

Abundance of drifting seaweeds in eastern East China Sea

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Abstract Drifting seaweeds play important ecological roles in offshore waters. Recently, large amounts of drifting seaweed rafts were found in the eastern East China Sea between the continental shelf and the oceanic front of the Kuroshio Current. However, so far there have been no quantitative reports about this particular area. Two research

cruises were organized to survey abundance and standing crop of drifting seaweeds in eastern East China Sea in May 2002 and March 2004, using visual census and net sampling of drifting seaweeds. Visual census data were composed of drifting seaweed raft diameter, perpendicular distance from the transect (navigation course of the research vessel) to the raft, and positions. Using these data, we calculated the “effective stripe width” using the DISTANCE software. Drifting seaweed abundance (composed exclusively of *Sargassum horneri*) in waters located between the continental shelf peripheral area and the Kuroshio oceanic front was estimated to be higher than in any other area within eastern East China Sea in March and May. Abundance means in May 2002 and March 2004 were 6.14 and 29.05 rafts km⁻², respectively, while standing crop reached 126.81 and 20.35 kg km⁻² (wet weight). Mean diameter and drifting seaweed rafts in May 2002 were significantly greater than in March 2004, reflecting seasonal growth of *Sargassum horneri*.

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Abbreviations

AIC Akaike's Information Criterion
ESW Effective Strip half-Width

Introduction

On rocky coasts along the northwestern Pacific, *Sargassum* species form a luxuriant forest in spring and a scanty one in summer (Komatsu et al. 1982). In spring, the *Sargassum* forest has a great influence on marine environments such as

water temperature (Komatsu et al. 1982, 1990, 1994; Komatsu 1985), pH (Komatsu and Kawai 1986), dissolved oxygen concentration (Komatsu 1989), downward illumination (Komatsu 1990) and water flow (Komatsu and Murakami 1994). Commercially important fish spawn in the *Sargassum* forest in spring, while abalone and turban shells are traditionally associated with this particular habitat. Therefore, *Sargassum* forests play very important ecological roles in nearshore coastal waters. Their stems or lateral branches generally attain several meters in length in spring when most of these species mature. From winter to spring, when they become longer, waves and currents detach the seaweeds from the benthic substratum (Yoshida 1963). *Sargassum* species have many vesicles filled with gas to provide buoyancy and, hence, *Sargassum* species can float after being detached. Once detached, they become drifting seaweeds and are common in Japanese waters (Yoshida 1963), as in the Sargasso Sea. In this particular area, drifting seaweeds spend their entire floating-life stage in a vegetative reproductive state (Parr 1939).

Drifting seaweeds play key ecological roles in offshore waters as well, as they play host to attaching or accompanying flora and fauna. Hence, drifting seaweeds constitute moving ecosystems (e.g., Cho et al. 2001). Thus, they serve as means of dispersal for littoral animals such as intertidal animals (e.g., Ingólfsson 1995). Moreover, seaweeds themselves also enlarge their habitats by means of drifting rafts. For example, Hernández-Carmona et al. (2006) reported that sporophytes of drifting *Macrocystis pyrifera* (Linnaeus) C. Agardh remained fertile with high germination success as long as sori were present (125 days). Since drifting fragments of *Sargassum muticum* (Yendo) Fensholt which invaded European waters in the 1980s could continue growth and become fertile, they have enlarged their geographical distribution (Rueness 1989).

With regard to fisheries, they are spawning habitats for flying fish (e.g., *Hirundichthys oxycephalus* Bleeker) (Ichimaru et al. 2006), Japanese halfbeak (*Hyporhamphus sajori* Temminck & Schlegel) and Pacific saury (*Cololabis saira* Brevoort) (Ikehara, 1986). They also serve as nursery habitats for larvae and juveniles of some commercially important pelagic fish species, such as yellowtail (*Seriola quinqueradiata* Temminck & Schlegel,) or jack mackerel (*Trachurus japonicus* Temminck & Schlegel) (Senta 1965), which spawn in the East China Sea (Fig. 1). Consequently, investigating the distribution and abundance of drifting seaweeds in this specific area is of primary interest for fishery purposes.

Yoshida (1963) reported that most of Japanese drifting seaweeds are found in nearshore coastal waters (within 20 km from the shore) in the vicinity of oceanic fronts west or north of Kyushu Island in the East China Sea (Fig. 1). Yoshida (1963) also underlined that the abundant season of

