United Nations University
Institute for Water, Environment and Health (UNU-INWEH) & Scottish Association for Marine Science (SAMS)

POLICYBRIEF

Safeguarding the future of the global seaweed aquaculture industry

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Highlights

1. Global aquaculture production continues to increase, whilst capture fisheries stagnate. Many wild fisheries have been overexploited. Cultivation, if managed sustainably, is a viable alternative.

2. The seaweed industry is undergoing a rapid global expansion and currently accounts for ~49% of the total mariculture production. Unabated exponential growth in the last 50 years has meant that the value of the industry reached US$6.4 billion in 2014, providing jobs, predominantly in developing and emerging economies.

3. There is increasing need to address new challenges imposed by trade and market demand. Case studies clearly show that valuable lessons can be drawn from the major seaweed-producing nations and other aqua- and agriculture sectors.

4. Improving biosecurity, disease prevention and detection measures are critical, together with establishing policies and institutions. This will provide incentives and steer the long-term economic and environmental development of a sustainable seaweed aquaculture industry.

5. This policy brief highlights key issues that need to be addressed to create longterm sustainability of this emerging global industry, as it prepares itself for playing an important role in the 'blue' ocean economy agenda.

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www.sams.ac.uk/globalseaweed

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Challenges

Seaweed production is undergoing global expansion raising new challenges for producers and the environment. Currently, the majority of the seaweed production is for human consumption, whilst the remainder is used for animal feed additives and fertilisers. In the last decade, a significant expansion of the global seaweed cultivation industry has been driven by the growing demand for contaminant-free seaweed and by the commercial sector requiring seaweed-derived products for biotechnological, and medical applications in countries with little traditional interest in seaweed aquaculture or consumption. Furthermore, seaweed cultivation is increasingly being used to reduce the environmental impact of intensive finfish aquaculture through integrated multi-trophic aquaculture (IMTA) techniques.

The rapid expansion of any industry can typically result in unforeseen ecological and socio-economic impacts, particularly in the early stages in new geographical areas, where policies to regulate and manage the industry are in their infancy. These impacts can pose significant challenges for the industry, including; stocks that are highly susceptible to disease and epiphyte outbreaks caused by a reliance on a highly limited genetic stock, the displacement and reduction of wild native stocks through competition and inter-breeding with non-indigenous escapees, intentionally introduced for cultivation purposes and the unintentional introduction of non-indigenous 'hitch-hiker' species, including pathogens. The increased vulnerability of farm sites to natural disasters, which have intensified due to climate change, and the resulting impact on coastal environments by abandoned infrastructure, potential conflicts with other users of the marine environment and growing dissatisfaction of the low-gate prices for the crops are also major challenges.

The aim of this policy brief is to highlight the current challenges facing the global seaweed industry and to provide policy recommendations, which can incentivise this emerging 'global' industry to promote a more sustainable balance between economic growth and ocean health (i.e. blue ocean economy), thus safeguarding its long-term future.

The rise of the global seaweed industry and its environmental and socio-economic consequences

