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Ecological Studies on Micro Algae in Lake Yunoko, Central Japan

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I INTRODUCTION

There have been many algal studies in Japanese lakes with respect to the relationship between water quality and plankton and its seasonal succession. In contrast with these studies on planktonic algae, there are few studies in which the planktonic and epilithic or epipelic communities have been followed quantitatively at the same time.

The present work was undertaken to develop methods for the estimation of planktonic and benthic algal communities in order to analyse population changes for several years at a number of places in one small lake and also in order to investigate the correlation between three different algal types, namely phytoplankton, limnetic benthos and littoral one. For the purpose of ascertaining the origin of the limnetic benthos, detailed studies were undertaken at various collecting stations by distinguishing the live cells from the dead ones, a method for which is considered to be one of the characteristic points in this study.

Culture experiments were attempted to ascertain the heterotrophic ability of Fragilaria pinnata and F. pinnata var. lancettula which were the commonest diatom growing on the comparatively deeper lake bottom. Less is known of heterotrophic capabilities of diatoms, especially the freshwater forms. Lewin (1953) found that 13 isolates, representing 3 species of the 29 isolates studied, were heterotrophic and she also ascertained that Navicula pelliculosa can utilize only glucose as the substrate which supports the growth in the dark. More recently Lylis and Trainor (1973) determined the

organic compounds which support the growth of freshwater diatoms, and the light conditions under which organic compounds would support diatom growth.

In the present study, an attempt was made to determine whether F. pinnata and F. pinnata var. lancettula can grow heterotrophically under dark, utilizing glucose.

The reason for selecting Lake Yunoko as a field of the algal study is that the size of the lake is suitable for a detailed study and many limnological data are easily obtained because this lake was selected as a field of I.B.P. (1968 - 1972).

II HISTORICAL SKETCHES

Many limnological investigations have been made in Lake Yunoko. The first paper was written by Miyoshi (1899). He suggested that Lake Yunoko is rich in plankton and that the color of its water varies in summer, because a great deal of Asterionella gracillima survive and Cyclotella comta, Synedra sp. and Melosira sp. are also present.

Hattori (1899) illustrated a form of Asterionella gracillima which was collected in Lake Yunoko.

Inaba (1932) found fifteen species of plankton in which 7 species of phytoplankton were contained. The dominant species are Volticella sp., Asterionella gracillima and Melosira italica.

Ueno (1934) conducted an investigation of lakes in Oku-Nikko. In his reports the water color of Lake Yunoko varies in summer and autumn owing to the appearance of a great deal of waterbloom. Main diatom composing the waterbloom is Melosira and a great deal of Asterionella are also present from July to October. In his another study(Ueno 1936), he recognized 18 species of plankton, 11 species of which are phytoplankton including 9 species of diatoms, and he insisted that the waterbloom is formed mainly by Melosira granulata. In this paper, he also referred to the relationship between plankton and chemical components of the lakes in Nikko district.

The standing crop and the distribution of phytoplankton and of zooplankton in summer season are reported by Furuta (1964) and he observed that the phytoplankton community is

dominated by Synedra acus, Fragilaria crotonensis, Melosira italica f. curvata and Dinobryon sp. in June 1962 and unicellula green algae, Asterionell formosa, Synedra acus, Mel. italica f. curvata and Dinobryon sp. in August 1962 and the most abundant biomass is found almost at the central part of the lake.

Yamaguchi and Ichimura (1970) reported that the seasonal changes in phytoplankton flora are fairly simple : Asterionella formosa and Fragilaria crotonensis dominate during the summer, and Melosira italica in other seasons, and that phytoplankton is the main primary producer in this lake, being formed in terms of carbon of several tens of tons per annum, and it is composed mainly of diatoms accompanied by a small population of green algae.

Aoyama and Kurasawa (1970) investigated the distribution and the standing crop of phytoplankton and reported that the number of cells per ml ranged from 10^2 to 10^4 ; the minimum appears in June and the maximum in December or January.

Watanabe (1971, 1972) studied the relationship between the variation of the amount of seston and the rate of deposition. He found that the succession of the dominant phytoplankters at surface layer is observed with fluctuation of the amount of seston and a sudden reduction of seston after phytoplankton bloom is caused by sedimentation of seston onto the lake bottom.

Hashizume (1975) referred to the relationship between the algal standing crop and the trophic status of lakes and classified the phytoplankton in respect to the trophic status of

lakes. He concluded the diatoms are most sensitive to eutrophication. He also pointed out that Lake Yunoko is a highly eutrophicated lake.

III STUDY AREA AND METHOD

Lake Yunoko is 1478 m above the sea level and situated at the eastern base of Mt.Shirane. The surface area is 0.35 km^2 with a maximum depth of 12.5 m and a water volume of 252 x 10^4 - 272 x 10^4 m^3.

On the north shore of this lake, there are hot spring hotels which flush the waste of the spa into the lake through two main drainages and a stream Shiranesawa. There are a sewage work and its drainage at the northwest corner of the lake. The westernhalf of the north shore constitutes the alluvial fan of the valley between Mt. Maeshirane and Mt. Konsei. A waterfall, Yudaki, which is the only one outflow is located at the southernmost tail of this lake. On the east shore, there is a projection, Usagijima. As for the running-in amount of water as a surface water, a small stream Shiranesawa which supplys water only in rainy season and usually drys up, a few drainages of sewage from Yumoto Town on the north shore and the treated water from the sewage works of the town should be considered. The most amount of water (about 90 %) may be taken from the springs distributed on the shore. The largest spring is located on the northern part of the west shore. Annual average amount of outflow is 6.8 x 10^4 m^3 per day and average residence time is considered to be 20 - 60 days (Tochigi Pref. 1975).