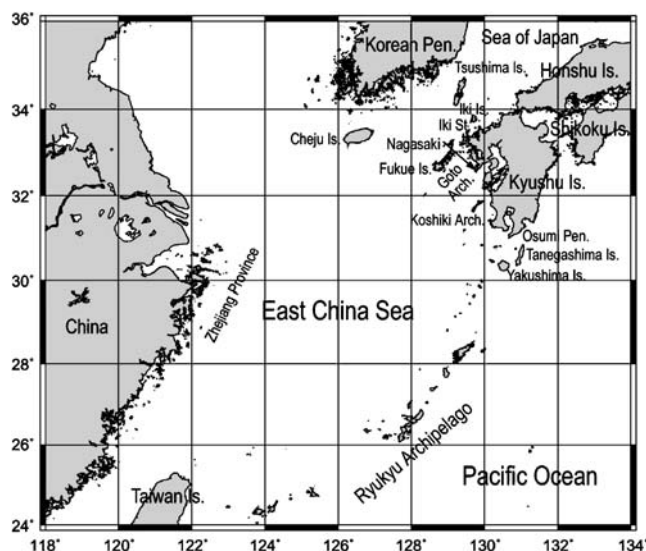


Fig. 1 Map showing the geographical positions of the East China Sea

drifting seaweeds stretches from March to May and that abundance becomes generally significantly lower in waters located south of the Osumi Peninsula, especially south of Tanegashima Island and Yakushima Island. Senta (1965) reported that drifting seaweeds were not present in the oceanic front, between continental shelf waters and the Kuroshio Current. Mitani (1965a) investigated distribution of drifting seaweeds off the west coast of Kyushu Island, based on results of Segawa et al. (1959a, b, 1960, 1961b, 1964) and Yoshida (1963). He recorded drifting seaweeds mainly in the Iki Strait and off Fukue Island, as predicted by Segawa et al. (1961a). As a result, it has been reported since the 1960s that drifting seaweeds are hardly present in offshore East China Sea waters. However, data about geographical distributions of saury eggs and vesicles of *Sargassum* species reported by Shojima (1981) studying the distribution of Pacific saury eggs, which are usually associated with drifting seaweeds, questioned this.

Recently, Konishi (2000) and Komatsu et al. (2007) reported that drifting seaweeds are found on the continental shelf along the East China Sea oceanic front (between Kuroshio and continental shelf waters) between March and May. These drifting seaweeds were composed of only one species, *Sargassum horneri* (Turner) C. Agardh. Even though it is now admitted that floating seaweeds occur in this specific area, little is known about their abundance. The Kagoshima Prefectural Fisheries Technology and Development Center investigated this question, mainly by visual survey, in order to fix an open season on yellowtail juveniles (Kubo 2004, 2006). However, efforts were concentrated on coastal waters and the abundance of drifting seaweeds in deeper waters remained unstudied.

Quantitative studies dealing with drifting seaweeds are generally based on either neuston net sampling or visual survey. The former method was, for instance, applied to

drifting seaweeds of *Sargassum fluitans* (Børgesen) Børgesen and *S. natans* (Linnaeus) Gaillon in the north-western Atlantic (Stoner 1983). This method is quantitative because the net mouth frame is constant. It enables the sampling of small floating objects, but surveys have to be limited to very narrow areas. Conversely, visual surveys have been used to estimate the biomass of the giant kelp *Macrocystis pyrifera* in the northeast Pacific (e.g., Kingsford 1995; Hobday 2000) and *Carpophyllum* species in waters around New Zealand (Kingsford 1992). Thiel and Gutow 2005 suggest selecting a sampling method with reference to both the size of the target and the area under scrutiny. As a result, visual survey was considered a suitable method in our case.

This study aims at acquiring details about drifting seaweeds abundance in March and May along the continental shelf and the Kuroshio Current in eastern East China Sea using the visual survey method.

Materials and methods

Visual censuses were conducted at sea, in good conditions (i.e. wave height less than 1 m) and from sunrise to sunset. Two sessions were organized: from 11 to 19 May 2002 (R/V Hakuho Maru, KH02-1 leg 1) and from 9 to 16 March 2004 (R/V Hakuho Maru, KH04-1). Observations were taken from the vessel deck at a height of 11.5 m above the sea surface. The vessel navigated along designed transects. The following elements were recorded at each floating seaweed occurrence: time, position, the perpendicular distance from the boat, seaweed diameter. Distance and diameter were estimated by four trained researchers (two teams of two people), operating alternately. Some rafts were sampled randomly every day using an ORI ring net with a diameter of 1.6 m. Samples were identified and weighted (wet weight).

Drifting seaweed abundance was estimated with reference to the Line Transect Method (Buckland et al. 2001) and calculated with the software DISTANCE 4.1. Release 2 (Thomas et al. 2002, 2004). Following Thomas et al. (2002), we estimated the parameter $\hat{\mu}$, called the effective strip half-width (ESW), and defined as the maximum limit for distinction.

$$\hat{D} = \frac{n}{2\hat{\mu}L}, \quad (1)$$

where \hat{D} , n and L are respectively the abundance of drifting seaweed rafts, the total number of rafts of drifting seaweeds along a transect and the length of the transect. $\hat{\mu}$ was estimated via three different models fitted to the frequency distribution of drifting seaweeds per distance classes. In order to take into account the lack of homogeneity in sea and meteorological conditions between transects, the model was fitted to data separately for each transect. Akaike's Information Criterion (AIC) provides an objective, quantitative

method for model selection. The model which displayed the lowest AIC [defined by eq. (2)] was adopted as the reference model (Buckland et al. 2001).

$$AIC = -2 \cdot \log_e(\Lambda) + 2(q) \quad (2)$$

where Λ is the maximized likelihood and q the number of estimated parameters. This number of estimated parameters was the number of parameters based on combination key-function and adjustment-term provided by the program DISTANCE4.1. The maximized likelihood was obtained from maximum likelihood estimation (Buckland et al. 2001).

Rafts of drifting seaweeds were classified into classes (0–10 m, 10–20 m, 20–30 m and 30–40 m), this distance representing the perpendicular distance between the boat and the raft. We ignored those situated further than 40 m as it became impossible to estimate the distance and difficult to observe the seaweed. Calculation results for each model are indicated in Tables 5 and 6. The number of rafts within EWS was obtained.

The ratio of wet weight/diameter (g m^{-1}) of drifting seaweed rafts in May 2002 was estimated by dividing the mean wet weight of rafts by the mean diameter of rafts sampled in May 2002. Then the mean wet weight of rafts along each transect was calculated by multiplying the mean diameter of rafts along this transect by the ratio. The upper and lower values of wet weight of drifting seaweeds were calculated using the standard deviation of the diameter of the rafts. The population mean for the wet weight along each transect was estimated by using the relation between diameter and wet weight of drifting seaweed rafts collected by the ORI ring net during the observation in March 2004. Mean diameter of drifting seaweed rafts along each transect was converted to wet weight using the equation representing this relation. The upper and lower values of wet weight of drifting seaweeds were calculated using the standard deviation of the diameter of the rafts.