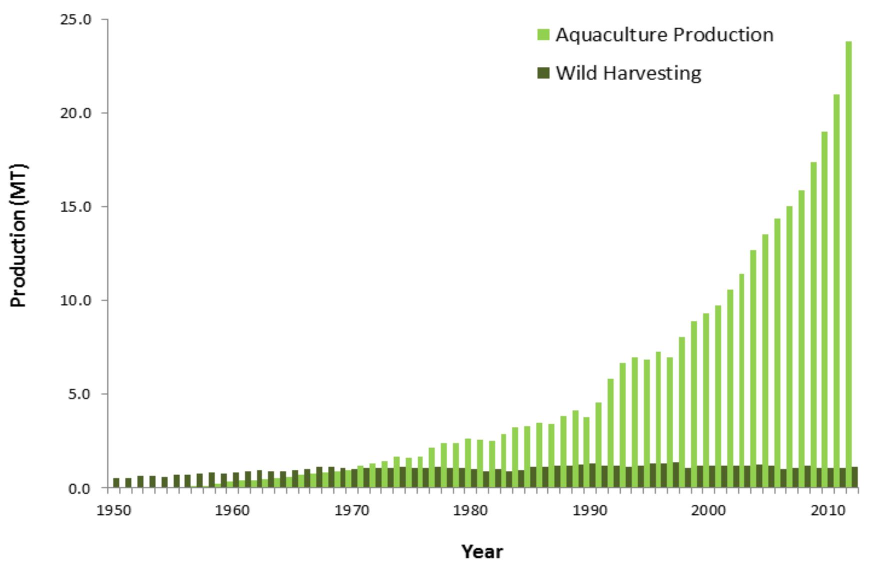

***Figure 1.* Global seaweed aquaculture production (1950-2014). FAO (2015)**

Seaweed aquaculture contributed ~49% to the global mariculture production of 27.3 million tonnes in 2014 and is undergoing a rapid global expansion raising new challenges for producers and the environment. The industry, worth US$ 6.4 billion in 2014, has grown significantly in the last 50 years and is supplying 96% of the global demand (Figure 1). Currently, most seaweed production is for human consumption, whilst the remainder is used for animal feed additives and fertilisers. Countries such as China, the Republic of Korea, Indonesia, the Philippines and Japan are producing the vast majority of seaweed for these purposes. In 2014, China alone produced 12.8 million tonnes of seaweed (54 % total global production), followed by Indonesia at 6.5 million tonnes (27.4 %). The main commercial seaweed species produced for food or food additives in 2015 were *Kappaphycus alvarezii* and *Eucheuma spp.*, *Saccharina japonica*, *Gracilaria* species, *Undaria pinnatifida* and *Pyropia* (formerly *Porphyra*) species.

In the last decade, the rapid expansion of the industry has been driven by the growing global demand for edible seaweeds that are contaminant-free, with a high level of traceability and for products for pharmaceuticals, nutraceuticals and antimicrobial and biotechnological applications. The accessibility of non-indigenous seed plants, typically supplied by the buyers, the rapid spread of technological and scientific knowledge, the requirement for only basic technology and minimal capital investment and the promotion by government agencies supporting economic development, particularly in rural communities has also contributed.

In addition, with world marine capture fisheries stagnating and animal aquaculture expanding at an average annual rate of 9.5 % in 1990 - 2000, aquaculture is becoming the main source of marine dietary protein. The research on seaweed to mitigate the environmental impact of intensive fin-fish aquaculture through IMTA is, therefore, receiving increased attention in developed countries. Seaweed farming, therefore, now expands across several continents from South-East Asia to South America, Northern Europe, Canada and East Africa, contributing to global food security, supporting rural livelihoods, alleviating poverty and improving the health of our oceans.

The rapid expansion of any industry, however, can result in unforeseen ecological and societal consequences. These can include: disease outbreaks, introduction of non-indigenous pests and pathogens, reduction in the genetic diversity of native seaweed stocks and changes in farm management practices (i.e. placing the cultivation nets closer together, thus making the crop more vulnerable to disease transfer and natural disasters). In addition, the illegal use of algicides/pesticides, with unknown but likely detrimental consequences for the wider marine environment, user conflicts for valuable coastal resources and rising dissatisfaction over the low gate prices for the crop can all result in negative impacts on the industry. For example, the red seaweed *Kappaphycus* is one of the most valuable crops grown for its carrageenan content, a product used widely in food, pharmaceuticals and nutraceuticals. As a result, the cultivation of this crop has been promoted in over 30 countries worldwide. The occurrence of 'ice-ice' disease - a bacterial infection causing whitening of the seaweed branches (Figure 2) and epiphyte infestations, however, have led to dramatic declines in the productivity of this crop in the Philippines, where this seaweed originated, in many of the other countries where it has been introduced (e.g. Madagascar and Tanzania). In the Philippines alone, disease caused a 15% loss in production of *Kappaphycus alvarezii* between 2011 and 2013 (a reduction of 268,000 tonnes), equating to a loss of over US$ 310 million based on a value of 1.09 USD/kg (farm-gate price).

