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Chlorophyll Content and Primary Production of the Sessile Algal Community in the Mountain Stream Chigonozawa Running Close to the Kiso Biological Station of the Kyoto University[1)]

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ABSTRACT The chlorophyll standing crops and the photosynthesis—light intensity curves of the sessile algal communities together with the light condition as the environments were measured during 1964 to 1966 in the stream Chigonozawa, flowing in the montane region of central Japan. Algal communities were mainly composed of blue greens and diatoms and the light condition was studied by using photographs of celestial hemisphere.

A linear correlation between light condition and chlorophyll content was found. The annual mean value of chlorophyll content was 0.030 g/m^2, and the annual gross production was estimated to be 0.13 kg·glucose/m^2. In the whole water course, total sum of the gross production, the amount of respiration and the net production were 86.45 kg·glucose, 53.68 kg·glucose and 32.78 kg·glucose respectively. The photosynthesis—light intensity curve showed a shade-type one with marked photo-inhibition both in summer and autumn (I_k was ca. 3200 lux).

Introduction

Chigonozawa is a small tributary stream running through mountain valley close to the Kiso Biological Station of the Kyoto University situating at latitude 35°50′ and about 800 m above the sea level and flows in canyon section of the river Kisogawa. The water is clear and rapid. As shown in Table 1, the water temperature is lower throughout the year. It was 14 to 14.5°C even in summer. The pH value is usually found in circum-neutral range being 7.1 in summer and 7.2 in winter.

In the stream, the investigations of the behavior and the productivity of the consumers mainly of *Salvelinus pluvius*, a kind of char, were carried on by the investigators

1) Contribution from the Ôtsu Hydrobiological Station, Kyoto University, No. 219.

of the Kyoto University. With regard to this investigations of the mountain stream ecosystem, the present studies were started so as to get the productivity of the primary producer growing on the stream bed. The stream bed is covered with pebbles of various sizes. The producer of the stream is sessile algal community composed mainly of blue greens and diatoms.

For the estimation of the primary production in the river, especially in such a mountain stream as Chigonozawa, measurement of the light condition is indispensable. The method employed in the previous work of the author was also usefull for this time.

Method

As shown in Map 1, ten stations had been settled by the investigators of the Kyoto University when the present studies were started. Algal materials used for the measurements of chlorophyll and photosynthesis and the species analysis were collected simultaneously on August 3 in 1964, February 14 and October 13 in 1965 and March 16 in 1966 alternately from the said stations i.e. Station 1, 3, 5, 7 and 9.

For the measurement of chlorophyll, sessile algal communities were collected quantitatively with the same procedure as employed in the author's previous work.[5] Namely the algae on a surface of the rock having a minimum dimention greater than 10 cm were covered with the protection of a 5×5 cm^2 polyethylene cloth, then the rest were brushed away completely and the rock was rinsed with stream water. After stripping off the polyethylene cloth, the protected algae that remained on the rock surface were then brushed out into a tray and filtrated with a filter paper (Toyo No. 5A). The filtrated paper with algae were kept in a portable ice-box and brought to the laboratory. The chlorophyll in residues on the paper was determined after the method of SCOR-UNESCO.[9]

The photosynthesis was measured by the well-known light and dark bottles method using Winkler's method. The sessile algae removed from the river bed were suspended in the bottles filled with river water. The bottles were laid on the stream bed at Station 1 from which materials were taken and left an hour in the midday. For one series measurement, six bottles were prepared and each group of them was exposed under the light of 5, 10, 20, 50 and 100% of full sun light. To reduce light intensities during the incubation, white vinyl chloride cloths were used. For example, wrapps providing 50% transmission were made two layers of these cloths. To achieve complete darkness, bottles were wrapped in alminium foil.

As pointed out in the author's previous work,[6] the light condition on the bottom of the mountain river varied conspicuously from place to place with the difference of the shade formed by the mountains, trees, shrubs and herbs standing and growing along the both sides. Therefore, the diffused light intensity and duration of insolation on the stream bed were determined with the photographs of the celestial hemisphere. Since the both sides of the stream were covered closely with deciduous trees or herbs, the photographs were taken twice a year. One was in summer when leaves were green and the other was in early spring when leaves were still cast.

Table 1. Locational and seasonal changes in chlorophyll amount on the rock surface having a minimum dimention of 10 cm or greater and water temperature in the mountain stream Chigonozawa. Values corrected by the rock size category are in the parentheses.

Season / Station	Spring Mar. 16		Summer Aug. 3		Autumn Oct. 13		Winter Feb. 14		Average
	W.T.	Chl. mg/m²	W.T.	Chl. mg/m²	W.T.	Chl. mg/m²	W.T.	Chl. mg/m²	Chl. mg/m²
1	5.0	73.6 (20.24)	14.5	46.4 (12.81)	13.2	82.4 (22.74)	3.6	48.8 (13.47)	62.8 (17.32)
3	4.8	36.8 (24.71)	14.0	21.2 (14.76)	13.2	42.0 (29.23)	3.5	19.6 (13.64)	29.9 (20.59)
5	4.9	17.2 (11.97)	14.0	9.2 (6.40)	13.0	13.2 (9.19)	3.5	32.0 (22.27)	17.9 (12.46)
7	4.8	28.0 (12.66)	14.0	20.4 (9.22)	12.5	31.2 (14.10)	3.4	30.0 (13.56)	27.4 (12.39)
9	4.8	8.4 (4.46)	14.0	5.6 (3.64)	12.5	18.8 (10.38)	3.4	13.2 (7.29)	11.5 (6.49)
Average		32.8 (14.84)		20.56 (9.37)		37.52 (17.13)		28.72 (14.05)	29.9 (13.85)

