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Biomass of marine macrophyte debris on the ocean floor southeast of Hokkaido Island adjusted by experimental catch efficiency estimates

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Abstract: Most marine macrophytes detach from the bottom substrate after attaining highest biomass in their maturation season. Some marine macrophytes washes ashore or remain in the beds in coastal waters, the others are transported to offshore waters. There is little information on the fate of transported macrophytes. To estimate the biomass of marine macrophyte debris on the offshore deep–sea floor of the northwestern Pacific Ocean (off the southeastern coast of Hokkaido, Japan), we conducted bottom trawl surveys on the continental shelf and slope at depths from 330m to 920m during the summer season in 2008. The nets retrieved samples of macrophyte debris in 20 (83%) of 24 trawl tows. To quantify the *in situ* biomass, we calculated the catch efficiency of the bottom trawl net. We used two procedures to estimate a catch efficiency of 16.7% for *Sargassum horneri* fragments. Subsequently, we calculated that an average biomass density of macrophyte debris was 50.0 mg wet weight m^{-2} in our study area. Macrophyte debris included sargassaceous fucoid (70.0%), kelp (22.1%), seagrass (7.8%), and other brown and red algae (0.1%). We suggest that offshore transport of detached marine macrophytes, especially sargassaceous fucoid, constitutes an important pathway of organic carbon from coastal surface euphotic waters to the offshore deep ocean floor.

Keywords: *marine macrophyte debris, ocean floor, bottom trawl net, catch efficiency*

Introduction

Macrophyte beds of seaweed and seagrass in shallow coastal waters of the world's oceans are among the highest primary producer systems on the planet (SMITH, 1981; UNEP, 2009). Net primary production in macrophyte beds (i.e., mass of CO_2 fixed per unit area) is much higher than in phytoplankton blooms or in mangroves and closely similar to that in terrestrial rain forests (SMITH, 1981; SUZUKI, 1997). Most macrophytes are removed from the coastal seafloor by waves and currents, after attaining their highest biomass in their season of maturation (YOSHIDA, 1963; YATSUYA *et al.*, 2007; ITO *et al.*, 2009; KOMATSU *et al.*, 2009). Two surveys conducted in a bay on the Pacific coast of Japan (MIKAMI 2007) and in a bay facing the Sea of Japan (YATSUYA *et al.* 2007) reported that 80% of the annual primary production of sargassaceous fucoid fronds drifted from their beds with seaward outflow. After becoming detached from the substratum, macrophytes with positive buoyancy, including sargassaceous fucoid and seagrass, can float on the sea surface. These rafts of drifting macrophytes occur in ocean waters worldwide (THIEL and GUTOW, 2005; HERNÁNDEZ–

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CARMONA *et al.*, 2006; HINOJOSA *et al.*, 2010). In the waters surrounding Japan, drifting sargassaceous fucoid with positive buoyancy is the most common floating macrophyte (YOSHIDA, 1963; OHNO, 1984; HIRATA *et al.*, 2001; KOMATSU *et al.*, 2007).

After buoyant macrophytes lose positive buoyancy, they sink to the seafloor at velocities of 119–160m h^{-1} (in the case of sargassaceous fucoid) (SCHOENER and ROWE, 1970; JOHNSON and RICHARDSON, 1977; MIKAMI, 2007) and 98–120m h^{-1} in the seagrass species *Zostera caulescens* Miki (author's unpubl. data). Consequently, sinking macrophyte rafts may reach depths of about 2500m in one day.

Clumps of sargassaceous fucoid debris have been photographed in abyssal waters (SCHOENER and ROWE, 1970). Several photographic surveys using ROVs have found marine macrophyte debris aggregated in concave areas of the seafloor such as ocean basins and submarine canyons, where benthic material can easily accumulate (TORBEN, 1976; SMITH, 1978; LOWSON *et al.*, 1993; HARROLD *et al*, 1998; VETTER and DAYTON, 1999). Non–buoyant macrophytes such as *Eckloniopsis radicosa* (Kjellman) Okamura, *Undaria pinnatifida* (Harvey) Suringar, and *Undaria undarioides* (Yendo) Okamura have been found on the slopes of steep submarine valleys at depths of 200–400m off the coast of Suruga Bay, Japan (TAKAI *et al.*, 2010).

We suggest that buoyant macrophytes transported offshore by surface currents will eventually sink and become widely distributed on the ocean floor, while non–buoyant macrophytes heavier than seawater will be transported by bottom currents and gravity to offshore seafloors.

Hokkaido, the most northern major island of Japan, is in the subarctic North Pacific Ocean. Non–buoyant macrophyte species of kelp occur in this cold water region. Some cold water species of buoyant macrophyte, seagrass and sargassaceous fucoid, are also distributed around the island. IKEHARA (2004) observed sargassaceous fucoid of *Cystoseira hakodatensis* (Yendo) Fensholt floating in the waters offshore from southern Hokkaido (in the present study, *C. hakodatensis* was included in sargassaceous fucoid for simplicity, following HIRATA *et al.*, 2001).

