Viability Analysis for an International Tropical Seaweed Resilience Institute

Conducted by

HATCH Innovation Services

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Acknowledgements

The urgency of addressing challenges within the tropical seaweed industry, especially the lack of quality seed supply and productive cultivars, has been underscored by researchers and industry experts for some time. Over the past decade, the international research community has repeatedly flagged up the need for a dedicated tropical seaweed resilience institute to strengthen the sector.

This initial viability study represents a comprehensive exploration of the need for, and potential scope of, such an institute/organization. It aims to outline the critical steps required for its establishment and operation. Drawing from lessons learned from terrestrial agriculture and utilizing a proven methodology developed by Hatch Innovation Services, this study leverages Hatch's expertise and track record in developing successful center initiatives within the aquaculture industry.

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Valeria Montalescot, Seaweed Specialist, Cargill, France

Michael Y. Roleda, Professor, University of the Philippines Marine Science Institute

Alan T. Critchley, Research Fellow, Verschuren Centre for Sustainability in Energy & Environment, Canada

R A Narayanan, Head of Ocean AgTech, Sea6 Energy, India

Burhanuddin Zein, Fisheries and Aquaculture Program Manager, Konservasi Indonesia

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- **Resilience** can be defined as the intrinsic capacity of crops (in this case seaweeds) to effectively withstand and recover from adverse conditions and disease threats.
- **Seaweeds** are not true plants, but we often apply terminology from land plants to describe their structure and reproduction. Seaweeds do not have true roots, stems, leaves, flowers nor seeds; they have analogous structures.
- **Vegetative propagation** is a method of plant reproduction through the vegetative parts of a parent plant, such as stems, leaves, or roots. Unlike sexual reproduction, which involves the fusion of male and female gametes, vegetative propagation produces genetically identical offspring, or clones, to the parent plant. Examples of vegetative propagation techniques include cutting, layering, and tissue culture.
- **Micropropagation** and **tissue culture** is a laboratory technique in which small pieces of plant tissue (e.g., stems, leaves, or embryos) are placed in a sterile medium to grow and develop into whole plants. It is a method used for the rapid propagation and preservation of plant species and can be used effectively with seaweeds, a few cells of which can grow into entirely new individuals (i.e., they are totipotent).
- **Seed or seedling** - smallest unit of vegetative propagation of eucheumatoid seaweeds (not to be confused with true seeds in plants)
- A **thallus** (sing; plural thalli) is the name given for the whole seaweed body - it is analogous to the plant body and can be made up of various parts.
- **Epiphytes** are nonparasitic plants that grow on other plants, thriving on algal thalli in marine ecosystems. In commercial seaweed farming, epiphytic outbreaks can lead to reduced growth, biomass loss, and inferior quality raw material, posing significant economic challenges to farming activities.
- A **seed bank** is a facility that stores seed material from various plant species for preservation and future use, particularly in conservation efforts. Seeds are kept in a dormant state, ready for germination when needed. A biobank is a broader term that encompasses the storage of various biological materials, not limited to seeds. It can include genetic material, tissues, and even whole, living organisms, such as microorganisms, in addition to seeds.
- **Crop breeding programs** aim to develop new varieties for enhanced yield, ensuring food security and poverty reduction. These programs involve three main steps: creating genetic variation through targeted crosses, selecting superior candidates, and testing, propagating, and releasing improved varieties. Breeders identify promising individuals through extensive field trials.. Finally, registered varieties are made available to farmers, the process can take up to 10-20 years. .
- A **hatchery** is a facility that cultivates and propagates seaweed from spores or gametes, similar to how fish hatcheries raise fish from eggs. A **nursery** in the context of seaweeds is a facility where young seaweed thalli are grown before they are transplanted into their natural habitat or commercial farms.
- **Land-based** and **sea-based nurseries** are the common forms of nurseries within tropical seaweed.. **Land-based nurseries** offer laboratory conditions, and a sterile environment, providing controlled conditions. In contrast, **sea-based nurseries** operate within the natural environment and are therefore exposed to natural risk factors, which makes them cheaper to operate.
- **Cultivar**, the short form for "cultivated variety," is a plant that has been selected and cultivated by humans for specific desirable characteristics, such as flower color, fruit size, or disease resistance. Cultivars are often propagated through clonal methods to maintain their unique traits.
- **Strains** are often used to refer to distinct genetic variants within a species, typically characterized by specific traits or adaptations.
- **Genotype** refers to the genetic makeup of an organism, including the specific combination of genes that determine its traits and characteristics. It represents the plant's genetic potential.
- **Intellectual property rights** are among the most important considerations for crop breeding. Breeders may need to obtain plant breeder's rights (PBRs) or patents to protect their innovations. PBRs are a form of IP that gives breeders exclusive rights to propagate, sell, and license their new cultivars. Patents can also be used to protect new cultivars, but they are typically more expensive and time-consuming to obtain than PBRs.

Executive summary

Seaweeds, particularly the tropical red, carrageenan-producing eucheumatoids, are emerging as one of the most sustainable crops of the future, offering a potential pathway to unlock novel, low-carbon value chains in bioplastics, fabrics, and beyond. With a global market already spanning food processing, pharmaceuticals, cosmetics, and nutraceuticals, these seaweeds have become a cornerstone of economic development in tropical regions. In countries like Indonesia, the Philippines, Malaysia and Tanzania, seaweed cultivation provides a livelihood for hundreds of thousands of families, offering accessible income opportunities, especially for women.

However, the development of the eucheumatoid sector has lacked a cohesive vision and farmers currently face significant challenges, including the loss of genetic diversity due to decades-long reliance on clonal propagation methods for the main commercial species. This genetic uniformity not only impedes productivity, but also compromises the resilience and disease resistance of farmed and wild seaweeds, especially in the face of climate change-induced threats such as rising sea temperatures.

Recognizing that sustaining the sector requires a profound understanding of biology, reproduction, and genetics, as well as the preservation of maximum biodiversity within species, mitigation measures are needed. A dedicated international effort to improve tropical seaweed resilience, in the form of an umbrella institute, has been proposed by the global seaweed community, including researchers and industry experts, for some time.

The funding for this viability analysis conducted by Hatch Blue has been provided by Cargill, Konservasi Indonesia and Conservation International.

Aims and methodology

This report assesses the need and feasibility for a tropical seaweed resilience institute to protect biodiversity, and ensure that fundamental research and seed banks remain open source. It also aims to enhance collaboration between scientists in tropical seaweed growing countries, drawing inspiration from the model of well established international centers dedicated to terrestrial crops.

Employing a comprehensive research methodology - including over 50 primary interviews, secondary data analysis, and case study evaluation - this report elucidates the strategic priorities for such an initiative and has identified existing gaps. Subsequently, it looks towards lessons from terrestrial plant crop resilience centers, particularly those focusing on seed banking and genetic improvements required for climate resilience. It also addresses managerial considerations and strategic recommendations for a dedicated, international tropical seaweed resilience institute.

Key findings of this report

Our extensive research confirms the need for an international organization dedicated to the preservation, development, and distribution of high-quality improved strains of tropical seaweeds, with a working title of: "the Tropical Seaweed Resilience Institute" (TSRI)*. The analysis underscores how the TSRI can help protect the industry from climate change and enhance international collaboration among existing tropical seaweed research facilities, to improve efficiency and reduce costs, as well as support the establishment of new facilities. The institute is not expected to retain IP and will share findings and disseminate standard operating procedures and best practices to the global, tropical seaweed cultivation community.

Figure1: The five strategic action areas for the Tropical Seaweed Resilience Institute

This report provides insights into the key aspects that need to be developed for the institute to be successful, including governance structures, funding mechanisms, and strategic partnerships. It also provides a roadmap for how to navigate the complexities of establishing the TSRI, to ensure alignment on the development of its central vision, mission, and business model. Furthermore, it includes a dedicated fundraising and partnership strategy to ensure seed financing for the institute's inception and ongoing operations.

Recommended steps:

1. International stakeholder engagement and ideation workshops, drawing participation from researchers, industry, governmental bodies, NGOs, and potential funding partners to collect input for a Strategic Results Framework.
2. Election of an international steering committee comprising a diverse array of stakeholders to oversee the institute's direction, supplemented by subcommittees tasked with exploring specific themes identified during the workshops.
3. Development of a comprehensive business plan that maps out core strategic pillars, and services provided, identifies potential partners for funding, researches grant opportunities, and proposes a multi-year strategy with key operational milestones.
4. Outreach for international partnerships and collaboration for funding and research.

Through concerted efforts and strategic partnerships, the TSRI will secure long-term funding to create a more resilient and sustainable tropical seaweed industry, underpinned by its overarching aspiration of empowering local communities, enriching livelihoods, and safeguarding the invaluable biodiversity of seaweeds. As the international research and industry communities unite in support of this transformative initiative, the recommendations from the initial phase will serve as the cornerstones of subsequent strategy development.

*While this report identifies the initiative as the Tropical Seaweed Resilience Institute, it is acknowledged that the name is only a working title, subject to further refinement and consensus among stakeholders. The choice of title aims to reflect the core objectives of the institute: enhancing resilience in the face of biological, economic, and social challenges, and fortifying the future of the tropical seaweed industry.


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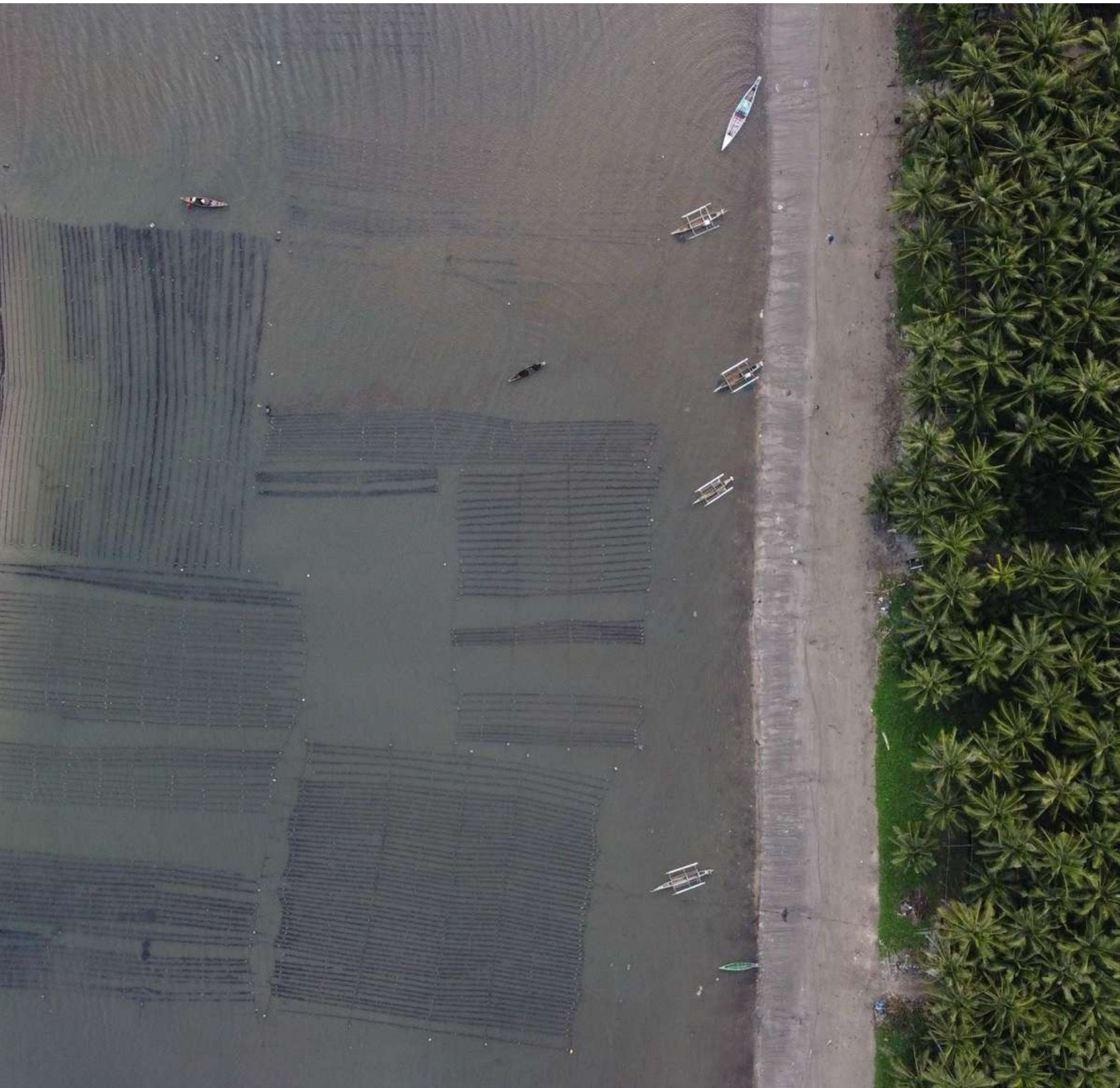
Research methodology



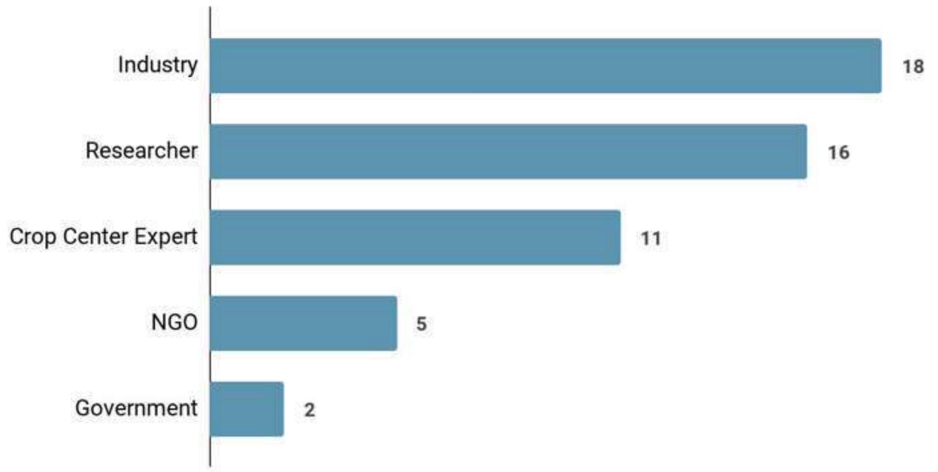
The primary goal of this report was to identify and articulate the gaps and challenges within the tropical seaweed sector, highlighting the lack of quality and climate change-resilient seaweed crops, and pointing to the necessity of establishing a dedicated institute. Additionally, the research sought to analyze how strategies and insights from institutes and initiatives from land-based crops could be tailored and applied to tropical seaweeds globally.

