

## Present status and future scope of seaweed aquaculture in Japan

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**Abstract:** Around 1,500 seaweed species are distributed in the area near Japan, providing one of the most biodiverse marine environments globally. Seaweeds have played crucial roles in Japanese culture and food for centuries. Seaweed beds, known as “MOBA,” provide ecological benefits such as nutrient cycling, water purification, and coastal protection while also support fisheries and cultural traditions. However, natural seaweed beds in Japan have declined by 30–40% since the 1990s due to overgrazing by sea urchins and herbivorous fish, rising water temperatures, and increased water turbidity. This decline threatens marine ecosystems and traditional practices like AMA dive fishing and Shinto rituals. Seaweed aquaculture, particularly of nori, kombu, and wakame, forms the foundation of Japanese seaweed industry. However, recent warming waters have shortened the cultivation periods and increased fish grazing, which has reduced the seaweed yields. Alternative strategies to maintain stable growing conditions of seaweeds include cultivation of them in land-based tanks and use of deep ocean water. While small seaweed species could be cultivated in tanks, cultivation of large species like kombu under artificial conditions is still in the process of development. Restoration of natural seaweed beds involves the removal of grazing animals and employing novel cultivation techniques that establish the seaweed clusters. Artificially restored seaweed beds, termed “SHIN-MOBA,” could help sustain the biodiversity and conditions of fishery resources. Our expertise in seaweed cultivation and seaweed bed restoration will offer hope for adapting to climate change and taking over rich marine ecosystems worldwide.

**Key words:** aquaculture, climate change, MOBA, seaweed bed, SHIN-MOBA

### Introduction

Seaweed and seagrass grow in various marine environments worldwide. Seaweed types vary depending on the environmental conditions of the area where they grow. Although seagrasses are distributed globally, large cold-water kelp species are found in localized cold marine areas. Temperate kelp species are distributed in the mid-latitudes, and brown algae of the genus *Sargassum* are primarily distributed in low-latitude tropical zones. Japan, located in the mid-latitudes, has an exceptionally diverse range of seaweed species, and thus is one of the world’s richest regions for marine seaweed biodiversity (Fig.1).

Approximately 15,000 species of seaweed exist worldwide, approximately 1,500 species of which are distributed in Japan.

Surrounded by the sea where seaweeds are abundant, Japanese people have been utilizing seaweeds into their daily life since ancient times. Seaweeds and seagrasses are also used as fertilizers for agriculture. Seaweeds have long been used as food ingredients in various regions in Japan (Fig.2). However, seaweed beds in Japan are changing due to the effects of climate change (Terada *et al.* 2021).

### Current State of Seaweed Beds in Japan

The current state of seaweed beds, which support a wide variety of seaweed species, is critical in Japan. Seaweed beds play various ecological roles in marine ecosystems. The first is their supportive role in photosynthesis and nutrient cycling. The second is their regulatory role, which includes water

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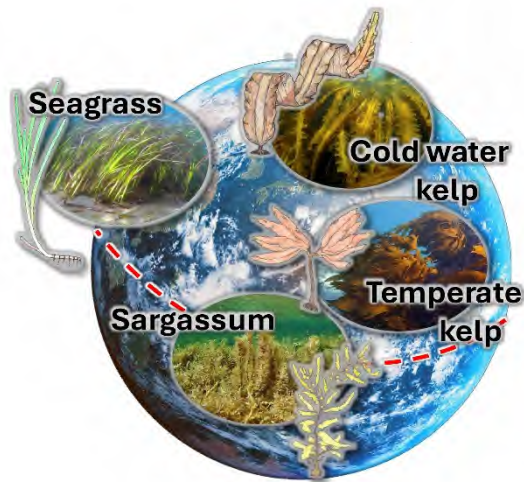


Fig.1 Differences in seaweed and seagrass distribution by latitude



Fig.2 Seaweed has been used in Japan for a long time

purification and coastal protection. The third is their spatial role as nursery grounds where fish and benthos gather and grow, and the seaweeds themselves serve as food for them, some of which are harvested by commercial fishery. Finally, seaweed beds play a cultural role by providing spaces for recreation and environmental education.

Seaweed beds therefore have a wide range of ecological functions. In Japan, seaweed beds are referred to as “MOBA” in Japanese. The term “MOBA” in Japan does not simply refer to a cluster of seaweeds; it encompasses various roles since seaweed beds support marine ecosystems and human livelihoods. As certain Japanese words such as “sushi,” “tempura,” and “samurai” have become globally recognized, we hope that the term “MOBA” will also become popular worldwide.