Non–buoyant kelp species that grow inshore around Hokkaido may be transported to offshore seafloors when their blades erode. Buoyant macrophytes such as sargassaceous fucoid may eventually sink to offshore seafloors when their gas bladders deflate and lose their positive buoyancy. To determine the fates of non–buoyant and buoyant macrophytes, we conducted a field survey offshore from Hokkaido searching for fragments of macrophyte debris on the deep–sea floor.

Bottom trawling was used to survey the continental shelf and the continental slope between depths of 330 and 920m, at distances approximately 10–60km offshore from the southeastern coast of Hokkaido. Bottom trawl nets have a wide net mouth that enables collection of samples on the flat seafloors. Hence, this gear is commonly used for efficient sampling of deep benthic organisms (SPENGLER and COSTA, 2008). Substantial amounts of marine debris are frequently brought to the surface as bycatch in bottom trawl nets (PRENA *et al.*, 1999; PROBERT *et al.*, 1997).

An estimate of the catch efficiency of sampling gear is crucial in calculations of macrophyte biomass on the ocean floor. We used two different procedures to estimate the catch efficiency of the bottom trawl net and then proceeded with biomass calculations. We also determined the proportions of non–buoyant and buoyant species in the seafloor macrophyte debris accumulations.

Materials and Methods

Bottom trawling

We conducted systematic surveys southeast of Hokkaido from June to July 2008 using the R/V *Wakataka–maru* belonging to Tohoku National Fisheries Research Institute. We sampled the waters of the continental shelf and slope by trawls towed at depths of 330–920m at 24 stations (Fig. 1). The bottom trawl net had a wingspread of about 20m, a 27.4m head rope, and a 38m ground rope. The net was rigged with bridles and otter windows. A cylindrical rubber bobbin with a diameter of 150mm and steel sinkers were attached to the ground rope.

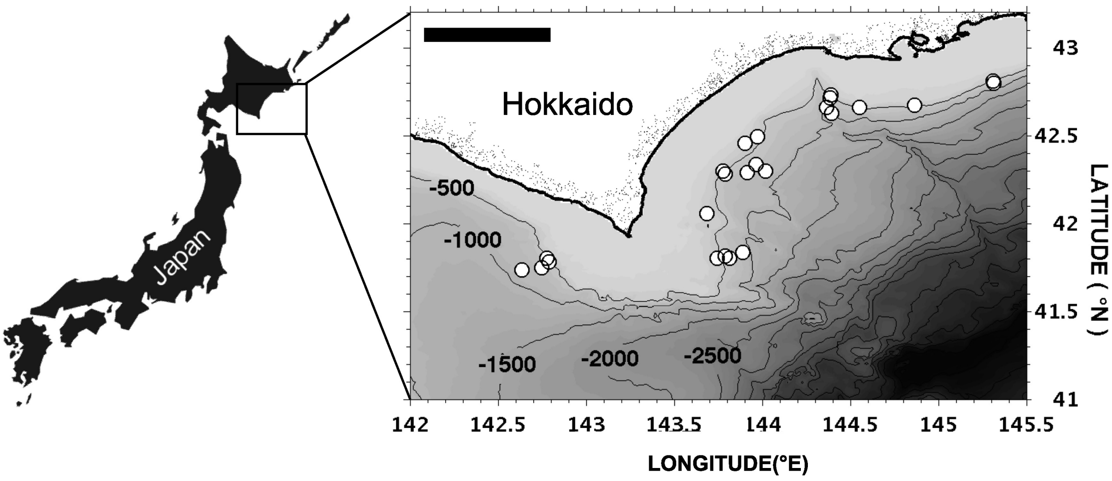

Fig. 1. Research area and macrophyte debris collection sites. Locations of bottom trawl casts in relation to bathymetric contours (m). Bathymetric depths are shown by a grayscale, with darker color indicating greater depth. Each trawl tow is represented by a circle plotted at the midpoint of deployment. Black scale bar＝50km.

The bottom trawl net was composed of a two–layered structure, each layer with a different mesh size: 50mm for the inner net, and 8mm for the outer net. The mean towing time from landing on the bottom to lifting the net from the bottom was 20 min at speeds of 2.5 to 3.5 knots. Every object captured in the bottom trawl was carefully investigated and analyzed immediately on board.

Sample treatment

Samples collected by bottom trawling may include floating macrophytes that are caught during the ascent or descent of the net. To distinguish between macrophyte debris from the seafloor and floating macrophytes, the relative densities of the samples in relation to seawater were examined onboard as follows. Macrophyte samples were immediately transported to a tank filled with surface seawater. Samples that were heavier than the water were classified as macrophyte debris obtained from the seafloor, while those that were lighter were classified as buoyant macrophytes and excluded from the analysis.

Macrophyte debris was weighed, identified to species, and preserved in a freezer at －40℃. All samples were photographed with a digital camera to record colors, and the images were used to verify species identifications.