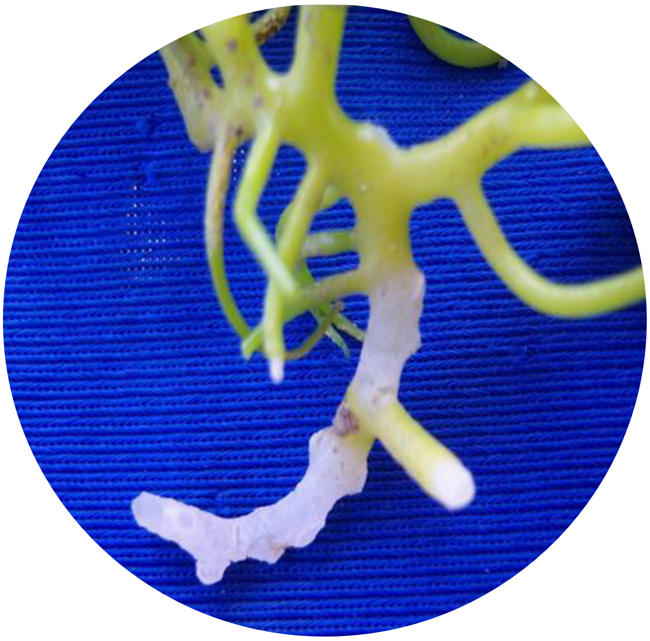

***Figure 2.* Thallus bleaching or 'ice-ice' disease that affects the main thallus in a cultivated *Kappaphycus sp* in the Phillipines © Ronald Simbajon, creative commons (unmodified)**

The increase in demand for contaminant-free edible seaweeds, with a high level of traceability, and their products, will continue to drive the need for greater intensification of global seaweed cultivation, as has been observed in many other aqua- and agricultural sectors. Valuable lessons learnt by these other sectors, include: the importance of biosecurity for preventing the introduction of disease and non-indigenous pests and pathogens, early disease detection, the need to build capacity within the sector and for marine spatial planning (MSP) to resolve conflict for finite coastal marine resources.

Improved biosecurity should underpin the sustainable development of the seaweed industry

As with any form of cultivation, the spread of disease and non-indigenous pests are major factors in halting the expansion of an industry. Biosecurity is a means of controlling the spread of disease and the accidental introduction of non-indigenous pests, thus protecting public health, ensuring the sustainability of the industry, safe-guarding the environment and mitigating any adverse impacts that may result. Indeed, it is not a new concept and there are many examples in the agriculture and aquaculture industries where strict biosecurity measures have been introduced following major disease outbreaks.

The viral disease, Infectious Salmon Anaemia (ISA) of Atlantic salmon (*Salmo salar*) for example, first diagnosed in Norway in 1984, caused up to 80% fish mortality at certain farms in 1990 and led to significant economic losses for the industry. Strict new legislation and biosecurity requirements were rapidly introduced, which not only enabled the industry to respond to, and contain more rapidly, ISA outbreaks, but also other diseases that have since arisen.

In the shrimp farming industry, estimated losses due to globally pandemic viral diseases, such as white spot disease (WSD) caused by White Spot Syndrome Virus (WSSV) led to cumulative losses exceeding $1bn per annum, since emergence in the early 1990s. Movement of live animals is recognised as a major pathway of introduction for Transboundary Aquatic Animal Diseases (TAADs) and as a result, certain countries will now only allow the import of disease-resistant strains of shrimp from bio-secure hatcheries for on-growing, following the introduction of new legislation on biosecurity.

As the seaweed aquaculture industry grows and diversifies into new species and geographical areas, new diseases are likely to emerge and the risk will intensify of introducing non-indigenous pathogens and pests to the new regions.
The implementation of effective biosecurity and the rapid detection of disease / non-indigenous pests, therefore, are vital for the sustainability of this industry. Future challenges for the seaweed cultivation industry involve establishment of ‘local’ breeding and production management centres to reduce the dependency on imported non-indigenous stocks and the development of diagnostic technology to detect disease/non-indigenous pests, as seen in the terrestrial and aquatic animal sectors, together with pathway management, contingency planning and capacity building at both institutional and farm level, to manage an outbreak, should one arise.

