Mitsui & Co. Global Strategic Studies Institute Monthly Report *May 2024*

SEAWEED MONITORING TECHNOLOGIES GAINING IMPORTANCE AMID GROWING INTEREST IN BLUE CARBON

— ALSO CONTRIBUTING TO SMARTER SEAWEED FARMING —

Shunsuke Nozaki
Industry Innovation Dept., Technology & Innovation Studies Div.
Mitsui & Co. Global Strategic Studies Institute

Ryota Mima
Digital Technology Strategy Dept., Integrated Digital Strategy Div.
Mitsui & Co., Ltd.

SUMMARY

- Seaweed is gaining attention as a marine resource for the sequestration of CO2 and its storage as blue carbon. To quantify seaweed-derived blue carbon, it is necessary to identify the area of distribution and the type of seaweed. This points to the importance of seaweed monitoring technologies that can obtain such information in a low-cost and efficient manner.
- As radio waves are easily attenuated underwater, seaweed monitoring requires monitoring technologies that are different from those used on land. Against this backdrop, progress is being made with innovative technologies such as green lasers that can be used underwater.
- The monitoring technologies discussed in this report will not only contribute to the systemization of blue carbon credits, but are expected to find applications in other seaweed-related industries.

1. INCREASING IMPORTANCE OF SEAWEED MONITORING TECHNOLOGIES

In 2024, Japan became the first country in the world to report greenhouse gas reductions from seaweed forests, including seagrasses, in its greenhouse gas inventory (GHG inventory[1]). To calculate reductions, it is necessary to identify the distribution area of seaweed forests and the types of seaweeds, meaning monitoring technologies that can obtain this information are vital.

1-1. Seaweed forests attracting attention as a blue carbon ecosystem

In recent years, seaweed has been drawing interest for the role it can play as an ecosystem for “blue carbon.” Blue carbon is carbon dioxide that is absorbed and stored in marine ecosystems. Carbon dioxide in the atmosphere can be sequestered and captured as deposits in the soil of coastal areas where there are mangroves and seaweed forests.

A comparison was made of the amount of carbon dioxide absorbed by forests and oceans against the amount absorbed by conservation and restoration of blue carbon ecosystems (Figure 1). It is estimated that conservation and restoration of blue carbon-related ecosystems helps reduce global carbon dioxide emissions

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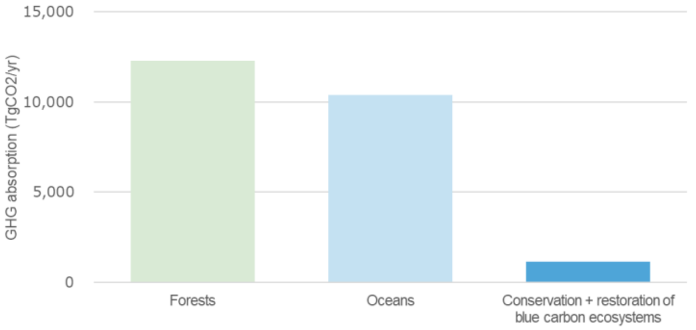
[1] Data on the amount of greenhouse gases emitted and absorbed by a country in a year: Calculations and Reporting of Greenhouse Gas Emissions and Absorption, Etc. (in Japanese) by Japan’s Ministry of the Environment

by approximately 1-3%[2], showing that the contribution to climate change mitigation is not insignificant[3]. In addition to contributing to the reduction of global CO2 emissions, these conservation and restoration efforts are also expected to create secondary effects such as promoting biodiversity. As for relevant global trends, Australia, the US, and the UK are starting to include mangroves and other blue carbon ecosystems in their GHG inventories.