Standing crop of drifting seaweeds along a transect was obtained by multiplying the density of rafts obtained by the program DISTANCE4.1 by the weighted mean of the rafts collected along this particular transect. Then, the total biomass along each transect was calculated by multiplying the standing crop by the survey area obtained from $\hat{\mu}$ and L .

Results

Distribution of drifting seaweeds

May 2002

In May 2002, lots of rafts were distributed in the area located between the continental shelf waters and the

Table 1 Results for distribution of drifting seaweed rafts observed along the transects 2002. Results for distributions of drifting seaweed rafts observed along the transects from 11 to 19 May 2002

Date	Length of transect (km)	Number of rafts	Mean diam. (m)	SD of diam.	Mean perpen. dist. (m)	SD of perpen. dist.
11 May	179.64	14	2.00	0.55	11.43	9.49
12 May	212.31	40	1.03	0.16	13.93	9.87
14 May	216.83	9	1.56	0.53	4.44	5.27
15 May	151.14	2	1.00	0.00	10.00	0.00
16 May	173.61	0	–	–	–	–
18 May	202.82	12	1.33	0.49	10.83	11.645
19 May	201.32	35	2.71	1.20	11.61	10.08

diam Diameter of raft, perpen dist perpendicular distance

oceanic front, especially in the East China Sea (Table 1, Fig. 2). Surface water temperatures in this area ranged from 20 to 24°C while those in the Kuroshio Current went beyond 24°C (11th Regional Coast Guard Headquarters 2002). We collected 20 rafts during the research cruise using the ORI ring net. Although one individual of *Sargassum macrocarpum* C. Agardh was observed near Kyushu Island on 13 May 2002, the other samples of drifting seaweeds were all *S. horneri*. Diameter mean and wet weight mean for drifting seaweed rafts along the different transects (Tables 1 and 2) were higher than those in March 2004 (see Tables 3 and 4). A one-way analysis of variance (ANOVA) indicated that this difference was statistically significant ($F_{0.05(1),1,318}=3.87$; $p<0.001$). Amongst the 2002 transects, wet weight mean was the highest on 19 May (Table 2).

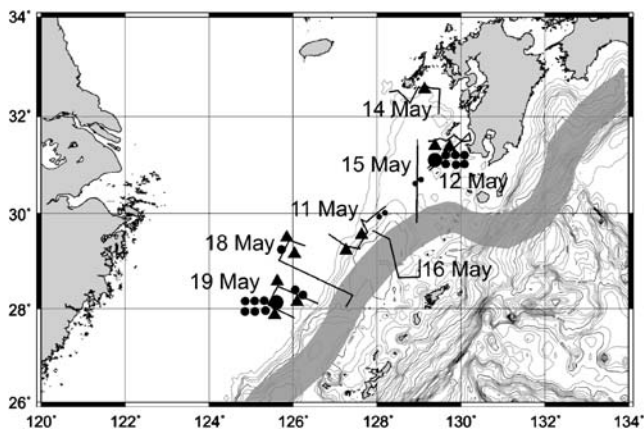


Fig. 2 Visual survey transects for drifting seaweed rafts (solid lines) in the East China Sea during R/V Hakuho Maru cruise, KH-02-1 leg1, and the distribution of the latter (closed circles and triangles) in May 2002. Large, medium and small closed circles are drifting seaweed rafts with diameters over 3 m, of 2–3 m, and 1–2 m, respectively. Triangles are groups of drifting seaweed rafts with diameters below 2 m. Dark stripe represents the path of Kuroshio Current (source: Hydrographic and Oceanographic Department of Japan Coast Guard, 2002)

Table 2 Estimated wet weight mean for drifting seaweed rafts observed along the transects from 11 to 19 May 2002

Date	Mean wet weight (g) of rafts	Lower value of wet weight of raft (g)	Higher value of wet weight of raft (g)
11 May	1,524 (264)	1,105 (191)	1,943 (336)
12 May	7,849 (1,359)	6,630 (1,148)	9,069 (1,570)
14 May	1,189 (206)	785 (136)	1,593 (276)
15 May	7,621 (1,320)	7,621 (1,320)	7,621 (1,320)
16 May	0 (0)	0 (0)	0 (0)
18 May	10,136 (1,755)	6,402 (1,109)	13,870 (2,402)
19 May	20,653 (3,576)	11,508 (1,993)	29,798 (5,160)

Higher and lower values of wet weight of drifting seaweeds were calculated using the standard deviation of the diameter of the rafts. Numbers inside parentheses are dry weights calculated from wet weights based on a relation between wet weight and dry weight of *S. horneri* (Mikami 2007)

March 2004

Figure 3 shows observation transects (solid line), observed rafts of drifting seaweeds (closed marks) and the Kuroshio Current position (dark stripe) during the March 2004 cruise. Drifting seaweeds were clearly present in waters located between the continental shelf and the oceanic front of the Kuroshio Current. Most of them were found in an area with sea surface temperatures ranging from 14 to 17°C (11th Regional Coast Guard Headquarters 2004). We collected 14 rafts during the cruise using the ORI ring net. Analysis of species composition of the rafts showed that *S. horneri* was the only species recorded. Mean diameter of drifting seaweed rafts was less than 1 m in March (Table 3). Many