Estimation of trawl catch efficiency

The catch efficiency of the bottom trawl net for macrophyte debris was examined by two procedures: a “frame–trawl experiment” and an “extra–net experiment.”

Frame–trawl experiment

An experimental frame–trawl net was deployed using the same ground rope as used on the actual bottom trawl net (Fig. 2). Two video cameras (Panasonic, DMC–FT1) were mounted on the center of the upper part of the frame trawl mouth and were oriented to view the entire length of the ground rope.

Sargassum horneri (Turner) C. Agardh was used for the experiment. It was freshly harvested from the sargassaceous fucoid bed in Funakoshi Bay, northeastern Japan, on 8 July 2009. We converted *S. horneri* to debris by removing all of the airbladders, thus eliminating positive buoyancy. Two hundred *S. horneri* debris fragments of 50 g each were prepared and randomly submerged on a sandy seafloor in a 20m square experimental area in Funakoshi Bay at a depth of 15 m (the center of the

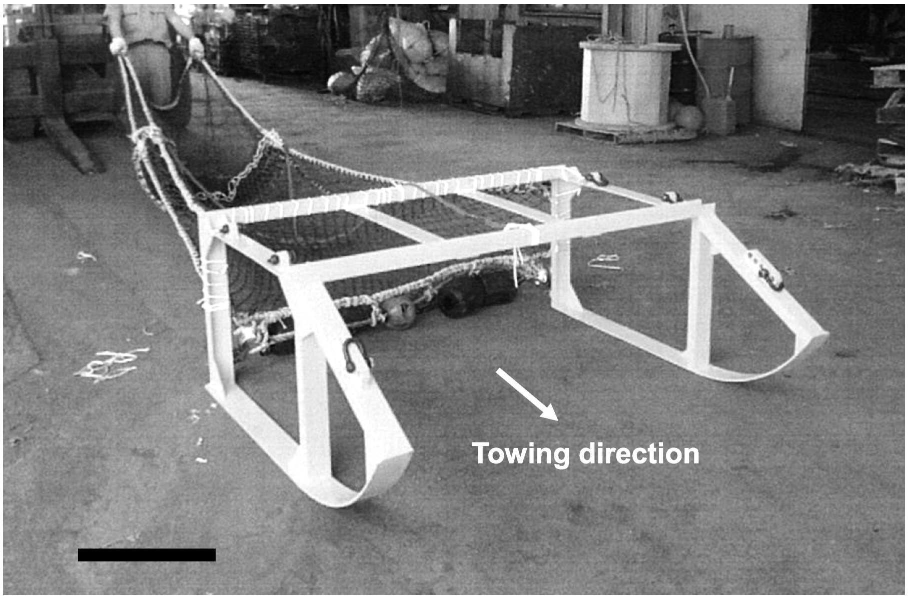

Fig. 2. Image showing the frame–trawl net used in the experimental catch efficiency test of the bottom trawl net. The ground–rope of this net was identical to that used in the actual bottom–trawl net assembly. Black scale bar＝50cm.

experimental area was at 39° 23.0′N, 141° 56.5′ E). Fragments of *S. horneri* were collected with the experimental frame–trawl net and images of the ground rope were captured by video cameras. All trawls were towed at a speed of 2.0 knots.

Using the video images, we counted the number of *S. horneri* fragments that passed through the mouth of the frame–trawl in each tow. We calculated the efficiency of the bottom trawl net by comparing the numbers of *S. horneri* passing through the mouth and the numbers of fragments caught in the net. Sandy substratum dominated both the experimental site and the locations where we performed the bottom trawl surveys.

Extra–net experiment

The macrophyte debris catch efficiency of the bottom trawl net was also examined in 23 sampling tows in waters off the Pacific coast of northeastern Japan at bottom depths of 150–450m during April 2010. Trawls were deployed from the T/V *Tanshu–maru* belonging to Kasumi Senior High School, Hyogo Prefecture. The exterior of the net was covered by an extra net with an 8mm mesh and a chain ground rope (Fig. 3). Assuming that the catch efficiency (E) of the extra net was 100%, we estimated the efficiency of the bottom trawl net by comparing the masses of macrophyte debris caught by the regular and extra nets, expressed as the ratio of catch in the trawl net (TN) and catch in the extra net (EN) for each tow: $E=TN/(TN+EN)$. The mean towing duration was 10 min and towing speeds were those used in the normal bottom trawling survey (2.5 to 3.5 knots).

