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Seaweed resources as a source of carbon fixation

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Abstract Approximately 2 gigatons of carbon a year is estimated to diffuse across the air-sea interface into the dissolved CO_2 pool of surface ocean water. The total area of algal and seagrass beds along the coasts of Japan is 2,012 km^2. We are currently estimating the macrophyte production along the coasts of Japan by estimating the annual net production and carbon content, and it is likely to be a value of ca. 2,700,000 tons of carbon a year. Additionally, the Japanese people have historically used seaweeds as food source. Economically important genera (*Porphyra*, *Laminaria*, *Undaria* etc.) are cultivated and harvested, with an estimated annual production of cultivated seaweeds of 530,000 tons wet weight. The total amount of annual carbon absorption by seaweed cultivation is estimated to be approximately 32,000 tons, corresponding to 1.2 % of the annual macrophyte production along the coasts of Japan. It is also well known that seaweeds have a positive impact on moderately eutrophic water by absorbing nutrients from surrounding waters. Seaweed resources are an important source of carbon fixation.

Key words: seaweed, carbon fixation, CO_2

Anthropogenic carbon fluxes and ocean uptake

Human activities have led to considerable emissions of greenhouse gases. In particular, for the period from 1980 to 1989 carbon dioxide emissions from fossil-fuel burning and tropical deforestation amounted to 7.1 billion tons of carbon being released a year (Table 1). Increases in atmospheric carbon dioxide concentration can account for about half of the carbon dioxide emissions for this period (Siegenthaler and Sarmiento, 1993).

The ocean has also taken up large amounts of anthropogenic carbon dioxide, and according to IPCC (Intergovernmental Panel on Climate Change)'s esitmate; the amount of oceanic carbon dioxide uptake is 2 billion tons of carbon a year (Table 1). By contrast, Tans *et al.* (1990) estimated an oceanic uptake for the same period of less than 1 billion tons of carbon a year, from surface-water partial pressure of CO_2 (pCO_2) measurements for the Northern Hemisphere and the interhemispheric difference in atmospheric CO_2 concentrations (Tans *et al.*, 1990). Thus, there have been conflicting estimates of this uptake. One of the reasons being that there is not enough annual production data for primary producers including marine plants. Future studies are needed to improve our understanding of the amount of carbon absorption by marine plants.

The amount of carbon absorption of marine plant beds in Japan and in the world

We are currently estimating the annual net production of marine plants and the amount of carbon absorption of marine plant beds along the coasts of Japan. It is known that in 1991, the total area of marine plant beds on the

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coasts of Japan was 2,012 km^2 (Kikuchi, 1994; Table 2). In a Ministry of Environment report, the area of marine plant beds was classified into several types by dominant species. The largest marine plant beds in Japan were *Sargassum* beds (garamo-ba), followed by *Ecklonia* beds (arame-ba), Seagrass beds (amamo-ba), and *Laminaria* beds (kombu-ba). We have been gathering and analyzing data about the standing stock, P-B ratio (Production-Biomass ratio) and carbon content in each species. Using the total areas of each type and these figures, we estimate the total annual carbon absorption to be about 2,700,000 tons of carbon a year (Table 2).

On the other hand, there are few reports of global annual marine plant production; moreover, the figures differ greatly. According to Suzuki (1997), the total area of marine plant beds in the world is about 600,000 km^2 (Table 3). He estimates the global production of marine plant beds to be 460,000,000 tons of carbon a year. This figure is equivalent to 23 percent of the amount of oceanic carbon dioxide uptake in the estimation of Siegenthaler and Sarmiento (1993). Compared with data from the coast of Japan, the total area of marine plant beds in Japan is equivalent to 0.34 % of the global area. In terms of production, it is equivalent to 0.59 % of global production.

The annual carbon absorption by seaweed cultivation

The Japanese people have historically used seaweeds as a food resource. Economically important genera, for example, *Porphyra* (nori), *Laminaria* (kombu), and *Undaria* (wakame) are cultivated and harvested from natural beds in Japan. The total commercial seaweed production in Japan from natural beds and from cultivation grounds was estimated to be approximately 650,000 tons wet weight annually (Table 4). Of this, the production of cultivated seaweeds was about 530,000 tons wet weight, about 82 % of the total. Thus, in Japan, most consumed seaweeds are provided by cultivation. By using the data on carbon content in each species, we estimated that the total amount of carbon-based biomass of cultured seaweeds to be ca. 32,000 tons of carbon a year. This figure is equivalent to about 1.2 % of the total amount of annual carbon absorption by marine plant beds in Japan.

On the other hand, the global production of cultivated seaweeds was about 9,461,000 tons wet weight in 1999 (Table 5). Although Japan is the 3rd largest seaweed cultivating country in the world, the amount of production is equal to only 5.9 % of the whole, China comprises 77 % of the total production. In China, *Laminaria* is the most commonly produced seaweed by cultivation, and 60 % of the production is used as material for alginic acid (Wu, 1998). Using this figure and data on carbon content, the estimate of global production by seaweed cultivation in carbon would be about 600,000 tons.

Are seaweed resources set to carbon fixation?

