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Comparative photosynthetic studies of *Ecklonia cava* bladelets with and without zoosporangial sori*

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Photosynthetic rates were compared between parts with and without zoosporangial sori of *Ecklonia cava* bladelets sampled from the subtidal zone (about 5 m deep) in Nabeta Bay, Shimoda, Japan. Photosynthetic rates of bladelets were apparently lower in sorus portion than in non-sorus portion on an area basis, on a dry weight basis, and on a chlorophyll *a* basis. Respiratory rates were higher in sorus portion than in non-sorus portion on an area basis and on a chlorophyll *a* basis, while they were almost the same on a dry weight basis. The differences were mainly due to big difference in dry weight per unit bladelet area between sorus and non-sorus portions. Light compensation points were higher in sorus portion than in non-sorus portion. It is suggested that light is greatly attenuated to reach the assimilatory layer within bladelets when sori are formed.

Key Index Words: Ecklonia cava—*Phaeophyta—photosynthesis—respiration—seaweed—zoosporangial sori.*

Ecklonia cava KJELLMAN (Laminariales, Phaeophyta) occurs in the subtidal zone along the Pacific coasts from central Honshu to Kyushu, Japan, and its sporophytes form extensive seaweed beds together with *Eisenia bicyclis* SETCHELL and *Sargassum* spp. Several investigators have studied structural aspects of the community (IWAHASHI 1968a, b, IWAHASHI *et al.* 1979, HAYASHIDA 1977, 1984, 1986, KIDA and MAEGAWA 1982, 1983, OHNO and ISHIKAWA 1982, KASAHARA and OHNO 1983, MAEGAWA and KIDA 1984), productivity (YOKOHAMA 1977, YOKOHAMA *et al.* 1987, MAEGAWA *et al.* 1987, 1988a) and longevity (MAEGAWA *et al.* 1988b) of *E. cava*.

In previous papers (ARUGA 1981, YOKOHAMA *et al.* 1987, HAROUN *et al.* 1989a, b, SAKANISHI *et al.* 1988, 1989) we reported the interrelation between seasonal variation of standing crop, growth process and photosynthetic characteristics of *E. cava*. *E. cava* communities attain a maximum standing crop in summer and a minimum in winter; this is mainly related to the seasonal variation of the pinnate blade biomass. Photosynthetic rates are usually higher during the period from late autumn to early spring and lower during the period from late spring to early autumn (SAKANISHI *et al.* 1989). Zoosporangial sori are formed in the bladelet of *E. cava* during late spring to summer, the period of lower photosynthetic activity. However, the effect of zoosporangial sori formation on, or its relation to, photosynthetic activity of *E. cava* bladelets has yet to be studied.

In the present study we investigated the difference in photosynthetic and respiratory rates of *E. cava* bladelets with or without zoosporangial sori, because the bladelets with zoosporangial sori occupy a greater part of the standing stock and this affects the rate of production of *E. cava* community during summer.

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Material and methods

Samples of mature *Ecklonia cava* sporophytes were collected from a depth of about 5 m in Nabeta Bay, Shimoda, on the Pacific coast of central Japan in August 1985. They were kept in an outdoor water tank before use. Bladelets with few attached organisms were selected and detached from the sample plants, and were transported to the laboratory. Discs of 3.6 cm^2 or rectangular samples of about 15 cm^2 were cut out from parts with or without zoosporangial sori of the bladelets (cf. Fig. 2). These discs and rectangular samples of bladelets were kept in running seawater overnight (for about 12 h) in the laboratory before measuring photosynthesis and respiration to avoid unreliable results due to cutting (SAKANISHI *et al.* 1988).

Differential gas-volumeters (YOKOHAMA and ICHIMURA 1969, YOKOHAMA *et al.* 1986) were used to measure photosynthesis and respiration. Vessels with a capacity of about 50 or 200 m*l* were used as reaction and compensation vessels of the gas-volumeter. For the measurements a blade sample was placed in the reaction vessel with 10 or 50 m*l* of filtered seawater in the former or the latter vessel. A slide projector (Elmo S-300) with an incandescent lamp (Kondo 100 V 300 W) was used as the light source. Light intensity was measured with a lux meter (Lichtmesstechnik) and a quantum meter (LI-COR LI-185B). Various light intensities were attained by using neutral density glass filters.