Estimation of biomass density

To estimate the density of macrophyte debris, the wet weight of each catch was divided by the area swept in each tow (following calculation procedures of Kitagawa and Hattori, 1998). The wingspread of the bottom trawl net was measured with an otter recorder (Furuno, CN–22A) 10 min before ascent of the net from the seafloor. Differential GPS was used to calculate towing distance. To measure the duration of each tow, the times when the net

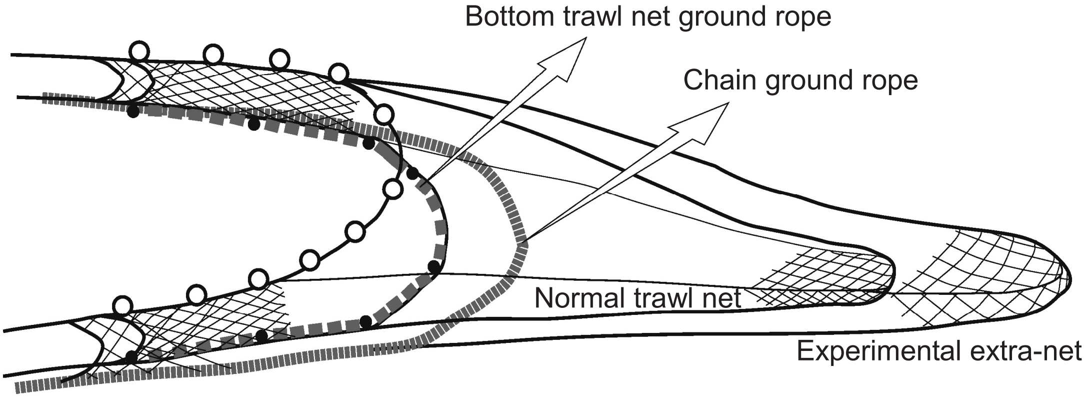

Fig. 3. Schematic of the extra–net used in the bottom–trawl net catch efficiency experiment. The experimental extra–net with a chain ground rope enveloped the bottom–trawl net.

Table 1. Marine macrophyte species netted in the survey trawls measured in terms of wet weight and frequencies of occurrence. The species are listed in decreasing order of weight. Catch efficiency of the bottom trawl net was not taken into consideration. Numbers in parentheses are frequencies of occurrence. Total number of hauls and areas sampled by the bottom trawl net were 24 and 0.60 km^2, respectively.

types		species name	wet weight (g) (number of occurrence)
seagrass		*Zostera marina* Linnaeus	
		Phyllospadix iwatensis Makino	372 (17)
seaweed	sargassaceous fucoid	*Cystoseira hakodatensis* (Yendo) Fensholt	2292 (12)
		Sargassum horneri (Turner) C. Agardh	595 (3)
		Sargassum siliquastrum (Turner) C. Agardh	34 (1)
		Sargassum muticum (Yendo) Fensholt	23 (1)
		Sargassum sp.	18 (1)
	kelp	*Arthrothamnus bifidus* (Gmelin) Ruprecht	6500 (1)
		Costaria costata (C. Agardh) Saunders	250 (3)
	other algae	*Coilodesme japonica* Yamada	7 (2)
		Petalonia binghamiae (J. Agardh) Vinogradova	4 (1)
		Ptilota filicina J. Agardh	6 (1)

reached and left the bottom were determined acoustically using a net–mounted probe attached to the head rope. Based on the measured wingspread and towing distance, the swept area was calculated (mean±SD) as 0.025km^{-2} ±0.009km^2. The biomass density D (mg wet weight m^{-2}) of each towing location was estimated as follows:

$$D = \frac{W}{A \times E} \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \quad (1)$$

where A and W are the swept area and the wet weights of macrophyte debris samples collected from each towing location, respectively. To correct biomass density estimations, the calculated W/A was multiplied by the reciprocal of experimental catch efficiency E.

Results

Marine macrophyte debris

Marine macrophyte debris was collected from a wide area of the continental shelf and gentle slope in the study area. Eleven species of seagrasses and seaweeds (brown and