Data Collection

Our approach to understanding the landscape for tropical seaweed cultivation and the crop resilience centers and initiatives involved both primary and secondary data collection.

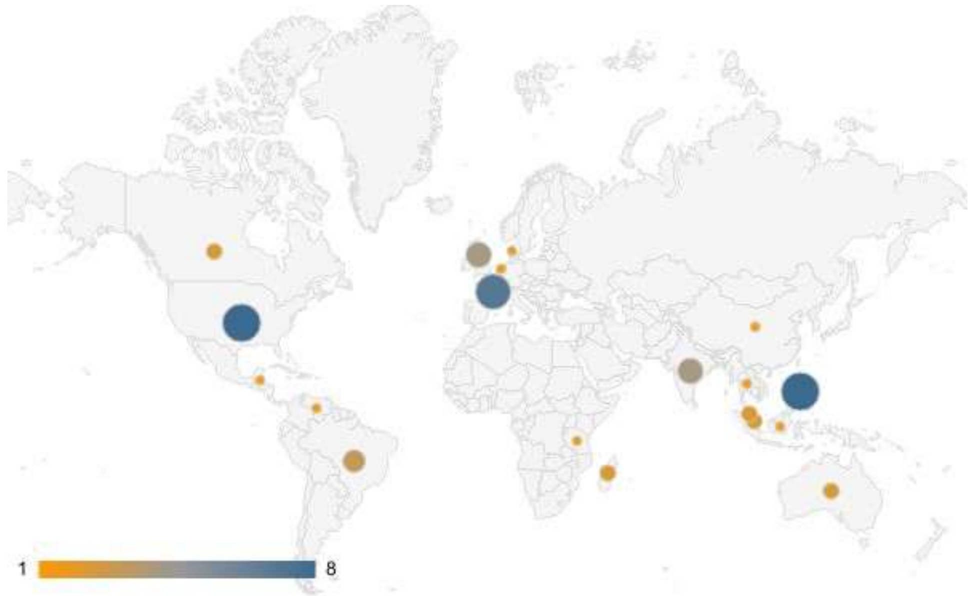
Primary Data: We conducted interviews with 51 professionals from both research and industry sectors to gather insights. These interviews provided first-hand perspectives on the challenges and opportunities within the sector and gave us a global perspective. Around 71 % were individuals and organizations working within the tropical seaweed sector, therefore they were familiar with the particular challenges and current state of the industry. The remaining 29% were experts and representative from terrestrial crop center initiatives.

Figure 7: Number of interviews by stakeholder type



The interviews also extended beyond tropical regions, ensuring a comprehensive and global perspective.

Figure 8: Map of the locations of the interviewed party



Secondary Data: This analysis encompassed a broad array of secondary sources including research papers, articles, and publicly available data from other crop resilience initiatives such as websites, annual reports, and financial statements. This approach helped add depth to the primary data and provided valuable insights into the governance and funding structures of the case studies referenced in this report.

Gap analysis and enabling factors of the tropical seaweed industry

Drawing on the data gathered, we conducted an analysis to pinpoint the main challenges facing the tropical seaweed sector, including issues such as seed banking and infrastructural shortcomings. We also looked into the driving forces behind these challenges, laying the groundwork for strategic planning on how an initiative like this can be approached for maximum impact and longevity.

Mapping international land plant crop resilience centers and institutes

To devise strategies for addressing the identified gaps, we looked towards the learnings from typical land crop resilience centers, particularly those focusing on seed banking and genetic improvements required for climate resilience. This involved creating a long list of centers dedicated to crop resilience, with a focus on common initiatives dedicated to improvements of crop resilience to climate change whilst conducting a high-level analysis of crop resilience initiatives to understand which cases would be most relevant as applied to the benefits of tropical seaweeds.

Case study analyses

We selected five crop resilience initiatives for in-depth case studies. These studies focused on analyzing the governance and funding structures of the centers, their strategic approaches to crop resilience, and their relevance when applied to tropical seaweed value chains. These analyses aimed to derive actionable learning and recommendations, focusing on diverse strategies and best practices that should be adopted, or adapted, to an initiative for tropical seaweed resilience.

Applying lessons learned

Building on the insights from our case study analyses of crop resilience centers, we discuss a proposed high-level setup and potential funding models for establishing a 'Tropical Seaweed Resilience Institute'. This section synthesizes our findings, highlighting the major lessons learned and proposing how these can inform the development of the proposed institute. We outline strategic recommendations for its formation, addressing potential challenges and mapping out steps for future progression.

*In this report, "crop resilience centers" refers to initiatives with a physical locations and those without.

History and current state of the tropical seaweed industry

We are living in the Anthropocene era, in which human activity is the primary force driving environmental change [1,2]. Predictions suggest the population will reach 10 billion by 2050, placing additional stress on our food systems [3]. Our current agricultural practices and diets are unsustainable, contributing to biodiversity loss, freshwater scarcity [4,5], and pollution in aquatic and terrestrial ecosystems from fertilizer runoff like nitrogen and phosphorus [6–8]. These practices threaten the planet's capacity to support human life, leading to issues such as deforestation, as we seek to create more farmland [9].

The utilization of selected seaweeds (>12, 000 spp. globally) has emerged as a **promising solution to various global challenges** - many of which fall under the United Nations' Sustainable Development Goals, e.g., improving food security [10] , mitigating climate change [11], improving human health [12], addressing eutrophication [13], reducing rural poverty [14], and tackling gender disparities [15]. The diverse applications of various seaweed species and their commercial potential for cultivation and multitudinous potential products are increasingly recognized for providing **alternative, sustainable, low carbon value chains**.

Traditionally, seaweed farming was primarily conducted in colder water regions of Asia, but recent developments sparked global interests, with many countries now exploring cultivation [16]. Most of these align with circular, blue economy goals of fostering economic growth through sustainable utilization of coastal waters and some oceans, with seemingly vast expanses still available for development.

Despite having over 50 years of history in some places, the seaweed farming industry still has a long way to go before it can reach the sophistication level of many terrestrial crops and the sector's development will require practices such as seed banking and breeding programs.

This approach is particularly vital for tropical seaweeds, where such strategies have been largely overlooked and areas where coastal communities rely heavily on seaweed are already experiencing the dire consequences of this oversight. The following chapters will delve into the world of tropical seaweeds, briefly discussing their cultivation history, main producing countries, and positive community impacts. In particular, the report examines the rise of tropical seaweed farming, assesses the main challenges this sector is facing today and highlights gaps and opportunities (i.e., the low hanging fruit), in the tropical seaweed industry and associated research.

1.1 Current status of the tropical, red seaweed sector

Eucheumatoids belong to a group of tropical red seaweeds (the Rhodophyta) which began to be commercially farmed in the 1970s in the Philippines. *Kappaphycus alvarezii* and *Eucheuma denticulatum* are the most commonly cultivated species, as they are **processed** to **extract carrageenans** (kappa and iota forms respectively) - which are global commodities - widely used in the **food processing, pharmaceutical, cosmetics** and **nutraceutical industries** for their gelling, thickening and stabilizing properties.

Since the cultivation methods of carrageenan-containing red tropical seaweeds is fairly simple and similar, and many farmers grow these interchangeably, they are referred to as **eucheumatoids** in this report. There are many different morphotypes (shapes and sizes), from cultivars of the same species that can also range in color: from green, to brown, to red.

The eucheumatoid industry plays a crucial role in providing essential income for hundreds of thousands of smallholder farmers, especially those in economically challenged coastal regions of developing countries such as Indonesia, the Philippines, Malaysia (collectively known as the Coral Triangle) and Tanzania.

There is also a growing interest in seaweed farming from other nations in Africa and Latin America, with over 30 countries now producing eucheumatoids, although the main production is still in the Coral Triangle, often in quite remote areas (which is only possible due to the close-knit network of all value chain actors).

Figure 2: Global Production Map of Eucheumatoids in 2021

The positive impacts of this industry extend beyond direct employment, contributing to wider socio-economic improvements by stimulating local economies through the procurement and trading of essentials such as: wood, PVC, string, boats, and fuel. Additionally, portions of the income generated from seaweed farming are invested in enhancing vital community services, including transport, education, and healthcare facilities. The positive transformation seen in many coastal communities due to seaweed farming underscores its potential as a sustainable development model worth emulating.[17] [18]

Euchematoid farming in most tropical regions is carried out by household or smallholder farmers instead of commercial companies. These smallholder farmers typically operate independently, as a family or as a larger household and sell their seaweed crops individually. They are not usually members of farmers' organizations or co-operatives. Depending on the region, being paid per job completed (i.e., piecework), is the most common model for farm workers. Tying on seedlings to lines, deploying and harvesting the crops are very labor intensive.

In most regions, **women are deeply involved with farm activities and, since seaweed farming does not have to be a full-time activity, mothers and older generations can participate, too.** Families living in coastal and small island communities depend on seaweed farming activities – often as their primary source of livelihood. Many of these farmers are former fisherfolk who could no longer make their living from their fish catch.

Seaweed provides a fast harvest, is easy to cultivate with simple technologies, and has low production costs, making it a safe income stream and a viable alternative to fishing.

The cultivation of seaweeds in these communities had a knock-on effect of a surge of investment in infrastructure like roads and pipe systems for fresh water and drainage. Farmers also report being able to improve their own livelihoods. In many cases, the **additional income generated from seaweed farming has been invested in education for younger members of the community**. Many farmers with only a primary school education are proud to explain that their children are attending high school or university.[17,19]

Figure 3: Collection of pictures showcasing different tropical seaweed farmers in the coral triangle

Beyond its social advantages, **eucheumatoid farming can offer numerous environmental benefits**. These include the improvement of coastal water by removing organic pollutants, pathogens, and heavy metals, [20], the alleviation of eutrophication through the absorption of surplus nutrients from coastal waters [21]. These characteristics also show the importance of tropical seaweed farming - not only for the livelihoods of smallholder farmers and coastal communities but also for environmental benefits and enhanced biodiversity, if managed conscientiously.

1.2. Increasing market demand for eucheumatoids

Today, the primary uses of these cultivated seaweed is destined for the carrageenan production. The demand for these types of hydrocolloids derived from eucheumatoids has been growing consistently over the past decades and is forecasted to grow at around 5% Compound Annual Growth Rate (CAGR) globally for the upcoming years.

However, the untapped potential of the seaweed industry extends far beyond its current applications, poised for substantial growth and market diversification.

Figure 4: Expected market size of the carrageenan industry

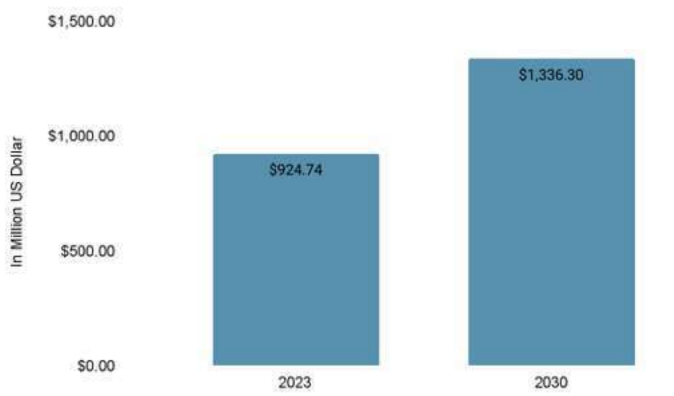


Chart: Global Market Insights (2023)

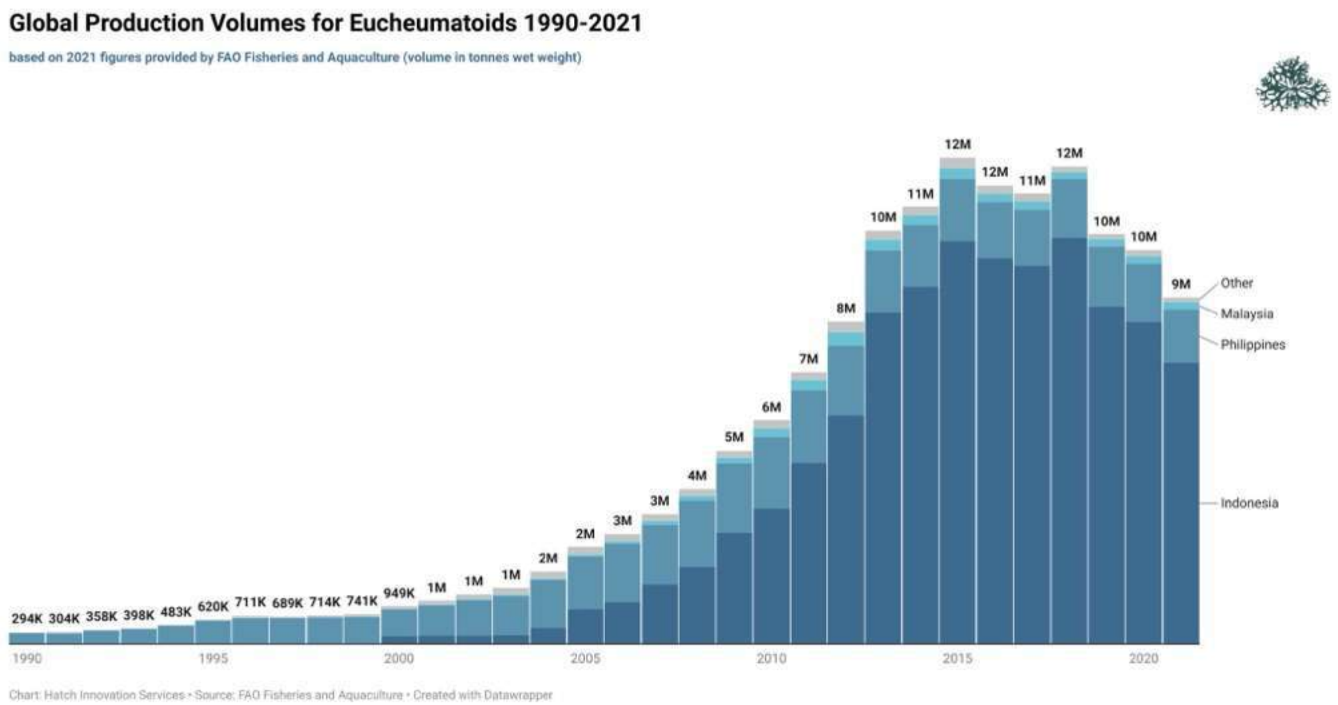
The horizon for seaweed-based products is broadening. Beyond traditional carrageenan, a slew of innovative applications is emerging, positioning red, tropical seaweeds as a key sustainable biomass for future low-carbon value chains, such as biostimulants, pet food, animal feed, and biomaterials.

