Interactive Learning

The vertical distribution of seaweeds and their photosynthetic characteristics

Yasuhiro Kanaizuka[1], Kumiko Fujioka[1], and Nobuyasu Katayama[2]
Ochiai Junior High School, Shinjuku-ku, Tokyo 161-0033[1]; Department of Biology, Tokyo Gakugei University, Koganei, Tokyo 184-8501[2]; Japan

A laboratory exercise was developed for junior high school students to help them understand the relationships between the vertical distribution of seaweeds and their photosynthetic characteristics. The fronds of a red alga, *Mastocarpus yendoi*, and a green alga, *Ulva pertusa* were used. Both were cultured under room conditions and shown to maintain their photosynthetic activities for more than two weeks. The photosynthetic rates of these fronds were measured under light of different colours by using a gas-volumeter, 'Productmeter'. The overall procedure for measuring the photosynthetic rates can be completed within 50 minutes, one Japanese junior high school class. While *M. yendoi* showed the same photosynthetic rate regardless of the colour of light, in *U. pertusa* there was a significant difference in the photosynthetic rates under white light and green light conditions. We introduced the laboratory exercise into a junior high school advanced science class, in which the photosynthetic responses of red alga and green alga to the different wavelengths of light were compared. Some trials have been carried out, and the results described below indicate that this laboratory exercise is effective in teaching this topic.

Key words: Photosynthesis, Secondary biology, Seaweeds, Students' laboratory.

Introduction

Since seaweeds play an important role as producers in a marine ecosystem, they are one of the key organisms in teaching marine ecology. Additionally, they are appropriate materials in teaching the diversity and unity of plants. In spite of such importance, there have been only a small number of studies on the use of seaweeds in teaching biology or on the development of student laboratory exercises.

In Japan, people are familiar with seaweeds because they eat many kinds. However, there is very little subject matter concerning algae, especially seaweeds, in biology education at schools. Under the Japanese new science curriculum standards (Ministry of Education, Science, Sports and Culture, 1998a, b), there are no chapters on algae at elementary school level and little time can be allotted to study seaweeds at junior high school level. Thus, Japanese students have only a few opportunities to study algae, especially seaweeds, during the nine years of compulsory education. Although some seaweeds have been shown to be useful materials for experiments in teaching photosynthesis (Katayama *et al.*, 1986; Jinno and Fujita, 1996; Kanaizuka and Katayama, 1996; Reed and Orr, 1997), no laboratory exercises using living seaweeds for teaching photosynthesis currently appear in Japanese junior high school science textbooks.

There are several reasons why seaweeds have rarely been used as teaching materials. Firstly, most science teachers are not familiar with using seaweeds. Secondly, for most science teachers in schools don't find it easy to obtain fresh seaweeds, especially in inland schools; and thirdly, if fresh seaweeds can be obtained it might be difficult to keep them fresh until use (Imai and Katayama, 1996).

The present authors reported suitable conditions for culturing seaweeds in junior high school science laboratories and ways to use these cultured seaweeds for detecting photosynthetic activity qualitatively in junior high school science classes (Kanaizuka and Katayama, 1996). The red seaweed *Mastocarpus yendoi (Gigartina mamillosa)* Masuda et Yoshida was found to be very useful material for many laboratory exercises in biology at the primary and secondary levels because it can be cultured for about a month under controlled conditions (Table 1) and also under room conditions. The alga is a good experimental material for teaching photosynthesis, because it allows students to realise that not only green plants, but also some other plants whose colours are not green can photosynthesise (Kanaizuka and Katayama, 1996).

The zonation (vertical distribution) of plants is an interesting topic in ecology. So far, the topic has been taught only using terrestrial plants. However, the vertical distribution of seaweeds is observed in seashore communities and is useful for teaching the zonation of plants. As explained below, this phenomenon is closely related to the photosynthetic characteristics of seaweeds and is also useful for teaching the relationships between the photosynthetic characteristics of seaweeds and environmental factors such as light.