Greater genetic diversification and disease-resistant strains can improve resilience to disease

Agri-and aquaculture globally is typically based on species, where market demand already exists and certain traits lend the species to large-scale aquaculture. A lack of suitable native species, or insufficient information on the culture requirements of a particular native species to enable commercialisation, also leads to national and international trade and translocation of non-indigenous species, which can be cultured successfully. Many of the seaweed species that are transferred to new geographical areas throughout the world for seaweed production are from stocks that have either been produced from a limited pool of parent individuals via sexual or asexual (clonal) propagation methods. The later method enables the rapid production of genetically identical plants, with consumer-preferred traits and excellent cultivation performance.

The monocultures that result from this method of propagation, however, are highly vulnerable to disease and once a farm has been infected, can result in the total loss of the cultivated stock. These monocultures also present a high risk, as highly susceptible entry points for new diseases and may become infection loci for other farms as well as to wild native species. This loss can not only jeopardise the export trade for this species, but also the regional food provision and local economy.

CASE STUDY

Bananas and the Panama Disease - how genetic diversity in new banana cultivars could reduce susceptibility to disease

Panama disease affects bananas and is caused by the soil borne fungus *Fusarium oxysporum f. sp. cubense* (Foc), which infects the roots of the plant and subsequently causes the death of susceptible banana plants (Fig. 3). The widest diversity of Foc is present in the centre of origin of its host, South East Asia. Thus far, current genome analysis techniques have shown that particular genotypes of Foc disseminate internationally, thereby addressing inadequate international awareness and quarantine procedures.

Bananas belong to the genus *Musa*, which is the host of Foc, and comprises a wide variety of species. In general, all bananas are derived from two indigenous species (*M. acuminata* and *M. balbisiana*), which produce hundreds of seeds in each fruit. Edible commercial bananas, such as the 'Gros Michel' and the 'Cavendish' varieties, however, have lost the capacity to produce seeds. Due to their seedlessness, bananas are clonal crops that result in extraordinary, genetically identical monocultures. The export trade – which only represents 15% of the global banana production - is dominated (>90%) by the 'Cavendish' clones, but they are also increasingly important for large domestic markets such as in China, India and the Middle-East. Moreover, the 'Cavendish' clones are highly susceptible to several diseases, including the Panama disease. This disease has a particularly bad reputation, as it wiped out the 'Gros Michel' based banana crops in Central America over the last century. 'Cavendish' bananas saved the industry as they are resistant to the Foc strains that caused this epidemic. However, a new Foc variant, known as Tropical Race 4 (TR4), which is indigenous in the Indonesian archipelago, is currently on the move. This new variant is extremely pathogenic on 'Cavendish' clones and many other regionally important banana varieties that serve local markets, thereby affecting the livelihoods of thousands of small growers.

In order to manage the globally developing epidemic, both short and long-term actions need to be taken. In the short term, current exclusion/control methods have to be scrutinized, as the spread of TR4, also within plantations, overwhelmingly demonstrates their inaccuracy and low efficacy. Reliable and standardized tools and protocols for the detection and management of Foc are urgently required, e.g. the use of fungicides and biological crop protection agents / methods. Long(er) term solutions, however, should include: scrutinizing recommended alternatives for the 'Cavendish' clones and, foremost, highly technologically driven and commercially oriented professional breeding programs should eventually diversify the current market with a variety of new banana cultivars that meet consumer preferences and break-up the conservatism of monoculture. Technology, however, has to engage with society and the environment in multidisciplinary approaches for a sustainable future of the banana and its producers.