Figure 1: Potential GHG sequestration by blue carbon ecosystem conservation and restoration



Source: Compiled by MGSSI based on Global Carbon Budget 2023 for forests and oceans and from Nature Reviews Earth & Environment, 2, 826-839 (2021) for blue carbon ecosystem conservation and restoration

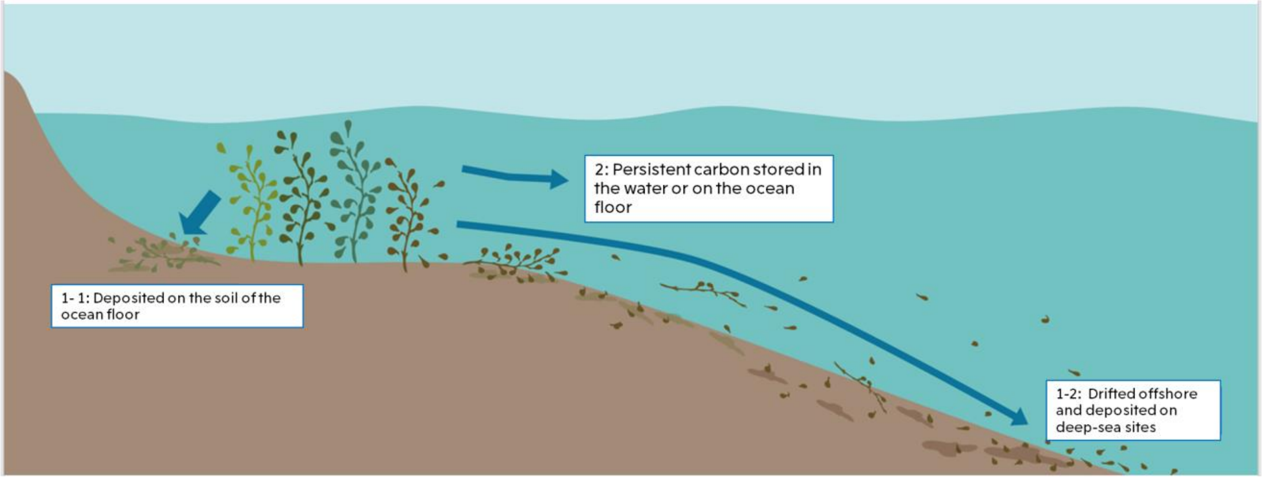
Japan has become the first country in the world to submit a GHG inventory report that includes CO2 emissions removals by seaweed to the secretariat of the United Nations Framework Convention on Climate Change (UNFCCC). In April 2024, Japan recorded 360,000 metric tons of blue carbon derived from seagrasses and seaweed forests.

Japan has the sixth longest coastline in the world, and it is estimated that the country's coastal seaweed forests have the potential to capture 1.3 million metric tons of carbon per year[4].

1-2. Identification of distribution areas and seaweed types needed for blue carbon quantification

Carbon sequestration by seaweed can be broadly categorized into two processes (Figure 2)[5]. (1) The process by which dead or torn seaweed is deposited on the ocean floor and stored as carbon, and (2) the process of storing persistent carbon released from seaweed and other marine sources in the water or on the ocean floor.

Figure 2: Schematic of the carbon sequestration process by seaweed



Source: Japan Blue Economy (JBE) Association, Application procedures for J blue credit certification Ver. 2.4

The basic formula for calculating seaweed-derived blue carbon is: (1) the area of seaweed distribution multiplied by (2) the seaweed-specific absorption coefficient (the amount of carbon dioxide absorbed per unit area). To determine (1), the area of distribution, the boundaries of the seaweed habitat must be accurately mapped, and at the same time, the location information must be verified. In addition, the accuracy of the calculation can be improved if the density of the habitat, called the degree of cover, is known. The absorption coefficient of (2) depends on the type of seaweed, and as such, it is necessary to identify the type of seaweed to determine the

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[2] Nature Reviews Earth & Environment, 2, 826-839(2021), "Blue carbon as a natural climate solution"

[3] Japan's emissions amount to approximately 3% of global emissions.

[4] Japan Blue Economy Association

[5] Japan Blue Economy Association, March 2024, Application procedures for J blue credit certification Ver. 2.4

absorption coefficient to be used. Seaweed monitoring technologies that can measure the above two points will figure prominently.

