the seagrass meadows protection, but its management plan should allow fishermen and coastal communities to develop sustainable alternatives, such as seaweed farming in places where it was carried out successfully. Agreements with local communities can be arranged to contribute to establishing sustainable fisheries practices (e.g., Lobster), sea turtle seasonal nesting areas conservation, to reduce sea turtle consumption, and to contribute to seagrass meadows conservation, in exchange for sustainable small-scale seaweed farming areas, expected to have non-significant effects on other ecosystems (e.g. Syamsudin, 2023), if it is carried out properly, not doing it over extended areas right over the seagrass meadows by shading and trampling them (Duarte et al., 2021; Moreira-Saporiti et al., 2021).

However, seaweed farming needs to consider weather extreme events such as storms, strong winds, and hurricanes that are common in the Caribbean. Although the marine ecosystems of the La Guajira peninsula may be one of the most fertile regions of the CC, due to the seasonal presence of upwellings bringing nutrients from the bottom to the surface, there are strong winds (December to March-July) and rainy season (October- November) (Álvarez-León, et al., 1995). During upwellings, there is a noticeable drop o seawater temperature and higher salinity with higher primary productivity, and during the rainy season salinity is reduced, so these events need to be considered for seaweed farming.

On the other hand, according to Palacios & Peña (2004), Diaz & Medellin (2011), and Peña & Palacios (2011), *K. alvarezii* may produce allelopathic substances having a potential impact on herbivores. Hay et al. (1987) reported that these allelopathic substances are generally halogenated and non-halogenated terpenoids that occur frequently in the Caribbean flora (cymopol and caulerpicin in green algae; stypotriol in brown algae; aplysina, isolaurinterol, and elatol, among others, in red algae). However, herbivores on *K. alvarezii* farms by fishes and invertebrates has been widely documented (e.g., Ask & Azanza, 2002; Ganesan et al., 2006; Sellers et al., 2015; Ma’ruf & Mustafa, 2017; Albright et al., 2022) and should be considered.

➢ Aquaculture Considerations

Several pilot projects with different species showed a different range of good and bad experiences in the seaweed trials with different methods tested (García & Pardo, 2002; Delgadillo & Newark, 2008; Rincones & Moreno, 2011; Camacho & Montaña, 2012; Molina-Vargas & Álvarez-León, 2014), in which environmental conditions show a challenge for a successful cultivation.

Algae methods and systems of cultivation used in the open sea are simple and inexpensive. The type of structures used depends on the characteristics of the place (e.g., depth, waves, currents, turbidity of the water), where polypropylene ropes are used to hold the implants that grow vegetatively; production cycles may vary in time according to the species, depending on the species ability to adapt to the conditions and variations of the selected site, the frequency and intensity of biotic and abiotic disturbances, the time of year, and farmer´s agronomic diligence and maintenance of the cultivation systems used (Doty & Álvarez, 1975; Hurtado, 2013).

Epiphytism was reported by some authors (e.g. Celis et al., 1999; Alvarez- Leon et al., 2007; Delgadillo & Newark, 2008; Molina-Vargas & Álvarez-León, 2014, among others) in the CC. In the Jimoula Initiative (2004-2006) varied seasonally during the year and was conditioned to the health of the implants affected by the levels of sedimentation, light, variations in salinity and temperature caused by runoff waters in the rainy season causing stress in plants. Low levels of salinity caused farm deterioration, with almost total coverage of the implants by bryozoans, cyanobacteria, sponges, sea squirts, and barnacles (*Balanus balanoides*), other macroalgae such as *Gracilaria damaecornis* and *Caulerpa taxifolia*, and bivalves, particularly juveniles of pearl oysters such as *Pinctada imbricata* and *Pteria colymbus* (Figure 3) (Cuartas, 2004).

Figure 3. Juveniles of pearl oysters *P. imbricata* and *P. colymbus* growing on implants of algae grown in Ishorshimana, Cabo de La Vela. (Source: Cuartas (2004).