#### Natural Seaweed Beds in Japan

Natural MOBA, which is vital to marine ecosystems and human life, had covered approximately 2,000 km<sup>2</sup> of the Japanese coastal waters until the 1990s. However, about 30-40% of these algal beds are thought to have disappeared so far (Fig.3). In addition to the decline in natural seaweed beds, poor growth and reduced production have been observed in seaweed aquaculture. The decline in seaweed beds not only degrades marine ecological functions but also threatens Japanese traditional culture.

Traditional Japanese female divers, referred to as “AMA,” have been significantly affected by the decline in seaweed beds. As turban shell (*Saxea*), abalones (*Awabi*), and spiny lobster



Fig.3 Japan's seaweed beds are in decline

(*Iseebi*) have become more difficult to harvest due to the decline in seaweed beds, the number of AMA has halved over the past decade. Furthermore, seaweeds have long played crucial roles in Japanese religious and cultural traditions. Many Shinto shrines use seaweeds in their traditional religious rituals. However, the decline in seaweed beds has made it difficult to conduct the traditional ceremonies (Kimura and Kudo 2011). At the coastal areas of the Seto Inland Sea, there used to be approximately 400 rock cave saunas that used the steam generated by burning a seagrass (*Zostera marina*). However, as the seagrass population declined, these saunas have been closed. Thus, the recent decline in seaweed beds in Japan has been affecting not only the marine ecosystems but also our traditional culture.

### Causes of the Decline in Seaweed Beds in Japan

The largest factor contributing to the decline in seaweed beds in Japan is the grazing by sea urchins, followed by the grazing by herbivorous fish. Grazing by the marine animal is estimated to account for approximately half of the decline. Other contributing factors are the rise in water surface temperature, increased turbidity, and sediment accumulation on the bottom (Fig.4). Warmer water temperatures have increased the activity of sea urchins and herbivorous fish, thereby accelerating the decline in the seaweed beds (Kumagai *et al.* 2018).

The decline in seaweed beds in Japan's temperate zones typically follows the pattern below:

1. Extremely high temperatures inhibit the seaweed growth.
2. Fish grazing also increases, causing a rapid decline in the seaweed populations.
3. As the seaweeds become shorter in length, sea urchins then begin to consume them.
4. After the seaweeds disappear, seaweed spores newly settled on the bare rocks begin to grow, but they are rapidly consumed by the sea urchins.

Once the seaweed bed disappears, restoration becomes extremely difficult. In addition to seaweeds, seagrasses are also grazed by marine animals. In subtropical areas such as Okinawa, seagrasses have declined because of the grazing by sea turtles.

As the grazing increases, seaweed biomass gradually decreases. However, seaweed beds tend to collapse suddenly once the impact of grazing reaches a certain point. If the grazing could be controlled (for example, by removing fish), the seaweed bed will be regenerated. However, due to the extreme difficulty in the restoration of a collapsed seaweed bed, it is crucial to monitor the situation of seaweed beds and take an immediate action for restoration of seaweed beds at the first sign of decline.

### Seaweed Aquaculture in Japan

In addition to harvesting wild seaweeds from natural shores, various techniques have been developed for stable seaweed cultivation in Japan. The primary seaweeds cultivated in Japan are nori (laver), ma-kombu (kelp), wakame (undaria), sujiao-nori (green laver), hitoegusa (monostroma), and okinawamozuku (*Cladosiphon okamuranus*). Among the cultivated seaweeds, nori has the highest production volume, followed by kombu and wakame. Nori and wakame cultivation constitutes

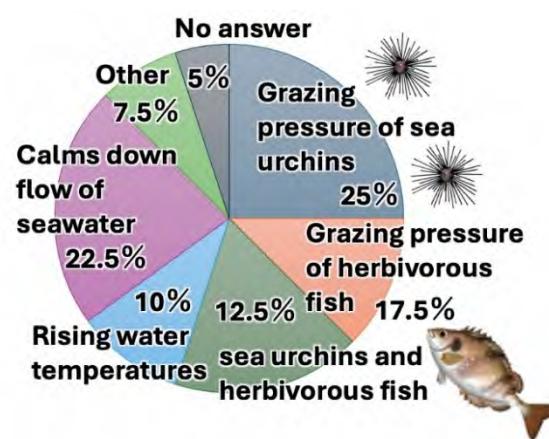


Fig.4 Factors contributing to the decline of seaweed beds in Japan

the foundation of seaweed aquaculture industry in Japan.