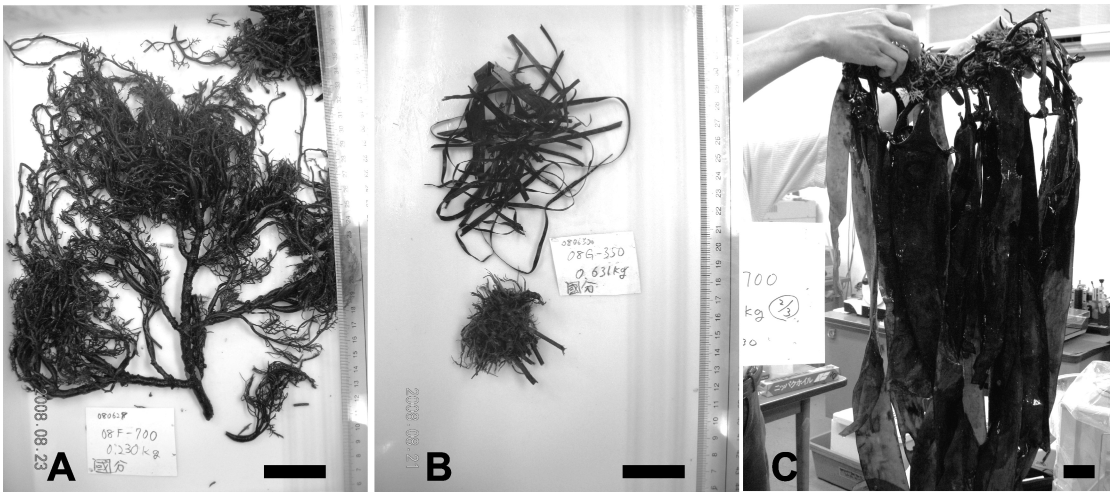

Fig. 4. Examples of frequently collected marine macrophyte debris. Fresh sample of *Cystoseira hakodatensi* (A) collected from a bottom depth of 880m at 41°50.00′N,143°53.26′E. (B) Seagrass (a mix of *Zostera marina and Phyllospadix iwatensis*) collected from a bottom depth of 330m at 42°3.47′N, 143°41.07′E. Most seagrass blades were discolored (dark green or black) and were presumed to be dead. (C) Kelp species (*Arthrothamnus bifidus*) collected from a bottom depth of 770m at 42°17.38′N, 143°54.88′E. Black scale bar＝5cm.

red algae) were collected (Table 1). The most abundant was sargassaceous fucoid. Among the species of sargassaceous fucoid, *C. hakodatensis* was dominant in the wet biomass (Fig. 4, A). *Cystoseira hakodatensis* occurs only in northern regions of Japan, mainly around Hokkaido (YOSHIDA, 1963; YOSHIDA, 1984). Two seagrass species, *Zostera marina* Linnaeus and *Phyllospadix iwatensis* Makino were also common (Fig. 4, B). Two kelp species, *Arthrothamnus bifidus* (Gmelin) Ruprecht and *Costaria costata* (C. Agardh) Saunders, were found. A large 6500 g fragment of *A. bifidus* debris was sampled at a bottom depth of 770 m (42°17.38′ N, 143°54.88′ E) (Fig. 4, C). Most of the sargassaceous fucoid samples appeared fresh, whereas most of the seagrasses were discolored (black) and appeared to be old.

Sargassaceous fucoid occurred in 14 of the 24 tows. The frequencies of kelp and seagrass occurrence were 4 and 17 of 24 tows, respectively. The quantity of seagrass collected was small, while their frequency of occurrence was high.

Catch efficiency of bottom trawling

Frame–trawl experiment

In video images, *S. horneri* fragments were seen to escape entrapment by the ground rope of experimental frame trawl (Fig. 5). Comparing the amount of *S. horneri* passing through the mouth with the amount caught in the net, we calculated a catch efficiency of 19% (N＝5, SD＝14.0).

Extra–net experiment

In 10 of 23 tows, fragments of *S. horneri* debris were caught in either the regular or extra nets. In 4 of 23 tows, *S. horneri* was caught in "both" nets at the same time and the catch efficiency was estimated as 14.5% (N＝4, SD＝7.3) (Table 2). Other types of macrophyte debris were not netted during the experiments.

Biomass estimations of marine macrophyte debris

The catch efficiencies estimated from the frame–trawl and extra–net experiments were similar at 19% and 14.5%, respectively. The similar estimates based on two quite different approaches convinced us that our calculations

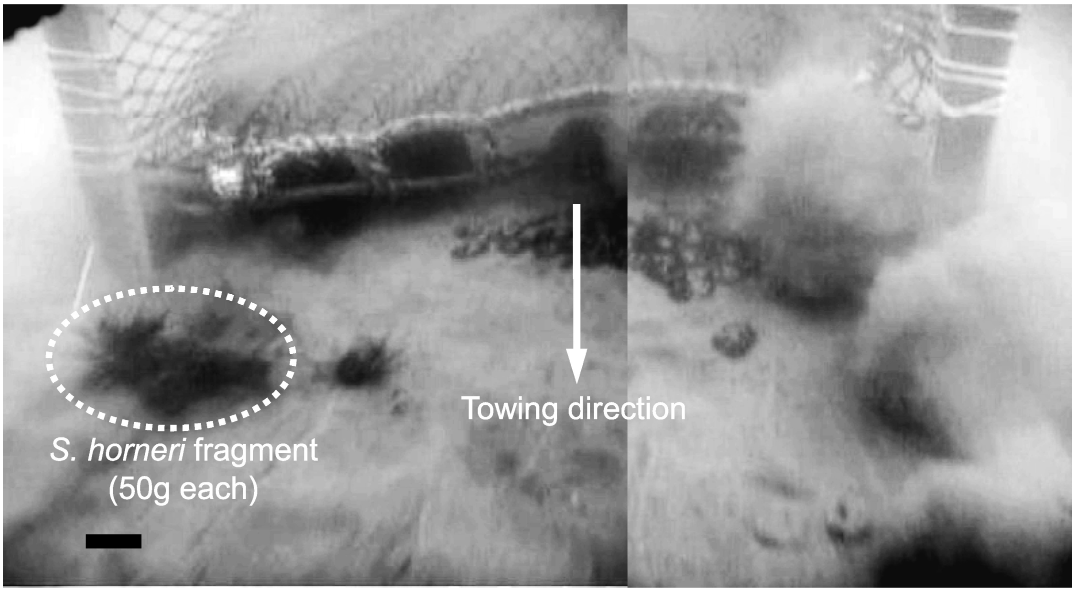

Fig. 5. Video image showing the frame–trawl net ground rope and *S. horneri* fragments in front of it during the frame–trawl experiment. Black scale bar＝10cm.