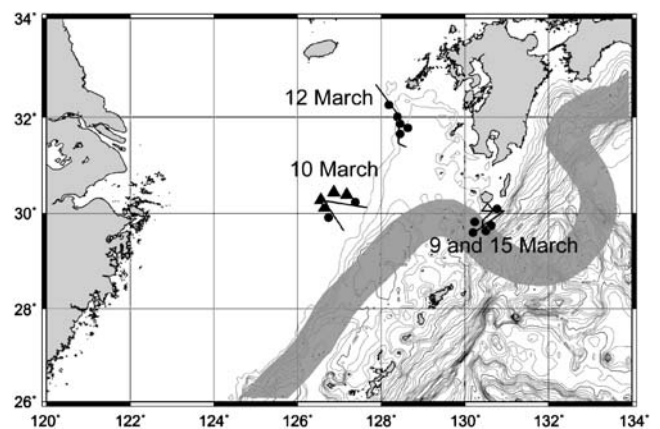


Fig. 3 Visual survey transects for drifting seaweed rafts (solid lines) in the East China Sea during R/V Hakuho Maru cruise, KH-04-1, and the distribution of the latter (closed circles and triangles) in March 2004. Large, medium and small closed circles are drifting seaweed rafts with diameters over 3 m, of 2–3 m, and 1–2 m, respectively. Triangles are groups of drifting seaweed rafts with diameters below 2 m. Dark stripe represents the path of Kuroshio Current (Source: Hydrographic and Oceanographic Department of Japan Coast Guard, 2004)

Table 3 Results for distributions of drifting seaweed rafts observed along the transects on 9, 10, 12, and 15 March 2004

Date	Length of transect (km)	Number of rafts	Mean diam. (m)	SD of diam. (m)	Mean perpen. dist. (m)	SD of perpen. dist. (m)
9 and 15 Mar	143.14	27	0.69	0.44	7.19	4.40
10 Mar	187.85	1887	0.79	0.58	11.46	8.51
12 Mar	183.10	50	0.66	0.44	8.48	10.46

diam Diameter of raft, perpen dist perpendicular distance

drifting seaweeds were found along the 10 March transect. Since the 9 March and 15 March transects overlapped (Fig. 3), we considered the results as one unique transect (Table 3). The exponential model appears as a suitable model to explain the relation between diameter (D_i) and wet weight (W_i) of drifting seaweed rafts: $W_i=1.2222 D_i^2-0.0787D_i$ (Fig. 4; $R^2=0.962$). Combined with mean diameter data for each transect, this relation enables to estimate the mean wet weight for the drifting seaweed rafts observed. Amongst transects, the mean wet weight was the lowest along the 12 March transect (Table 4).

Generally receptacles are formed apically on a branchlet in *S. horneri*. However, we found a branchlet growing from the apex of mature receptacle of *S. horneri* during both research cruises of May 2002 and March 2004 in the East China Sea. *Sargassum horneri* found in the East China Sea has a unique development feature different from those distributed in near shore coastal waters.

Abundance and biomass of drifting seaweeds

May 2002

In May 2002, ESW values for all the transects ranged from 8.4 to 13.8 m, but on 11 May reached 18.0 m (Table 5), due

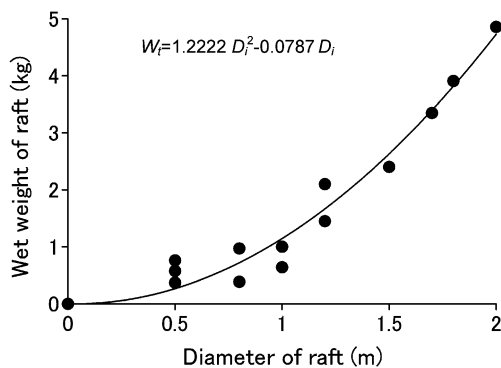


Fig. 4 Regression curve ($R^2=0.962$) showing the relation between diameter (D_i) and wet weight (W_i) of drifting seaweeds rafts collected during the R/V Hakuho Maru cruise, KH-04-1. This relation is expressed by the equation: $W_i=1.2222 D_i^2-0.0787D_i$

Table 4 Estimated wet weight mean for drifting seaweed rafts observed along the transects on 9, 10, 12 and 15 March 2004

Date	Mean wet weight (g) of rafts	Lower limit of wet weight of raft (g)	Higher limit of wet weight of raft (g)
9&15 Mar	528 (91)	326 (56)	730 (126)
10 Mar	701 (121)	335 (58)	1,066 (185)
12 Mar	480 (83)	278 (48)	682 (118)

Higher and lower values of wet weight of drifting seaweeds were calculated using the standard deviation of the diameter of the rafts. Numbers inside parentheses are dry weights calculated from wet weights based on a relation between wet and dry weight of *S. horneri* (Mikami 2007)

probably to extremely calm sea conditions. Raft densities of drifting seaweed along the 12 and 19 May transects were extremely high (Table 2, Fig. 5). No drifting seaweed was observed in Kuroshio Current waters (Figs. 2 and 5). Mean diameter and mean wet weight for drifting seaweed rafts were the highest on 19 May (Tables 1 and 2). Similarly, this transect displayed the highest standing crop (126.81 kg km⁻² wet weight (WW)) (Fig. 6). Using the relation between wet weight and dry weight of *S. horneri* (Mikami 2007), wet weight was converted into dry weight. Hence, the highest standing crop equals 21.99 kg km⁻² dry weight (DW). Total biomass along this particular transect was estimated at 660.87 kg WW (observed area = 5.21 km⁻²).