In this study, we examined the photosynthetic responses of

Table 1 The effects of temperature on morphology, i.e., the shape and colour of the fronds, of *Mastocarpus yendoi* in culture. The fronds of *M. yendoi* were cultured at 10, 15, 20, 25 and 30°C under the light intensity of 50 μE/m²/s, L : D = 12:12 light regime for one month from May to June (Kanaizuka and Katayama, 1996).

Temperature in culture (°C)	*Seaweed morphology*		
	After 10 days	*After 13 days*	*After 30 days*
30	+	+	X
25	O	O	O
20	O	O	O
15	O	O	O
10	O	O	O

O: no change; +: partially decolorized; X: partially degraded.

green and red algae to the different light colours white and green in order to develop a new experiment for laboratory exercise on photosynthesis in advanced science classes, offered to the third-year students of Japanese junior high schools. The aims of the laboratory exercise were:

(1) to allow students to notice that seaweeds of different colours show different photosynthetic responses to light of different colours;
(2) to allow students to understand the relationships between the vertical distribution of seaweeds and their photosynthetic responses to light conditions.

We used *M. yendoi* and the green seaweed *Ulva pertusa* Kjellman, both of which could be cultured using filtered seawater under room conditions and whose photosynthetic activities could be maintained for more than two weeks. By using a gas-volumeter, we could measure their photosynthetic rates within 50 minutes, one Japanese junior high school class. We made a lesson plan on photosynthesis, including the laboratory exercise for junior high school advanced science classes and carried out the lesson several times. We will report the results of the implementation of the lesson in detail in another paper.

Relationships between the vertical distribution of seaweeds and their photosynthetic characteristics – biological background

There is an apparent vertical distribution (zonation) of seaweeds in seashore communities, in which green ones occur at the higher position, brown ones at the middle, and red ones at the lower position of the intertidal and subtidal zones. For many years, this phenomenon has been thought to be explained by the theory of complementary chromatic adaptation, which came from Engelmann's experiments in the 1880s and has now been shown to be inaccurate (Lobban and Harrison, 1994). Actually, the growth of seaweeds is limited by the spectral distribution (light quality) as well as by the intensity of light (light quantity). The zonation is caused by the differences in the photosynthetic pigments that each seaweed group possesses (Lüning, 1990; Sze, 1997). Yokohama (1973a, b) showed the different photosynthetic responses of a green seaweed occurring at an upper position in the intertidal zone and a red seaweed occurring at 20 m in depth. The green one could not photosynthesise under green light at the same rate as under white light. On the other hand, the photosynthetic rates of the red seaweed under green light and white light were the same. The laboratory exercise developed in the present study followed the work of Yokohama mentioned above.

Materials and Methods

Algal material and culturing conditions

The fronds of *M. yendoi* were collected in June, July and August 1996 at Shiraiso Beach in Manazuru, Kanagawa Prefecture, 110 km from Tokyo Gakugei University. The fronds of *U. pertusa* were collected in June 1996 at Shiraiso Beach and in September 1996 at Nabeta Bay in Shimoda, Shizuoka Prefecture, 160 km from the university. The fronds were kept in a cooler box, which was maintained at a temperature below 15°C using ice, and were carried to the university laboratory. The fronds were cleaned and cultured in an incubator at 20°C under a light intensity of about 30 μE/m²/s and L: D = 12:12 light regime for about one month, while changing seawater once a week. The vessels used for culturing were deep Petri dishes, nine centimetres in diameter, containing about 80 ml of filtered seawater (Kanaizuka and Katayama, 1996).

Measurement of photosynthetic rates

The photosynthetic rates of these seaweed fronds under light of different colours (green and white) were examined quantitatively. The photosynthetic rate was measured using the improved Productmeter (Yokohama *et al.*, 1986), a gas-volumeter, which was purchased from Nikko Kagaku Co. Ltd., Tokyo. The equipment is commonly used in Japanese senior high school biology laboratories to measure the photosynthetic oxygen evolution from a plant material and the respiratory oxygen consumption by an organism.