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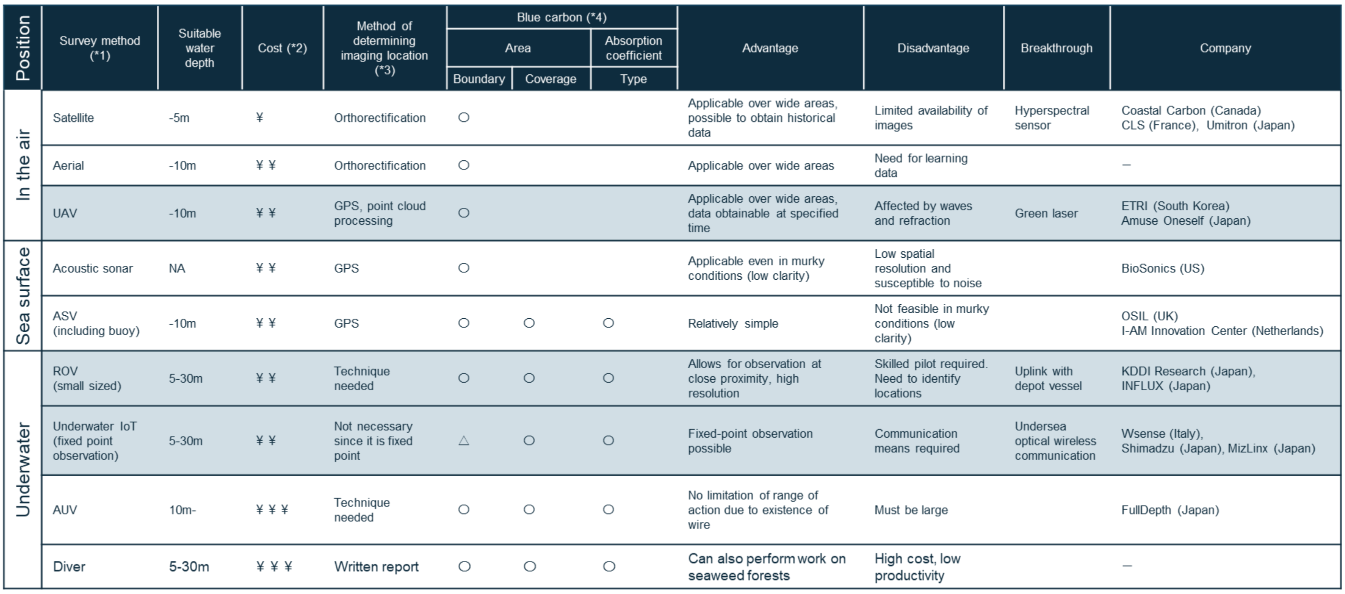
2. SEAWEED MONITORING TECHNOLOGIES

One of the major challenges in monitoring seaweed is that radio waves cannot be used underwater in the way they can be used on land. This is because the radio waves used for sensing and data communication are easily attenuated when submerged. Therefore, technological breakthroughs are needed. The currently available technologies that are highly applicable to seaweed monitoring are shown in Figure 3.

Figure 3: Technologies highly applicable to seaweed monitoring **(Technologies covered in this report)**