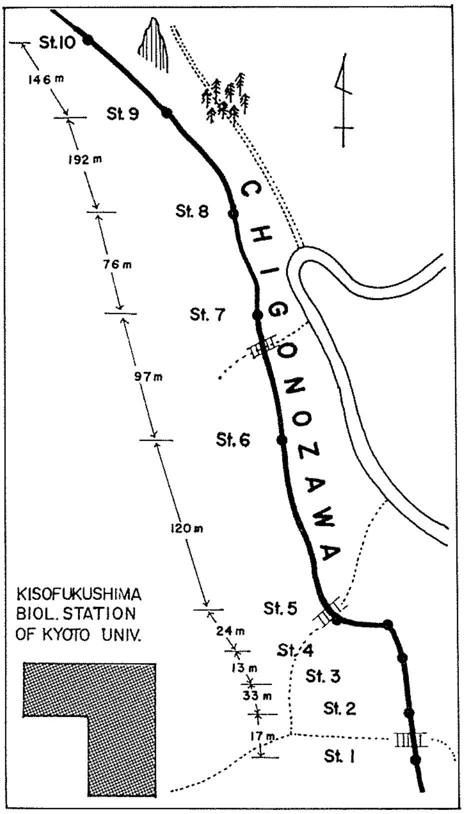
Result and Discussion

1. *Standing crops of chlorophyll and light condition*

Locational and seasonal changes in chlorophyll amount on the surface of the rocks having a minimum dimention of 10 cm or greater are shown in Table 1. As already suggested by McConnel and Sigler,[7] chlorophyll amount on the rock surface fluctuates with the size category of the rocks. In this stream, those rocks having a minimum dimention between 2 cm to 10 cm supported about 60%, and the bottom sand having a minimum dimention smaller than 2 cm supported about 8% of the chlorophyll on the rocks having a minimum dimention of 10 cm or greater. Values corrected by rock size category per unit area in each station are also included in the parentheses of the same table.

At Station 1, 10% of the stream bed was occupied by the rocks 10 cm or greater and 20% was occupied by the rocks 2 cm to 10 cm and the rest was sand. Whereas at Station 3, these values were 50%, 30% and 20% respectively. Therefore, the values in the parentheses i.e. standing crops of chlorophyll per unit area of the stream bed, are not directly proportional to the values shown without parentheses.

The possible factors controlling the photosynthesis of the sessile algae are the light condition, the nutrient concentration and the water temperature. As seen in the Map 1, distance between Station 1 and 10 is only 718 m. The nutrient concentration and the water temperature cannot be so much fluctuated as to affect the locational changes in chlorophyll amount within the water course. The water temperature at the same sampling time showed quit stable state (Table 1). On the other hand, considerable fluctuation was found among the values of the chlorophyll amount.



Map 1. A sketch showing the stations and the watercourse of the stream Chigonozawa.

In this stream, it is evident that these remarkable fluctuation of algal growth is caused mainly by the light condition introduced both diffused light condition and duration of insolation. Fig. 1 shows the photographs taken at Station 8 in summer and winter, and the interpreted tracing of the photographs taken at each station. White portion on the figures represents the open sky area of summer foliate season and the obliquely striated area represent deciduous trees and herbs which intersept insolation completely in summer and allow the penetration of light in some degree during defoliate season.

Diffused light intensity reaching algae on the bottom of the stream is shown in Table 2, in which the values in foliation are deduced indirectly from the ratio of white portion to the whole area of the tracing which represents the whole celestial hemisphere, and the values of defoliate season are also deduced by calculating the open sky area in summing up the area of the white portion and the half of the obliquely striated portion. The diffused light intensity from blue sky is about 10 klux on daily average, whereby the station having the open sky of a area may receive the diffused light of 10·s/S klux, where S being the area of the whole celestial hemisphere.

As seen in Table 2, the open sky ratio is 3.1% to 29.9% during the period of foliation and 16.9% to 39.2% during the period of defoliation. Thereby the algae growing on the stream bed receiving 3.1% of diffused light are roughly assumed as to receive only 300 lux on a cloudy day or in the shaded duration on a fine day. According to the data taken from the mountain river Arakawa,[6] the open sky ratio is 20% to 50% in the canyon section. The values of the Chigonozawa are comparable to those of extremely shaded site of the Arakawa.

Fig. 1. Interpreted tracing of photographs of the celestial hemisphere at various stations in the stream Chigonozawa, photographs of the celestial hemisphere taken at Station 8 in foliate and in defoliate seasons, and transparent overlay of sun course at latitude 35°50′. N and n indicate the true north and the magnetic north.