***Figure 3.* Panama disease affects bananas and is caused by the soil borne fungus *Fusarium oxysporum f. sp. cubense* © Gert Kema**

CASE STUDY

How disease-resistant strains in Penaeid shrimp has contributed to the growth of the industry

Domestication (continuous and controlled reproduction of brood-stock and production of offspring, independent of wild stock) in crustacea is limited to a handful of shrimp species within the genus *Penaeus*. Of these, *P. vannamei* and *P. monodon* support most of the global production, equating to 3.5M metric tonnes and a product value of $12-15bn.

ABOVE: Whiteleg shrimp *Penaeus vannamei* healthy (upper) and infected with Taura syndrome virus (lower) (c) Herman Gunawan CC BY-SA 3.0 https://commons.wikimedia.org/w/index.php?curid=2878079

Whilst early farming operations relied on larvae resulting from wild-captured brood-stock, significant losses, due to disease during this early period, required an increasingly stable larval supply as the industry intensified to supply a globally traded commodity. As such, the use of wild seedstock was progressively replaced by a reliance on domesticated penaeid shrimp lines, often possessing beneficial traits for commercial rearing (such as specific pathogen free [SPF] status for key pathogens affecting the industry). This transition was undoubtedly a key factor in the impressive growth in global shrimp yield in subsequent decades.

The utilisation of SPF stocks, coupled with improvements in selective breeding and, adoption of on-farm biosecurity practices were identified as key requirements for future expansion and long term sustainability of the global shrimp industry. However, the selection of animal lines specifically for their freedom from certain pathogens is attracting some criticism.

Although SPF stock lines are categorised free from specifically listed pathogens (e.g., those of importance in international legislation), the same lines cannot be considered as either 'pathogen free' or indeed, any more able to resist infection and disease associated with emergent diseases. In fact, examples of devastating new diseases continue to occur in otherwise SPF stocks, arising from relatively limited germ-lines, which have been farmed at national, regional and even inter-regional scales.

The most prominent recent example, early mortality syndrome (EMS) - a condition associated with acute hepatopancreatic necrosis disease and possibly infection with the microsporidian *Enterocytozoon hepatopenaei* - caused multi-billion dollar losses in single production years in specific countries such as Thailand following emergence in 2010.

A more integrated approach to on-farm biosecurity and provision of high health status brood-stock is, therefore, critical for maximising potential for successful grow-out. Further, a move towards better understanding of the interactions between host, pathogen and the environment in preventing disease outbreaks will undoubtedly allow for further evolution of the SPF-concept towards the provision of stock animals, which are resilient to their external environment. Basic research applied to host-pathogen interactions and development of concepts for genomic based immunity (a key feature of tolerance to pathogens in invertebrates) will provide the next frontier for expansion of this industry.

The seaweed cultivation industry, particularly in China, has developed new commercial varieties of the introduced kelp *Saccharina japonica*, including disease-resistant strains following large reductions in yield caused by disease. This production of novel varieties was enabled by the development of novel culture techniques in kelps, which considerably reduced the time, cost and labour intensity compared to the routine breeding methods. This kelp is now the main commercial seaweed crop in China with cultivation covering more than 40,000 ha and an annual production of ~1 million ton in dry weight.

In the Philippines, efforts are also being made to select only the disease-resistant cultivars of *Kappaphycus alvarezii* using a micro-propagation technique, however, this technique is not currently used on a commercial scale.

Even in China, however, challenges still remain for the kelp breeders, including limited supply of exotic wild germplasm resources and reduced genetic diversity, as a consequence of the intensive intra-specific inbreeding and successive selection. To date, the technology transfer of seedling breeding from research to industry still remains a challenging task. Yet, it is believed that this is the most promising technology for breeding novel cultivars.

For the sustainable growth of the seaweed aquaculture industry, therefore, the future challenges include: technical improvements in increasing the genetic diversity of cultivars, breeding new disease-resistant strains and establishing disease-free 'seed-banks' or nurseries to assist with the restocking of sites where the crop has been lost to disease.