March 2004

In March 2004, ESW values for the three transects ranged from 9.6 m to 12.1 m (Table 6). Raft density was the

Table 5 Results for models applied to the distribution of drifting seaweed rafts along each transect during May 2002 by the program DISTANCE 4.1

Date	Model (key + adjustment)	AIC	ESW	\hat{n}	\hat{D}	\hat{D}_{LCL}	\hat{D}_{UCL}	\hat{D}_{CV}
11 May	Half +Hermite	56.9	18.04	14	2.16	1.05	4.43	0.342
12 May	Half +Hermite	127.8	13.81	37	6.31	4.14	9.62	0.210
14 May	Unifo+Poly	24.7	8.44	9	2.46	0.99	6.13	0.412
15 May	Unifo+Poly	8.6	12.47	2	0.53	0.00	0.00	0.873
18 May	Half +Hermite	34.4	12.47	10	1.98	0.83	4.71	0.398
19 May	Half +Hermite	107.6	12.94	32	6.14	3.92	9.64	0.224

AIC Akaike’s Information Criteria, ESW effective strip width, \hat{n} total number of rafts within ESW, \hat{D} density of rafts, \hat{D}_{LCL} lower confidence limit of \hat{D} , \hat{D}_{UCL} upper confidence limit of \hat{D} , \hat{D}_{CV} coefficient of variation of \hat{D} Half, Unifo, Hermite and Poly are Half-normal, Uniform, Hermite and Polynomial distributions, respectively

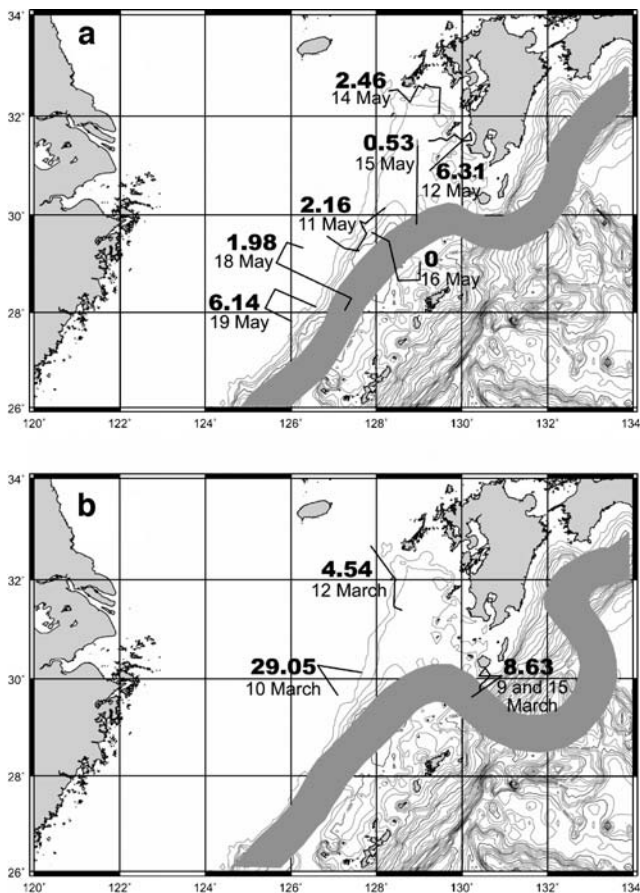


Fig. 5 Estimated raft densities of drifting seaweeds (in bold; rafts km⁻²) along the observation transects (solid lines) in the East China Sea during R/V Hakuho Maru cruises, KH-02-1 leg1, in May 2002 (a) and KH-04-1, in March 2004 (b). Dark stripe represents the path of Kuroshio Current

highest along the 10 March transect (Table 3, Fig. 5). Mean wet weight for this transect, M , equals 701 g. This was the highest mean (Table 4). This transect displays the highest standing crop (20.35 kg WW km⁻²) (Fig. 6). This is equivalent to 3.56 kg DW km⁻². Total biomass along this transect was estimated at 92.39 kg WW (observed area = 4.54 km⁻²).

Discussion

Some common characteristics between drifting seaweeds collected in May 2002 and March 2004 occurred: most of them were distributed in the East China Sea, between the continental shelf and the oceanic front of the Kuroshio Current (125–128 E, 28–31 N), and not in coastal waters. This contradicts previous conclusions with regard to the East China Sea (Senta 1965).

The number of drifting seaweed rafts in March 2004 was greater than in May 2002, while the mean for drifting seaweed diameter in May 2002 was significantly higher

than in March 2004. In the East China Sea, drifting seaweeds consisted almost exclusively of *S. horneri*, which are generally small in winter before growing up in spring, when they mature along the Japanese coast (e.g., Umezaki 1984). Drifters, whose position was tracked by satellite, attached to drifting seaweed rafts deployed near Chinese coasts in March 2004, traveled up to waters located in the east coast of Kyushu Island, under the influence of Kuroshio Current, and Cheju Island, Korea, under the influence of Tsushima Warm Current, where we lost contact in June (Komatsu et al. 2007). Mikami (2007) reported that drifting seaweeds keep on growing once detached from the bottom, despite not being mature. Smaller sizes reported in March 2004 are consistent with *S. horneri* living on the benthic substratum around Japanese (e.g., Umezaki 1984) and Chinese coastlines without the influence of warm water brought from the Kuroshio Current. On the other hand, *S. horneri* distributed along the coastline of Honshu Island facing the Kuroshio Current matures in March when it attains its maximum branch length (e.g., Mikami 2007).