This expansion, however, is hindered on the ability to produce seaweed at scale and with significant initial volumes. If tackled, the **potential growth of eucheumatoids farming, could scale the industries, replacing fossil fuels in textile and plastic production, and offering critical ecosystem services** like carbon sequestration and nitrogen cycling. Moreover, the growth of the seaweed industry promises to improve socioeconomic well-being in coastal communities, marking a significant step towards sustainable development and environmental conservation.

1.3 Challenges affecting production

Although the demands for red tropical seaweed continues to grow, the production of its primary raw material, i.e., eucheumatoid seaweeds, is encountering numerous challenges - which have collectively led to an overall, year-on-year decline in global production volumes since 2015.

Figure 5: Global Production Volumes for Eucheumatoids 1990-2021



The Food and Agriculture Organisation (FAO) data illustrates a consistent decrease from approximately 12 million tonnes of eucheumatoids produced in 2018 to 9 million tonnes in 2021, which is the latest available year of these official statistics. Indonesia experienced the most significant decline. In an in-field survey by Hatch across seven major producing regions in 2022, **farmers have repeatedly reported harvesting only half of their previous yields**. This became particularly evident, especially in areas where seaweed cultivation has been practiced for over two decades.

The industry and researchers blame several factors for this decline.

I. Reliance on repeated vegetative propagation

Seed production of eucheumatoids is simple. Individual plants are vegetatively propagated via cuttings, large thalli are broken into smaller fragments or seedlings, of about 30 - 100g, each of which can grow back to larger thalli ready for harvesting within 30-60 days. As a result of this, vegetative fragments, cuttings, or seedlings, are clones. This method has been used since commercial farming began in 1970, and has enabled rapid adoption and scaling of farming across many new farming communities within, and across, international borders.

However, this simple method of propagation has been a reason for its decline in that it also encouraged a narrowing of genetic diversity. Initial stocks, which might have been just a few kilograms of live materials, were shipped from one place to another to establish new farming regions. In new localities, it is the hands-on farmer who deploys the first crop and chooses the best-suited individuals, with that in mind an additional layer of in-field selection of the cultivars takes place. **This repetitive method of seedling production, without sexual reproduction (i.e., no combination of genes from different parents) and continuous planting in the same area (i..e., monocropping) has weakened the most commonly farmed seaweed strains.**[22] This practice makes marine crops more susceptible to diseases and pests, therefore harming the overall crop yield and carrageen quality, which in the end reduces the value to the processors.

II. The lack of quality seed material

Only propagules that are young, vigorous, and visually healthy, with no signs of epiphytes, spots, biofilm, bleaching, or wounds from grazing, should be used as seed material. However, these are not always available to the farmers who need them.[18,19] Across all tropical regions the lack of quality seed supply has been mentioned as a severe challenge to the farmers, being the number one challenge in Indonesia and the Philippines.

Figure 6: Interview results on the future of eucheumatoids in the tropical triangle

Future of Farm for Eucheumatoids

based on 66 interviews conducted across 7 major producing regions in 3 countries

	Ranking	Indonesia	Philippines	Malaysia
Farm Challenges	1	Lack of (quality) seedlings	Lack of (quality) seedlings	Poor market access
	2	Lack of drying facilities / space	Poor access to capital	Lack of (quality) seedlings
	3	Poor access to capital	Extreme weather events	Poor access to capital
	4	Filamentous algae (seasonal)	Lack of drying facilities / space	Natural predators (grazers)
	5	Ice-ice syndrome (seasonal)	Poor market access	Ice-ice syndrome (seasonal)
	6	Strong price fluctuations	Strong price fluctuations	Filamentous algae (seasonal)
Farm Wishlist	1	Space to expand	Drying platform	High quality seedlings
	2	Boat with engine	Boat with engine	Access to more buyers
	3	Materials to expand	Materials to expand	Better prices
	4	Drying platform	Storage facility	Materials to expand
	5	High quality seedlings	Access to high quality seedling	Drying platform

Table: Hatch Innovation Services • Source: Field Level Data Collection in Asia 2022 • Created with Datawrapper

It seems that this is especially severe in regions that have been farming for more than 10 years. Farmers often reuse seedlings for several cycles, leading to a serious decrease in quality and a significant reduction in productivity. **The majority of farmers do not have access to improved seedlings. It has been often suggested that with improved seed material, the yield could easily increase by a factor of 20.**

In case of diseases, poor quality, or low volume harvests, farmers also buy seed material from other farmers in the same village or receive new stocks from local collectors. In some locations, we witnessed a lack of seedling material altogether, especially in some locations in the Philippines, where strong (super) typhoons had wiped out the entire seaweed stocks. As a consequence, not having quality seed available inhibits farming activities at scale and is a major challenge, especially across the Coral Triangle.

III. Diseases

One of the first recognized diseases in the eucheumatoids is the so-called 'ice-ice ', appearing as localized bleaching and disintegration of thallus segments, as the picture shows on the right hand side. Farmers generally practice basic management by removing affected parts, allowing unaffected portions to recover and then they continue to use those thalli to plant the next generation of seedlings. The widespread outbreak of ice-ice is attributed to the trade and dispersal of seemingly healthy seedlings that unknowingly harbored endophytic remnants of harmful epiphytes. This practice, fueled by seedling shortages, facilitated the unintentional spread of the infection across many regions of cultivation.

Ice-ice disease and other pathogens are linked to the low genetic diversity of commonly farmed strains of *Kappaphycus* and *Eucheuma*. Extended periods of solely using the same limited stock through vegetative propagation have left them vulnerable to these threats. [23]

IV. Climate change

With the already existing problems, tropical seaweeds face yet more growing challenges when it comes to adaptation to the stresses caused by climate change. Research shows that rising seawater temperatures induce a significant impact on the growth rate, photosynthetic performance, carrageenan yield and quality, pigment content, and production of reactive oxygen species (i.e., indicative of stress response). [24]

The previously mentioned problems of deteriorating genetic diversity and an increased incidence of diseases, like ice-ice, will inevitably be accelerated by climate change. These issues are incredibly serious as reduced productivity directly leads to reduced income for coastal farmers, producing increased poverty, worry, and stress in their communities.

As RA Narayanan, Head of Ocean AgTech, Sea6 Energy, India, notes: *"In Bali, the birthplace of tropical seaweed farming in Indonesia, today we have only one, or just a few, varieties which vegetatively propagate and they are falling apart."*

To counteract this, the industry is in desperate need of climate-resilient, tropical seaweed varieties and there is a critical need for farmers to access high-quality seed stocks: specific strains or cultivars that are resilient to climate change, resistant to diseases, and consistently remain high yielding.

"We have a critical window of approximately five to fifteen years to transition from the current state of the industry to where we envision it needs to be" Alan T. Critchley, Research Fellow, Verschuren Centre for Sustainability in Energy and Environment, Canada

***Case study to showcase the desperate situation of the industry:* Eucheumatoids in Tanzania**

Wild seaweed harvesting, notably of the Cottonii and Spinosum varieties, emerged as a significant economic activity in Tanzania in the 1930s, with peak exports in the mid-20th century. However, the industry faced a setback in the 1970s due to the depletion of wild stocks, leading to the introduction of commercial cultivation of industry-supplied cultivars by the 1980s. Cottonii (*Kappaphycus alvarezii* a source of kappa carrageenan) preferred for its industrial applications and higher market value, thrived alongside Spinosum (*Eucheuma denticulatum* - iota) until the early 2000s when the marine climate change began to severely impact production. Increased seawater temperatures and the prevalence of diseases such as ice-ice, along with epiphyte infestations, have led to a significant decline in Cottonii yields, especially. This environmental sensitivity has not only affected Cottonii but also started impacting Spinosum, although to a lesser extent, through issues like fouling by toxic microalgae. The decline in seaweed production due to these environmental challenges has resulted in economic instability for the farmers, predominantly women, and shifts in cultivation practices and species selection.[25]

1.4 Crop research and breeding centers have ensured long-term sustainability for major terrestrial crops around the world

The tropical seaweed cultivation sector's problems are rapidly growing and the seaweed industry is far behind other land-based crops that have had breeding programs and seed banking for a long time. Modern agricultural advancements and food security rely heavily on the enhancement of plant crop varieties through breeding programs aimed at increasing yield, nutritional content, and resistance to various stressors, many of which relate to a changing climate. International initiatives and organizations have been successful in safeguarding crucial crops for decades to tackle the aforementioned challenges that have been and are still, present for other crops. The approach of international breeding programs for the commercial sustainability of these crops in regions that in general do not have access to newly developed strains started in the 1970s and 1980s.

Central to these efforts are **seed banks,** or gene banks, which are instrumental in conserving the genetic diversity vital for breeding initiatives. These repositories safeguard genetic material from numerous plant species, serving as a resource for breeders to introduce or enhance selected traits in crops. The genetic diversity housed in seed banks is key to identifying and leveraging genes that offer benefits such as improved drought tolerance, disease resistance, and nutritional quality and catering to the dynamic demands of global agriculture.

By providing access to a broad spectrum of genetic information, seed banks have significantly accelerated the breeding process. This strategic utilization of seed banks not only accelerates the creation of improved crop variants but also underscores the importance of genetic conservation in achieving resilience, conserving biodiversity, and enhancing food security.[26]

The example of bananas (see case study) shows what could happen if such measures are not urgently taken for Eucheumatoids.

Case study showcasing when crop resilience efforts are not considered: **Bananas under threat**

The banana industry, which is dominated by a single variety, faces significant challenges due to disease pressure, climate change, and monoculture practices. Notably, 99% of exported bananas are of the Cavendish variety, underscoring the industry's heavy reliance on a single cultivar. Historically, the Gros Michel variety dominated the market until the Panama Disease led to its demise in the 1950s, prompting the widespread adoption of the Cavendish. However, the emergence of *Fusarium* wilt Tropical Race 4 (TR4) poses a severe threat to the Cavendish, with no known cure caused also by the repetitive vegetative propagation. Colombia's declaration of a state of emergency in 2019 following the confirmation of TR4 underscores the industry's vulnerability. Despite calls for diversification and sustainability, efforts to develop disease-resistant varieties faced hurdles, including long breeding timelines and resistance to gene modification.

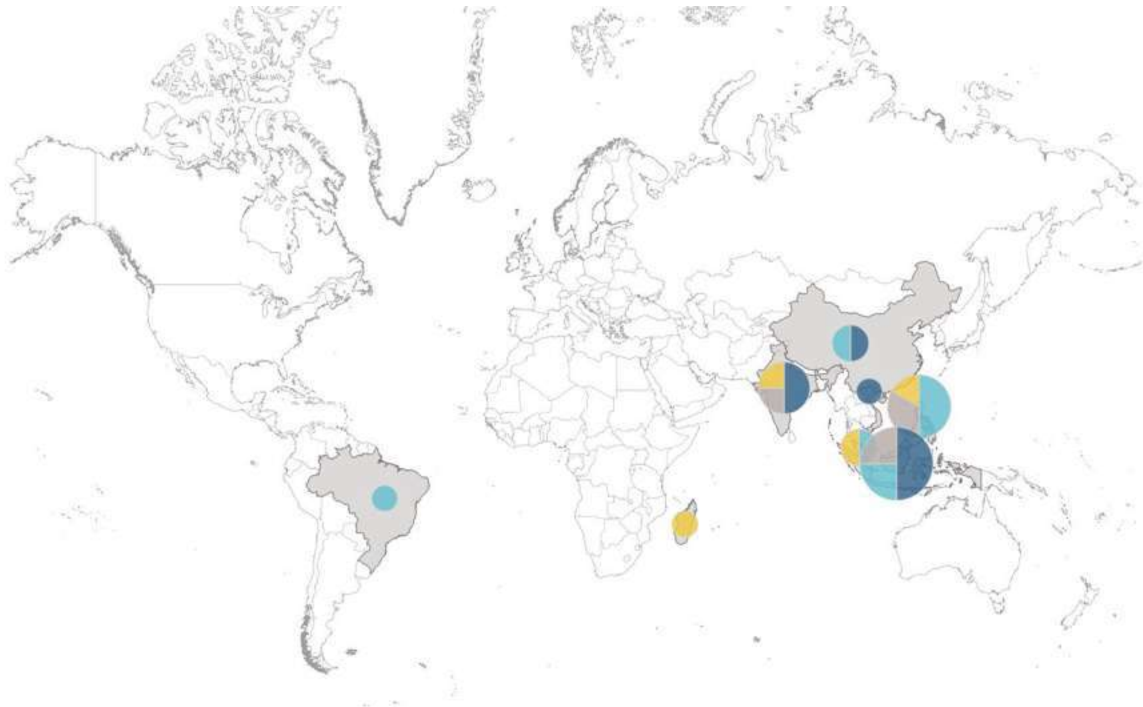
Despite the resistance Australia and New Zealand allowed for the release of gene-modified Cavendish strain to help save the industry. The reliance on a genetically uniform crop highlights the need for a more resilient and adaptable approach to banana cultivation and breeding improved strains to mitigate future threats.[27,28] The industry's over-reliance on a genetically uniform crop underscores the urgent need for a more resilient and adaptable approach to banana cultivation, which could have been facilitated by forward-looking international seed banking and breeding efforts several decades ago. A huge downside to chemical treatments of banana diseases is threats to human health due to the nature and toxicities of the pesticides used.