Light of different colours was obtained by using a green or neutral filter. We purchased these filters from Tokyo Butai Shomei Co., Tokyo, but similar filters can be obtained from some other companies: Wagner and Wagner, 1995. The spectral distribution of light that passed through each of the filters (Figure 1) was examined by a Shimadzu U-160A spectrophotometer. The filters were cut into squares about 16 cm² and attached to the front of the lens of a 300 W slide projector which was used as a light source. The intensity of the light penetrating the filter was measured by a photometer.

The photosynthetic rate of a cultured frond was measured according to Kanaizuka and Katayama (1996). Photosynthesis was measured using about 0.1 g fresh weight of algal frond with eight millilitres of filtered seawater. The rate of oxygen evolution from the algal frond was measured at 50 μE/m²/s of light intensity and at 20°C. The apparent photosynthetic rate (μl O_2/ h/ g fresh weight) was calculated according to Yokohama *et al.* (1986). The measurements were repeated at least four times with different fronds.

Results

Algal materials and culture conditions

The fronds of *M. yendoi* and *U. pertusa* are found throughout the year at the collection sites mentioned above. By using a cooler box, kept at a temperature below 15°C, the fronds of these seaweeds could be carried to the university laboratory from the collection sites without seriously damaging them. These fronds could easily be cultured using filtered seawater at room temperature and maintained their photosynthetic activities for more than two weeks (Kanaizuka and Katayama, 1996). Figure 2 shows the fronds of *M. yendoi* and *U. pertusa*, which

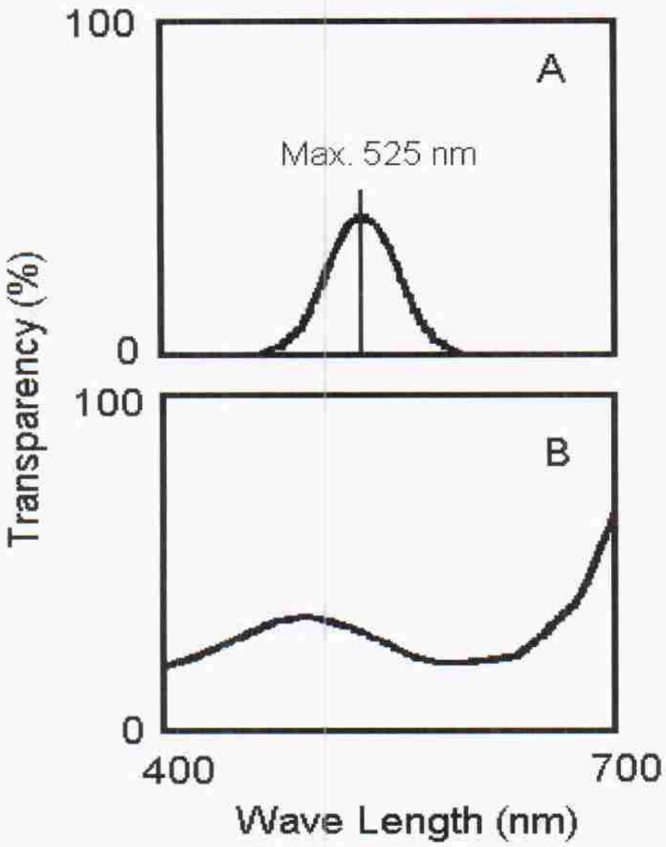

Figure 1 *The spectral distribution of light passed through a green filter (A) and neutral filter (B). By using these filters with a slide projector, green light and white light were obtained.*

were cultured for two weeks. Both fronds kept their original shapes and colours: deep-dark red in *M. yendoi* and green in *U. pertusa*.