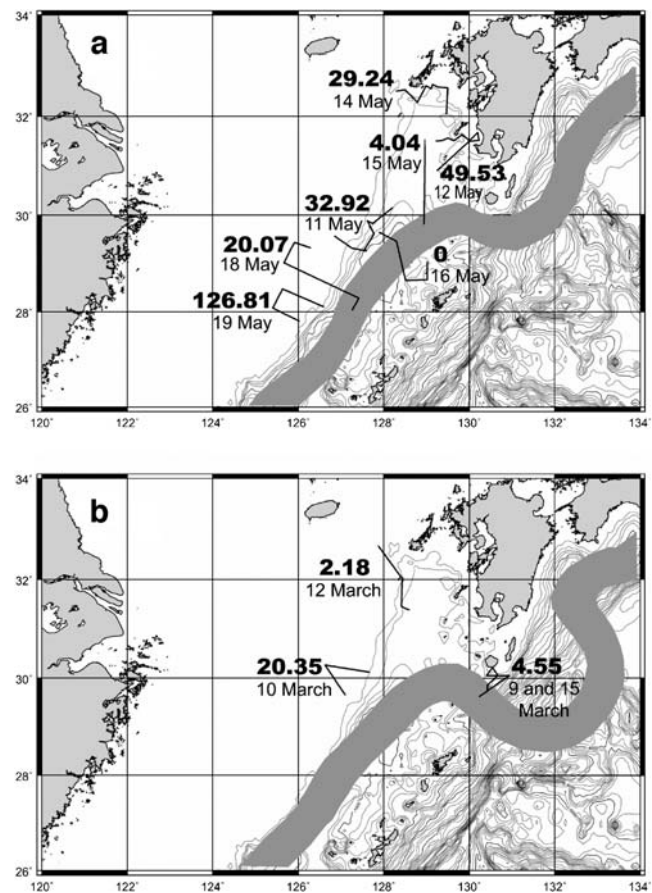


Fig. 6 Estimated standing crop of drifting seaweeds (kg WW km⁻²) along the observation transects (solid lines) during R/V Hakuho Maru cruises, KH-02-1, in May 2002 (a) and KH04-1 in March 2004 (b). Dark stripe represents the path of Kuroshio Current

Table 6 Results for models applied to the distribution of drifting seaweed rafts along each transect during March 2004 by the program DISTANCE 4.1 Abbreviations are identical to the ones in Table 5

Date	Model (key + adjustment)	AIC	ESW	\hat{n}	\hat{D}	\hat{D}_{LCL}	\hat{D}_{UCL}	\hat{D}_{CV}
10 Mar	Half+Hermite	423.2	12.10	132	29.05	5.23	161.24	0.210
9&15 Mar	Half+Hermite	88.2	11.34	28	8.63	5.35	13.91	0.236
12 Mar	Half+Hermite	46.4	9.62	16	4.54	2.11	9.80	0.302

In 1959, Segawa et al. (1961b) investigated abundance and distribution of drifting seaweed between north Kyushu Island and Tsushima Island (Fig. 1). They used classes for wet weight (below 1 kg, from 1 to 10 kg, from 10 to 50 kg, from 50 to 100 kg) and estimated it through visual observation. They also estimated standing crop of drifting seaweeds at about 1,670 kg WW km⁻² in June, when the highest abundance of drifting seaweeds was observed. This result is almost identical to Parr's study (1939) (5,367 kg WW nautical mile⁻²: 1,565 kg WW km⁻²) in Sargasso Sea, using a neuston net. Yoshida (1963), who investigated biomass of drifting seaweed around Japan from May to June using the Segawa et al. (1961b) method, reported that standing crop of drifting seaweed in south of Kyushu (Fig. 1) was about 900 kg WW km⁻², about 100 kg WW km⁻² off Tohoku and about 500 kg WW km⁻² around the Noto Peninsula in the Sea of Japan. The differences in standing crop estimation between our study and the previous ones may be due to sampling method, as well as the weight estimation method.

Mitani (1965b) estimated biomass of drifting seaweed based on the relationship between the diameter of the drifting seaweeds observed from an airplane and the diameter/wet weight of drifting seaweeds sampled from the research vessel. He estimated the standing crop at about 114.1 kg WW km⁻² in the area located southeast off Goto Archipelago (northern limit of East China Sea), about 101.1 kg WW km⁻² in the area located between south of Goto Archipelago and south of the Nagasaki Peninsula, about 10.9 kg WW km⁻² located in the area located north of Koshiki Archipelago, and about 0.3 kg WW km⁻² in the area located south of Koshiki Archipelago (Fig. 1). Since the estimation method used by Mitani (1965b), where the airplane was maintained at constant altitude and speed, is much more accurate than the one employed by Segawa et al. (1961b) and Yoshida (1963), his estimation of standing crop, though much smaller, looks more realistic.

In May 2002, south of Goto Archipelago, the standing crop of drifting seaweeds was about 29.24 kg WW km⁻², and about 49.53 kg WW km⁻² in the area located between Koshiki Archipelago and south Kyushu Island (Fig. 1). Our estimation is almost equal to Mitani's (1965b). This may indicate that the method used by Buckland et al. (2001) and Thomas et al. (2002) is efficient.

The highest standing crop of drifting seaweeds, in March as in May, was located between the continental shelf and the oceanic front of the Kuroshio Current (20.35 kg WW km⁻² in March and 126.81 kg WW km⁻² in May). With reference to current maps and buoys tracking data, these drifting seaweeds are likely to come from Chinese coasts, especially Zhejiang Province (Fig. 1), where *Sargassum* beds were mainly composed of *S. horneri* (Komatsu et al. 2005). In May, the standing crop in this area is higher than in March simply because *S. horneri* generally reaches its maximum size (and biomass) in late spring (Umezaki 1984; Komatsu et al. 2005) in areas without influence of warm water brought by the Kuroshio Current in winter, such as the coast of the Sea of Japan and west coast of the East China Sea.