This chapter provided an overview of tropical seaweed farming, outlining its ecological, commercial, and socio-economic importance, yet also the dire challenges affecting production today. Despite the promising potential of tropical seaweed farming, various challenges such as environmental stressors, disease outbreaks, and limited genetic diversity hinder its production and sustainability potential. This chapter also underscored the vital role of land plants, crop research, and breeding centers in ensuring long-term sustainability for major crops (terrestrial and marine) going forward globally.

Assessment of the tropical seaweed research map and gaps

This chapter assesses the landscape of existing organizations in the global, tropical seaweed research space working on seed banking and providing improved varieties of tropical seaweeds and highlights the existing gaps.

Figure 9: Map and type of tropical seaweed centers



The mapping exercise indicated that the majority of research in this field was concentrated in Southeast Asia, particularly in Indonesia and the Philippines, which match the major production areas. In contrast, the African and South American continents have relatively few research facilities available to support the industry. This geographical disparity highlights a significant gap in the global distribution of resources and expertise dedicated to the sector of providing seaweed raw materials for processing.

Seed banking in the context of tropical red seaweeds

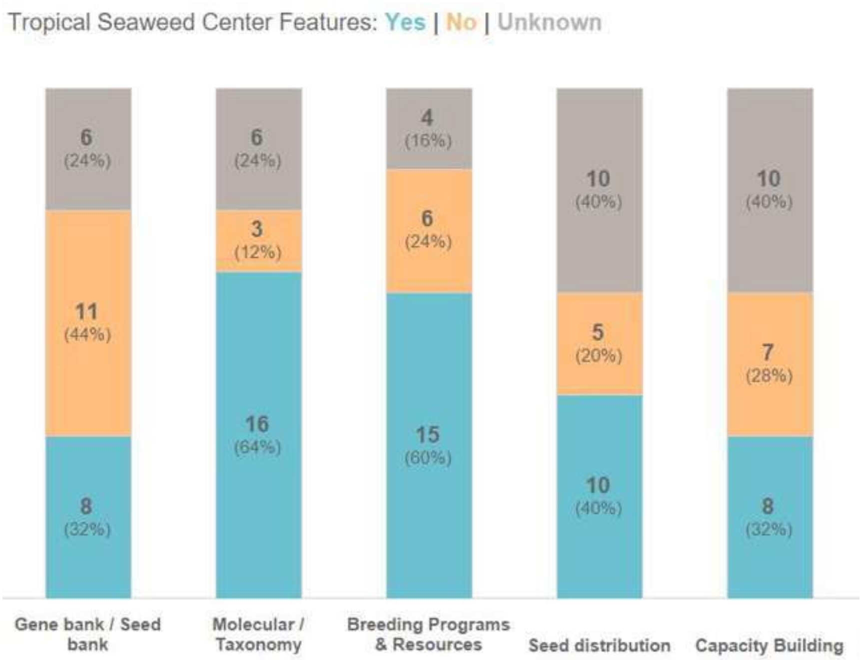
A standard, terrestrial seed bank typically preserves plant embryos (diploid, as a result of fertilization/sexual reproduction involving flowers and male and female organs) but may also manage isolated or excised meristematic tissue to safeguard genetic diversity, thus earning the name "gene bank." This facility serves breeders aiming to enhance crop yield, disease resistance, environmental stress tolerance, and nutritional traits, amongst others for plants grown at scale. Seed and gene banks serve as repositories of invaluable genetic information, including strategies for combating plant stress. These resources can later facilitate the breeding of improved cultivars.

For warm water seaweed crops such as the eucheumatoids, which are primarily propagated clonally through branch cuttings (i.e., no sexual/fertilization phase), traditional seed banking methods are impractical, due to the lack of flowers, as well as the microscopic size and unique characteristics of their spores (i.e., tetraspores [haploid] and carpospores [diploid], approximately 20μm in size, which are distinctly different from terrestrial crop seeds). Consequently, common techniques, such as cryopreservation of meristematic thalli and spores, are neither available, nor feasible.

In light of this, the most suitable methods for preserving eucheumatoid cultivars involve in vitro banks and field (hatchery) gene banking. In an in vitro bank, meristematic tissues (typically branch cuttings) are preserved under specific conditions (light, temperature, and nutrient levels) in a gel or liquid medium. This approach is ideal for preserving seedless crops, i.e., those that reproduce asexually, or those requiring preservation as clones, including various commercial cultivars or novel eucheumatoid strains.

Supplementing the in vitro technique, a field (hatchery) gene bank offers convenient access to genetic resources of crops while continuously characterizing, evaluating, or utilizing them. Meanwhile, the same materials are conserved in the in vitro bank as meristematic tissue (branch cuttings). Through the field (hatchery) gene bank, detailed phenotypic studies are conducted on live thalli, undergoing continuous maintenance and growth monitoring. This allows for the comparison of traits amongst species and strains/cultivars.

Figure 10: Distribution of key features across tropical seaweed research institutes



**Based on the 25 marine laboratory stations that were identified to have relevance in providing seed banking and improvement efforts for a range of tropical red seaweeds.*

Tissue culture has emerged as the main method for improving the quality and availability of eucheumatoid seedlings in the Coral Triangle region. However, using this technology to support farmers in nursery production and for producing seedlings at the required scale will require significant external capital support and has several limitations.

It is imperative for the relatively young tropical seaweed industry to be cataloging and preserving the diversity of both wild populations and selected strains/cultivars. The study of taxonomy is not only crucial for understanding the biodiversity and relatedness of seaweeds but also serves as a valuable tool for the industry, particularly in evaluating traits such as gel content, which is of significant commercial interest. This highlights the broader issue of insufficient research infrastructure across the global, tropical regions. In particular, there is a general scarcity of adequately resourced research institutions, characterized by a critical paucity of human resources, equipment, and funding, necessary for comprehensive studies and the development of seaweed cultivation, including aspects of seed banking.

Our quantitative analysis revealed a targeted focus on breeding programs, which, although varying in sophistication, clearly demonstrated recognition of the need for improved specific strains of seaweeds. Promising public and private initiatives are currently underway to produce more disease-resistant cultivars. This scenario presents an opportunity to consolidate these efforts, aiming for a more cohesive and streamlined approach to breeding program development, especially if knowledge, techniques, and best practices are shared on a common platform. By capitalizing on the existing initiatives, there is potential to foster collaboration between public and private entities, leveraging their respective strengths.

Interviews revealed a gap in scalable seed banking, breeding, and propagation efforts, particularly in broad-scale seed distribution. Nevertheless, this is not a blank slate. Notably, in countries such as Indonesia, the Philippines, Malaysia, Brazil, and Madagascar, there are established laboratories that could potentially act as initial launch points. **Given the absence of a developed industry for scaled breeding and propagation of tropical seaweeds, corresponding nurseries are similarly lacking.** This situation presents a dual challenge for the center: not only must it bridge the connection to farmers, but it also needs to foster entrepreneurship throughout the value chain. This encouragement is crucial for the emergence and development of nurseries and breeding companies.

It must be pointed out that the analyses performed identified a notable shortfall in capacity-building efforts for nurseries, local farmers, and seed banks within the traditional framework. As a key takeaway, **knowledge transfer and capacity building were notably lacking along the tropical seaweed value chain.** Whilst improved strains offer potential advantages, such as higher yields and disease resistance, farmers may prioritize cost-effectiveness and practicality as well as the return of effort and investment in their fundamental decision-making processes. Therefore, it is essential to emphasize that the true impact on yields of cultivated seaweeds often comes from implementing better access to financing, farming practices, and improving post-harvest handling techniques, rather than solely relying on the genetic potential of improved strains. It is never a one-size-fits-all solution.

Investing in access to finance, education, and training programs specifically focuses on optimizing farming management of methods, pests, and diseases effectively, and implementing efficient post-harvest handling practices would significantly improve overall crop productivity and quality as "low-hanging fruit". **Establishing a robust framework for knowledge exchange and capacity building is crucial for empowering farmers with the tools and techniques needed for advanced cultivation, enabling researchers to innovate, and supporting the creation of nurseries and cooperatives that can sustain the industry's growth and competitiveness.**

Two primary gaps have been identified that, if addressed, could significantly impact the sector:

A. Insufficient seed banking efforts

The tropical red seaweed seed banks existing are limited in their equipment and their scale. **To safeguard the biodiversity of these crucial organisms, seed banks must continuously save and store the genetic diversity of seaweeds**, with sufficient funding to allow them to constantly grow as new strains are found.

These facilities are essential for combating the decline in biodiversity and for protecting natural habitats, especially considering that many Eucheumatoids are often non-native species. They should also have the potential to support disaster relief for regions and farmers. Specifically, that the common way of seedbanking of tropical seaweed, has been done in the water, as opposed to land-based facilities.

B. The lack of dedicated and scaled breeding programs

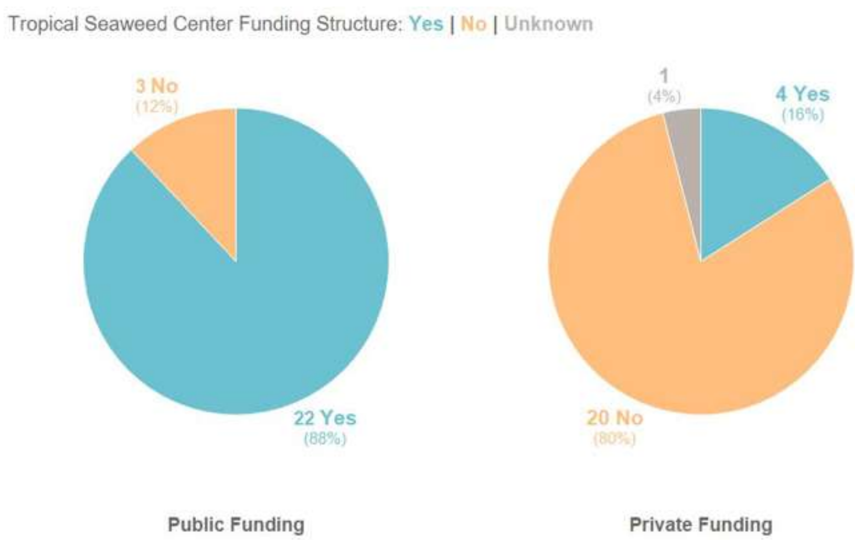
A significant obstacle to the resilience of the tropical seaweed industry is the lack of comprehensive and funded international breeding programs. **Leveraging the foundation laid by seed banks, these programs are crucial for developing strains that can be efficient in a changing climate, resist diseases, and yield high returns.** Such breeding programs are fundamental to advancing the industry, yet the scale of existing initiatives is too limited to make a substantial impact at regional, national, or global levels.

Industry realities that are reinforcing these gaps:

1. A notable barrier to progress is the informal dynamics of the supply chain. Unlike other agricultural sectors that have seen the emergence of breeding companies, nurseries, and well-organized farmers' cooperatives, the tropical seaweed sector has yet to establish similar structures. This indicates **a need for development and support of the upstream industry, which in turn could lead to economic growth and job creation at the local level.**

2. Long-term funding for established institutes is lacking. Governments and industry stakeholders have been turning a blind eye when it comes to tropical seaweed farming. For a long time, this sector has not been a focus point for funding and legislation to promote the industry. Currently, researchers in this area are applying for the same grants, which creates a competitive environment in a space that would benefit from collaboration. **Long-term funding to allow for fundamental research and the development of breeding programs is crucial for the resilience of the industry**, yet require a long-term commitment, as new cultivar development for commercial usage can typically require 10-20 years.

Figure 11: Distribution of the funding structure for tropical research institutions



3. International collaborations are constraint

Researchers and farmers are geographically detached. Sharing of knowledge on fundamental research and breeding techniques, data, and results accelerates learnings and advances between researchers, farmers, and industry. Alongside the sharing of knowledge, the sharing of genetic material is fundamental to breeding high-value species and also to testing in different environments.

Material transfer agreements (MTAs) and the Nagoya Protocol (see fact box below) are essential for seed banking, breeding programs, and distributing improved tropical seaweed strains, involving stakeholders like governments, research bodies, and indigenous communities. These frameworks promote biodiversity conservation, sustainable genetic resource use, and equitable benefit-sharing. However, most **seaweeds lack specific legal structures for their genetic materials' international exchange and improvement.** This complicates the effective exchange and breeding of seaweed strains across borders, limiting the potential for innovation and improvement within the sector. Such frameworks would facilitate the seed banking, breeding, and widespread distribution of superior cultivars, contributing to the sustainable growth of the seaweed industry. By ensuring equitable benefit sharing, these legal measures would encourage greater global collaboration, unlocking the full potential of tropical seaweed.