Photosynthetic rates under light of different wavelengths

Figure 3 shows an example of the apparent photosynthetic oxygen evolution from a frond piece of *M. yendoi* at 20°C under 50 µE/m^2/s of white light, as a function of time. The graph is nearly linear (proportional) at least during the first 20 minutes of measurement. From such a graph, the apparent photosynthetic rate can be calculated.

Table 2 shows the apparent photosynthetic rates of *U. pertusa*, collected in June and September, and *M. yendoi*, collected in June, July and August, under white light and green light. Each of the data shown in the table is the average of the photosynthetic rates of four different fronds, which were measured three times on different days during the first week of culturing. The seasonal changes in the photosynthetic activity are not apparent either in *U. pertusa* or in *M. yendoi*. There is a significant difference in the photosynthetic rates under different light conditions in *U. pertusa*, but not in *M. yendoi*.

Discussion

The use of living seaweeds in teaching photosynthesis in science classes

In Japan living seaweeds are thought to be too difficult to use in laboratory exercises for teaching photosynthesis in secondary schools. However, this seems merely to be speculation because

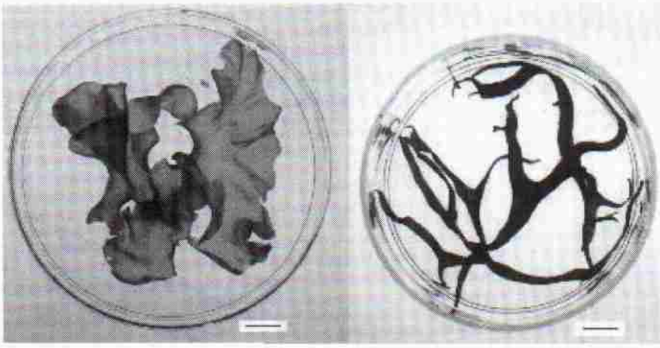

Figure 2 *The fronds of* Ulva pertusa *(a green alga, left) and* Mastocarpus yendoi *(a red alga, right) which were cultured at 20°C under a light intensity of about 50 µE/m^2/s and L : D = 12 : 12 for two weeks. Both fronds kept their original shapes and colours: Deep-dark red in* M. yendoi *and light green in* U. pertusa. *Scale bar indicates 1 cm.*

there have only been a small number of studies on introducing seaweeds into laboratory exercises related to photosynthesis (Kanaizuka and Katayama, 1996).

Jinno and Fujita (1996) used seaweeds to detect photosynthetic activity by an improved Indigo Carmine Method and introduced the experiment in senior high school biology classes. However, they did not consider how to prepare materials for laboratory exercises in an inland school. They also did not discuss how the experiment could be introduced into junior high school science classes. In addition, their laboratory exercise was not a quantitative experiment.

The seaweed species used in this study, *M. yendoi* and *U. pertusa*, are found in the intertidal zone of rocky seashores in the central and northern parts of Japan through the year (Masuda *et al.*, 1987; Masuda, 1993; Tatewaki, 1993). So, the fresh fronds of these seaweeds can be collected at any time when required for lessons. Furthermore, since these seaweeds can be cultured under classroom conditions for at least two weeks, they can be used in laboratory classes during that entire period. These seaweeds occur in the upper or middle positions of intertidal zones and can tolerate considerable temperature changes so could be sent with seawater in a bottle by post from a coastal area to an inland school.

The result shown in Figure 3 indicates that the photosynthetic activities in cultured fronds of *M. yendoi* are high enough that their photosynthetic rates can be measured quantitatively by the Productmeter within 20 minutes. The photosynthetic rates in cultured fronds of *U. pertusa* are higher than those of *M. yendoi*. These seaweeds, therefore, can be used as well as

Table 2 Apparent photosynthetic rates of *Ulva pertusa* and *Mastocarpus yendoi* under white light. and green light

	*Photosynthetic rates**		
	Under white light	*Under green light*	
U. pertusa			
June	1300.9 ± 245.4	776.8 ± 152.6	#
September	975.0 ± 163.6	654.6 ± 86.6	#
M. yendoi			
June	318.9 ± 69.5	299.6 ± 83.2	
July	221.9 ± 32.1	238.7 ± 41.9	
August	201.9 ± 82.0	243.2 ± 41.7	

* Photosynthetic rate: µl O_2/ h/ g fresh weight. Each value is mean ± SD (*n*=12). #, between "Under white light" and "Under green light," mean values are significantly different at 0.1% level by the *t*-test (two-sided test).