There was little difference in ESW between the two sampling sessions. This suggests that visual surveys were correctly conducted during both cruises. During both cruises, a peak of seaweed biomass was recorded in the center of East China Sea, where yellowtail and jack mackerel larvae usually accompany drifting seaweeds in spring and early summer (Konishi 2000).

Interestingly, as pointed out by Yoshida (1963), drifting seaweeds did not appear in Kuroshio Current waters but between the coast and the oceanic fronts in the East China Sea. It is estimated that most of drifting seaweeds are slowly transported to the east along the Japanese coasts by weak coastal currents. Therefore, yellowtail juveniles that accompany drifting seaweeds have a high possibility of leaving them in coastal waters off Honshu Island (Yamamoto et al. 2007) rather than in offshore waters of the Pacific Ocean.

Drifting seaweeds were then found in the area, including the continental coastal waters and the continental shelf part of East China Sea, in February (Shojima 1981), March (this study), April (Konishi 2000) and May (this study). The origin of drifting seaweeds is partially clarified by Komatsu et al. (2007). However, it is unknown where drifting seaweeds found in February originate.

Our results suggest large amounts of drifting seaweeds are distributed in the peripheral area of continental shelf waters in the East China Sea. They are probably transported from Chinese coasts. During the economic development of Japan, seagrass and seaweed beds have been lost in

nearshore shallow waters due to pollution and reclamation (Komatsu 1997). In China, developing industries and increasing population produce water pollution and need land reclamation to build factories, ports and home sites, especially in coastal waters as in those of Japan from the 1960s to 1980s. It is necessary to investigate and monitor distribution, biomass and origin coasts of drifting seaweed in the East China Sea in order to preserve and manage them in a sustainable way.

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References

- 11th Regional Coast Guard Headquarters (2002) Oceanographic Rapid Report, No. 10, 1–2
- 11th Regional Coast Guard Headquarters (2004) Oceanographic Rapid Report, No. 5, 1–2
- Buckland ST, Anderson DR, Burnham KP, Laake JL, Borchers DL, Thomas L (2001) Introduction to distance sampling - estimating abundance of biological populations. Oxford University Press, New York, 432pp
- Cho SH, Myoung JG, Kim JM (2001) Fish fauna associated with drifting seaweed in the coastal area of Tongyeong, Korea. *Trans Am Fish Soc* 130:1190–1202
- Hernández-Carmona G, Hughes B, Graham MH (2006) Reproductive longevity of drifting kelp *Macrocystis pyrifera* (Phaeophyceae) in Monterey Bay, USA. *J Phycol* 42:1199–1207
- Hobday AJ (2000) Abundance and dispersal of drifting kelp *Macrocystis pyrifera* rafts in the Southern California Bight. *Mar Ecol Prog Ser* 195:101–116
- Ichimaru T, Mizuta K, Nakazono A (2006) Studies on the egg morphology and spawning season in the mirror-finned flying fish *Hirundichthys oxycephalus* in the waters near Kyushu, Japan. *Nippon Suisan Gakkaishi* 72:21–26. (in Japanese with English abstract and figure legends)
- Ingólfsson A (1995) Floating clumps of seaweed around Iceland: natural microcosms and a means of dispersal for shore fauna. *Mar Biol* 122:13–21
- Kingsford MJ (1992) Drift algae and small fish in coastal waters of northeastern New Zealand. *Mar Ecol Prog Ser* 80:41–55
- Kingsford MJ (1995) Drift algae: a contribution to near-shore habitat complexity in the pelagic environment and an attractant for fish. *Mar Ecol Prog Ser* 116:297–301
- Komatsu T (1985) Temporal fluctuations of water temperature in a *Sargassum* forest. *J Oceanogr Soc Jpn* 41:235–243
- Komatsu T (1989) Day-night reversion in the horizontal distributions of dissolved oxygen content and pH in a *Sargassum* forest. *J Oceanogr Soc Jpn* 45:106–115
- Komatsu T (1997) Long-term changes in the *Zostera* bed area in the Seto Inland Sea (Japan), especially along the coast of the Okayama Prefecture. *Oceanol Acta* 20:209–216
- Komatsu T, Kawai H (1986) Diurnal changes of pH distributions and the cascading of shore water in a *Sargassum* forest. *J Oceanogr Soc Jpn* 42:447–458
- Komatsu T, Murakami S (1994) Influence of a *Sargassum* forest on the spatial distribution of water flow. *Fish Oceanogr* 3:256–266
- Komatsu T, Ariyama H, Nakahara H, Sakamoto W (1982) Spatial and temporal distributions of water temperature in a *Sargassum* forest. *J Oceanogr Soc Jpn* 38:63–72
- Komatsu T, Kawai H, Sakamoto W (1990) Influence of *Sargassum* forests on marine environment. *Bull Coast Oceanogr* 27:115–126, 1990. (in Japanese with English abstract)
- Komatsu T, Murakami S, Kawai H (1994) Some features of jump of water temperature in a *Sargassum* forest. *J Oceanogr* 52:109–124
- Komatsu T, Tatsukawa K, Wang W, Liu H, Ajisaka T, Zhang S, Tanaka K, Zhou M, Uwai S, Sugimoto T (2005) Species composition and biomass of *Sargassum* beds in Gouqi Island, Zhejiang Province, China. *Jpn J Phycol* 53(1):103 (in Japanese)
- Komatsu T, Tatsukawa K, Filippi JB, Sagawa T, Matsunaga D, Mikami A, Ishida K, Ajisaka T, Tanaka K, Aoki M, Wang WD, Liu HF, Zhang SD, Zhou MD, Sugimoto T (2007) Distribution of drifting seaweeds in eastern East China Sea. *J Mar Syst* 67:245–252
- Konishi Y (2000) Drifting seaweeds coming from China too. *Seikai Fisheries Research Institute News* 11–15 (in Japanese)
- Kubo M (2004) The present situation report about the floating seaweeds investigation for the yellowtail larva fishery in Kagoshima Prefecture. *Kaiyo Monthly* 36(6):458–463 (in Japanese)
- Kubo M (2006) Passing year change of flow algae appearing in Kagoshima sea area. *Kaiyo Monthly* 38(8):575–582 (in Japanese)
- Mikami A (2007) Estimating the net primary production of *Sargassum* species (Phaeophyceae) throughout different life stages: from fixation to drifting. Doctor Thesis, University of Tokyo, Tokyo (in Japanese)
- Mitani F (1965a) At attempt to estimate the population size of the “Mojako”, the juvenile of the yellowtail, *Seriola quinqueradiata* Temminck et Schlegel, from the amount of the floating seaweeds based on the observations made by means of airplane and vessels -I. State of distribution of the floating seaweeds. *Bull Jpn Soc Sci Fish* 31(6):423–428 (in Japanese with English abstract)
- Mitani F (1965b) At attempt to estimate the population size of the “Mojako”, the juvenile of the yellowtail, *Seriola quinqueradiata* Temminck et Schlegel, from the amount of the floating seaweeds based on the observations made by means of airplane and vessels -II. Estimate of the amount of the floating seaweeds. *Bull Jpn Soc Sci Fish* 31(6):429–434 (in Japanese with English abstract)
- Parr AE (1939) Quantitative observations on the pelagic *Sargassum* vegetation of the western North Atlantic. *Bull Bingham Oceanogr Coll* 6:1–94
- Rueness J (1989) *Sargassum muticum* and other introduced Japanese macroalgae: biological pollution of European coasts. *Mar Poll Bull* 20:173–176
- Segawa S, Sawada T, Higaki M, Yoshida T (1959a) Studies on the floating seaweeds-I. Annual vicissitude of floating seaweeds in the Tsuyazaki region. *Sci Bull Fac Agri Kyushu Univ* 17:83–89 (in Japanese with English abstract)
- Segawa S, Sawada T, Higaki M, Yoshida T (1959b) Studies on the floating seaweeds-II. Floating seaweeds found in Iki-Tusima region. *Sci Bull Fac Agri Kyushu Univ* 17:291–297 (in Japanese with English abstract)
- Segawa S, Sawada T, Yoshida T (1960) Studies on the floating seaweeds-V. Seasonal change in amount of the floating seaweeds off the coast of Tsuyazaki. *Sci Bull Fac Agri Kyushu Univ* 17:437–441 (in Japanese with English abstract)
- Segawa S, Sawada T, Higaki M, Yoshida T, Kamura S (1961a) Studies on the floating seaweeds-VI. The floating seaweeds of the West Kyushu region. *Sci Bull Fac Agri Kyushu Univ* 18:411–417 (in Japanese with English abstract)
- Segawa S, Sawada T, Higaki M, Yoshida T (1961b) Studies on the floating seaweeds-VII. Seasonal changes in the amount of the