Position	Survey method (*1)	Suitable water depth	Cost (*2)	Method of determining imaging location (*3)	Blue carbon (*4)			Advantage	Disadvantage	Breakthrough	Company
					Area		Absorption coefficient				
					Boundary	Coverage	Type				
In the air	Satellite	-5m	¥	Orthorectification	○			Applicable over wide areas, possible to obtain historical data	Limited availability of images	Hyperspectral sensor	Coastal Carbon (Canada) CLS (France), Umitron (Japan)
	Aerial	-10m	¥ ¥	Orthorectification	○			Applicable over wide areas	Need for learning data		–
	UAV	-10m	¥ ¥	GPS, point cloud processing	○			Applicable over wide areas, data obtainable at specified time	Affected by waves and refraction	Green laser	ETRI (South Korea) Amuse Oneself (Japan)
Sea surface	Acoustic sonar	NA	¥ ¥	GPS	○			Applicable even in murky conditions (low clarity)	Low spatial resolution and susceptible to noise		BioSonics (US)
	ASV (including buoy)	-10m	¥ ¥	GPS	○	○	○	Relatively simple	Not feasible in murky conditions (low clarity)		OSIL (UK) I-AM Innovation Center (Netherlands)
Underwater	ROV (small sized)	5-30m	¥ ¥	Technique needed	○	○	○	Allows for observation at close proximity, high resolution	Skilled pilot required. Need to identify locations	Uplink with depot vessel	KDDI Research (Japan), INFLUX (Japan)
	Underwater IoT (fixed point observation)	5-30m	¥ ¥	Not necessary since it is fixed point	△	○	○	Fixed-point observation possible	Communication means required	Undersea optical wireless communication	Wsense (Italy), Shimadzu (Japan), MizLinx (Japan)
	AUV	10m-	¥ ¥ ¥	Technique needed	○	○	○	No limitation of range of action due to existence of wire	Must be large		FullDepth (Japan)
	Diver	5-30m	¥ ¥ ¥	Written report	○	○	○	Can also perform work on seaweed forests	High cost, low productivity		–

*1: UAV (Unmanned Aerial Vehicle), ASV (Autonomous Surface Vehicle), ROV (Remotely Operated Vehicle), AUV (Autonomous Underwater Vehicle)
*2: ¥ = ¥0-1 mn/km^2, ¥ ¥ = ¥1 mn-10 mn/km^2, ¥ ¥ ¥ = 10 mn or more/km^2
*3: In the case of photographs taken using central projection from above, it is necessary to perform a process called orthorectification to correct distortion and align the photographed image with a map.
*4: To estimate the area of blue carbon, it is necessary to obtain information on the boundary (area of seaweed growth), coverage (percentage of area covered by the surface), and seaweed type (for determining the absorption coefficient).
Source: Compiled by Mitsui & Co. and MGSSI based on various materials

There are a variety of underwater monitoring technologies. For example, cameras and acoustic sonar installed on autonomous underwater vehicles (AUVs) or large remotely operated vehicles (ROVs) are used in marine environmental surveys and submarine cable laying operations, for which large equipment can be used in deep waters. Satellite imagery is also used for monitoring in cases requiring the collection of data from locations close to the sea surface over a wide area. The above listed technologies may continue to be used for seaweed monitoring, but more cost-effective technologies are needed. As technologies that have become viable for monitoring seaweed forests at depths of 5 to 30 m at low cost, thanks to technological breakthroughs for addressing the challenges noted earlier, this report discusses (1) unmanned aerial vehicles (UAVs), (2) small ROVs, and (3) underwater IoT.

2-1. Technology of interest (1): UAVs for wide-area monitoring

While UAVs are suitable for extensive seaweed monitoring, as they can be typically flown about 1 meter above sea level and cover large areas, the effects of waves and water refraction have posed limitations to deep underwater observation using UAVs. However, the recent development of a technique using a green laser to penetrate water is allowing for detailed observation of underwater structures, and now more detailed monitoring is possible with the use of UAVs equipped with these green lasers (Figure 4). As an example in Japan, a company called Amuse Oneself applied this new technology in an initiative[6] to survey a marine area of approximately 2.6 kilometers in length and 1 kilometer in width to a depth of approximately 17 meters in

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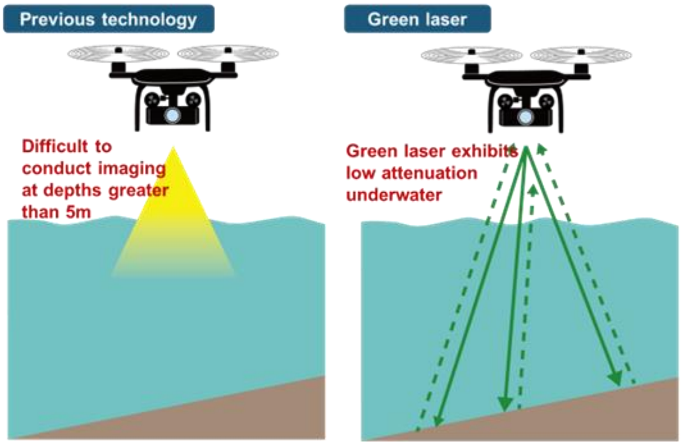
[6] Undertaken in collaboration with the Port and Airport Research Institute

approximately 4 hours, and succeeded in capturing the seafloor topography as point cloud data with an average spacing of 12 cm and an average margin of error of ±2 cm.