Material transfer agreements (MTAs) and the **Nagoya Protocol** are key international agreements governing the exchange and utilization of genetic resources. MTAs are contractual agreements that outline the terms and conditions for **transferring biological materials** between parties, ensuring equitable sharing of benefits arising from their use. They are used by academic and commercial entities to formalize exchanges of genetic resources between providers and users, such as universities, research institutions, biotechnology companies, and agricultural organizations.[30,31]

The Nagoya Protocol, a supplementary agreement to the **Convention on Biological Diversity,** aims to promote fair and equitable sharing of benefits arising from the utilization of genetic resources. The contracting parties include countries that have ratified the protocol, along with those involved in **accessing and utilizing genetic resources**, such as research institutions, biotechnology companies, and indigenous communities.[32]

In light of numerous ongoing investigations into seaweed physiology, genetics, and ecology, it is evident that the field lacks a cohesive, well-funded, and future-oriented strategy to synergize these individual efforts. This hampers the sector's ability to fully leverage its potential impact and ensure the long-term sustainability of the seaweed industry. Moving forward, **a more collaborative and forward-thinking approach is imperative to consolidate existing research and propel the industry toward a more sustainable future.**

In the next chapter, we will investigate how such collaborative approaches have been successfully implemented in major terrestrial crops globally. Through selected case studies, we will delve into strategies and lessons that can inform and inspire a more unified approach in the seaweed industry.

Learnings from crop resilience center initiatives globally

To understand the challenges and learnings from land-based crops and their effort toward a sustainable future, this chapter analyzes the history of crop resilience centers, their main characteristics, focus areas, and their stakeholders.

Throughout history, agricultural plant breeding and crop research have continuously improved crop yield and quality. However, achieving higher yields often requires extensive support and protection against various stresses. Despite these efforts, approximately 20% of crops globally are lost to environmental stresses. With climate change exacerbating these challenges, crop resilience has been a focal point for land-based agriculture to ensure global food security.

Timeline on the history of international crop research and breeding initiatives:

17th to 19th Century: the emergence of formal breeding programs

Formal crop breeding programs started in the 17th century and the 19th century saw significant progress with Gregor Mendel's genetics foundation through pea plant experiments.

20th Century: seed banking and preservation efforts

The early 20th century introduced seed banking as a response to industrialization, urbanization, and wars, focusing on conserving genetic diversity. The Vavilov Institute of Plant Industry, established in Russia in 1921 by Nikolai Vavilov, pioneered modern seed banking, crucial for protecting against crop failures and aiding future breeding efforts.

Mid-20th Century: Green Revolution

This period was defined by intensive research and the development of high-yielding rice, wheat, and maize varieties. This significantly increased global food production and addressed hunger crises. Key institutions included the International Rice Research Institute (IRRI) and the International Maize and Wheat Improvement Center (CIMMYT).

Late 20th Century to Present: Modern biotechnology and genomics

Advances in biotechnology and genomics have led to rapid changes in crop breeding, with the development of techniques like marker-assisted selection (MAS), genetic engineering, and genome editing. These advancements have facilitated the creation of crops with improved disease resistance and nutritional quality. Collaborative global efforts are supported by entities such as the CGIAR consortium and the Global Crop Diversity Trust.

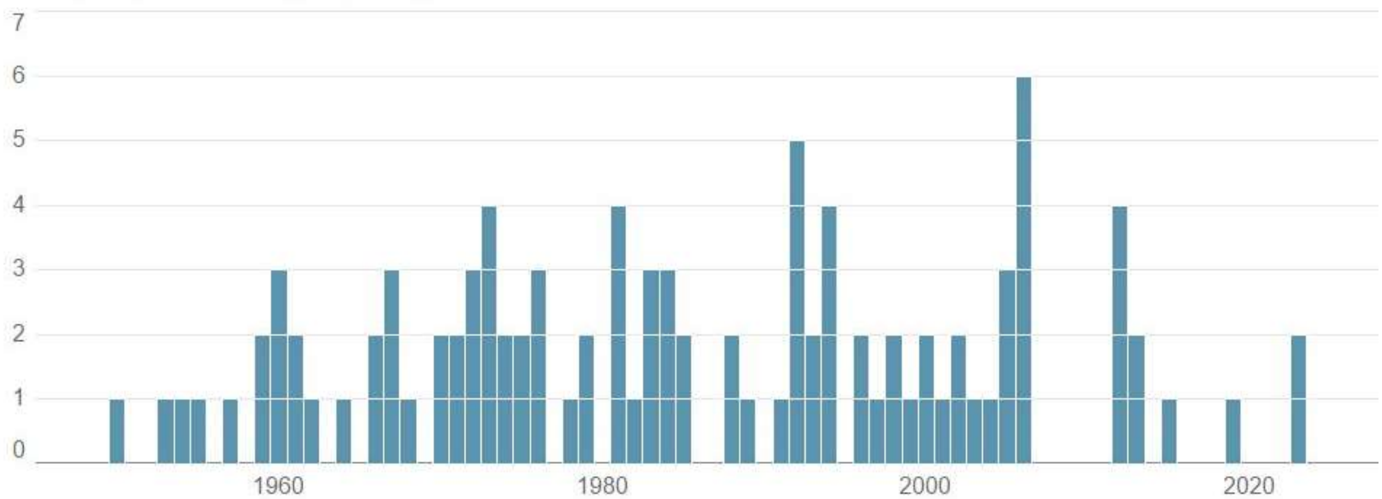
21st Century: Focus on sustainability and climate resilience

Current breeding programs focus on sustainability and climate resilience, aiming to develop crops that can adapt to varying conditions, withstand climate extremes, and reduce environmental impacts. There is also an emphasis on incorporating traditional knowledge and farmer preferences to ensure social equity and cultural relevance in crop breeding.

International crop research centers and institutes focused on seed banking and breeding programs were initially established in the 1970s and 1980s, mainly with the mission to maintain food security. To extract lessons learned from these established initiatives and apply them to the tropical seaweed case, we mapped existing crop centers globally.

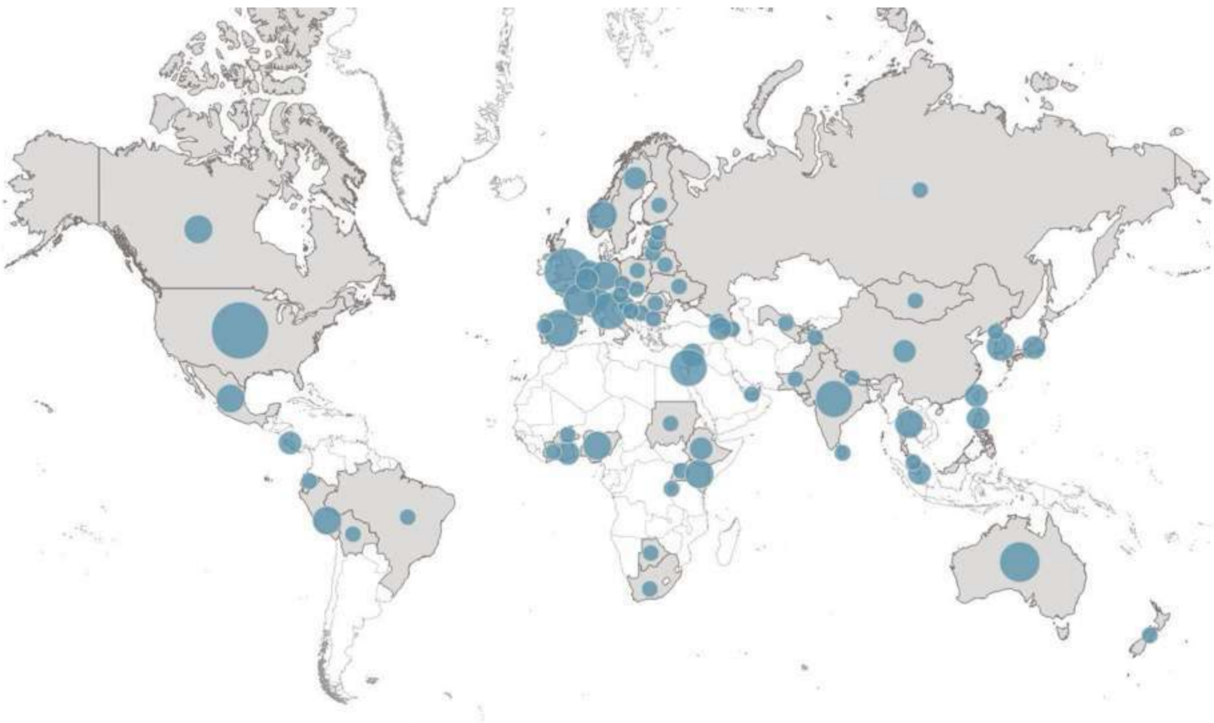
This is a non-exhaustive list, but with 146 crop resilience centers and international seed banks mapped, it provides a solid overview of the trends.

Figure 12: Global crop centers by founding year



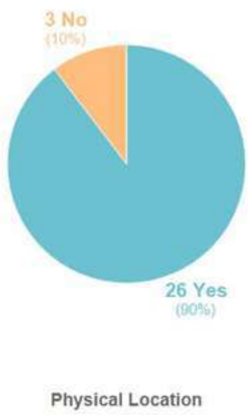
The majority of the centers were established towards the second half of the 20th century and in the first 10 years of the 21st century.

Figure 13: Distribution of mapped crop centers globally



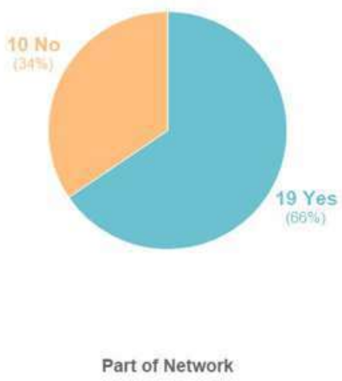
The origin and strong presence of global agricultural conglomerates in developed countries, shapes to some extent also the research landscape and priorities of their home base. This concentration aligns with the availability of greater funding opportunities for research in developed countries, fostering strong ties between universities, research centers, and crop breeding initiatives. Yet, as the relevance of international research and development partnerships is growing, the allocation of international funds towards crop resilience initiatives in developing countries has enabled the establishment of many more dedicated centers globally and encouraged even the governments of developing countries to increase their funding towards fundamental research and crop resiliency programs.

Figure 14: Proportion of crop resilience centers with and without physical locations



The high percentage of entities with physical locations highlights the importance of on-the-ground operations. Most crop resilience centers, regardless of their physical location, establish extensive connections with satellite stations and national or regional institutions, allowing them to have a global reach while ensuring regional relevance.

Figure 15: Proportion of crop resilience centers that are part of a network



These collaborations may occur either under the same umbrella organization or through conventions, demonstrating the global network and partnerships these centers engage in. Two-thirds (66%) of the centers analyzed are part of broader networks, enabling collaboration and knowledge exchange globally. The most prominent *Global Crop Resilience Networks* are listed below.

Global crop resilience networks

Some of the key players and research networks to which many centers are connected or can be described are highlighted below:

National Agricultural Research and Extension Systems (NARES)

National Agricultural Research Institutes (NARIs) are core components of (NARES), in agricultural innovation, generating knowledge and disseminating technology to farmers. These institutes serve as hubs for scientific research and new agricultural practices tailored to local conditions. Working with NARES, NARIs bridge the gap between research and practice so that farmers benefit from scientific insights and innovations.

Global Crop Diversity Trust

CROP TRUST

The Global Crop Diversity Trust, established in 2004, preserves the genetic resources of multiple key crops in the Svalbard Global Seed Vault. It also facilitates the exchange and utilization of these genetic resources. Through strategic partnerships with national and international institutions, the trust supports genebanks and breeding programs worldwide, providing financial assistance, technical expertise, and capacity-building initiatives.

Consultative Group on International Agricultural Research (CGIAR)

CGIAR, established in 1971, is the largest agricultural research partnership globally, addressing the challenges facing agriculture and food security worldwide via a network of 13 research centers. CGIAR develops climate-resilient crop varieties capable of withstanding extreme weather conditions and changing climatic patterns. Through training programs and partnerships with NARIs, CGIAR empowers scientists, policymakers, and farmers with the tools needed to address local and regional agricultural challenges effectively.

AIRCA: Collaborative Innovations for Agricultural Resilience

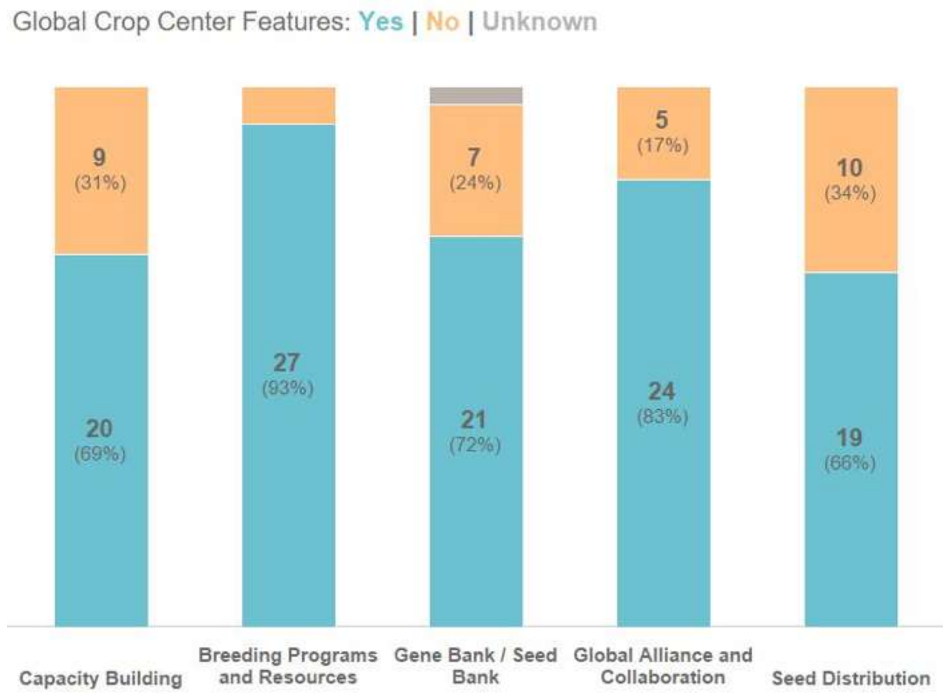
The Agricultural Innovation Partnership (AIRCA) represents an alliance of leading agricultural research institutions committed to addressing the complex challenges facing global food security. Established in 2012, AIRCA promotes collaboration and innovation across various research themes, including crop breeding and climate adaptation, leveraging the diverse expertise of its members to address agricultural challenges.