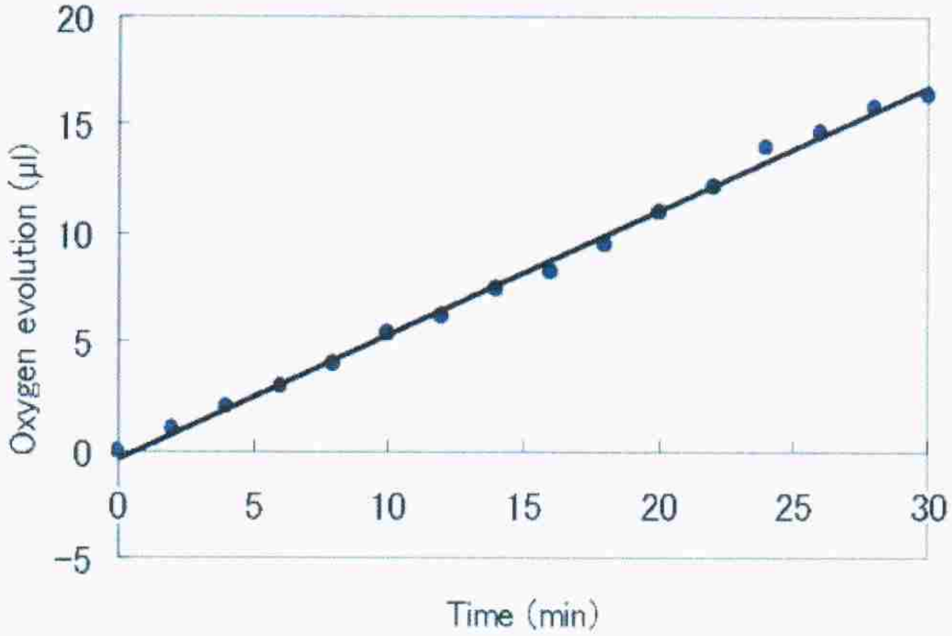

***Figure 3** An example of time course data of apparent photosynthetic oxygen evolution from cultured fronds of* Mastocarpus yendoi *measured by the Productmeter at 20°C under a intensity of 50 µE/m²/s of white light. About 0.1 g fresh weight of frond was used for measurement.*

Cladophora rudolphiana, which could be cultured using a commercial artificial seawater under laboratory conditions and could be used for measuring photosynthetic rates quantitatively (Katayama *et al.*, 1986). With the exception of a few matured fronds of both seaweeds, there were no considerable differences in the photosynthetic activities of fresh fronds collected at different sites during the period from April to September. This is the best season to collect these seaweeds, because the low ebb occurs in daytime and the habitat of these seaweeds can easily be accessed. Thus, we recommend teachers to carry out this exercise during this period, though both seaweeds can be collected throughout the year.