Herbivorism was reported too in open sea seaweed farming trials previously mentioned in the CC. It was also observed in the experimental crops carried out in La Guajira (Rincones & Gallo, 2004) with losses of up to 95% in less than 24 hours in extreme cases. The presence of the fishes *Acanthurus coeruleus* and *Diodon holocantus,* and the gastropod *Lithopoma* sp. (Figure 4) seriously predated the algae particularly in tender and small apices changing considerably the implant´s morphology.

In some places, the grazing effect was so severe that activities were suspended causing total implant loss in less than 48 hours (Rincones & Gallo 2004; Cuartas 2004). In January 2004, a cold front reduced alga´s growth that were covered with epiphytes and finally attacked by herbivorous fishes, but when conditions improved, the algae regained their vigor and increased their weight and growth rates close to 5% /day in February. Herbivorism on *K. alvarezii* was reported in the Caribbean by Cano (1996), Serpa-Madrigal et al. (1997), and Serpa-Madrigal & Areces (1998).

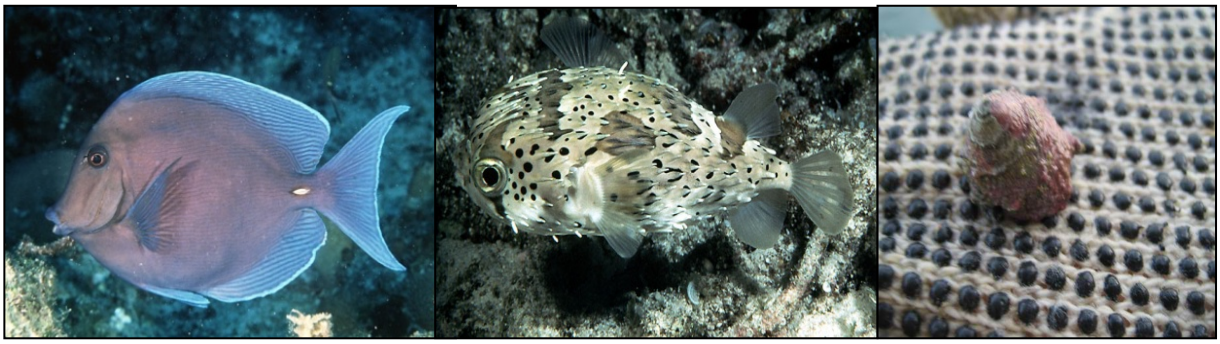

Figure 4. Main predatory organisms of algae: fish: *A. coerelus* and *D. holocanthus* (from left to right) and the gastropod *Lithopoma sp.* (Source: Rincones & Gallo, 2004).

According to Arias Echeverry et al. (2022) native macroalgae species have limited success for an environmentally profitable open sea seaweed farming since projects and trials in the open sea gave poor results until now. They proposed that land-based seaweed farming may be a better option in Colombia. However, trials in open sea were basically experimental with no success first results. Other alternatives should be carried out in open sea seaweed farming in places where the conditions are suitable for its development. Although there are many challenges to overcome, it is considered that seaweed farming can be a good alternative taking the necessary precautions.

- **Legal Considerations**

Gutierrez (2011) made an analysis of the institutional duty to introduce, transplant or restock wild fauna and flora, modified organisms, and microorganisms. Although the analysis needs to be updated due to changes or no longer existence of some government entities, it still works as a baseline for these procedures. In the case of Resolution 848 of 2008 (R848) (Minambiente, 2008) including *K. alvarezii*, the prohibition of introduction did not apply (article 2), since the species was introduced some years before the issuance of this regulation.

Jaramillo et al. (2021) gathered the institutional and legal frame, the plans and policy instruments, and gaps for the legal management of aquaculture in Colombia showing a complicated situation in which different sectors and institutions may have direct or indirectly duties or actions to carry out the activity in the country. The marine aquaculture falls under multiple jurisdictions (environment, fisheries, local authorities), resulting in a fragmented permitting process, and lack of specific regulations. However, this activity may be an alternative for depleted communities hoping to improve their live conditions in the frame of an environmental and social sustainability.