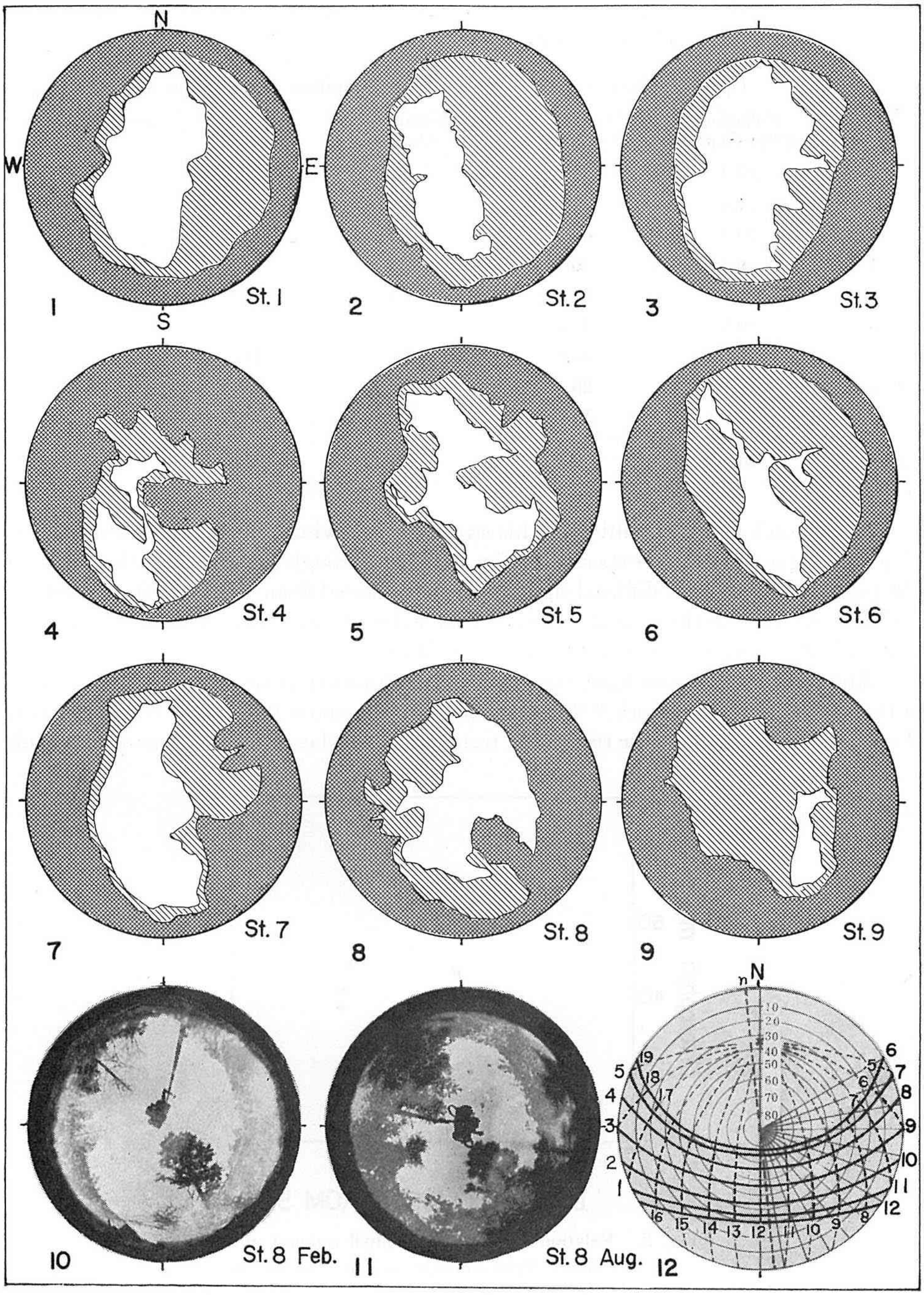

N
W
E
S
1
St. 1
2
St. 2
3
St. 3
4
St. 4
5
St. 5
6
St. 6
7
St. 7
8
St. 8
9
St. 9
10
St. 8 Feb.
11
St. 8 Aug.
12

Table 2. Open sky area and duration of insolation in foliate and in defoliate seasons.

Station	Open sky area (%)		Duration of insolation (hr.)		
	Foliation (May-Sept.)	Defoliation (Oct.-Apr.)	Foliation (Aug.)	Defoliation (Mar.)	Defoliation (Feb.-Oct.)
1	24.4	39.2	3.5	5.4	4.5
2	14.8	36.6	2.7	4.6	4.0
3	29.9	40.3	4.6	4.65	4.1
4	6.8	16.9	0.7	3.5	3.4
5	17.4	27.8	4.3	3.75	2.6
6	10.6	31.8	2.6	4.2	3.2
7	23.9	33.8	3.3	3.8	3.7
8	19.7	28.8	2.7	2.9	2.7
9	3.1	19.7	0.7	3.25	2.0
Average	16.7	30.5	4.0	2.8	3.3

Under such a dim condition as this stream, it is obvious that the favorable growth of sessile algae cannot be expected. Fig. 2 shows a rough linear correlation between chlorophyll amount and diffused light intensity obtained from the sampling stations in various seasons. In the case of this figure, the value of correlation coefficient calculated at 0.66 indicate an existence of the mutual relation.

Another factor of the light condition is the duration of insolation. As indicated in the author's previous work,[6] the intercepted insolation on the stream bed at any time of a year is determined by the reading of transparent overlay of the sun course at latitude

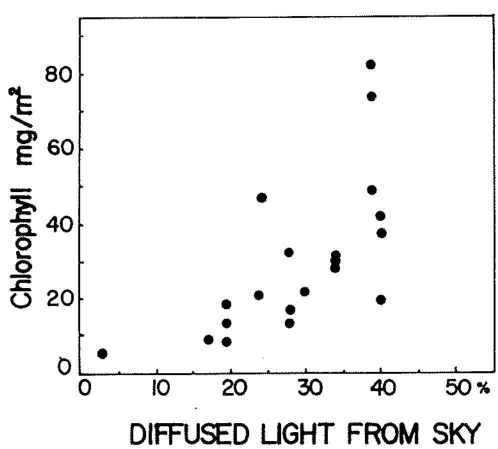


Fig. 2. Relation between chlorophyll amount and diffused light intensity at each station in various seasons.

35°50′ where the Chigonozawa situated. As can be seen in Table 2, the sunshine duration on the stream bed varies through a year and also with the shape of the open sky. In these values except the readings of August, the actual duration of insolation passing through the obliquely striated portion assuming as a half of the direct reading in that portion. For example, the readings of the duration of insolation in March at Station 1 are 32 hours within white area and 4.6 hours within obliquely striated area, accordingly the value is computed as 5.4 hours.

These values in Table 2 are conspicuously lower. The algae on the stream bed can only receive one third to one fourth of the daily insolation directly in usual. The extremity is seen at Station 9 where the duration of insolation is surmised as only 0.7 hours in August and 3.25 hours in March. As seen in Fig. 3, the close relation was also found

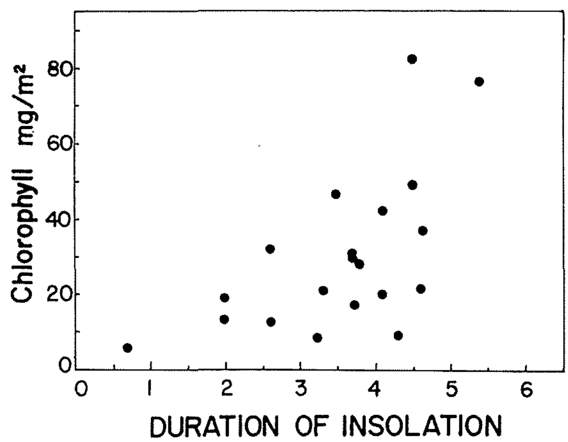


Fig. 3. Relation between chlorophyll amount and duration of insolation at each station in various seasons.

between the chlorophyll standing crop and the duration of insolation. In this case the correlation coefficient is calculated at 0.6. From these results, it can be surmised that the light condition of the stream bed is one of the most important factors determining the primary production of such a stream receiving extremely low light.