After the measurements, the blade samples were rinsed with freshwater, dried at 85°C for 24 h in an electric drying chamber and weighed with a chemical balance to obtain dry weight. The blade discs of 0.57 cm^2 for the quantitative analysis of chlorophyll *a* were cut out from portions close to those used for measurements of photosynthesis and respiration, and ground with 90% acetone in a mortar to extract photosynthetic pigments. Absorbances of the extract were measured at 630, 645, 663 and 750 nm with a Shimadzu UV-3000 recording spectrophotometer and the chlorophyll *a* concentration was calculated by the formula of SCOR-Unesco (1966).

Results

Figure 1 shows photosynthesis-light curves of *Ecklonia cava* bladelets with or without zoosporangial sori on an area basis, on a dry weight basis and on a chlorophyll *a* basis, which were determined from six measurements at 20°C. In each case, the photosynthetic rate increased almost linearly with increase in light intensity up to about 25 $\mu E\ m^{-2}s^{-1}$, and slowly increased with further increase in light intensity to reach the light saturation at about 200 $\mu E\ m^{-2}s^{-1}$. Photosynthetic rates of sorus portion were always lower than those of non-sorus portion. The light-saturated net photosynthetic rate was 24.5 $\mu l O_2\ cm^{-2}h^{-1}$ (0.95 $\mu l O_2$

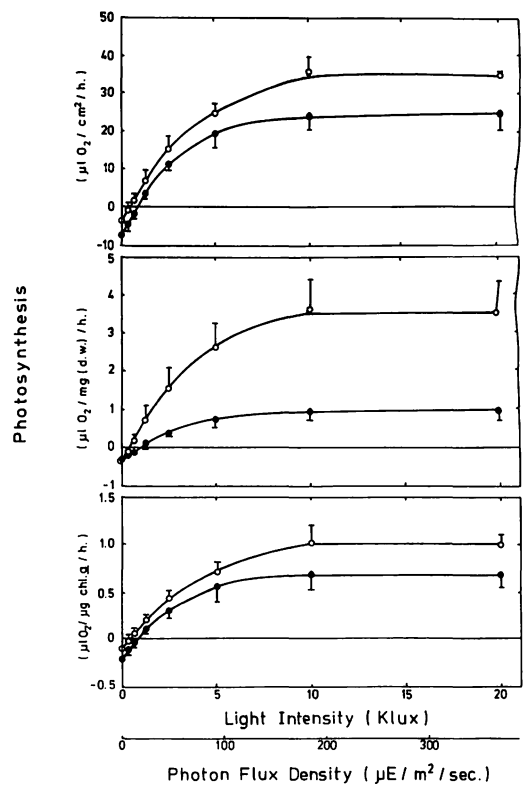

Fig. 1. Photosynthesis-light curves of sorus portion (solid circles) and non-sorus portion (open circles) of *Ecklonia cava* bladelets at 20°C. Mean with SD of 6 measurements.

Table 1. Comparison of dry weight per unit area (mg cm^{-2}) in sorus and non-sorus portions of *Ecklonia cava* bladelets used for measurements of photosynthesis and respiration.

Date	(a) Sorus portion	(b) Non-sorus portion	(a)/(b)
Aug. 17	26.5	15.4	1.7
18	25.8	8.6	3.0
25	29.2	7.4	3.9
26	27.3	10.2	2.8
29	21.9	9.8	2.2
30	24.7	10.7	2.3
Average	25.9	10.4	2.7
SD	2.5	2.6	0.8

mg(d.w.)$^{-1}$h^{-1}, 0.68 μlO_2 μg(chl.*a*)$^{-1}$h^{-1}) in sorus portion, whereas it was 35.0 μlO_2 cm^{-2}h^{-1} (3.50 μlO_2 mg(d.w.)$^{-1}$h^{-1}, 1.00 μlO_2 μg(chl.*a*)$^{-1}$h^{-1}) in non-sorus portion. Photoinhibition of photosynthesis was not observed in the light intensity range employed (maximum 370 μE m^{-2}s^{-1}).