- **Socioeconomic Considerations**

In tropical developing countries, the cultivation of marine macroalgae has a great socioeconomic impact having generated direct and indirect jobs for thousands of people, being an alternative to fishermen, and coastal communities with high needs (Valderrama et al., 2013, Porse & Rudolph, 2017). Support of governments, international projects, and private entrepreneurs to seaweed cultivation is shown in different countries of the Caribbean (Table 1). Coastal communities usually work in sowing, harvesting, transporting, and selling in algal biomass, developing this other activity due to the overexploitation of fisheries resources or environmental issues caused by the anthropic and steady deterioration of the economic conditions of their communities.

In the Colombian Caribbean, most seaweed farming initiatives were generated by the Academia (universities or research institutions) (Table 2), being experimental research that usually didn´t go to stages to involve communities more than necessary to carry out them, hoping that if research were successful, become the baseline for implementation of further stages with their participation.

The pilot projects in the northern Guajira Peninsula included the most active work with coastal communities (Rincones & Gallo 2004; Rincones & Moreno 2011). This area is inhabited by the Wayúu ethnic group, in which coastal fishery communities are called "*Apalaanchi*" (Wayunaiki language), which literally means people of the beach; someone who lives by the sea and depends on it (Guerra & Munera, 2001; Martinez, 2011) although they also call themselves "*Jolojui lime"* (fishermen). These communities have in general a high index of unsatisfied basic needs with a poverty rate of 81.1% (DANE, 2021), no medical care, significant difficulties accessing to drinking water and sewerage, poor attendance of children to school, and high infant mortality by malnutrition, with no presence of government institutions of any kind.

The Terrazul Foundation and SENA (for its acronym in Spanish: National Learning Service) Project (2009-2010) made a participatory community diagnosis, reporting that electric energy is limited by power plants, and fuel is usually expensive; some villages use car batteries charged from time to time. No garbage collection and proper disposition; no public transportation routes so that most townships are quite isolated. Drinking water is transported in tank cisterna trucks provided by the Uribia City Hall to Carrizal, the main town in the area. Other communities get water from cow ponds called "jagüeyes" that are filled up during the rainy season, transporting the water by their own cars or with horses. Houses are basic and made with the dried cactus wood (*Lemaireocereus griseus*) called "*Yotojoro*". Each township has a community kiosk ("*enramada*") to perform daily life activities or to hang hammocks for getting a nap during the day. Main activity is small-scale fisheries with fishing traps, nets or harpoons in small fiberglass or wooden canoes for sailing, rowing or with small outboard engines (9-15 HP). Fishing products prize is fixed by buyers coming from main towns (e.g., Uribia, Manaure, Riohacha, Maicao) with no fishing product storage facilities, so that all is sold fresh on the beach. Some people are partially dedicated to grazing animals (goats or sheeps), but it is limited due to the lack of land and water ponds. The weaving of handicrafts is basically a gender activity for women and girls, some with a high economic value depending on the fabric (e.g., hammocks). This diagnosis needs to be updated, although it is presumed that their situation haven´t changed much since then.

Results of the Jimoula Initiative and the Terrazul Foundation and SENA Project (2009-2010) showed that seaweed farming can support these communities to i) offer of new marine products as an alternative to those traditionally harvested, ii) offer occupational options that may avoid migration from the coastal zone, iii) include women into an alternative productive work giving more participation, equitable income distribution, contributing to gender equity iv) socioeconomic improvement of communities, v) contribute to sustainable use of fishing resources.

Fishery activity may continue as main activity for a long time to finally get balanced with seaweed farming, which may become a women´s activity (Figure 5) getting a role in planting, harvesting, post-harvest and maintenance facility or other work on land (rope´s preparation, implants´ weavings, algae´s drying and storage, and bower and dryer´s maintenance) (Rincones & Gallo, 2004), assuring their financially recognition in the process; this may be a step forward in gender equity.

Figure 5. Participation of Wayúu women in algae cultivation work in Cabo de La Vela, La Guajira Peninsula (Source: Gallo & Rincones 2003; Rincones, 2006)

Seaweed farming may give an outstanding option to vulnerable coastal communities to rise their quality standard life level. If a proper and fair-trade network and appropriate strategies are established together with an assured market; profits of the eventual seaweed farming will go to increase life standard levels and benefits can be placed and maintained according to their fishing vocation, territorial control mechanisms, and sociopolitical structure where the Wayúu emphasizes the use of common resources. Seaweed farming may be seen as a new activity of the "*Jolojui lime"* Wayúu people, since they can still apply their traditional knowledge about tides, winds, currents, and climate, among others. Only if a tangible economic profit is evident, the transition from fishermen to farmer may be successful.