In comparison with the designation proposed by Aruga and Monsi,[1] the lowermost value of 0.006 g chl./m^2 obtained at Station 9 in summer corresponds to oligochlorophyllaceous lake and the uppermost one of 0.082 g chl./m^2 at Station 1 in autumn correspond to euchlorophyceous lake. However, the annual average of 0.029 g chl./m^2 is comparable to mesochlorophyllaceous lake. The annual average of 0.025 g chl./m^2 in the canyon section of the river Arakawa[5] is also comparable with that in this stream.

2. *Photosynthetic Nature of the Sessile Algae*

Fig. 4 presents six curves showing the rate of photosynthesis as a function of light intensity of the sessile algae at Station 1 in February, March, August and October. And in Fig. 5, the same curves are presented in another way. The curves are relative, light

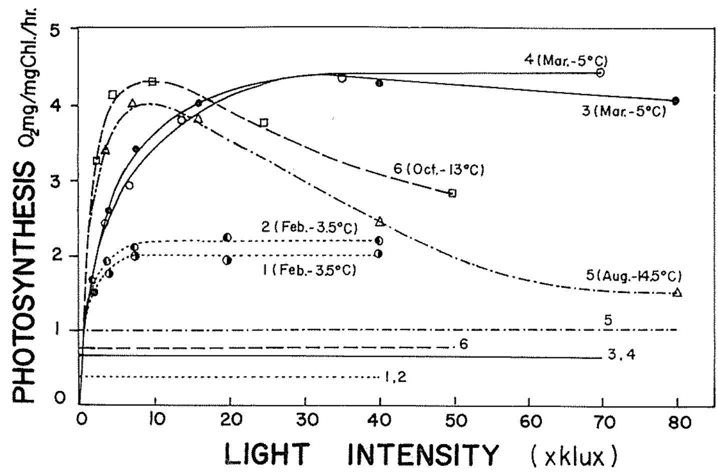


Fig. 4. Photosynthesis light intensity curves of the sessile algae at Station 1 in spring (March), summer (August), autumn (October) and winter (February). Straight lines drawn at the lower part showing the respiration values.

saturated in all cases being put at 100 per cent. In general, photosynthetic nature of the river algae is considered to have the curves that present shade-type cold water and sun-type in warm water, and that have no clear inhibition by intense light. In fact, almost all the curves of the river algae reported by Kobayasi,[6] Tominaga and Ichimura,[15] and Ichimura and Aruga[2] showed sun-type in summer, shade-type in winter. Furthermore, they have no clear photoinhibition.

In the present, though the curves obtained in winter season showed low rate of the light saturated photosynthesis and that obtained in summer or autumn also showed relatively high rate of the said photosynthesis, the slopes of the curves at low intensity are quite identical. The I_k that was proposed first by Talling[14] as an index of the characteristics of photosynthesis-light curve, is in this case about 3200 lux. As mentioned by Jorgensen and Steeman Nielsen[3] "Due to adaptation, I_k seems always to be higher in algae grown at high light intensities than in algae grown at low intensities", the I_k values and the shape of the curves obtained from summer and autumn algae growing on the river bed of Chigonozawa indicate the adaptation of these algae to the low light condition. On the other hand, the curves obtained in spring from the algae grown under relatively lighted condition, showed sun-type having a rate of the light saturated photosynthesis at high light intensity. The I_k value in this case is about 6000 lux to 8500 lux.

It is noticeable that the typical shade-type having a marked photoinhibition was obtained in summer and autumn. As seen in Fig. 4, the light saturation occured at low light intensity of about 8 klux and photo-inhibition was evident at about 15 klux. Similar phenomenon is reported by Takahasi *et al.*[13] in their culture samples grown under low light condition. According to Steeman Nielsen and Hansen,[12] and Rhyther and Menzel[9] the inhibition of photosynthesis by strong light is successively profound with increase in the sampling depths. From the above mentioned findings, it may probably be a main causual factor for these phenomenon of photo-inhibition that the dim light condition of the area induced both by low light intensity of diffused light and the shorter period of the duration of insolation.

3. *Algal Component of the Materials*

Dominant or subdominant species of the materials used in the estimation of the rates of photosynthesis as a function of light intensity are shown in Table 3. In winter, coccoid form seems to be a *Palmella*-stage of *Hydrurus foetidus* and *Diatoma hiemale* var. *mesodon* were abundant and some species of diatoms such as *Achnanthes lanceolata, Ceratoneis arcus* var. *recta, Rhoicosphenia curvata* were subdominant.

Table 3. Light-saturated photosynthetic rate of sessile algal communities and their dominant(*) or subdominant species.

Season & Date	Exp. water temp. (°C)	Gross photosynthesis O_2mg/chl.mg/hr. (Cmg/Chl. mg/hr.)	Dominant(*) or subdominant species
Summer Aug. 3 (1964)	15.4	4.6 (1.7)	**Achnanthes lanceolata* (diatoms) *Gomphonema parvulum* (〃) *Achnanthes convergens* (〃) *Navicula decussis* (〃)
Autumn Oct. 13 (1965)	13.0	3.8 (1.4)	**Homoeothrix janthina* (blue greens) **Chamaesiphon minutus* (〃) *Chamaesiphon polonicus* (〃) *Gomphonema parvulum* (diatoms) *Achnanthes convergens* (〃)
Winter Feb. 14 (1965)	3.5	2.0 (0.7)	**Palmella* (*Hydrurus foetidus?*) (golden-browns) **Diatoma hiemale* v. *mesodon* (diatoms) *Achnanthes lanceolata* (〃) *Ceratoneis arcus* v. *recta* (〃) *Rhoicosphenia curvata* (〃) *Nitzschia hantzschiana* (〃)
Spring Mar. 16 (1966)	5.0	3.3 (1.2)	**Homoeothrix janthina* (blue-greens) **Phormidium autumnale* (〃) *Gomphonema sumatorense* (diatoms) *Chamaesiphon carpaticus* (blue greens) *Achnanthes convergens* (diatoms) *Achnanthes lineariformis* (diatoms) *Cymbella turgidula* v. *nipponica* (diatoms) *Gomphonema olivaceum* v. *quadripunctatum* (diatoms)