I have discussed the carbon absorption effect of natural marine plant beds and seaweed cultivation. It was shown that the quantity of the carbon absorbed by marine plants was very large. Especially, absorbed carbon by seaweed cultivation are removed from the ocean by harvesting, and never returned until they are consumed. However, to equate the amount of carbon absorption to carbon fixation, some problems still remain. One of the most important problems is the 'turnover time' of the marine plants. According to Smith (1981), most terrestrial ecosystems have a relatively high biomass and a turnover time of several years to decades. By contrast, although marine macrophytes have the highest biomass among marine ecosystems, the turnover time is about 1 year. It means that most production of marine plant beds outflowed within one year. Ecosystems with a rapid turnover of stored carbon may be biologically important, but they are ineffective as carbon sinks. For this reason, it has been considered that marine plant ecosystems are more effective carbon sinks than

Table 1. Anthropogenic carbon fluxes; 1980 to 1989 (IPCC, 1994)

Carbon dioxide sources	GtC/year
Fossil fuel burning, cement production	5.5±0.5
Changes in tropical land use	1.6±1.0
Total anthropogenic emissions	7.1±1.1
Partitioning among reservoirs	
Storage in the atmosphere	3.2±0.2
Oceanic uptake	2.0±0.8
Uptake by Northern Hemisphere forest regrowth	0.5±0.5
Additional terrestrial sinks: CO_2 fertilization, nitrogen fertilization, climatic effects	1.4±1.5

Table 2. The estimate of carbon absorption by marine plant beds on the coasts of Japan.

Type	Area (km^2)	Standing stock (g/m^2)	P-B ratio	Carbon cont. (%)	C absorption ($\times 10^3$ tonC/year)
Seagrass (amamo-ba)	495	200-1,200	4.0	30-40	485
Laminaria (kombu-ba)	357	3,700-5,400	3.5	25-31	1,156
Sargussum (garamo-ba)	857	120-1,800	1.2	33-37	346
Ecklonia (arame-ba)	645	1,000-3,700	1.1	32-34	562
Gelidium (tengusa-ba)	190	220	1.1	36-40	17
Others	615	140-980	1.0	30	103
Total	2,012	-	-	-	2,669

Data: Area of each seaweed are from BIODIC Database (Ministry of the Environment) Standing stocks are from data of CO_2 Project (1999-2002) Carbon contents are from the same data above.
Estimation: C absorption = Total area × Standing stock × P-B ratio × Carbon content

Table 3. Global annual marine plant production (Suzuki 1997)

Type	Area (km^2)	Production ($\times 10^6$tC/year)
Seagrass	300,000	140
Laminaria	150,000	210
Sargassum	150,000	110
Sargasso sea	-	0.05
Total	600,000	460

planktonic ecosystems, but terrestrial ecosystems are much more effective as carbon sinks.

Fig.1 shows the annual change in cultured seaweed production in Japan for recent years. The difference in the numerical value is not large between years. It suggests that most cultivated seaweed is consumed within a year.

Thus, the effect of marine plants as a carbon sink is temporary. However, it cannot be said that marine plants are not necessarily inferior to terrestrial ecosystems as a carbon sink. Mann (1973) showed that some marine plants are among the most productive and that their productivity is as high as, or higher than, some of the most productive terrestrial systems. Ramus (1992) estimated that the turnover time of *Sargassum* in the Sargasso Sea is 10 to 100 years. Moreover, although the turnover time of

Table 4. Seaweed harvesting and cultivation in Japan (Fisheries Agency; 2000) (unit: tons w.w.)

	harvesting	cultivation	total
Laminaria (kombu)	93,611	53,846	147,457
Undaria (wakame)	3,396	66,676	70,072
Hizikia (hijiki)	7,247	-	7,247
Gelidium (tengusa)	2,824	-	2,824
Porphyra (nori)	-	391,681	391,681
Nemacystus (mozuku)	-	16,324	16,324
Others	11,808	47	11,855
Total	118,886	528,574	647,460

Table 5. Seaweed cultivation in the world (Fisheries Agency; 1999)

Country	$\times 10^3$tons w.w.	$\times 10^3$tons C
China	7,254	435.2
Philippines	621	37.3
Japan	556	33.4
Korea	474	28.4
Other countries	556	33.4
Total	9,461	567.7

terrestrial ecosystems are several years to decade, it is known that developed forests absorbs very little additional carbon dioxide. On the other hand, many marine plant species absorb carbon throughout their lives. For these reasons, we should reexamine the importance of marine plants as a carbon sink.

In addition, we have to estimate the amount of long-term carbon sink. In terrestrial ecosystems, a part of the production is isolated in the soil, and plays a role as a long-term carbon sink. For marine plants, it is thought that a part of marine plant production also becomes detritus, which serves as part of marine deposition, and is isolated from carbon circulation. That is, it is thought that this works like the biopump in planktonic ecosystems (Schimel, 1995). However, there is little data about how much of the total quantity of production of marine plant become deposition. To know the quantitative significance of marine plants on a global long-term carbon sink is to understand the role and position of marine plant ecosystems in the global carbon sink with accuracy.

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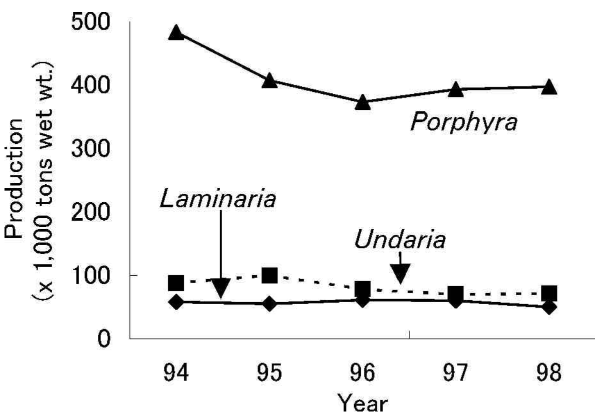

Fig. 1. Annual production of cultured seaweeds in Japan (MAFF)

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