These open seaweed farming experiences showed that seaweed farming was in the process of succeeding, despite the environmental obstacles and may play a relevant role from a socioeconomic perspective in very vulnerable ethnic communities providing a job alternative. If seaweed farms are settled stronger, they may grow until environmental and socioeconomic conditions allow to. Small-scale seaweed farms that reach profitable, environmental, and social balance to offer new jobs for coastal communities, but projections are subject to i) the available cultivation area, ii) crop productivity, iii) the agronomic diligence of the farmers, and iv) the organizational and operational systems established.

Kappaphycus alvarezii as an invasive species in Colombia

In order to understand the invasive status of *K. alverezzi* in Colombia, a review of this condition around the world was made. Various studies have reported *K. alvarezii* as invasive species in the Kaneohe Bay (Hawaii) (e.g., Russel, 1983; Cocklin & Smith, 2005; Neilson et al., 2018). Hawaii invasive species council (https://dlnr.hawaii.gov/hisc/info/invasive-species-profiles/kappaphycus-algae/) reported that the alga is only in Kaneohe Bay, and its impacts were i) high growth rate, ii) can overgrow coral by smothering, shading it from sunlight and abrasion, iii) grows faster than native seaweeds and coral, iv) cause a shift from diverse coral reef to a seaweed-dominated low diversity reef, v) change the bottom structure of the reef vi) habitat loss may impact commercial and recreational fisheries. However, unlike other exotic macroalgae species evaluated in the region, *K. alvarezii* has a limited range of dispersion since it has negative buoyancy, limited ability to attach to the substrate, and is unable to grow freely in the water column or move long distances without human help (Russell, 1983; Oliveira & Paula, 2003; Pickering et al., 2007), being confined to the original place where was introduced, dispersing over short distances (Rodgers & Cox, 1999; Smith & Renard, 2002; Sellers et al., 2015). Zuccarello et al. (2006) confirmed by molecular studies that invasive algae in Kaneohe Bay synthesized iota-type carrageenan which is not from *K. alvarezii* but from *Euchema denticulatum*, being the dominant invasive species in this place (Zemke-White & Smith, 2006; Pickering et al., 2007). *K. alvarezii* has been reported as invasive species in southern India as well (e.g., Chandrasekaran et al., 2008; Sandilyan et al., 2018; Mulyani et al., 2021; Arasamuthu et al., 2023), mainly due to its effects in coral reefs and fauna associated.

However, *K. alvarezii* is being introduced in several Caribbean countries, but none reported any adverse effect on biodiversity or ecosystems, or evidence of invasive behavior; in some places, did not survive due to intense herbivory or unfavorable environmental conditions (Ask, 1999; Oliveira & Paula, 2003; Ask et al., 2003; Pickering et al., 2007). No Caribbean country has declared *K. alverezii* as an invasive species, and despite complex processes, cultivation permits have been finally issued by competent authorities. The most successful seaweed farming in the Caribbean is in Venezuela and Brazil has also successful seaweed farming since 2004.

On the other hand, Cuba carried out a risk assessment for two introduced species (including *K. alvarezii*) reporting no potential risk to the region's biodiversity due to the synergic combination of high herbivory and low rates of growth, restricting cultivation sites and alga´s canopy extent that can affect benthic communities (Areces et al., 2014). In Brazil, a risk assessment for *K. alvarezii* was carried out using species distribution to support public policies for its cultivation (Castelar et al., 2015); areas identified of high risk (coral reefs), medium risk that deserve more research, and low risk, where seaweed farming has been established since 2004 with no evidence of invasion. Smith et al. (2021) made another risk assessment for Bardados and other lesser Antilles countries but did not consider *K. alvarezii* as high or medium risk. Although studies are not comparable, since methods used were different, only one risk assessment in Colombia showed high risk of invasion for *K. alverezii*.