The rate of dark respiration was higher in sorus portion than in non-sorus portion both on an area basis and on a chlorophyll *a* basis, but was almost the same on a dry weight basis: 7.24 μlO_2 cm^{-2}h^{-1}, 0.28 μlO_2 mg (d.w.)$^{-1}$h^{-1} and 0.21 μlO_2 μg(chl.*a*)$^{-1}$h^{-1} in sorus portion; 3.45 μlO_2 cm^{-2}h^{-1}, 0.36 μlO_2 mg(d.w.)$^{-1}$h^{-1} and 0.10 μlO_2 μg(chl.*a*)$^{-1}$ h^{-1} in non-sorus portion. The light compensation point was apparently higher in sorus portion than in non-sorus portion.

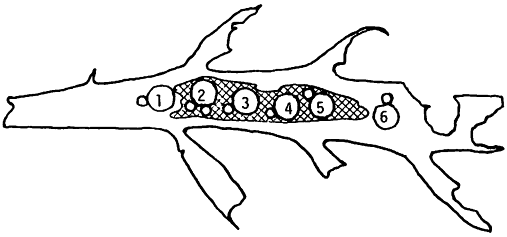

Fig. 2. Trace of an *Ecklonia cava* bladelet indicating the position of blade discs used for measurements of photosynthesis (Fig. 3), dry weight and chlorophyll (Table 3). The shaded part shows sorus portion.

Dry weight per unit area was 25.9 mg(d.w.) cm^{-2}, in average, in sorus portion, while it was only 10.4 mg(d.w.) cm^{-2}, in average, in non-sorus portion of bladelets (Table 1). This indicates that sorus portion is thicker than non-sorus portion. Chlorophyll *a* content per unit area was not

Table 2. Comparison of chlorophyll *a* content per unit area (μg cm^{-2}) in sorus and non-sorus portions of *Ecklonia cava* bladelets used for measurements of photosynthesis and respiration.

Date	(a) Sorus portion	(b) Non-sorus portion	(a)/(b)
Aug. 17	37.5	37.5	1.00
18	40.4	34.1	1.18
25	29.4	33.0	0.89
26	45.4	39.3	1.16
29	33.2	30.6	1.08
30	31.4	34.0	0.92
Average	36.2	34.8	1.04
SD	6.0	3.2	0.12

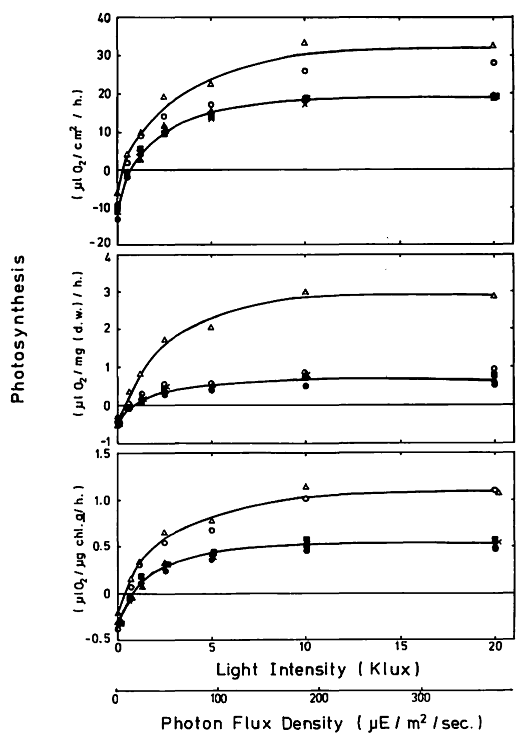

Fig. 3. Photosynthesis-light curves of various parts of an *Ecklonia cava* bladelet at 20°C. 1, open circle; 2, solid circle; 3, solid triangle; 4, solid square; 5, cross; 6, open triangle (cf. Fig. 2).