Encouraging a wider environmental and socio-economic approach to sustainable development of the seaweed industry

The cultivation of seaweed is widely perceived as one of the most environmentally benign types of aquaculture activity, as it does not require additional feed or fertilisers. Consequently, it has been actively promoted by government initiatives, particularly in many developing countries where communities have reduced access to alternative livelihoods or are involved in more destructive fishing methods (e.g., dynamite fishing). The cultivated seaweed and the associated infrastructure provide multiple direct and indirect environmental benefits on both a range of spatial and temporal scales.

The direct benefits include:

- provision of nursery grounds for juvenile commercial fish and crustaceans,
- removal of dissolved nutrients that may otherwise cause eutrophication,
- the protection of the underlying seabed where otherwise seabed scouring through bottom-trawling would have occurred.

Indirectly, seaweed farming has reduced overfishing in many regions, by providing coastal communities with an alternative livelihood and in Tanzania, it has enabled women to become economically active.

The research on seaweed to mitigate the environmental impact of intensive fin-fish aquaculture through integrated cultivation techniques has also received increased global attention in recent years.

In recognition of the increasing demands that the aquaculture industry is placing on the marine environment, an ecosystem-management approach is being developed as a means of marine spatial planning (MSP) for aquaculture, whilst regulating, managing and protecting the wider marine environment. The European Commission recently adopted legislation to create a common framework for MSP implementation, reasoning that competition for maritime space (e.g. renewable energy, aquaculture, fisheries etc) required more efficient management practices to avoid potential conflict and to create synergies between different users. This included the need to develop relevant policy tools to increase coordination between different users, promote cross-border (regional) cooperation in jointly boosting the commodity growth and to create a common understanding on protecting the environment, whilst retaining economic return from resource use.

With seaweed aquaculture set to expand into more developed countries in the next few years, there is potential for this approach to be used to avoid spatial and temporal conflicts in governance in other regions.

It is becoming increasingly apparent, however, that there are wider environmental and socio-economic costs associated with seaweed aquaculture. In the case of the former, non-indigenous macroalgae in particular may alter both ecosystem structure and function by changing food webs, monopolising space, developing into ecosystem engineers and spreading far beyond their point of introduction, due to their efficient dispersal capacities. In the 1970s, the Asian red seaweed *Kappaphycus alvarezii* was introduced to Hawaii for aquaculture purposes. It has since spread via vegetative propagation to corals reefs up to six km from the initial site of introduction, where it overgrows the live coral and can lead to coral mortality.

The inter-breeding of native farm 'escapees' with wild species (known as crop-to-wild gene flow), may also lead to the impoverishment in the genetic resources of wild stocks, as seen in wild salmon populations in Norway, impacting on ecosystem resilience and reducing the potential for new cultivar production. The level of inter-breeding between cultured and wild seaweeds, however, remains virtually unknown. The introduction of non-indigenous stock and the transfer of native stock to new regions for aquaculture purposes, can also lead to the unintentional introduction of 'hitch-hikers', including potentially disease-causing pathogens and parasites.

Socio-economically, if a farm collapses or profits are seriously compromised through a disease outbreak or a natural disaster, there can be devastating economic consequences on the community. In the Philippines, approximately 116,000 families (~1 million people) are reliant on seaweed farming and many could lose their livelihoods as a consequence of a major disease outbreak. Seaweed farmers are also beholden to traders/processors in some developing countries or to government agencies for the provision of seed stock and / or farming equipment, considerably reducing their price-negotiating power. In the Philippines, seaweed farmers are beginning to take advantage of micro-financing schemes to fund their capital investments, which would allow them more independence in their negotiations with the buyers.