In Colombia, Gutiérrez et al. (2010) carried out a risk assessment for freshwater and marine species after the issuance of R848 (2008). Several methods were analyzed and finally proposed a method with 45 questions, each one with a certain value. The analysis was addressed to assess the risk of whether it was or not considered an invasive species, establish an impact on ecosystems, communities, populations, and native species, the feasibility of management and control, and the purpose of the introduction. The method was adapted for that one implemented for invasive plants (Cardenas et al., 2010); According to the final list provided by INVEMAR (Gutierrez et al., 2010), introduced species were one reptile, two fishes, eight decapods, one crustacean, eight bivalve mollusks, one annelid, two bryozoans, two corals, and one alga. However, reported species with final scores showing high risk of invasion according to the methodology used, were shown for two corals, four crustaceans, five mollusks, and one fish; no score was shown for *K. alvarezii*, but reported that the AvHRI selected *K. alvarezii* as an invasive species in 2005.

Since the species was introduced in Colombia, it is worth reviewing the evidence to confirm declaring it as an invasive species. At first, it is important to state clearly what is an Invasive Alien Species (IAS).. According to the Convention of Biological Diversity (https://www.cbd.int/idb/2009/about/what/), IAS are plants, animals, pathogens, and other organisms that are non-native to an ecosystem, and which may cause economic or environmental harm or adversely affect human health. The International Union for Conservation of Nature (UICN) define an IAS as animals, plants, or other organisms that are introduced by humans, either intentionally or accidentally, into places outside of their natural range, negatively impacting native biodiversity, ecosystem services or human economy and well-being (https://www.iucn.org/our-work/topic/invasive-alien-species#:~:text =Invasive %20alien20species%20are%20animals,human%20economy%20and%20well%2Dbeing). In Colombia, R848 (2008) declared that exotic species of invasive nature are those that have been able to effectively colonize an area where the geographical barrier has been interrupted and have spread without direct human assistance in natural or semi-natural habitats and whose establishment and expansion threatens ecosystems, habitats, or species with economic or environmental damage. Baptiste et al. (2021) defined an IAS as an exotic species (or equivalent terms) that establishes and disperses on natural or seminatural ecosystems. It is an agent of change and causes or has the potential to cause environmental, economic, or public health impacts. These species overcome geographic and reproductive barriers, establish viable populations, and have negative effects on native species and ecosystems, as well as on the economy, health, and social or cultural traditions, according to the IUCN specialist group.

On the other hand, the concepts of invasiveness (Richardson & Pysek, 2013; Baptiste et al., 2021) and invasibility (Lonsdale, 1999; Baptiste et al., 2021) have been managed to work on invasive species in Colombia. The first one refers to the characteristics of an exotic organism, such as its life history and reproduction strategies, which define its ability to invade or overcome various barriers to invasion, and the second one refers to the susceptibility of the environment to the invasion of new species, which is an emergent property of ecosystems potentially affected by various factors including local weather, disturbances, and competitive skills of native species. According to Babtiste et al. (2021), greater invasiveness is related to the lack of competitors and natural enemies, or to the presence of other organisms able to establish mutualistic relationships. Another relevant concept to this case, is the Propagule pressure (introduction effort) (Blackburn & Duncan, 2001; Babtiste et al., 2021), referring to the number of individuals released or introduced where they are not native (Carlton, 1996). These concepts are key to reviewing the real invasiveness of *K. alvarezii* through the years or the marine environmental invasibility where it was cultivated in the CC.

Nineteen years after finishing the Jimoula Initiative in 2006, cultivation areas were abandoned, and it was expected the species to be spread out all around the CC but there is no evidence of it; a main concern with introduced species was the abandonment of cultivation areas without planning and maintenance where the vegetative remains may be reproductive material and posterior dispersion by spores according to the environmental conditions (Paula & Pereira, 2003; Peña & Palacios, 2011). However, Sellers et al. (2015) showed limited dispersion of *K. alvarezii* in the abandoned cultivation areas in Panama; Albreit et al. (2022) reported the species to be abundant in 2014 but no individuals registered one year later.