Table 3. Comparison of dry weight and chlorophyll *a* content per unit area in sorus and non-sorus portions of an *Ecklonia cava* bladelet on Ang. 11 (cf. Fig. 2) and Ang. 13 (cf. Fig. 4). Samples 1 and 6, non-sorus portion; samples 2–5, sorus portion (cf. Fig. 4).

Date	Dry weight (mg cm^{-2})						Chlorophyll *a* (μg cm^{-2})					
	1	2	3	4	5	6	1	2	3	4	5	6
Aug. 11	30.4	35.6	31.2	26.5	23.3	11.1	25.4	40.4	35.4	32.2	32.9	29.1
13	25.8	32.2	28.1	24.6	22.8	10.2	36.5	43.7	42.4	44.2	43.6	29.8

significantly different between sorus and non-sorus portions (Table 2).

Photosynthesis-light curves were compared with discs from various portions of an *E. cava* bladelet (Fig. 2). Figure 3 shows photosynthesis-light curves of 6 blade discs from the same bladelet including sorus and non-sorus portions. Blade discs from sorus portion had almost the same photosynthetic rates on an area basis, on a dry weight basis and on a chlorophyll *a* basis, irrespective of the position in a bladelet. The photosynthetic rate of blade discs from non-sorus portion was slightly higher at the apical part than at the basal part of a bladelet on an area basis, while on a dry weight basis it was clearly higher at the apical part than at the basal part.

As indicated in Table 3, dry weight per unit area was higher in the basal part than in the distal part within sorus portion, being also higher in sorus portion than in non-sorus portion near by; and in non-sorus portion it was considerably higher at the basal part than at the tip part of a bladelet (Figs. 2 and 4). Thus, the photosynthetic rate on a dry weight basis was apparently lower in the basal part without zoosporangial sori of a bladelet. Chlorophyll *a* content per unit area was significantly higher in sorus portion than in non-sorus portion (Table 3).

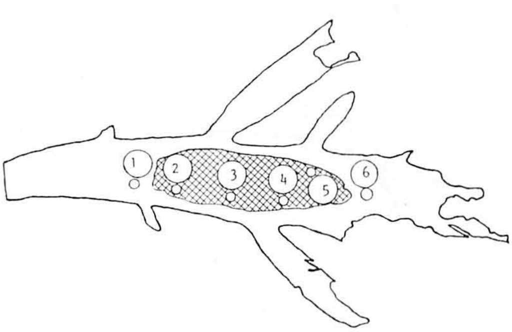

Fig. 4. Trace of an *Ecklonia cava* bladelet indicating the position of blade discs used for measurements of dry weight and chlorophyll *a* in Table 3.

Discussion

Sporophytes of *Ecklonia cava* in Nabeta Bay usually begin to form zoosporangial sori in their bladelets in July. Sorus portion of bladelets occupied 18.9% of the total dry weight of blades in August and 28.9% in September 1985 as illustrated in Fig. 5 which was compiled by the technique of MONSI and

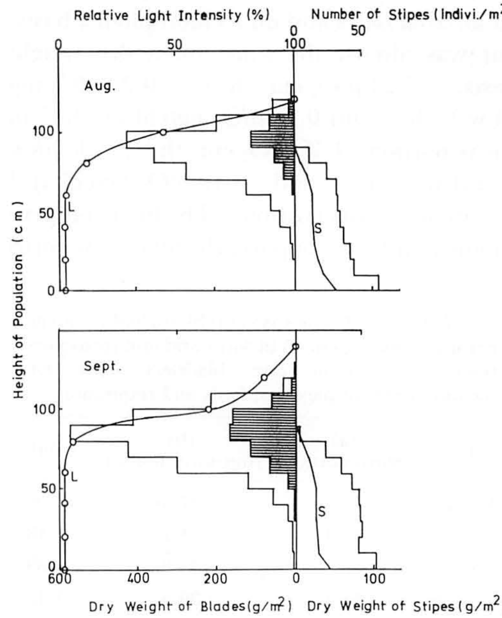

Fig. 5. Production structure diagrams of *Ecklonia cava* communities measured after the technique of MONSI and SAEKI (1953) in Nabeta Bay in August and September 1985. Shaded part indicates sorus portion. L, relative light intensity; S, number of stipes.