Figure 4: Breakthrough UAV technology

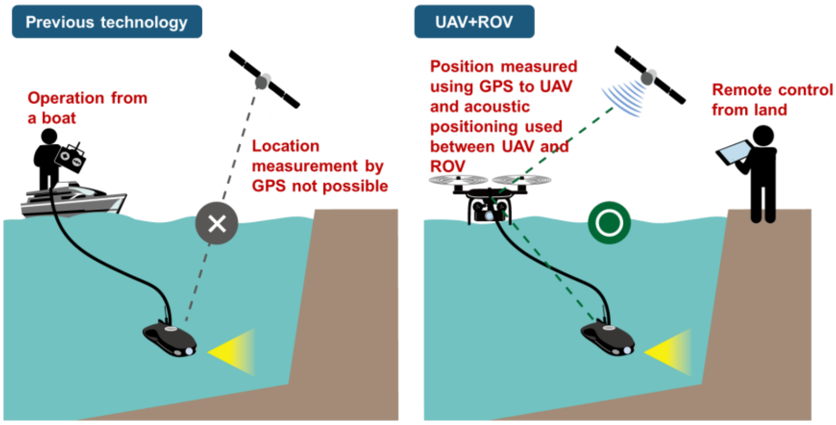


Source: Created by MGSSI

2-2. Technology of interest (2): Compact ROVs suitable for high-resolution monitoring

ROVs, which are remotely operated unmanned submersibles, are suitable for high-resolution seaweed monitoring. One of the challenges, however, is the difficulty of accurately identifying locations. To address this particular problem, methods have been engineered to connect ROVs to UAVs and ASVs and use acoustic positioning technology to determine location (Figure 5). An example of such innovative technology is the “Sea-Air Integrated Drone” developed by KDDI (Figure 6). The ROV is carried to its destination by the UAV, and features technology that enables wide-area monitoring. This integrated drone is expected to be used for improved efficiency of operations at sea.

Figure 5: Breakthrough ROV technology



Source: Created by MGSSI

Figure 6: KDDI’s integrated sea-air drone

Source: https://www.kddi-research.jp/newsrelease/2024/032601.html “Successful remote underwater inspection of bridge piers using a sea-air integrated drone — DX for safety management work on aging bridge facilities”

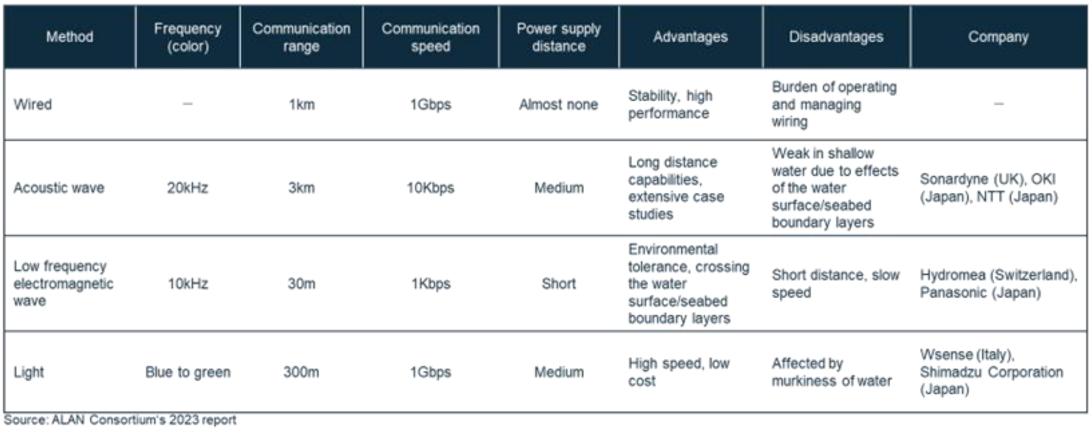
An example of related groundbreaking technological developments overseas is the MoniTARE project being undertaken with the cooperation of Seaweed Solutions of Norway. The ROVs used in this project utilize visual data and biosensors to assess the extent of biological contamination.