An important action area of crop resilience centers is capacity building, which involves transferring knowledge to researchers, nurseries, and farmers. This exchange of information is essential for empowering stakeholders with the skills and insights needed to contribute effectively to resilience efforts.

Moreover, these centers actively engage in seedbanking and breeding programs to enhance crop varieties. By leveraging genetic material from their own seedbanks or collaborating with others, they strive to improve crop resilience through selective breeding and genetic enhancement.

To extend their impact globally, resilience centers forge alliances with institutions worldwide and establish satellite stations or hubs in strategic regions. These partnerships facilitate the exchange of resources, expertise, and information on a global scale, fostering collaborative efforts towards sustainable agriculture.

Additionally, the physical presence of these centers is paramount. While virtual collaborations exist, on-the-ground operations are essential for conducting research, experimentation, and field trials. These physical locations serve as hubs for innovation and collaboration, driving progress in crop resilience and contributing to food security worldwide.



Most crop resilience initiatives have a multi-stakeholder approach, meaning they play a central role in bringing several key actors together, fostering collaboration and leveraging on these partners resources.

Figure 17: Stakeholder map for international crop resilience centers

- **National research institutes** play a crucial role in conducting fundamental research, developing new cultivars, and testing their adaptability to local conditions. They can collaborate with other institutions to ensure that new cultivars meet the specific needs of smallholder farmers.
- **International research centers** possess specialized expertise in breeding and crop improvement, particularly for staple crops in developing regions. They can provide technical assistance, germplasm resources, and training to NARIs and other partners.
- **Non-governmental organizations (NGOs**) often have strong ties to smallholder farmers and can provide valuable insights into their needs and preferences. They can facilitate participatory breeding initiatives, promote the adoption of new cultivars, and provide extension services.
- **Farmer organizations and cooperatives** represent the interests of smallholder farmers and can play a vital role in disseminating information, distributing seeds, and advocating for policies that support sustainable agriculture.
- **Private sector companie**s, including agribusinesses and seed producers, can bring their expertise in commercialization, market linkages, and product development to the table. They can collaborate with public institutions to ensure that new cultivars reach smallholder farmers and find viable markets.
- **Government agencies**, particularly ministries of agriculture, play a crucial role in providing funding, establishing regulatory frameworks, and implementing policies that support agricultural development. They facilitate collaboration among various stakeholders and ensure that new cultivars are integrated into national agricultural strategies.
- **Funders** provide financial support, resources, and expertise to enable the centers to conduct research, develop innovative solutions, and implement programs aimed at enhancing crop resilience and sustainability. Funders play a critical role in shaping the strategic direction of the centers, ensuring their operational sustainability, and driving positive impact in farming communities worldwide.

By fostering partnerships among these institutions, the development and commercialization of new cultivars are typically tailored to the specific needs of smallholder farmers in developing regions, leading to improved productivity, resilience, and market access for these essential crops.

5.1 Case study selection

In conducting our research on crop resilience centers and how their structure and methods can apply to tropical seaweed cultivation, we employed a systematic approach to ensure a comprehensive and diverse selection of case studies. Our methodology involved the creation of a funnel through which potential research centers were evaluated, based on specific criteria. These criteria were carefully chosen to encompass various aspects relevant to the success and sustainability of seaweed cultivation initiatives.

1. *Infrastructure assessment*: The first criterion considered was the infrastructure available to the research center, including existing facilities and the potential for collaboration with other institutions. This assessment aimed to determine the necessity and feasibility of having dedicated centralized facilities over a virtual organization and the potential of leveraging existing resources through collaboration.

2. *Governance structure*: We examined the governance structure of each resilience center to understand how decisions are made and how resources are allocated. This criterion provided insights into the organizational dynamics and dedicated IP strategies of crop resilience initiatives.

3. *International collaboration*: The criterion of international collaboration encompassed various aspects such as intellectual property (IP) agreements, material sharing, and capacity-building initiatives. This evaluation was crucial for assessing the benefits of leveraging global partnerships and resources.

4. *Long-term funding strategies*: Finally, we also evaluated their strategies for securing long-term funding, considering both private and public funding sources. This criterion was essential for understanding the financial sustainability of such an initiative and identifying effective funding models.

Based on the aforementioned criteria, we identified five case studies that represented a diverse range of research centers with varying infrastructure, funding strategies, international collaborations, and governance structures. These were selected to provide a wide range of lessons that could be applied to different parts of the seaweed sector.

Table 1: Overview of the agricultural research center case studies

	International Potato Center (CIP)	CropXR	International Wheat Yield Partnership (IWYP)	World Coffee Research (WCR)	World Vegetable Center (WVC)
Year Established	1971	2023	2015	2013	1961
Location	Lima, Peru	Utrecht, Netherlands	El Batán, Mexico	Portland, USA	Shanhua, Taiwan
Crop focus	Potatoes, Sweet Potatoes	Vegetables	Maize, Wheat	Coffee	Vegetable
Network	CGIAR, Crop Trust			Crop Trust	AIRCA
Type	International research organization	Partnerships/Alliances		Industry-Driven Research Program	International research organization
Action areas	Genetic Innovation (Breeding programs) Agrifood Systems (Capacity Building System Transformation (lobbying)	Breeding program Capacity Building Knowledge Transfer	Funding of breeding research	Breeding programs, Capacity building Knowledge transfer	Breeding programs Capacity Building Knowledge transfer Biofortification
Funding	Grants/Donations, Once CGIAR Trust fund	Foundations, government funding, private companies, universities	Government funding, private companies	Government funding, private companies	Grants

The *World Vegetable Center*

The *World Vegetable Center* is pivotal in enhancing the nutritional security and economic viability of smallholder farming through advanced vegetable research. It is instrumental in breeding nutrient-rich and disease-resistant vegetable varieties, promoting sustainable agriculture practices that mitigate poverty and malnutrition. The center's work is vital for integrating vegetables into the food systems of developing countries, aiming to improve health and livelihoods.

World Coffee Research

World Coffee Research focuses on the sustainability of the coffee sector amidst environmental and climatic challenges. By developing resilient coffee varieties and improving crop quality, it aims to secure the livelihoods of coffee farmers and the industry's future. This organization's research and development efforts are crucial for adapting coffee production to the demands of climate change and ensuring economic stability in coffee-growing regions.

The *International Wheat Yield Partnership (IWYP)*

The *International Wheat Yield Partnership (IWYP)* addresses the critical global demand for wheat through collaborative research aimed at enhancing wheat's genetic yield potential. IWYP's international research collaborations facilitate the discovery and implementation of innovative wheat varieties that promise higher yields under sustainable farming conditions. This initiative plays a key role in bolstering food security, particularly in wheat-dependent regions.

The *International Potato Center (CIP)*

The *International Potato Center (CIP)* focuses on improving the resilience and productivity of potatoes and sweet potatoes, crucial for food security in many parts of the world. CIP's research into climate-resilient varieties and sustainable agricultural practices aims to harness these crops' potential to strengthen food systems. The center's efforts are directed towards ensuring that these staple crops can meet the challenges posed by a changing climate.

The *CropXR Institute*

The *CropXR Institute* builds upon the concept of 'smart breeding' to accelerate the development of resilient crops. By fostering collaboration among scientists, companies, farmers, and other stakeholders, CropXR enhances the breeding pipeline, enabling the faster introduction of resilient crops to the market. Its multifaceted approach includes research on plant resilience, the development of a dedicated data infrastructure, and education initiatives aimed at equipping professionals with the skills to innovate in plant breeding and agriculture. CropXR's commitment to knowledge transfer and public-private partnerships underscores its mission to advance sustainable and climate-adapted agriculture worldwide.

In the next chapter, we conduct an analysis of governance and funding structures within the selected case studies. We highlight the most pertinent examples for each topic, demonstrating their applicability to tropical seaweed, as outlined in previous chapters.

Governance structure

6.1 Who initiated these centers?

The establishment of international crop resilience centers represents a collaborative effort between various stakeholders from both research and industry. Case studies such as the World Vegetable Center developed through public engagement facilitated by several international development agencies like the Asian Development Bank, exemplify this collaborative approach. Recent initiatives like CropXR, International Wheat Yield Partnership (IWYP), and World Coffee Research (WCR) display a mix of founding partners from research and industry backgrounds. Notably, WCR prioritized industry involvement in its establishment, driven by scientists who recognized the importance of private-sector collaboration.

An advantage of this integration of industry into crop resilience initiatives is that funding models increasingly emphasize private-sector engagement to ensure research outcomes align with economic development goals. **By involving industry stakeholders from inception, these initiatives streamline research efforts to produce results applicable to the industry, enhancing their effectiveness**. Emphasizing a balanced involvement of research and industry stakeholders from the outset is crucial for formulating strategies, values, and visions that align with the diverse interests of stakeholders and guide the institutes toward meaningful contributions to sustainability and economic development.

6.2 How are these centers governed today?

The governance structures of contemporary international crop resilience centers share commonalities in their designations and functions. The **Board of Directors**, serving as the overarching decision-making body, is crucial for providing strategic direction. The composition of these boards is deemed crucial, aiming for a diverse mix of stakeholders, each exceptional in their field and committed to collaborative efforts. Chaired by an independent leader, these boards comprise experts in research, government, and non-governmental institutions, along with industry representatives. Notably, organizations like World Coffee Research exclusively incorporate industry leaders from the coffee sector into their boards, reflecting a self-interest alignment.

The **Scientific Advisory Board,** responsible for offering the highest level of scientific direction, emphasizes inclusivity by gathering scientists and researchers with backgrounds in government, industry, and academia. This diversity ensures a holistic representation of key stakeholders and perspectives. The **Leadership Team,** responsible for strategy development and execution management, comprises industry experts and talented professionals with specific responsibilities. The execution of strategies is carried out by diverse teams, including HR, scientists, marketing, fundraising, and operations, with the prioritization of functions dependent on the organizational structure.

6.3 Regional mandate and footprint

The regional mandates and reach of crop resilience centers vary, with most having an international focus, particularly targeting developing countries and collaborating closely with national research institutes. While established centers with over 50 years of operation typically have headquarters and multiple country offices, newer initiatives like IWYP and CropXR leverage existing infrastructure within targeted countries. Notably, World Coffee Research operates with a single center, partnering directly with National Agricultural Research Institutes (NARIs) to focus on coffee, enhancing autonomy for collaborating countries and addressing critiques of centralized decision-making in breeding programs.

In addition, embracing partnerships with established facilities and supporting their improvement can significantly reduce the costs associated with building new infrastructure, enabling more efficient utilization of resources and accelerating the institute's impact.

6.4 Seed distributions

Seed distribution strategies vary among the selected case studies. Typically the centers collaborate with breeding companies and nurseries, either directly or indirectly through universities or national agricultural research and extension systems (NARES), with distribution often facilitated by the centers themselves, as seen in the case of the International Potato Center (CIP). **While seed distribution may be donated, costs are often covered by the receiving partners through particularly designed cost recovery models.**

Despite its industry-driven and -funded nature, World Coffee Research also provides developed seeds to national research institutes for further adaptation and distribution to breeding companies and nurseries, while the World Vegetable Center offers access to genetic material for breeding purposes to a wide range of stakeholders including agricultural research institutions and private sector companies.

The translation of these strategies to the tropical seaweed sector presents unique challenges due to the absence of established breeding companies and nurseries within the tropical seaweed industry, mainly because sea-based nurseries are typically unpredictable, and difficult to maintain with no guaranteed return on investment, and land-based nurseries are oftentimes too expensive to run.

Tropical seaweed yields a smaller amount of multiplication material compared to crops such as wheat and potatoes, which possess seeds and stems. This limits the scalability of sea-based nurseries, making them less profitable compared to selling the seaweed to downstream buyers for market applications. However, in a maturing industry, it is crucial to maintain traceability for strains and the supply of disease-free, high-quality raw materials. This underscores the importance of developing viable upstream infrastructure and facilitating sustainable growth within the value chain.

6.5 IP strategies

Intellectual property (IP) strategies among international crop resilience centers vary, based on their primary mission of widespread distribution of improved seed material to enhance smallholder farmers' livelihoods. These institutes, with a focus on collaborative research and knowledge-sharing, have not emphasized creating IP as it conflicts with their core mission. CIP and WVC grant time-limited exclusivity to encourage private sector involvement, but IP development remains a marginal aspect.

In the case of CropXR, the unique landscape of competing breeding companies makes IP development integral. Recognizing the competitive nature of the industry, CropXR places a significant emphasis on IP to address the interests of competing companies. Similarly, World Coffee Research adopts a country-level approach, acknowledging the competition among coffee-producing nations. National institutes in the coffee industry can obtain and improve developed strains, offering breeders the opportunity to file for plant variety protection.

Despite the potential for IP or plant variety protection, these centers refrain from filing for intellectual property. **Their primary goal remains the broad distribution of improved genetic material to accelerate breeding efforts for the benefit of all stakeholders.** This underscores that in initiatives focused on crop resilience, sexually but also vegetatively propagated crops like potatoes and potentially tropical seaweed do not necessarily require the enforcement of IP protection.