Table 2. Catch efficiency of marine macrophyte fragments (*Sargassum horneri*) captured with the bottom trawl net, estimated from experimental trawls with an extra net deployed outside of the main net. The total catch by the main net was divided by the catch of the extra net.

	Location		Depth operated (m)	Total catch by the botton trawl net (TN) (g)	Total catch by the extra net (EN) (g)	Catch efficiency (%) TN/ (TN＋EN)
1	38° 25.8′N	141° 59.7′E	350	10	80	11.1
2	38° 55.6′N	142° 5.4′E	350	20	110	15.4
3	38° 24.9′N	142° 3.4′E	450	3	38	7.3
4	38° 24.9′N	142° 3.4′E	450	9	28	24.3
						14.5 ± 7.3*

* Average bottom trawl net catch efficiency±SD
SD: Standard deviation

of catch efficiency were suitable for biomass estimation. We averaged the two estimates and obtained 16.7% for the catch efficiency of the bottom trawl.

This catch efficiency was applied to all other samples to adjust biomass densities, except for kelp which was always collected in large clumps. Because the large kelp clumps would not pass readily beneath the bottom trawl, we used a catch efficiency of 100% for kelp biomass estimation.

We calculated the average biomass density of

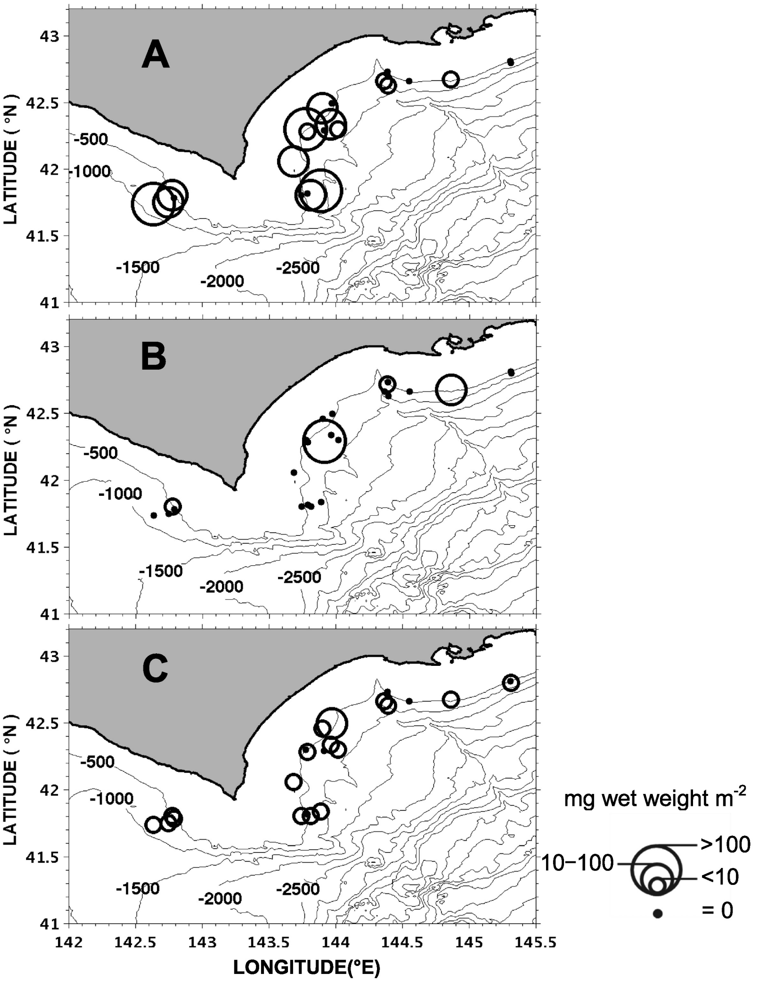

Fig. 6. Density distributions of macrophyte debris (mg wet weight m^{-2}). (A) Distribution of sargassaceous fucoid debris. (B) Distribution of kelp debris. (C) Distribution of seagrass debris. Biomass density at each station is indicated by the size of the circles.

total macrophyte debris as 50.0 mg wet weight m^{-2} (N=24, SD=67.0) across the entire study area. The total biomass in the survey area was composed mainly of species of sargassaceous fucoid, kelp, seagrass, and other brown and red algae in rank order. The average biomass density of sargassaceous fucoid was 35.0 mg wet weight m^{-2} (N=24, SD=52.9) (Table 3). Sargassaceous fucoid was made up with *C. hakodatensis, S. horneri*, and "other" sargassaceous species, constituting of 77%, 20%, and 3%, respectively. The average biomass density of kelp and seagrass were 11.0 mg wet weight m^{-2} (N=24, SD=51.0) and 3.9 mg wet weight m^{-2} (N=24, SD=7.6), respectively.