2-3. Technology of interest (3): Internet of Things (IoT) for continuous underwater monitoring

Looking ahead, the need for more frequent monitoring is anticipated. In this context, innovative technologies will also be required to continuously retrieve undersea data.

Underwater IoT technology is used for networking between submersible devices. Currently, it is being applied in the oil and gas sector, but in the future, it will be possible to reduce usage costs and adopt it for seaweed applications as well. The technology can also be used to monitor seaweed conditions in real time. Figure 7 lists the underwater IoT technologies available today. No GPS is needed to observe specific locations, and long-term continuous monitoring is possible. However, the transmission speed of conventional acoustic communication was slow. Currently, underwater optical communication technologies using blue-green wavelengths, which have high transmission rates underwater, are being developed and will enable data transmission at higher speeds and with greater reliability.

Figure 7: Breakthrough information and communication underwater IoT technologies



Method	Frequency (color)	Communication range	Communication speed	Power supply distance	Advantages	Disadvantages	Company
Wired	–	1km	1Gbps	Almost none	Stability, high performance	Burden of operating and managing wiring	–
Acoustic wave	20kHz	3km	10Kbps	Medium	Long distance capabilities, extensive case studies	Weak in shallow water due to effects of the water surface/seabed boundary layers	Sonardyne (UK), OKI (Japan), NTT (Japan)
Low frequency electromagnetic wave	10kHz	30m	1Kbps	Short	Environmental tolerance, crossing the water surface/seabed boundary layers	Short distance, slow speed	Hydromea (Switzerland), Panasonic (Japan)
Light	Blue to green	300m	1Gbps	Medium	High speed, low cost	Affected by murkiness of water	Wsense (Italy), Shimadzu Corporation (Japan)

Source: ALAN Consortium's 2023 report
https://www.alan-consortium.jp/wp/wp-content/uploads/2023/08/79d30cb3ebbab52b93624e586dbae428.pdf

An overseas example of underwater IoT technology is the system developed by the deep-tech Italian company Wsense. The company's technology combines a wireless mesh network with acoustic communication to cover large areas underwater, and it overcomes the limitations of physical cables (Figure 8). The system creates a flexible and reliable network that can adapt to different underwater conditions and operational requirements. A similar example in Japan is the work of the ALAN Consortium, an organization that aims to achieve high-speed data communication underwater, with a particular focus on promoting underwater wireless technology using light.

Figure 8: Underwater IoT platform by Wsense

Source: Wsense corporate website, https://wsense.it/

3. PROSPECTS GOING FORWARD

3-1. Establishing Japan's lead in blue carbon quantification technologies

Seaweed monitoring technologies are essential for accurate measurement of blue carbon, which will become the focus of much attention moving forward. Such technologies will also contribute to improving accuracy in the preparation of GHG inventories. In addition to utilizing accurate measurement data, low-cost monitoring is also required for calculating blue carbon credits. As mentioned above, Japan is taking a progressive approach as evidenced by already adding blue carbon derived from seaweed forests to its GHG inventory, and could be considered a pioneer in this respect[7]. In addition, further improvements in accuracy and reductions in the cost of the technologies discussed in this report would give Japan a technological edge.