6.6 Capacity Building

As already highlighted in the global scan, capacity building is a critical component of the efforts undertaken by international crop resilience centers to enhance the effectiveness and sustainability of their initiatives across various stakeholders. It needs to take place on different levels:

Researchers and seedbanks

Crop Trust plays a pivotal role in supporting seed banking efforts and providing training for researchers at institutions such as the International Potato Center (CIP), World Vegetable Center (WCR), and World Coffee Research (WCR). The emphasis is on ensuring high standards in seed banking practices and enhancing the skills of researchers involved in plant breeding. These training initiatives focus on best practices in seed collection, preservation, and management.

WCR also supports capacity building in the coffee industry directly by providing training and resources to researchers and institutions involved in coffee breeding and research. They offer workshops, seminars, and educational programs designed to enhance the skills and knowledge of coffee researchers and breeders. CropXR also contributes to capacity building by supporting the development and training of professionals in plant research and breeding and collaborating with universities to create courses and curricula.

Recognizing the **importance of extensive training for researchers and seed bank workers is crucial, given the novel nature of seed banking and breeding in the seaweed industry.** Collaborating with universities becomes essential to attract skilled labour, fostering a community of experts capable of meeting the highest standards.

Nurseries/businesses

WCR and CIP have dedicated efforts to support nurseries and breeding companies, aiming to adopt best practices for quality, disease-free, and scalable management. These centers actively disseminate the latest technologies and techniques to nurseries and breeding companies, recognizing the pivotal role of distribution in the success of breeding programs.

Considering the quasi-nonexistent nature of nursery and breeding businesses in the tropical seaweed industry **it is crucial to support the development of these enterprises by developing business plans and blueprints** to ensure the just dissemination of the improved varieties, to support the economic development along the upstream value chain and to ensure the traceability of the developed strains for the industry.

Farmers

The supported capacity building for farmers includes assistance in farming techniques, traceability, and background knowledge to enhance their understanding of the value of improved seed material. **Ensuring increased yields and fostering the adoption of specific strains are crucial aspects of the initiatives.**

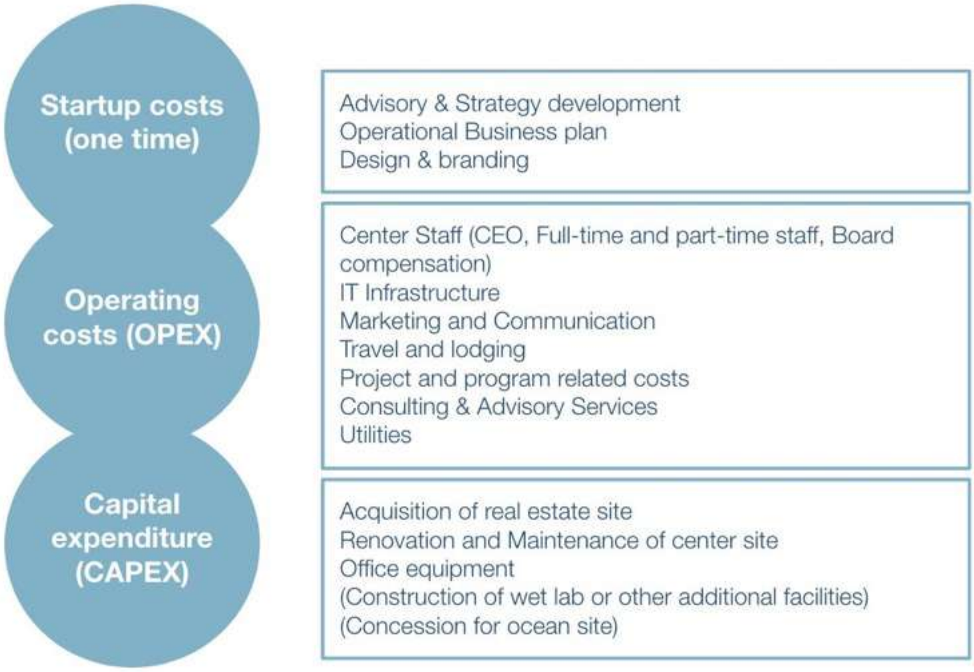
WCR supports farmers in the coffee industry by providing training and resources aimed at improving farming techniques, promoting traceability, and enhancing the adoption of new coffee varieties. They offer educational programs, field demonstrations, and technical assistance to help farmers increase yields, improve crop quality, and enhance their livelihoods. WCR's capacity-building initiatives for farmers focus on empowering them with the knowledge and skills needed to succeed in the coffee industry. CIP collaborates with Crop Trust and other partners to support capacity building among potato farmers. They offer training programs, extension services, and technical assistance aimed at improving farming practices, promoting sustainable agricultural techniques, and enhancing the adoption of new potato varieties.

In the context of tropical seaweed not only the improvement of strains is determining the productivity of the farmer, but also farming practices and the post harvest processing infrastructure.

Financing crop resilience centers

7.1 General cost components to consider

Figure 18: Costs associated with setting up and operating crop resilience initiatives



Equipment/infrastructure - These centers must budget for the upkeep of existing facilities or the costs associated with accessing necessary infrastructure. Physical centers like CIP have had high capital expenditures in the form of buying equipment, acquisition or building of facilities, and the maintenance of these facilities in comparison to initiatives like CropXR and IWYP that use existing infrastructure.

Program/project funding - The bulk of these organizations' spending is dedicated to financing their programs and projects. For example, World Coffee Research commits about two-thirds of its annual budget to these initiatives. This proportion is expected to rise as overhead costs decrease relative to the growing scale of the funded programs and projects. The expenses for the research programs at CIP are around 90% of the overall costs, with personnel costs related to these research projects at 50%. The World Vegetable Center has a personnel cost percentage of around 40% and 60% for operating expenses.

Personnel - Building up on the previous comment to attract and retain top talent, which gives potential funders trust in the team, these organizations must offer competitive compensation packages relative to the market.

Administration - Operating a center requires essential administrative expenses, including office operations, financial management, taxation, IT infrastructure, travel costs, compensation for the Board of Directors, and legal services. For World Coffee Research these were around 12% of their costs in 2022, while for IWYP they were around 15%.

Fundraising - The financial sustainability of these centers hinges on effective fundraising efforts. For instance, World Coffee Research allocates approximately 10% of its annual spending to fundraising efforts.

The funding allocated to various agricultural initiatives varies significantly, highlighting the diverse scale and scope of these projects.

Figure 19: Cost structure and analysis of the respective case studies

While many established centers have the physical infrastructure, which requires significant investment in infrastructure, newer initiatives, such as IWYP and CropXR are opting to collaborate with existing institutions instead of investing in their facilities. This approach allows for cost savings while still benefiting from established resources and expertise.

Figure 20: Infrastructure and geographical reach of the respective case studies

7.2 Funding sources

Table 2: Overview of the commonly used funding sources for crop resilience institutes

Public Sector			Private Sector	
Government agencies	Multilateral organizations	Development agencies	Companies (Industry)	Foundations
Funding type: Grants or project funding without expected return. Funding is allocated based on the institute's geographical location and national research priorities. **Average length of support:** 1-10 years, depending on project scope and objectives. **Example:** e.g. United States Department of Agriculture (USDA); **Case studies:** World Coffee Research CIP International Potato Center IWYP International Wheat Yield Partnership – Research to Deliver Wheat for the Future CropXR	**Funding type:** Financial and technical assistance through grants, loans, and capacity-building programs aimed at multiregional projects and initiatives. **Average length of support:** 5-10 years, due to the extensive scope and scale of projects. **Example:** World Bank, FAO **Case studies:** World Vegetable Center CIP International Potato Center CGIAR	**Funding type:** A mix of grants, technical assistance, and capacity-building efforts aimed at addressing agricultural development challenges. **Average length of support:** 3-7 years, tailored to project needs and development goals. **Example:** United States Agency for International Development (USAID), GIZ; **Case studies:** World Vegetable Center CIP International Potato Center CropXR	**Funding type:** Direct investment, partnerships, or in-kind contributions, focusing on innovation and product development. **Average length of support:** Varies widely from short-term (1-2 years) for initial research phases to long-term (up to 10 years) for the development and commercialization of technologies. **Example:** Syngenta, Bayer; **Case studies:** World Coffee Research CropXR	**Funding type:** Grants and partnerships focused on innovative projects and research with significant impact potential. **Average length of support:** Typically 1-5 years, depending on the project's goals and scale. **Example:** Bill & Melinda Gates Foundation, the Rockefeller Foundation; **Case studies:** World Vegetable Center CIP International Potato Center

Hybrid Model: In practice, many incorporate elements from different sources of funding, but typically, one or two main sources tend to predominate.

The reliance on public funding and private foundations underscores the need to attract more investments from the private sector to accelerate innovation, scale up successful projects, and ensure long-term sustainability. A hybrid approach, engaging with both government agencies and development agencies in the public sector, offers access to diverse funding opportunities. Furthermore, collaboration with private companies is essential, given the niche, yet significant, nature of tropical seaweed farming. **Drawing parallels with industries like coffee, which also represents a specialized agricultural sector, collaboration with industry partners can facilitate research and development efforts in non-traditional staple food crops.** This collaborative approach not only diversifies funding but also fosters applied and more targeted innovation, that enhances the resilience of the tropical seaweed farming industry.

7.3 Types of funding models

One of the main prerequisites for breeding programs and seed banks is the need for long-term funding. The case studies showcase diverse models to secure resources for their research and development initiatives.

A. Philanthropic donations

Philanthropic donations are contributions made by individuals, foundations, or corporations with the primary intention of supporting charitable causes. These donations are typically flexible, allowing the recipient organization to allocate funds according to its needs and priorities, and are also flexible in their duration Thus, donations presents an opportunity to secure funding that can support research endeavors and operational needs. Philanthropic organizations such as the Bill and Melinda Gates Foundation are known for their extensive financial support across various agricultural research and development initiatives, including several of the mapped crop resilience centers.

B. Grants

Grants represent a vital source of funding for specific projects or programs, originating from government agencies, foundations, or other entities. Unlike philanthropic donations, grants typically impose more stringent conditions regarding their application, necessitating that recipients meet exacting standards for goal achievement and report back on their progress. These funds may be procured through public calls issued by government bodies, philanthropic organizations with specific focus areas, or international development agencies. Most cases analyzed tap into these grant opportunities frequently to fund research projects that are in line with their mission and strategic goals, providing essential support to tackle the pressing issues facing the tropical seaweed industry. A notable challenge, however, lies in managing the variability of grant durations, which often range from one to three years, requiring adept planning and adaptability in project execution.

Endowment funding from universities can fall under the category of philanthropic donations or grants, depending on how the funds are managed and allocated. Endowment funds are typically large sums of money donated to universities to provide ongoing financial support for specific purposes, such as research, scholarships, or facility maintenance. Income generated from the investment of endowment funds can be used to support various initiatives, including dedicated breeding programs.

C. In-kind contributions

In-kind contributions refer to non-monetary resources provided by individuals, organizations, governments or corporations to support a cause or initiative. These contributions can include the provision of facilities, equipment, technology, expertise, or other resources that directly benefit the recipient organization. In-kind contributions play a vital role in enhancing research infrastructure and capabilities without requiring direct financial investment.

D. Project-based funding

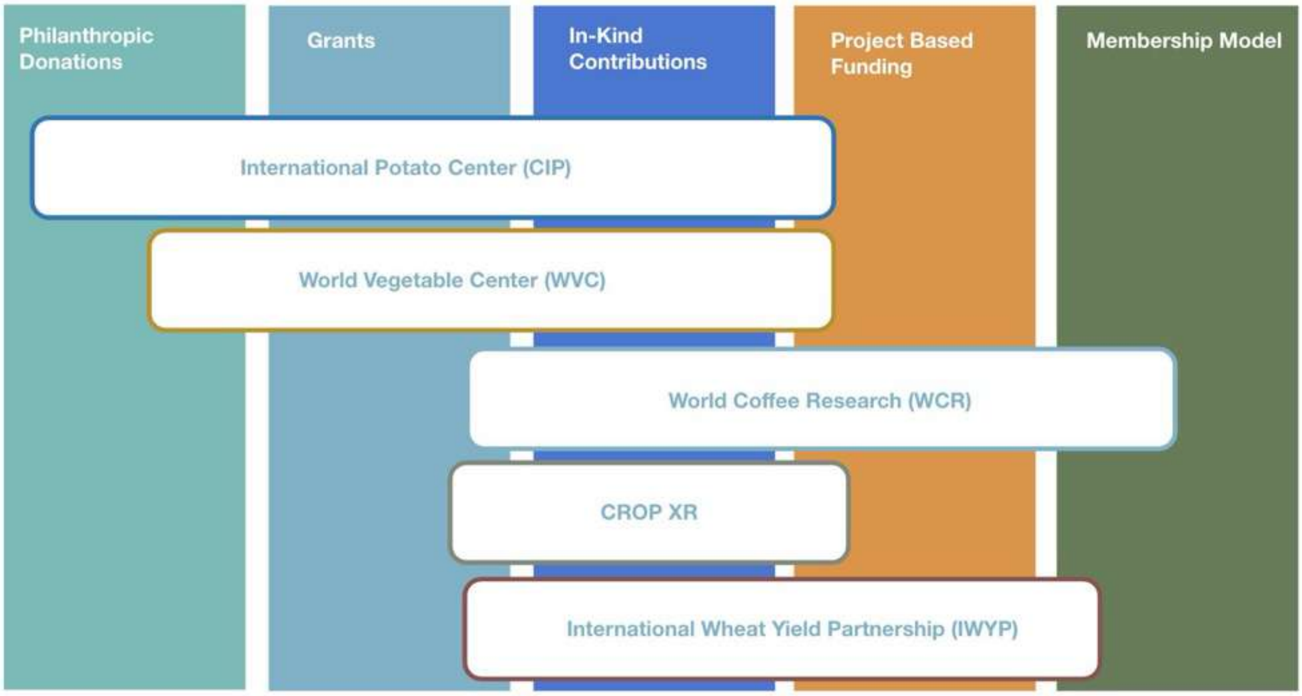
Project-based funding involves collaborations with private sector companies or foundations to support specific projects or initiatives with timelines of up to 10 years. These partnerships may offer funding in exchange for access to project outcomes, knowledge, or technologies developed through the collaboration. For example, organizations like CropXR may use project-specific funding to support research efforts in exchange for access to developed strains or data through the project. This funding model allows them to engage with industry partners and leverage their resources and expertise to advance a research and development agenda.