On the other hand, extreme weather events, such as the sea storm of December 2003 that hit and destroyed the first pilot Seaweed farm (Cabo Centro Village-Salaima, Guajira) washing up most algae (*K. alvarezii*) estimated at 2000 Kg (wet weight); only 20 kg were recovered in search campaigns going up to 20 km south of the pilot farm. In September 9 of 2004, the effects of Hurricane Iván affected the coast of the Guajira Peninsula for a week, considerably damaging the 38 pilot farms of six communities between the townships of Cabo de la Vela and Carrizal. An estimated 8.3 tons of algae (*K. alvarezii*) were shed from the ropes, washed on the beach, and buried in the sand by the strong waves in the cultivation areas. Another search campaign (fishermen, diving) was performed but no presence of the algae was reported dispersed in the marine environment. Additionally, Palacios & Peña (2004) mentioned that local fishermen reported the loss of cultivated material by strong sea weather and wind, which are frequent between September and December in the region.

Studies in different years after cultivation trials, some with intensive samplings carried out in the area where it was cultivated, reported several macroalgae species (around 21 species), but no presence of *K. alvarezii* (CORPOGUAJIRA & INVEMAR, 2012; Chasqui et al., 2013; INVEMAR-MADS, 2017), showing that *K. alvarezii* didn´t show any invasive behavior, despite having abandoned seaweed farms or strong weather events in Colombia. Although INVEMAR shows currently that the alga was used in a no successful cultivation trial, reports no evidence of presence in marine environments of the country (https://invasoresmarinos.invemar.org.co/de/especies/-/asset_publisher/bElCyyDQDNdI/content/kappaphycus-alvarezii).

Possible reasons for not spreading out along the CC and not behaving as an invasive species are: i) in the storm and hurricane described, implants were washed up to the beach, which was recovered afterward and dried for sale, ii) implants washed out offshore in climatic events served as food for different organisms in different ecosystems, iii) *K. alvarezii* has no buoyancy organs and has negative buoyancy (Salazar, 2000; Cabrera et al., 2019); if implants went to the bottom in areas deeper than 15m, surely perished due to the lack of light (Rincones & Rubio, 1999; Salazar, 2000), iv) cultivation trials were carried out with implants that have a vegetative or clonal growth not producing spores, so that fragments were not able to settle down, and v) low species' invasiveness and strong environment invasibility that didn't allow the alga to develop an invasive behavior.

According to the definitions given of an IAS, *K. alvarezii* has not caused any negative effect on the environment or on ethnic coastal communities, especially after finishing the Jimoula initiative in Cabo de la Vela. The species' invasiveness proved to be poor so far (its life history characteristics are not strong enough to overpass native species) and the environment invasibility is proving so far, that it is strong enough for not allowing this alien species to perform an invasive behavior so far. Moreover, the global invasive Species Database does not include *K. alvarezii* in detail, showing *Kappaphycus* spp. evidencing that there is no detailed record of the species (https://www.gbif.org/species/100221448).

K. alvarezii is certainly an exotic introduced species in the CC, but as for the evidence presented in this review, the species is not showing any invasive behavior. Although three studies showed no presence of *K. alvarezii*, another one may be carried out to confirm this trend. Castelar et al. (2009) and Mandal et al. (2010) considered the invasive potential of *K. alverezii* as remote, finding no spores in cultivated cuttings, no verified spore recruitment, or no spore viability; biomass loss of cuttings was restricted to the cultivation management and was low compared to native algal biomass. Possible causes are high herbivory, water transparency, hydrodynamics, water temperature, lack of functional reproductive cycle, and no microscopic phases in the life cycle may control its invasive potential.