In spring and autumn, one of the characteristic species in the stream, *Homoeothrix janthina,* grew in abundant. According to the former conception, this species was accepted as *Amphithrix janthina. Amphithrix* genus of the Cyanophyceae differs from *Homoeothrix* in having coalescent cells in the form of a disc at the base of the threads. Under carefull examination of Starmack,[11] however, the threads of this alga had neither a coalescent cells nor a group of lose cells at their bases. Therefore, the new combination of the species name, *Homoeothrix janthina* was given by Starmack. The specimens collected from the river bed of Chigonozawa seemed first to have a crust-like bodies at the base of the threads when observed under low microscope magnification. However, under high magnification the crust-like bodies appeared to be different species belonging to the genus *Chamaesiphon.* The results of the present observation agree fairly well with that of Starmack. As already reported by Kobayasi[4] (misidentified as *Phormidium foveolarum*) and Watanabe,[16] *Homoeothrix janthina* seems to be one of the most widely and abundantly distributed species in fast running habitats in Japan.

Together with *Homoeothrix, Phormidium autumnale* and *Gomphonema sumatorense* were dominant in spring. The later was restricted to this season in contrast with other members of this stream. A similar occurence of this species was found also in cool water of about 9°C of the tributary river Oochigawa of the river Arakawa.[7]

In summer, diatoms were abundant. *Achnanthes lanceolata* and *Gomphonema parvulum* were dominant, while blue greens were scarce.

In autumn, blue green colonies of *Chamaesiphon minutus* were found on the basal portion of *Homoeothrix janthina* threads. Always mixed with the former is brown cells of *Chamaesiphon polonicus* and long cells of *Chamaesiphon carpaticus.* In this season, diatoms were scarce.

As seen in Fig. 4, clear relations between dominant species and their rates or types in photosynthesis could not be found. Both curves resembling each other in having photo-inhibition at high light intensity were taken from different sources comprised by different species.

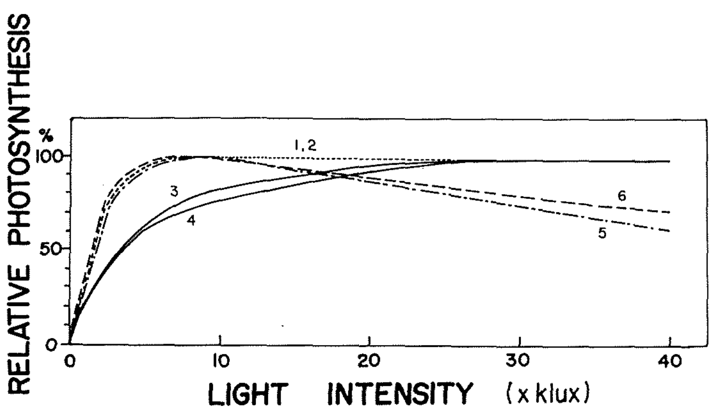


Fig. 5. Light intensity and relative rates of gross photosynthesis redrawn from the curves in Fig. 4.

The list of the dominant and subdominant species under taxonomic order are as follows.

(Cyanophyceae)

1. *Chamaesiphon carpaticus* Starmack, Acta Hydrobiol. 1: 161, Fig. 8, 1959 — Pl. 1, Fig. 3
2. *Chamaesiphon minutus* (Rostof.) Lemm. — Pl. 1, Fig. 2
3. *Chamaesiphon polonicus* (Rostof.) Hansg. — P. 1, Fig. 6, 7
4. *Homoeothrix janthina* (Born. et Flah.) Starmack, l. c. 149, Fig. 2–5 — Pl. 1, Fig. 4
5. *Phormidium autumnale* (Ag.) Gom. — Pl. 1, Fig. 5

(Chrysophyceae)

6. *Hydrurus foetidus* Kirch (*Parmella*-stage)? — Pl. 1, Fig. 1

(Bacillariophyceae)

7. *Diatoma hiemale* (Lyngb.) Heiberg var. *mesodon* (Ehr.) Grun. — Pl. 2, Fig. 27
8. *Ceratoneis arcus* (Ehr.) Kütz. var. *recta* (Cl.) Krasske, Arch. f. Hydrobiol., 35: 361, Pl. 10, Fig. 21, 1939 — P.l 2, Fig. 23
9. *Achnanthesleariformis* H. Kobayasi, Journ. Jap. Bot., 40: 347 Fig. 2a–c, 1965 — Pl. 2, Fig. 8, 9
10. *Achnanthes convergens* H. Kobayasi, l. c. 348, Fig. 5a–f — Pl. 2, Fig. 24–26
11. *Achnanthes lanceolata* (Breb.) Grun. — Pl. 2, Fig. 21, 22
12. *Rhoicosphenia curvata* (Kütz.) Grun. — Pl. 2, Fig. 10
13. *Navicula decussis* Oestrup, Denske Diat., 77, P.l 2, Fig. 50, 1910 — Pl. 2, Fig. 13
14. *Cymbella turgidula* Grun. var. *nipponica* Skv.; H. Kobayasi, Bull. Chichibu Mus. Nat. Hist., no. 12, 73, P.l 9, Fig. 62a–d, 1964 — Pl. 2, Fig. 20
15. *Gomphonema parvulum* (Kütz.) Grun. — Pl. 2, Fig. 18, 19
16. *Gomphonema sumatorense* Fricke; H. Kobayasi, l. c. 74, Pl. 10, Fig. 63a–j — Pl. 2, Fig. 14, 15
17. *Gomphonema olivaceum* (Lyngb.) Kütz. var. *quadripunctatum* Oestrup; H. Kobayasi, l. c. 74, Pl. 9, Fig. 61a–c — Pl. 2, Fig. 11, 12
18. *Nitzschia hantzschiana* Rabh. — Pl. 2, Fig. 16, 17

4. *Productivity and Dry Matter Production*

Seasonal and locational changes in the potentional photosynthesis were estimated by the procedure proposed in the author's previous work.[6] When a cloudy day and a fine day come alternately, the daily productivity per unit amount of chlorophyll can be obtained approximately as follows.

$$P_g = (P_{gf} + P_{gc})/2$$

where P_{gf} and P_{gc} are daily gross production on a fine day and a cloudy day. Then the daily net production is obtained from the usual equation, $P_n = P_g - R$, where R is the respiration.