Capacity building is clearly a critical component in transferring the scientific knowledge to the seaweed farmers regarding disease prevention, farm management practices and securing independent finance. In the Philippines, several nationwide training courses for seaweed farmers have taken place, organised by local, non-governmental organisations and financed by international donors. Other organisations have produced training manuals and posters, specifically tailored to seaweed farmers and the Open University, in conjunction with the GlobalSeaweed Programme has produced an open access online training course, specifically aimed at disease identification and management. In addition, global / regional networks of industry representatives, NGOs and the research community are emerging (e.g., GlobalSeaweed, Latin American Seaweed Network) to encourage cooperation and knowledge exchange on many aspects related to seaweed farming including production, research, ecosystem services, management of small-scale aquaculture, implementation of legislation and finance/ business management.
For the seaweed industry to grow sustainably, wider (innovative) environmental and socio-

economic approaches are required. The future challenges are to reduce the dependency on non-indigenous cultivars and the traders/ processors that provide these stocks and the farming equipment required to grow them, to reduce the investment risk, potentially through a government-run insurance scheme and to build capacity in the industry and government agencies, through education initiatives on micro-financing, farm management and marine spatial planning.

CASE STUDY

Integrated multi-trophic aquaculture: Using seaweed aquaculture to reduce eutrophication in China and the Republic of Korea

Integrated multi-trophic aquaculture (IMTA) can significantly increase the sustainability of aquaculture. By integrating fed aquaculture (finfish or shrimp) with inorganic and organic extractive aquaculture (seaweed and invertebrates), the wastes of one resource user becomes a resource (fertilizer or food) for others. The IMTA concept provides nutrient bioremediation capability, mutual benefits to the co-cultured organisms, economic diversification, increased profitability, significant ecosystem services and increased societal acceptability. It could also play a signifcant role in reducing ocean acidification at coastal levels.

China and the Republic of Korea have practiced IMTA for many years, and several IMTA types have been well developed in mariculture. In Sungo Bay located in the Shandong Peninsula of Northern China, IMTA has been practiced on a commercial scale for the last two decades. The system is based upon three groups: seaweed, abalone and sea cucumber. In this system, the abalone feed on the kelp and generate organic waste in the form of faeces, which together with the uneaten feed are used by sea cucumbers. The excretory and waste products generated by the abalone and sea cucumbers are then mineralised and assimilated by the kelp, which increases the seaweed productivity and recycles the waste nutrients. Kelp in turn is used as food for human or abalone consumption and produces oxygen, which meets the biological oxygen demand from the abalone and sea cucumbers. The IMTA system is driven only by sunlight, natural inorganic nutrients, as well as carbon dioxide and provides efficient food provisions, nutrient extraction and climate regulating services to the marine ecosystem.

In Sansha Bay, Fujian Province of China, the IMTA system is based on fish, oyster, abalone and seaweed. About 220,000 fish cages are situated in this bay and the annual production of fish, oysters, abalone and seaweed is 80,470 tons, 109,620 tons, 5,770 tons and 81,210 fresh weight (FW) tons, respectively. The seaweed production, however, was found to be insufficient to balance the waste from the fish production and it has been estimated that the optimal seaweed production should be increased to 100,000 FW tons. In Xiangshan Harbour in the Zhejiang Province of China, the IMTA of fish, shellfish and seaweed is well developed. The co-cultured seaweed species are primarily *Saccharina japonica, Pyropia haitanensis, Gracilaria spp* and *Sargassum spp.* and the total seaweed production is about 60,000 FW tons per year. Integrating the production of *Gracilaria verrucosa* with the finfish *Pseudosciaena crocea*, showed significant reductions in nutrients produced by the finfish.

In the Republic of Korea, three main seaweeds, including the brown seaweeds *Saccharina* and *Undaria*, and the red seaweed *Pyropia* represent nearly 98% of the entire seaweed production. Seaweed aquaculture technologies in this country have developed dramatically over the past decades and in certain areas where fish farms occur, IMTA technologies are being applied through the use of seaweed farms to reduce problems of eutrophication.

Aqua-culturalists and coastal managers in the Republic of Korea are also beginning to pay more attention to the ecosystem-based approach to aquaculture, particularly since it has been estimated that a seaweed harvest can remove approximately 66,000 tons of carbon and 4,400 tons of nitrogen every year from the marine environment.