In Colombia, R848 (2008) declared *K. alvarezii* as an invasive species. It also stated that invasive species were declared under the scientific and technical support of research institutes linked to the Ministry of Environment (Minambiente). Therefore, that technical support was requested by public request (in Spanish "derecho de Peticion") to INVEMAR and AvHRI. INVEMAR answered that no technical support was issued to declare this species as an invasive species, despite its competence in marine areas (INVEMAR, 2023). AvHRI answered that considerations of the resolution supported the legal and factual foundations and for further information, the request should be done to Ministry of Environment (ME), not giving any technical document to support the inclusion of the species in the R848 (AvHRI, 2023). The same request was made to ME, answering that was not able to find the technical concept that supports *K. alvarezii* as invasive species in R848, but this does not mean that the concept does not exist, and could be wrong filed, due to the Ministry´s change from one to another (Minambiente, 2023). At the end of this task, it was not possible to find any technical support or research done before May, 2008 (issuance month and year of R848) to support *K. alvarezii* to be included as an invasive species in the Colombian Caribbean. Thus, it appears *K. alvarezii* may have been included in the invasive species list as a precautionary measure informed by its invasive behavior elsewhere (e.g., Hawaii, India), rather than by evidence from Colombia.

Conclusions and Final considerations

Based on this review, both land-based and open sea seaweed farming have an opportunity to be sustainably developed in the CC and become an alternative to bring food security and life quality enhancement of depleted coastal communities.

As for the information compiled in this review based on the evidence to date, *K. alvarezii* did not show an invasive behavior in the marine ecosystems of the La Guajira Peninsula where it was cultivated or other places in CC. It was not possible to get access to the technical support for being included in the list of IAS of R848 (2008). Several studies look for macroalgae in the CC, and specially the last one (INVEMAR-MADS, 2017) has a specific section to look for for this species it was not found near or in places where cultivations trials were carried out. However, this review confirmed there are some few colonies according to villagers that so far show no invasive behavior.

The information at regional (Great Caribbean) and local level (CC) analyzed here deserves to be considered revisiting the status of *K. alvarezii* in R848 since there is no evidence of invasiveness in the wild for almost 20 years, since cultivation trials were abandoned or strong weather washed up the species' trials in northern CC. . It worth wondering, after such a time of no invasion evidence, if a precautionary approach still works, if this was the supporting argument to be included in the R848. To conclusively determine the invasive potential of *K. alvarezii* in Colombian waters, it is recommended a new formal risk assessment (e.g., using the Aquatic Species Invasiveness Screening Kit -AS-ISK- screening tool or a similar protocol- e.g., Copp et al., 2016) that consider in is evaluation factors such as climate match, history of invasiveness elsewhere, reproductive capacity, dispersal, and ecological impacts. This kind of analysis would systematically evaluate the species' biology against the Colombian Caribbean's environmental conditions and could either validate the findings of this review or identify any remaining risks. This risk assessment should be undertaken as part of a re-evaluation of *K. alvarezii*'s status under Colombian environmental regulations, but also with the active participation and collaboration of the aquaculture and fisheries authority.

According to this analysis, the principle of proportionality should be applied, meaning that regulations ought to be commensurate with the actual risk posed by the species. In this case, proportional management could involve permitted cultivation in designated low-risk areas, coupled with monitoring, rather than an outright ban. Therefore, it is worth to look for a concrete and well controlled and managed pilot commercial farming that develop proper guidelines and protocols and find a multi-stakeholder collaboration of government institutions (both aquaculture and environmental representatives) and coastal communities.

There are successful environmental management experiences implemented by environmental authorities where *K. alvarezii* has been introduced in the Caribbean, and Brazil, where introduction protocols, management plans and risk analysis have been developed (e.g. TNC, 2024; Hayashi et al., 2024).

The potential socioeconomic impacts that could be generated by seaweed farming of species with high economic value are significant, particularly in depressed communities and localities (Castelar et al., 2009; Ghilardi et al., 2008; Rincones, 2016). The coastal ethnic communities in la Guajira Peninsula (northern Colombia) can include seaweed farming with traditional activities such as fishing, raising of goats and cattle, as additional business that once established, may have a positive social impact, still being environmentally sustainable.

Local and national environmental authorities, the fisheries and aquaculture authority, academia, research centers, civil society organizations and the private sector may join efforts to place new opportunities to achieve changes and prosperity to communities in the frame of a sustainable development.

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Not applicable

Informed consent
Not available

Data availability statement
This review was elaborated based on information compiled by the authors. Technical reports or reference not available at internet may be requested to the corresponding author upon reasonable request.

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