The results of the estimation are shown in Table 4. In general, potential photosynthesis must be greater in spring and summer than in autumn and winter because

Table 4. Seasonal and locational changes in daily gross and net potential productivities in the stream Chigonozawa.

Station / Season & Month	Gross productivity O_2mg/mg.chl./day (Net productivity O_2mg/mg.chl./day) 1	2	3	4	5	6	7	8	9	Average	Seasonal Average
(Spring; R= 15.6)											
Mar.	34.6 (19.0)	33.6 (18.0)	32.5 (16.9)	19.4 (3.8)	29.2 (13.6)	29.5 (13.9)	30.7 (15.1)	28.5 (12.9)	23.3 (7.7)	29.0 (13.4)	
Apr.	37.0 (21.4)	36.6 (21.0)	36.1 (20.5)	22.3 (6.7)	33.3 (17.7)	32.1 (16.5)	33.3 (17.7)	31.5 (15.9)	25.4 (9.8)	32.0 (15.2)	29.0 (13.9)
May*	36.7 (21.1)	28.7 (13.1)	34.2 (18.6)	8.0 (−7.6)	29.2 (13.6)	23.9 (8.3)	31.1 (15.5)	32.2 (16.6)	10.0 (−5.6)	26.0 (13.0)	
(Summer; R=24.0)											
June*	42.5 (18.5)	34.1 (10.1)	40.4 (16.4)	11.4 (−12.6)	36.6 (12.6)	31.5 (7.5)	39.3 (15.9)	40.7 (16.7)	14.9 (−9.1)	32.4 (10.9)	
July*	38.9 (14.9)	32.0 (8.0)	36.8 (12.8)	13.5 (−10.5)	33.9 (9.9)	29.1 (5.1)	36.9 (12.9)	38.0 (14.0)	13.7 (−10.7)	30.3 (8.6)	30.3 (8.8)
Aug.*	35.6 (11.6)	29.7 (5.7)	36.8 (12.8)	10.4 (−13.6)	31.4 (7.0)	27.0 (3.0)	34.8 (10.8)	35.4 (11.4)	12.8 (−11.2)	28.2 (6.9)	
(Autumn; R=19.2)											
Sept.*	38.9 (19.7)	30.3 (11.1)	42.1 (22.9)	11.6 (−7.6)	31.9 (12.7)	27.0 (7.8)	35.6 (16.4)	35.4 (16.2)	13.1 (−6.1)	29.5 (11.6)	
Oct.	39.9 (20.7)	39.8 (20.6)	38.0 (18.8)	28.8 (9.6)	36.4 (17.2)	38.6 (19.4)	38.5 (19.3)	33.2 (10.4)	33.1 (13.9)	36.3 (17.4)	33.1 (14.4)
Nov.	36.6 (17.4)	36.3 (17.1)	33.8 (14.6)	27.1 (7.9)	32.9 (13.7)	35.2 (16.0)	35.5 (16.3)	36.7 (17.5)	28.4 (9.2)	33.6 (14.2)	
(Winter; R=9.6)											
Dec.	16.5 (6.9)	16.4 (6.8)	15.1 (5.5)	13.5 (3.9)	15.0 (5.4)	14.6 (5.0)	15.9 (6.3)	15.5 (5.9)	13.4 (3.8)	15.1 (5.5)	
Jan.	18.1 (8.5)	18.3 (8.7)	17.8 (8.2)	15.1 (5.5)	16.8 (7.2)	16.4 (6.8)	17.8 (8.2)	17.1 (7.5)	15.2 (5.6)	17.0 (7.4)	17.0 (7.4)
Feb.	20.4 (10.8)	20.3 (10.7)	20.7 (11.1)	16.6 (7.0)	18.8 (9.2)	18.3 (8.7)	19.5 (9.9)	19.0 (9.4)	16.8 (7.2)	18.9 (9.3)	
Average	33.0 (15.9)	29.7 (12.6)	32.0 (14.9)	16.5 (−0.6)	28.8 (11.7)	26.9 (9.9)	30.8 (13.7)	30.3 (13.2)	18.3 (1.2)	27.3 (10.3)	

*Months in foliation.

of the increase of the day time and the acceleration of the photosynthetic rate due to the increase of the water temperature. The highest values, however, were obtained in spring and autumn. As discussed in the foregoing section, serious effect of the dim light condition, especially during the foliation period, seems to be evident. The mean values of the net production were 13.9 and 14.4 mgO_2/mg·chl./day in spring and autumn, whereas the same value was 8.8 mgO_2 in summer. As can be seen in Fig. 6, the parallel correlation between potential activity and the open sky ratio at each station are also found

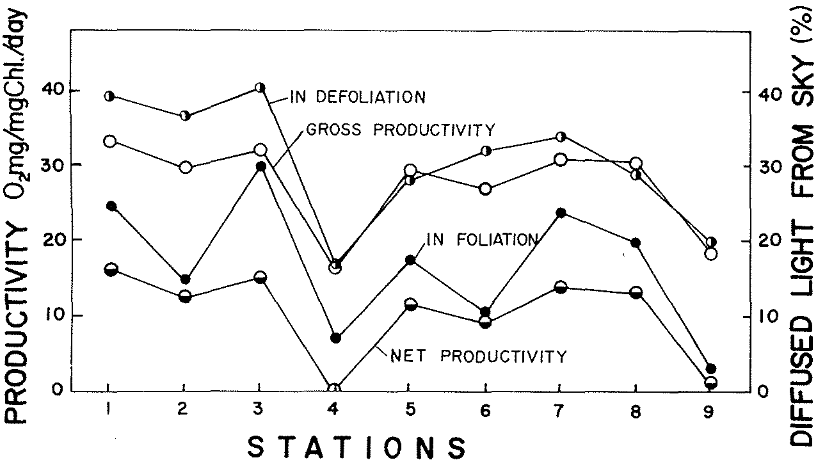


Fig. 6. Correlation between locational changes in potential productivity and that in diffused light intensity.

locationally, although the light adaptation evidently occured among these algae in having typical shade-type curves showing the rate of photosynthesis as a function of light intensity.