Teaching zonation (vertical distribution) by using seaweeds

U. pertusa could not utilise green light for its photosynthesis as efficiently as white light, while *M. yendoi* could (Table 2). The difference in their photosynthetic responses to white and green light appears to be related to the difference in the colours of their fronds. This is because of the difference in their accessory photosynthetic pigments. Most green algae do not have any accessory photosynthetic pigments that can absorb green light. On the other hand, red algae contain phycoerythrin as an accessory photosynthetic pigment, so they can absorb green light and use the light energy for photosynthesis (Lüning, 1990; Sze, 1997). In deeper sea areas, only blue-green light can penetrate. Thus, red seaweeds can grow in such areas where ordinary green seaweeds cannot grow. This is one of the causes of the vertical distribution of seaweeds (Yokohama, 1973a, b) and could be an interesting topic in plant ecology at the secondary level. However, no studies have been carried out so far to introduce this topic to junior high school science classes. We selected *U. pertusa* as the representative of green seaweeds found in the intertidal zone and *M. yendoi* as that of red seaweeds occurring in deeper sea areas, although the latter seaweed actually occurs in the intertidal zone. In other regions, any other species belonging to the genus *Ulva* such as *U. lactuca* (Reed and Orr, 1997) and some species related to *Mastocarpus yendoi* might be used in this laboratory exercise.

Equipment to measure photosynthetic rates

In the laboratory exercise developed, students are required to measure photosynthetic rates of seaweeds under white light and green light quantitatively. There are some methods and equipment to measure photosynthetic oxygen evolution from seaweeds quantitatively. The improved Productmeter used in this study is a gas-volumeter by which the volume of evolved oxygen can be measured (Yokohama *et al.*, 1986). The principle of measurement is the same as that for the equipment devised by Takaoki (Takaoki and Kitao, 1992; Takaoki and Mori, 1995), but for secondary school students the former is easier to operate than the latter. Compared to this equipment, an oxygen electrode (DO meter) seems to be more convenient and less time-consuming for measurement (Love and Spragg, 1986). However, the oxygen electrode is more expensive than volumeters. Since the principle of measurement by the oxygen electrode seems to be more complicated, junior high school students cannot understand what they are measuring. Thus we used the improved Productmeter in this laboratory exercise.

Implementation of the laboratory exercise

In order to evaluate the effectiveness of our laboratory exercise developed in this study we implemented it in a junior high school.

We made a three-hour lesson plan which included the laboratory exercise developed in the present study. The lesson plan was composed of:

(1) introduction
(2) laboratory exercise
(3) data analysis and discussion.

The lesson has been carried out repeatedly during the last four years in advanced science classes at Ochiai Junior High School.

In the implementation, students were separated into groups (three/four students in one group) and were asked to measure the photosynthetic rates of cultured fronds of *M. yendoi* or *U. pertusa* under white light and green light separately. They could obtain results, which were similar to those we had recorded, within one class hour. In analysing their results, they could realise the difference in the photosynthetic responses of seaweeds of different colours to the different wavelengths of light. With some further explanation of light penetration of seawater, given by the teacher and requiring about 15 minutes, students could understand the relationships between the vertical distribution of seaweeds and their photosynthetic responses to the light conditions. These results indicate that the laboratory exercise is effective for teaching this topic.

It does not seem to be difficult for ordinary senior high school students to carry out this experiment. If they have learnt the properties of light prior to the laboratory exercise, they can understand the relationships between the vertical distribution and photosynthetic characteristics of seaweeds. Thus this laboratory exercise could also be useful for ordinary biology classes in senior high schools.

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Websites

http://seaweed.ucg.ie/defaulttuesday.html
The Seaweed Site

Appendix

Suppliers

Yellow Springs Instrument Co, Inc.
Yellow Springs, Ohio, USA.

Nikko Kagaku Co. Ltd.
1-3-24 Sekimachi-higashi, Nerima, Tokyo 177-0052, Japan.

Nobuyasu Katayama (corresponding author) is an Associate Professor in the Department of Biology, Tokyo Gakugei University, Koganei, Tokyo 184-8501, Japan; Email: katayama@u-gakugei.ac.jp. Yasuhiro Kanaizuka teaches science at Ochiai Junior High School, Shinjuku-ku, Tokyo 161-0033, Japan. At the time this research was carried out, Kumiko Fujioka was a part-time teacher of Ochiai Junior High School. She now teaches at Yasaka Elementary School, Nerima-ku, Tokyo, Japan.