- floating seaweeds found on Iki- and Tsushima Passages. *Sci Bull Fac Agri Kyushu Univ* 19:125–133 (in Japanese with English abstract)
- Segawa S, Sawada T, Yoshida T (1964) Studies on the floating seaweeds-IX. The floating seaweeds found on the sea around Japan. *Sci Bull Fac Agri Kyushu Univ* 21:111–115 (in Japanese with English abstract)
- Senta T (1965) Importance of drifting seaweeds in the ecology of fisheries. A series of studies on fisheries 13. Japan Fisheries Resource Conservation Association, Tokyo, pp 1–54 (in Japanese)
- Shojima Y (1981) Studies about collection spawn of Pacific saury in Kyushu waters and East China Sea. In Fishing resource research conference 13th Float Fish sectional meeting minutes. Fishing Resource Workshop Executive Office, Tokyo, pp 88–99 (in Japanese)
- Stoner AW (1983) Pelagic *Sargassum*: evidence for a major decrease in biomass. *Deep Sea Res* 30:1259–1264
- Thiel M, Gutow L (2005) The ecology of rafting in the marine environment. 1. The floating substrata. *Oceanogr Mar Biol* 42:181–263
- Thomas L, Buckland ST, Burnham KP, Anderson DR, Laake JL, Borchers DL, Strindberg S (2002) Distance sampling. In: El-Shaarawi AH, Piegorisch WW (eds) *Encyclopedia of Environmetrics Volume 1*. Wiley, Chichester, pp 544–552
- Thomas L, Laake JL, Strindberg S, Marques FFC, Buckland ST, Borchers DL, Anderson DR, Burnham KP, Hedley SL, Pollard JH, Bishop JRB (2004) Distance 4.1. Release 2. Research Unit for Wildlife Population Assessment, University of St. Andrews, UK. Release 2. <http://www.ruwpa.st-and.ac.uk/distance/>
- Umezaki I (1984) Ecological studies of *Sargassum horneri* (Turner) C. Agardh in Obama Bay, Japan Sea. *Bull Jpn Soc Sci Fish* 50:1193–1200
- Yamamoto T, Ino S, Kuno M, Sakaji H, Hiyama Y, Kishida T, Ishida Y (2007) On the spawning and migration of yellowtail *Seriola quinqueradiata* and research required to allow catch forecasting. *Bull Fish Res Agen* 21:1–29. (in Japanese)
- Yoshida T (1963) Studies on the distribution and drift of the floating seaweed. *Bull Tohoku Reg Fish Res Lab* 23:141–186 (in Japanese with English abstract)