The gross primary production per square meter of river bed was calculated from the chlorophyll standing crops at each station shown in Table 1 and the average stational productivity shown in Table 4. As can be seen in Table 5, extremely low values of 0.13 kg·glucose/m^2 in annual average gross primary production in this stream was obtained. According to Tominaga and Ichimura,[15] Japanese lakes have an annual gross primary production of 0.8 to 2.0 kg·glucose/m^2 in eutrophic lakes, 0.2 kg to 0.4 kg in mesotrophic lakes and less than 0.2 kg in oligotrophic lakes. Therefore, the productivity in this stream can be compared with those of oligotrophic lakes in Japan. In addition to the low light condition, the stream bed was covered more than half with the rocks or coarse sand having a minimum dimention smaller than 10 cm. When the chlorophyll values were corrected by rock size category of each station, the said values were lowered as a rule than that of the direct use of the chlorophyll values obtained from the surface of the sampling rocks having a minimum dimention of 10 cm or greater. For example, if the average chlorophyll amount of 62.8 mg/m^2 at Station 1 is employed, the values is calculated at 0.8 kg·glucose/m^2.

The information of this subject is at present very scarce. McConnel and Sigler[8] computed the annual gross production of the mountain river Rogan at 1.2 kg·glucose/m^2 in canyon section and 0.81 kg·glucose/m^2 in lower river. Kobayasi[6] reported 0.21 kg·glucose/n^2 in canyon section and 0.81 kg in lower section of the mountain river Arakawa. On the other hand, Tominaga and Ichimura[15] computed high values of 2.2 kg·glucose/m^2 at the fixed station in the same river. At the time that the former values of the river Arakawa were calculated, the river bed was covered with the precipitation of the coarse bed load originated from the construction of the impoundment.

Table 5. Dry matter production in the stream Chigonozawa

Station	River bed area m^2/order	Glucose kg/order/year (Glucose kg/m^2/year)		
		Pg	R	Pn
1	22	4.33 (0.20)	2.27 (0.10)	2.06 (0.10)
2	34	6.06 (0.18)	3.51 (0.10)	2.55 (0.08)
3	16	3.60 (0.23)	1.95 (0.12)	1.65 (0.11)
4	19	0.71 (0.04)	0.71 (0.04)	– (–)
5	158	19.26 (0.12)	11.85 (0.07)	7.41 (0.05)
6	97	10.91 (0.11)	7.28 (0.07)	3.64 (0.94)
7	77	10.11 (0.13)	5.78 (0.07)	4.33 (0.06)
8	198	25.99 (0.13)	14.85 (0.07)	11.14 (0.06)
9	146	5.48 (0.04)	5.48 (0.04)	– (–)
Total (Average)	767	86.45 (0.131)	53.68 (0.075)	32.78 (0.056)

Accordingly the estimated chlorophyll content used in the calculation was far lower than that of the later. It is 72 mg/m^2 in the former and about 219 mg/m^2 in the later. As seen in this case, the algal growth on the river bed is affected by various possible factors peculiar to that environment. In order to get more precise information, further detailed investigations should be made.

Total gross production in the whole area of the Chigonozawa was calculated from the annual gross production at each station and the area of river bed. The productivity of each order in the water course was represented by the production at the chlorophyll sampling station within the orders. The calculation results are surmized in Table 5. The annual gross production of the 767 m^2 of the river bed was 86.45 kg·glucose. As already shown in Fig. 4, the amount of the respiration was calculated from the data obtained in the dark bottles. It is 15.6 mg·O_2 in spring, 24.0 mg in summer, 19.2 mg in autumn and 9.6 mg in winter respectively (Table 4). The annual values used in the calculation is 17.1 mg·O_2/day. By using these values, the organic matter consumed through the respiration was 53.68 kg·glucose. Finally the net production in the water course was 32.78 kg·glucose.

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Plate 1.

Fig. 1. *Palmella*-stage of *Hydrurus foetidus* Kirch

Fig. 2. *Chamaesiphon minutus* (Rostof.) Lemm.

Fig. 3. *Homoeothrix janthina* (Born. et Flah.) Starmack and *Chamaesiphon carpaticus* Starmack

Fig. 4. *Homoeothrix janthina* (Born. et Flah.) Starmack

Fig. 5. *Phormidium autumnale* (Ag.) Gom.