SAEKI (1953). In the present study, it is shown clearly that the photosynthetic rate was lower in sorus portion than in non-sorus portion of a bladelet either on an area basis, on a dry weight basis or on a chlorophyll *a* basis (Fig. 1). The light-saturated net photosynthetic rate of sorus portion was about 30% lower than that of non-sorus portion both on an area basis and on a chlorophyll *a* basis. The light-saturated net photosynthetic rate was about 72% lower in sorus portion than in non-sorus portion on a dry weight basis. This is mainly due to a great difference in dry weight per unit area between sorus portion and non-sorus portion, dry weight being 2.7 times as high in the former as in the latter (Table 1).

The rate of dark respiration was about twice as high in sorus portion as in non-sorus portion both on an area basis and on a chlorophyll *a* basis, whereas on a dry weight basis it was almost the same. It was shown that the light compensation point of sorus portion was about twice as high as that of non-sorus portion (Fig. 1). It is suggested that the bladelet becomes thicker when zoosporangial sori are formed in it, thus the light penetrating blade being attenuated more greatly to come to the assimilatory layer in thick sorus portion than in non-sorus portion. As it is expected that the respiratory rate is generally the same on a dry weight basis, thick sorus portion has higher respiratory rate on an area basis.

Although there was no significant difference in chlorophyll *a* content between sorus portion and non-sorus portion in the result shown in Table 2, the sample for Fig. 4 clearly indicated that chlorophyll *a* content per unit area was higher in sorus portion than in non-sorus portion (cf. Table 3) possibly due to additional chlorophyll *a* in sorus portion.

The rate of daily production of *E. cava* sporophytes in Nabeta Bay was reported to be highest in April–May and lowest in August–September (YOKOHAMA *et al.* 1987). The period of the lowest production corresponds to that of reproduction in *E. cava* sporophytes, sorus portion occupying about 30% of the total dry weight of blade as shown above. Sorus portions have higher compensation point and lower photosynthetic activity as compared with non-sorus portions as illustrated in Figs. 1 and 3. Thus, the lower photosynthetic rate of sorus portions is considered to be one of the causes for the lower rate of production in *E. cava* sporophytes in summer in Nabeta Bay.

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有賀祐勝[1]・豊島麻理[2]・横浜康繼[3]：褐藻カジメ側葉の子嚢班部と非子嚢班部の光合成の比較研究

褐藻カジメ *Ecklonia cava* の側葉の光合成活性を子嚢班部と非子嚢班部について比較した。静岡県下田の鍋田湾で水深約5mの群落の中から採取した試料を用い，光合成ならびに呼吸を差動式検容計で測定した。側葉の光合成速度は，単位面積あたり，単位重量あたり，単位クロロフィル *a* 量あたりのいずれでも子嚢班部では低く，非子嚢班部では高かった。呼吸速度は，単位面積あたり及び単位クロロフィル *a* 量あたりでは子嚢班部で高く非子嚢班部では低かったが，単位重量あたりではほとんど同じであった。このような光合成速度ならびに呼吸速度の差は，主として子嚢班部と非子嚢班部の単位面積あたりの重量の差によるものである。光合成の光補償点は，子嚢班部の方が非子嚢班部より高かった。子嚢班が形成されると，光は側葉の同化層に到達するまでに著しく減衰されるものと思われる。([1] 108 東京都港区港南4–5–7　東京水産大学藻類学研究室，[2] 104 東京都中央区豊海町4–18　(財) 日本水産資源保護協会，[3] 415 静岡県下田市5丁目10–1　筑波大学下田臨海実験センター)