Every year, both of nori and wakame cultivation begin in autumn when the water temperature reaches 23°C, with a full-scale production commencing when the water temperature drops to 18°C. The seaweed aquaculture schedule is governed by water temperature; therefore, rising water temperatures by global warming not only affect the seaweed growth but also delay the start of cultivation and shorten the duration of the cultivation. These changes lead to the reduction in production yields.

In addition to the rising water temperatures, fish grazing has become a major issue in seaweed aquaculture, too. Most herbivorous fish prefer warmer water; therefore, when water temperatures rise, they continue to feed on cultivated seaweeds, even in autumn and winter, which also reduces the production yields.

### Strategies for Adapting Seaweed Aquaculture to Climate Change

Both the area of wild seaweed beds and production in seaweed aquaculture in Japan have been declining due to climate change. Therefore, we must develop novel technologies of seaweed cultivation against these changes.

As for seaweed aquaculture, one adaptation strategy is to cultivate seaweeds in land-based tanks. Aonori (green laver) is the most widely cultivated seaweed in land-based tanks in Japan (Hiraoka and Oka 2008) (Fig.5). However, high water temperatures are inevitable problems even in the land-based tanks. Therefore, selective breeding of seaweed varieties that can withstand the high temperatures is a potential solution.

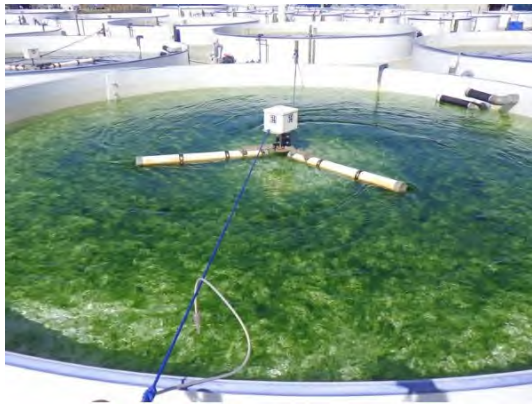


Fig.5 Seaweed cultivated in tanks on land



Fig.6 MOBA is a wild seaweed bed, and SHIN-MOBA is a new type of seaweed bed growing on artificial structures

Another strategy involves the use of deep ocean water, which is colder and rich in nutrients. Fourteen deep-sea water facilities are running in Japan, some of which are being used for seaweed cultivation. Recently, since cultivation techniques for several species of seaweeds have been established, seaweed production through the land-based cultivation has been increasing.

However, land-based tanks are primarily used to cultivate small seaweed species. Large species, such as kombu and wakame, have not yet been cultivated in the land-based tanks. This is due to technical problems, as well as the fact that large, beautiful kelp is popular in Japan. However, small kombu that could be cultivated in tanks will be consumed in salads. To develop Japanese seaweed culinary culture further, it is necessary to change the perception of the ideal appearance of seaweeds.

#### Restoring Natural Seaweed Beds to Adapt to Climate Change

Unlike land-based aquaculture, it is not meaningful to transplant natural seaweed beds onto land; seaweed beds must be established in the ocean. Since the primary cause of seaweed bed decline is the grazing by marine animals, eliminating these factors would theoretically allow seaweeds to grow healthily. In fact, there have been several cases where Japanese fishermen successfully restored seaweed beds by continuously removing the sea urchins.

If the removal of herbivorous animals alone is insufficient to restore the seaweed beds, advanced cultivation technology developed in Japan could be employed to establish seaweed clusters in the ocean. In the areas with heavy grazing pressure, seaweed beds could be protected by surrounding them with nets or hanging seaweed-filled baskets on them. Another approach is to cultivate seaweeds offshore or in deep waters, where herbivorous fish are less abundant. Even in such cases, it is necessary to cultivate sufficient amounts of seaweeds to exceed the grazing capacity of the fish.

Would the seaweeds growing on artificial structures, such as ropes or cages, be regarded as MOBA? Ideally, natural seaweed beds must grow on rocks; however, given the current challenges posed by climate change, it may be necessary to accept such artificially cultivated seaweed beds as a solution to recover the ecosystem.

Traditionally, "MOBA" refers to naturally growing seaweed beds. However, it is proposed that artificial seaweed beds be referred to as "SHIN-MOBA", with "SHIN" meaning "new" in Japanese. To conserve the biodiversity and ensure the sustainable use of marine resources, it is essential not only to protect existing seaweed beds but also to establish SHIN-MOBA in the barren areas (Fig.6). By applying the expertise in seaweed bed protection and seaweed cultivation in Japan, the goal is to create MOBA rich in seaweeds and marine life throughout the coastal areas in Japan.

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