E. Membership fees

The membership model involves securing annual funding from industry-leading companies within the sector. Companies pay membership fees, often based on market share or other relevant metrics, to become members of the research institute or consortium. In return, members gain access to research findings, networking opportunities, and other benefits. Organizations like World Coffee Research and the International Wheat Yield Partnership (IWYP) successfully utilize the membership model to secure sustained financial support from industry partners. A well-executed membership program can ensure a stable source of funding for its operations and research activities.

From our analysis, it has become clear that most crop resilience centers have elements of at least two or three sources of funding.

Figure 21: Funding sources of the respective case studies



Cost recovery models fit within the broader framework of funding models by effectively addressing the financial requirements of international research initiatives. One common practice involves charging fees for specific services offered by the seed bank or laboratory, such as seed processing, storage, analysis, and consultation services, often through commercial partnerships. Interestingly, the sale of seeds, plant materials, or research outputs to other research institutions, agricultural organizations, or commercial entities has not been found to significantly contribute to cost recovery in the analyzed cases.

Validation for a Tropical Seaweed Resilience Institute

Validation for a dedicated international Tropical Seaweed Resilience Institute (TSRI) is rooted in the recognition of the distinct hurdles within a young industry characterized by challenges such as low market value, frequent reproductive cycles, and fragmented smallholder farming landscapes. By acknowledging and addressing these circumstances, yet applying a forward-looking vision, the establishment of the TSRI emerges as a transformative initiative with the potential to drive meaningful change in the tropical seaweed industry.

This validation is further reinforced by insights gained from a comprehensive global data collection of crop resilience centers, which underscore the importance of specialized institutions on the forefront of agricultural innovation and sustainability. An in-depth understanding of the current landscape in tropical seaweed farming illuminates the pressing need for targeted interventions and strategic initiatives to enhance the resilience and viability of seaweed cultivation. However, it also underscores the strong groundwork and foundation that some of the marine laboratories already established in certain seaweed farming regions can provide for such an institute.

Thus, the establishment of the TSRI is not only a pragmatic response to existing challenges but also a forward-looking initiative aimed at fostering resilience, innovation, and sustainability within the tropical seaweed industry. By addressing the unique obstacles encountered in developing and commercializing new seaweed cultivars, the TSRI has the potential to catalyze transformative change, unlock new opportunities for economic development, and promote environmental stewardship on a global scale.

8.1 Managerial considerations and priority areas

The Tropical Seaweed Resilience Institute (TSRI) is recommended to function as an international umbrella organization for a network of satellite stations across producing countries. These satellite stations, selected from existing tropical seaweed research facilities identified earlier in this report, offer a strategic advantage in utilizing pre-existing infrastructure amidst challenges in securing funding for new facilities. By partnering with established facilities and supporting their enhancement, the TSRI can effectively reduce costs associated with infrastructure development, optimizing resource utilization and expediting the institute's impact. The objective is to fortify existing institutions while capitalizing on their robust foundation, particularly in Eucheumatoid genetic resource datasets from both wild and commercially cultivated strains in various regions.

Concurrently, significant emphasis should be placed on establishing new regional seed banks to conserve native varieties and biodiversity, supported by the international umbrella organization. Securing seed and long-term funding for these regional stations is paramount to alleviate grant competition among researchers and programs. Various funding models, including grants, philanthropic donations, project-based funding, and industry stakeholder memberships, should be explored to achieve this goal. **Crucially, the TSRI should prioritize securing long-term funding, at least with a 10 to 15 years time horizon, to sustain seed banking and breeding programs with a forward-looking approach.** Strategic preparation for fundraising activities is imperative to ensure adequate financial reserves for the general costs of breeding programs, necessitating meticulous financial planning and resource allocation to meet both immediate and future program needs. Furthermore, setting aside sufficient reserves is essential to ensure the long-term success of these breeding initiatives.

Regarding governance structure, the TSRI should establish a Board of Directors and a Scientific Advisory Board to safeguard the institute's vision and mission. The composition of these boards is pivotal, striving for diversity among stakeholders, each distinguished in their respective fields and dedicated to collaborative endeavors. A unique insight from this research is the consideration of social and diplomatic representation within these boards. Given the institute's engagement in diverse geopolitical contexts and with varied cultures, incorporating these perspectives is perceived as essential for comprehensive guidance and success.

Additionally, the TSRI, through its umbrella network, must be committed to encouraging building capacity in satellite stations among technical staff and researchers on necessary activities, including ensuring the ethical exchange of genetic material. The institute must support regional satellite stations to adhere to relevant regulations such as material transfer agreements and the Nagoya Protocol for genetic material exchange.

Beyond genetics, farmers' cultivation techniques, harvesting, and post-harvest practices also impact the yields and quality significantly. In the context of introducing improved strains of crops or seaweed varieties, it's crucial to recognize that farmers may be hesitant to invest more without clear evidence of tangible benefits. Capacity-building initiatives and knowledge dissemination efforts to enhance farming knowledge and standardize best industry practices should go in hand with improved seed material.

Figure 22: Proposed Strategic action areas for the Institute

Seedbanking and preservation

- Establish **blueprints and funding for the establishment and operation of regional seed banks** to safeguard native varieties and biodiversity in tropical red seaweeds.
- Address concerns about the costs of maintaining seed banks and labs through efficient resource allocation.
- Explore and optimize different preservation techniques, including cryopreservation or alternatives, to safeguard genetic diversity and facilitate research activities.

Breeding and crop improvement

- Establish **research and breeding programs aimed at developing new cultivars** with traits crucial for smallholder farmers in tropical regions.
- A focus should be put on developing and employing rapid cycle breeding techniques and prioritizing practical traits to enhance productivity and resilience. These traits include disease resistance, seedling health, carrageenan content, and adaptability to climate change.

Seed material multiplication and distribution

- Produce guiding legal frameworks for potential intellectual property development and plant variety protection.
- Develop **blueprints and business models for local community nursery operations** to facilitate equitable farmers' access to certified improved seed material year-round.
- Conduct studies on optimizing transport techniques for seaweed strains to minimize costs and enhance efficiency.

Capacity building and extension

- Develop training programs for local technicians and researchers to maintain seaweed strains.
- Develop training programs for farmers on best practices for cultivation techniques and guidelines and promote farmer-to-farmer extension networks for efficient knowledge dissemination

Regulatory frameworks and industry standards

- Establish industry-wide frameworks and regulations to guide sustainable practices and ensure the ethical exchange of genetic material (such as the adherence to the **Nagoya Protocol for access to genetic material**) promoting transparency and responsible research practice
- Support satellite stations with material transfer agreements and navigating high-level authorization in genetic material exchange

This collaborative approach is essential for addressing challenges highlighted by downstream industry players, researchers, and farmers, including the establishment of new seed banks and the initiation of breeding programs. The TSRI´s primary role is to align international efforts with the imperative need for industry preparedness, thus serving as a proactive force in enhancing the resilience of the tropical seaweed industry.

Thus, the input and perspectives of various stakeholders, including governments, research institutions, industry representatives, and local communities, will be invaluable in shaping and finalizing the core objectives of the institute, but inspired by the approaches adopted by the case studies, we propose the following **five core objectives of a successful international institute:**

- Build collaboration and trust among all stakeholders
- Genetic innovation as a core activity to achieve long-term impact
- Invest in strong extension and capacity building programs
- 'Do more with less' mentality
- Facilitate policy engagement

A Tropical Seaweed Resilience Institute should be a transformative initiative that can drive innovation, sustainability, and economic development in tropical seaweed farming. By focusing on research, breeding, capacity building, and industry collaboration, the TSRI could play a pivotal role in advancing the resilience and productivity of seaweed farming while empowering smallholder farmers and fostering sustainable livelihoods in tropical regions.

"We are running out of time so the institute should be off the ground and it should be working hard on developing new varieties at the earliest possible. So that we can be ready for climate change. Different negative future scenarios that people are predicting necessitates immediate action from the international seaweed community to build resilience." RA Narayanan, Head of Ocean AgTech, Sea6 Energy, India.

Strategic recommendations

The following recommendations outline a structured approach to further the development of the Tropical Seaweed Resilience Institute, ensuring thorough planning, stakeholder engagement, and strategic alignment to achieve its objectives.

Figure 23 - Recommendations for a detailed project and business plan

1. Build awareness

This step would kick start the process by gathering input, aligning objectives, and fostering collaboration among stakeholders to shape the vision and strategic direction of the TSRI.

1.1. Conduct stakeholder engagement/ideation workshops involving representatives from academia, research institutions, governmental agencies, non-governmental organizations, industry partners, and potential funding partners.

1.2. Facilitate interactive discussions to gather input, align objectives, and foster collaboration in shaping the vision and strategic direction of the TSRI.

1.3. Identifying potential satellite stations, based on a catalog of the various marine labs around the world and their capacities and facilities for applied tropical red seaweed research.

1.4. Elect an international steering committee comprising diverse stakeholders to guide the initiative

1.5. Form subcommittees to delve into specific topics identified during the workshops such as organizational structure, finance (including operations and intellectual property), beneficiaries (farmers) engagement, mission statement and impact metrics, and operations technology (public genome database, bioinformatics tool, etc)

2. **Develop strategic results framework**

Following the stakeholder engagement workshops, the development of the strategic results framework would provide a structured approach for defining key objectives, performance indicators, and impact metrics to measure the success and effectiveness of the TSRI's initiatives.

2.1. Based on stakeholder input, align on a clear mission, vision, and objective of such an institute.
2.2. Identify measurable outcomes aligned with the TSRI's mission and goals, including targets for research outputs, capacity-building activities, adoption of improved seaweed varieties by farmers, and socioeconomic impacts on coastal communities.
2.3. Define clear performance indicators to track progress towards achieving the identified outcomes, such as the number of new seaweed cultivars developed, adoption rates of improved farming practices, increase in seaweed yield and quality, etc.

3. **Develop a comprehensive business plan**

With the strategic results framework in place, the TSRI can then proceed to develop a comprehensive business plan that maps out core strategic pillars, and services provided, identifies potential partners for funding, researches grant opportunities, and proposes a multi-year strategy with key operational milestones.

3.1. Map out core strategic pillars guiding the TSRI's functions and identify services and program activities for each pillar, prioritizing them using a matrix.
3.2. Organizational and operational strategy between umbrella institute and satellite stations. Identify shared resources, virtual infrastructure needs, and effective collaboration models.
3.3. Develop a high-level 3-year operational budget for the startup phase and identify potential revenue sources for the medium to long term.
3.4. Propose 3-5 and 10-year strategies with key operational milestones and critical activities, recommending core functions and activities for the startup phase, and developing a customized set of performance evaluation and impact metrics.

4. **Develop fundraising & partnership roadmap**

The interaction with potential funders commenced with the initial viability study and will be an ongoing process throughout all recommended stages. However, it's only after the establishment of the business plan that TSRI can dedicate its efforts to crafting a strategic fundraising and partnership roadmap to secure the long term funding required

4.1. Identify and engage with potential fundraising partners, including philanthropic organizations, international development agencies, private sector companies, and governmental bodies.
4.2. Reach out to international development agencies and private sector entities to explore potential partnerships and funding opportunities aligned with the TSRI's objectives.
4.3. Research and identify potential grant opportunities to fund the Institute's activities, including research programs, capacity-building initiatives, and operational expenses.
4.4. Develop a comprehensive roadmap outlining fundraising strategies, partnership opportunities, and grant application processes, setting clear timelines and responsibilities for implementation.
4.5. Establish communication channels and engagement strategies to maintain ongoing dialogue with potential partners and donors, fostering relationships and securing long-term support for the Institute's initiatives.

3. **Implementation plan**

Subcommittees, specializing in specific areas, are already being formed during the stakeholder engagement workshops. However, the comprehensive planning and formulation of recommendations in these domains can only begin after securing long-term funding.

3.1. Reassess subcommittees and assign the responsibility of delving further into their designated topics, conducting thorough research, gathering input, and crafting detailed plans and recommendations for implementation.

3.2. Elections to appoint an official international governance board and a dedicated scientific advisory board

8.2 Limitations and areas for further consideration

The initial viability analysis has identified the following limitations and areas for further consideration to develop an effective Tropical Seaweed Resilience Institute.

Table 3: Limitations and considerations looking forward

Issue	Consideration
The limited understanding of operational aspects and challenges in nursery operations, coupled with the absence of a viable business model, impedes the establishment of seaweed nurseries.	Strategy development should involve conducting in-depth research and pilot projects to understand the operational dynamics of nurseries. This includes assessing production costs, optimizing cultivation techniques, and exploring revenue streams. Developing a robust business model for nurseries is essential, considering factors such as cost recovery, scalability, and market demand. This should prioritize exploring mechanisms to ensure fair and equitable access to improved seaweed strains for smallholder farmers. This may involve investigating subsidies, grant programs, or support mechanisms that enable farmers, especially in developing regions, to access high-quality seeds and genetic materials.
In certain established tropical seaweed farming regions, there exist significant biosecurity concerns arising from the interaction between non-native farmed species and wild seaweed stocks.	Laying out and complying with existing national and international regulations governing the importation, cultivation, and release of non-native seaweed species is essential for any activity under the TSRI umbrella. Compliance with relevant biosecurity protocols and obtaining necessary permits for all activities is paramount. A dedicated subcommittee, comprising experts in biosecurity and related fields, should be convened to focus on developing comprehensive guidance to mitigate these risks. CGIAR

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