CASE STUDY

Safeguarding the future of seaweed farming - the role of government-led insurance in the Republic of Korea

Managing the sustainable growth of the aquaculture industry is challenging, especially because natural disasters and disease outbreaks increase the risk of investing in this business. Aquaculture facilities are vulnerable to natural disasters due to their exposure to extreme wave action during heavy storms. When the infrastructure is damaged, the crop, growing nets and supporting poles may sink to the seabed causing long term environmental impacts and preventing the use of the farm site for future production. As Korean seaweed farmers are usually only licensed for 3-5 years, there is little incentive to remove the damaged infrastructure as their business is now bankrupt. This has, therefore, become not only a major threat for the marine environment, but to the growth of the Korean seaweed industry itself.

Korea has a long history of aquaculture production and has experienced several natural disasters, which have devastated the majority of sea farms in the country. The government, therefore, initiated the Aquaculture Disaster Insurance (ADI) scheme in 2007 to protect sea farmers from natural disaster. The main objective of this insurance is to support the sea farmers to remove damaged infrastructure from the seabed and to restart their businesses.

When a natural disaster occurs, the insurance company pays 70-80% of the average-yearly production of the farm on the condition that the seaweed farmers return their site to its prior state. Sea farmers can decide on the coverage and interest of the insurance and the government will then subsidise half of the insurance fee. ADI was first applied to flounder and abalone aquaculture in 2008 and now covers 21 marine species including two seaweeds. Initially, ADI primarily covered the physical damage caused to the aquaculture beds by severe weather, but this insurance now covers many biological hazards including red tides and disease epidemics. As a result, seaweed farmers are now more open to report the occurrence of disease outbreaks and have become more willing to try new treatment methods. For example, to treat oomycete diseases, farmers used to apply an acid-wash to their *Pyropia* cultivation nets, but are now trialling a non-acid treatments for these diseases.

It is important to reduce the investment risk for seaweed farming. The introduction of ADI has motivated seaweed farmers to remove damaged infrastructure and made them more open to report disease outbreaks. As the government is now made aware of the true scale of the economic damage caused by disease outbreak, more funding has been made available for research and development in disease identification and management. Eco-friendly treatment methods for dealing with algal diseases are consequently developing at a faster pace as more information is provided and methods are trialled by the seaweed farmers.

FURTHER READING

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POLICY RECOMMENDATIONS

The need for evidence-based policy decision making and sector management is paramount across all the following policy recommendations, which should be acknowledged as essential components of establishing the balance between economic growth and ocean health, and incentivised by policymakers:

1. **Establish centres of research excellence** to develop and identify new indigenous cultivars, specifically chosen for their disease resistance, high yields and ability to meet consumer preferences. To undertake pathogen profiling of key farmed seaweeds to inform risk assessments for trade of seed stock and progagules and to study the interactions of specific genetic variants within a particular geographical location.

2. **Establish national seed banks** which are responsible for maintaining a high health status of seed stock and where disease-resistant strains can be held for use by seaweed farmers following a disease outbreak. These could be part-funded by the government, industry and potentially non-government organisations.

3. **Maintain the genetic diversity in wild stocks** by preventing the introduction of non-indigenous species and encouraging the development of local indigenous cultivars.

4. **Exercise the precautionary approach** when introducing new or non-indigenous cultivars to the marine environment.

5. **Focus on developing and enhancing biosecurity programmes through capacity building**, including training in quarantine procedures and farm management practices and **incentivise the development of diagnostics** to rapidly detect disease and non-indigenous species, to enable adaptive risk management and better evaluation measures to be taken.

6. **Incentivise long-term investment in the industry**, potentially through part-government funded insurance policies to safeguard the business against natural disasters and disease outbreaks.

7. **Incentivise the integration of seaweed, and other extractive species with fin-fish in integrated multi-trophic aquaculture (IMTA) systems** to both reduce the eutrophication of the water column and benthic enrichment effects of fin-fish aquaculture and to minimise space used for aquaculture purposes in the coastal zone.

8. **Develop assessment tools** for evaluating spatial planning issues in relation to aquaculture (including seaweed) and to enable risk-based analysis of spatial management options to support the licencing process and facilitate future investments in infrastructure / insurance schemes to ensure the sustainable growth of this industry.