The distribution of macrophyte debris on the seafloor is shown in Figure 6. The frequently collected sargassaceous fucoid and seagrass were widely distributed and there were no discernible trends in their spatial distribution patterns within the survey area.

Carbon biomass of sargassaceous fucoid

The dry weight of sargassaceous fucoid is

Table 3. Biomass density (mg wet weight m^{-2}) of sargassaceous fucoid, kelp and seagrass calculated from the estimated catch efficiency and the bottom trawl operation. * Catch efficiency of 100% was applied to calculate the kelp biomass density.

sampling point				bottom depth	swept area (A)	2008 Spring								
latitude(N)		longitude(E)				sargassaceous fucoid			kelp			seagrass		
deg	min.	deg.	min.	(m)	(km^2)	catch efficiency (E)	wet weight (W) (g)	density W/(E×A) (mg wet weight m^{-2})	catch efficiency (E)*	wet weight (W) (g)	density W/(E×A) (mg wet weight m^{-2})	catch efficiency (E)	wet weight (W) (g)	density W/(E×A) (mg wet weight m^{-2})
42	48.70	145	18.65	480	0.025	0.167	0	0.00	1.00	0	0.00	0.167	0	0.00
42	47.91	145	18.85	600	0.016	0.167	0	0.00	1.00	0	0.00	0.167	3	1.03
42	40.42	144	51.78	390	0.016	0.167	7	2.73	1.00	224	14.33	0.167	1	0.40
42	39.57	144	33.15	500	0.025	0.167	0	0.00	1.00	0	0.00	0.167	0	0.00
42	43.92	144	23.33	450	0.038	0.167	0	0.00	1.00	0	0.00	0.167	0	0.00
42	42.92	144	23.18	540	0.027	0.167	0	0.00	1.00	10	0.38	0.167	0	0.00
42	39.68	144	21.99	780	0.021	0.167	13	3.73	1.00	0	0.00	0.167	14	4.02
42	37.57	144	23.61	880	0.021	0.167	24	6.94	1.00	0	0.00	0.167	11	3.06
42	27.31	143	54.12	340	0.024	0.167	277	67.94	1.00	0	0.00	0.167	8	1.99
42	29.69	143	58.39	440	0.028	0.167	0	0.00	1.00	0	0.00	0.167	170	36.48
42	20.10	143	57.94	720	0.016	0.167	154	57.47	1.00	0	0.00	0.167	6	2.29
42	17.96	144	1.23	880	0.014	0.167	12	5.08	1.00	0	0.00	0.167	6	2.63
42	3.47	143	41.07	330	0.035	0.167	573	98.73	1.00	0	0.00	0.167	52	8.93
42	17.97	143	46.67	500	0.026	0.167	637	148.47	1.00	0	0.00	0.167	0	0.00
42	16.75	143	47.49	570	0.034	0.167	15	2.69	1.00	0	0.00	0.167	8	1.40
42	17.38	143	54.88	770	0.026	0.167	0	0.00	1.00	6500	249.91	0.167	0	0.00
41	48.23	143	44.55	450	0.048	0.167	0	0.00	1.00	0	0.00	0.167	13	1.70
41	48.82	143	47.28	580	0.047	0.167	0	0.00	1.00	0	0.00	0.167	0	0.00
41	48.02	143	48.99	650	0.027	0.167	49	10.94	1.00	0	0.00	0.167	1	0.29
41	50.00	143	53.26	880	0.012	0.167	332	165.00	1.00	0	0.00	0.167	20	9.78
41	46.80	142	47.44	550	0.016	0.167	0	0.00	1.00	0	0.00	0.167	11	4.18
41	48.23	142	46.64	570	0.024	0.167	236	59.58	1.00	16	0.68	0.167	1	0.23
41	44.79	142	44.86	770	0.021	0.167	299	86.64	1.00	0	0.00	0.167	27	7.92
41	44.01	142	38.09	920	0.016	0.167	332	124.65	1.00	0	0.00	0.167	20	7.39
Average							123	35.02		281.26	11.05		15.50	3.90
Total							2961			6750			372	

generally approximately 20% of wet weight (Taniguchi, 1998; Ito *et al.*, 2009). The carbon content of sargassaceous fucoid is about 30% of its dry weight (Yoshida *et al.*, 2001). Using these ratios, we estimated the carbon biomass of sargassaceous fucoid from the wet masses of samples collected in our survey area. The average biomass density of sargassaceous fucoid (35.0 mg wet weight m^{-2}) is equivalent to a carbon biomass of 2.1 mg C m^{-2}. The average carbon biomass of sargassaceous fucoid in each of three bottom layer was calculated (Fig. 7). The average carbon biomass was high in the bottom layers deeper than 500 m.