3-2. Technologies to support the growth of seaweed farming

The growing attention being paid to blue carbon ecosystems is expected to lead to the expansion of the application of seaweed monitoring technologies to areas other than blue carbon, thereby creating new business opportunities. Among the latest trends in seaweed farming, which is expected to grow in scale, is a move toward smart farming (Figure 9). Earlier this year, Sea6 Energy (Indonesia) announced the launch of a large 1 km^2 mechanized tropical seaweed farm off the coast of Lombok, Indonesia. The company promotes mechanization of seaweed farming and develops and sells seaweed-derived biostimulants (a type of agricultural material), food additives, and bioplastics. It is hoped the market will see increasingly more smart products developed with the help of the monitoring and underwater IoT technologies described in this report. Also, the use of these

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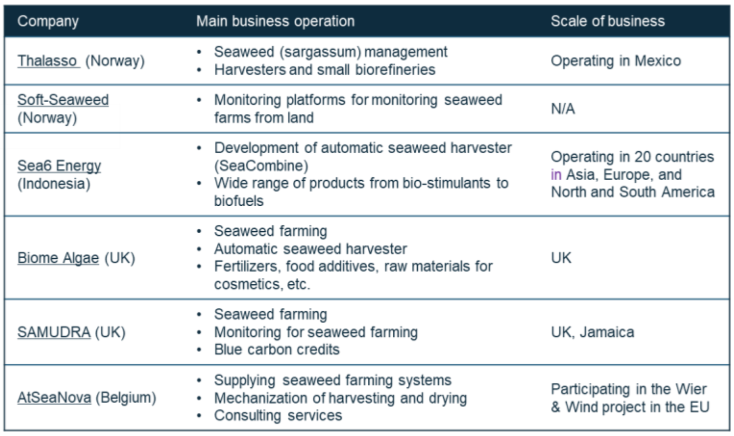
[7] Companies in other countries that are working to quantify seaweed biomass include Coastal Carbon (Canada), which uses AI and satellite imagery.

technologies in the renewable energy field, such as offshore wind power generation, is drawing interest[8]. For example, in the Netherlands, the non-profit organization North Sea Farmers is farming seaweed in the North Sea, in the space where an offshore wind farm is located. The NPO has also received funding from Amazon, and much attention is being given to the possibility of large-scale seaweed cultivation in the rough waters of the North Sea. A demonstration test is scheduled to begin in the fall of 2024, with the first harvest planned for the spring of 2025. If this demonstration test is successful, it will become realistic to use seaweed farming as a way to effectively utilize space at offshore wind farms, which are likely to continue to expand in the future.

Figure 9: Examples of companies engaged in smart seaweed farming



Company	Main business operation	Scale of business
Thalasso (Norway)	• Seaweed (sargassum) management • Harvesters and small biorefineries	Operating in Mexico
Soft-Seaweed (Norway)	• Monitoring platforms for monitoring seaweed farms from land	N/A
Sea6 Energy (Indonesia)	• Development of automatic seaweed harvester (SeaCombine) • Wide range of products from bio-stimulants to biofuels	Operating in 20 countries in Asia, Europe, and North and South America
Biome Algae (UK)	• Seaweed farming • Automatic seaweed harvester • Fertilizers, food additives, raw materials for cosmetics, etc.	UK
SAMUDRA (UK)	• Seaweed farming • Monitoring for seaweed farming • Blue carbon credits	UK, Jamaica
AtSeaNova (Belgium)	• Supplying seaweed farming systems • Mechanization of harvesting and drying • Consulting services	Participating in the Wier & Wind project in the EU

Source: Compiled by MGSSI based on information on each company's website

Seaweed monitoring technology can be used not only as a means of accurately quantifying blue carbon, but also as a technology to support the automation and efficiency of seaweed farming, which is expected to grow in scale. Blue carbon credits contribute to sustaining the activities of those involved in the fishing industry, and also give back to the community by promoting environmental education. It is hoped that Japan, which was the first country in the world to include seaweed-derived blue carbon in its GHG inventory, will lead the way on the technology front as well.

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[8] In addition to seaweed cultivation at offshore wind farms, as discussed in this report, it is also important to monitor the surrounding ecological environment. The US company MarineSitu is developing environmental monitoring systems that use underwater cameras to survey tidal current turbines, wave energy converters, and other machinery and structures. The goal is to reduce the underwater environmental risks associated with development, with the intention of maintaining harmony with marine life.