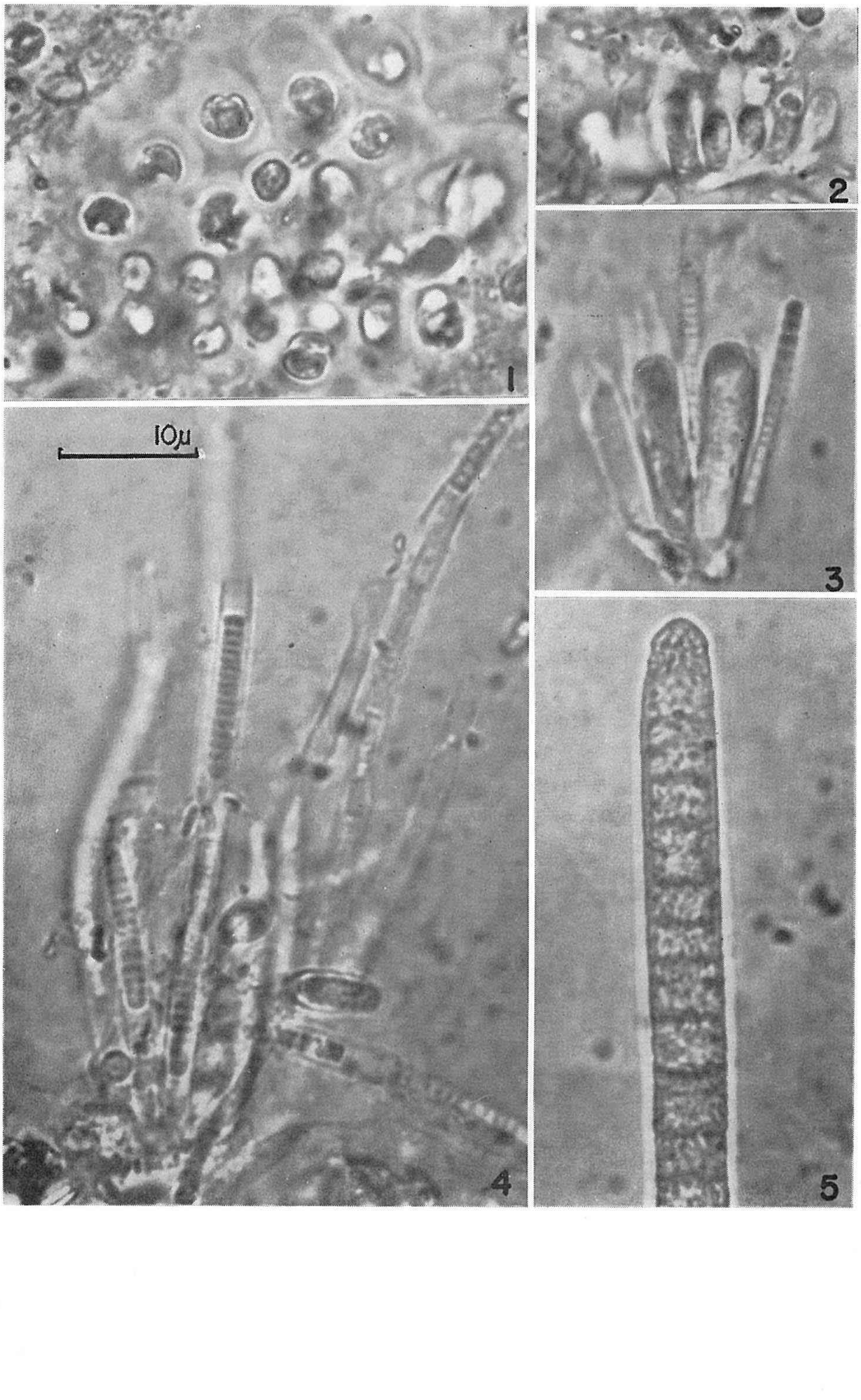
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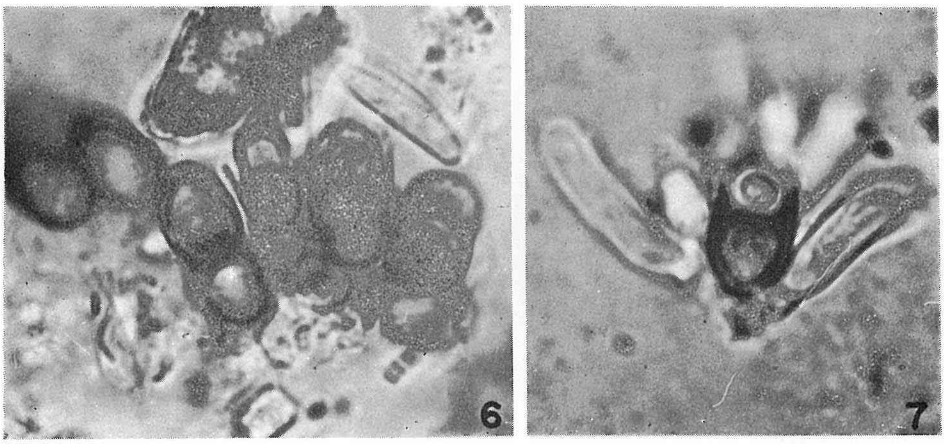
Plate. 2

Fig. 6.	*Chamaesiphon polonicus* (Rostof.) Hansg.
Fig. 7.	*Chamesiphon polonicus* sporangium between *Chamaesiphon carpaticus* sporangia
Figs. 8 and 9.	*Achnanthes leneariformis* H. Kobayasi
Fig. 10.	*Rhoicosphenia curvata* (Kütz.) Grun.
Figs. 11 and 12.	*Gomphonema olivaceum* (Lyngb.) Kütz. var. *quadripunctatum* Oestrup
Fig. 13.	*Navicula decussis* Oestrup
Figs. 14 and 15.	*Gomphonema sumatorense* Fricke
Figs. 16 and 17.	*Nitzschia hantszchiana* Rabh.
Figs. 18 and 19.	*Gomphonema parvulum* (Kütz.) Grun.
Fig. 20.	*Cymbella turgidula* Grun. var. *nipponica* Skv.
Figs. 21 and 22.	*Achnanthes lanceolata* (Breb.) Grun.
Fig. 23.	*Ceratoneis* (Ehr.) Kütz. var. *recta* (Cl.) Krasske
Figs. 24–26.	*Achnanthes convergens* H. Kobayasi
Fig. 27.	*Diatoma hiemale* (Lyngb.) Heiberg var. *mesodon* (Ehr.) Grun.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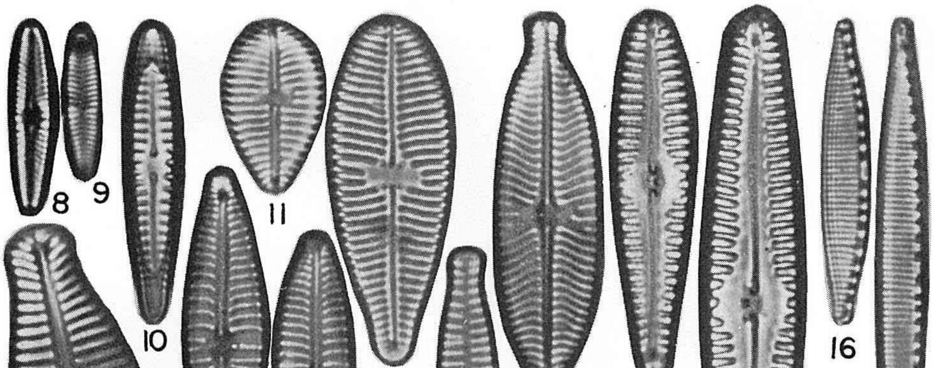
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