Discussion

Bottom trawling is among the most efficient methods for sampling organisms on the ocean floor (Spengler and Costa, 2008). We used this method and successfully obtained samples of macrophyte debris from the seafloor. However, the catch efficiency of a bottom trawl net is not 100%. Thus, the catch efficiency was estimated through two different procedures.

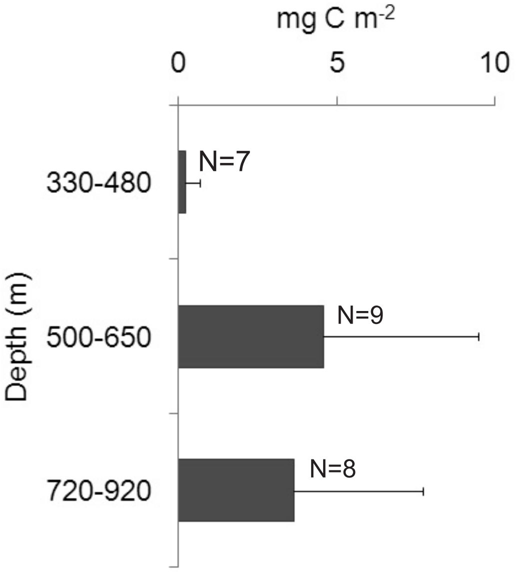

Fig. 7. Relationship between depth and carbon biomass of sargassaceous fucoid debris. Average carbon biomass (mg C m^{-2}) was calculated for depth layers of 330–480, 500–650, and 720–920 m. N values are the numbers of stations, while error bars indicate the standard deviation.

The catch efficiency of the bottom trawl net used in this study had been estimated previously for snow crab *Chionoecetes opilio* (FUJITA *et al.*, 2006). In the snow crab study, the ground–rope was observed with an underwater video camera attached at the trawl net mouth during the towing operation. The number of crabs caught in the net and the number of crabs approaching the ground–rope were compared, giving a catch efficiency estimate of 13.0%. Average carapace widths of the snow crabs measured during the experiment were 11.0cm for males and 6.8cm for females. In our "frame–trawl experiment," the observed diameters of *S. horneri* fragments in seawater were about 10–30cm, and the calculated catch efficiency was 16.7%. Thus, two kinds of benthic organism of similar size had similar catch efficiencies with the same net gear, which will allow some degree of generalization in future studies.

Drifting macrophytes with positive buoyancy are the most abundant floating objects on the world's oceans (THIEL and GUTOW, 2005), and the most common in Japanese waters are species of sargassaceous fucoid (YOSHIDA, 1963; OHNO, 1984; HIRATA *et al.*, 2001; KOMATSU *et al.,* 2007). In our study area, sargassaceous fucoid composed 70.0% of the total biomass of bottom samples. Sargassaceous fucoid of *C. hakodatensis* was the major macrophyte debris species off southeastern Hokkaido. Our results agree with those of IKEHARA (2004), who reported this *Cystoseira* floating in the offshore waters of southern Hokkaido. The specimens collected in our survey were still fresh, suggesting that they had sunk to the bottom shortly before collection. Hence, sargassaceous fucoid drifting from the coast of southern Hokkaido had lost its buoyancy and sunk to the offshore seafloor.

The primary organic carbon source for the ocean floor is generally thought to be sinking particles that originate mainly from phytoplankton in surface waters (JOSEFSON and CONLEY, 1997). However, TORBEN (1975) reported several photographic surveys conducted off the east coast of the USA and in the Caribbean Sea showing the utilization of seagrass debris by benthic isopods as a source of food and shelter on the deep–sea floor. Our study also indicates that macrophytes are supplied to the deep–sea floor off Hokkaido. Marine macrophytes transported from the coast of southern Hokkaido may play an important role in supplying organic carbon to the surrounding offshore deep ocean.

On the basis of published reports of carbon content ratio of sargassaceous fucoid, we estimated that 2.1 mg C m^{-2} of sargassaceous fucoid derived carbon accumulated on the seafloor throughout our study site. This value was similar to the biomass of giant kelp, *Macrocystis pyrifera* (Linnaeus) C. Agardh, on the bottom of the continental shelf off California USA (0.5–10 mg C m^{-2}) (HARROLD *et al.*, 1998). Therefore, the amount of seaweed–derived carbon on the continental shelf is similar off the east and west Pacific coasts. Hence, there is a global pathway of organic matter transport from coastal waters to the deep ocean driven by drifting macrophytes. The present study revealed an annual organic carbon pathway from temperate coastal waters to the ocean floor below the euphotic surface ocean, driven by newly recruited macrophytes grown up every year. This phenomenon probably also occurs in drifting seaweeds in boreal and tropical waters. To elucidate the fate of macrophyte –derived organic matter in the ocean, we plan further studies of macrophyte transport from the coast to the deep ocean.

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