Samples for the horizontal phytoplankton distribution though the sample numbers fluctuated in each season, were collected at 25 stations and those for the vertical distribution were collected at only one station, st.A (Fig.II .1).

Samplings for the horizontal distribution were performed in April, June, August and October 1976 and in June 1977 whereas samplings for the vertical distribution were carried out in July, October and December 1972 and in April, June and August 1976.

Surface water samples of 50 ml or 100 ml were preserved in formalin. The algae were allowed to settle for more than 2 days before the supernatant preservative was removed by an aspirator to obtain the proper concentration of algal cells and qualitative analyses were made with a microscope.

The studies on the distribution and seasonal succession of the benthic algae in the limnetic zone were carried out in July, October and December 1972 and in April, June, August and October 1976. Samples for the standing crop estimates were taken along 4 courses A, B, C and D and 4 points E (9 m deep), F (9.5 m deep), G (8 m deep) and CA where the observations of the vertical distribution of planktonic and the benthic algal flora were carried out and water analyses were also carried out. Station CA corresponds to st.A in the sampling of phytoplankton. The bottom sediments were mostly mud (Table III.1), and organic sapropel was distributed widely, but sand also occured, especially in course C. Chara and Elodea were often observed at shallow zone above 6 m.

As for the amount of hydrogen sulphide, Matsudaira (1929) measured 0.08 mg / l at 12 m, while Ueno (1934) reported 0.464 mg / l at 11 m. The color of the bottom mud was black to deep black occasionally with brown or gray thin layer.

The sample numbers of the bottom sediments were occasionally

fluctuated. Nearly intact sediments of 25 cm^2 surface area with approximately 5 mm thickness were collected with an Ekman-Berge dredge and were made up to a volume of 400 ml or less with formalin solution. The diluted sample was shaken vigorously to disperse the algal cells throughout the sample. While the sample was still being mixed, 0.1 ml aliquots were taken and cell counts were performed with microscope at a magnification of 600 x.

The samples in 1976 were counted separating dead cells from live cells judging from their protoplasmic condition and standing crop was expressed by cell number per 1 mm^2 of surface of the sediment.

The littoral benthic algae were sampled on 13 different dates ; March and July 1967, March, October and December 1968, September and December 1972, March 1973, April, June, August and October 1976 and June 1977. Ordinarily 12 sampling stations were investigated and at each station samples were collected at different distances from the shore in 1972, 1973 1976 and 1977. The water depths of each sampling station ranged from 6 to 68 cm. A tooth brush was used to scrape 25 cm^2 of attached material from each of 3 separate stones at each station. The stones were collected at random from the station. As for the samples at st.2 and st.4 epipelic algae were collected from 25 cm^2 of sandy bottom because of the absence of the suitable stones except in June 1977. The dislodged algae were washed into a bottle and fixed with formalin solution. The total number of cells in the sample was determined by diluting the material in distilled water to

obtain a suitable density for count. The diluted samples were shaken vigorously and 0.1 ml aliquots were sucked quickly with a pipette, and the algae were counted and identified with microscope. About 500 individuals in each sample were counted at a magnification of 600 x. In reference to certain filamentous blue-green algae (e.g. Oscillatoria and Homoeothrix) counts were limited to filaments rather than cells. Ignition loss was also measured in samples of 1976.

IV ENVIRONMENTAL FACTORS

Water temperature : The water temperature of littoral zone ranged from 21.6 to about 0°C and the maximum water temperature seldom exceeded 20°C throughout a year. As for that of the bottom layer, it varied from a low of 2.8°C to a high of 10.6°C over the studied period. The lake water showed stagnation nearly perfectly in June. The thermocline was found 2 to 3 m below the surface, but its thermal gradient was not remarkable because of small-sized lake and a great effluent of surface water from the Yudaki (Yamaguchi and Ichimura 1970). The autumnal circulation period perfectly developed in October. In winter, the surface froze except for the hot spring area near st.1 and other spring welling portions of the lake (e.g. st.5) and the inverse stratification developed under the ice. In early spring there was a great difference of temperature horizontally, because thermal bar which was the boundary between two different types of watermass and played the role of a barrier to the horizontal movement, developed in this season (Horiuchi, et al. 1972). The vernal circulation period was found at the end of March. As the horizontal and vertical distributions of temperature in the lake were strongly affected by valley wind and mountain breezes, their differences were quite small except in early spring.

Transparency : The transparency was measured as 1.4 to 4 m. It declined at the circulation period and reached its maximum at the beginning of the stagnation period in early summer.

p^H : The p^H values at littoral zone ranged from 6.4 to

8.0. Comparatively low values were observed at st.1 where hot spring containing sulfur flowed. There were no great seasonal and horizontal differences among littoral 13 stations. As to the vertical distribution, observed at st.CA, a slight difference was found synchronizing the fluctuation of the water temperature, but even when the greatest difference was observed in August 1976, the difference was only 0.9.

Dissolved oxygen : Dissolved oxygen was measured by Winkler's method in April, June, August and October 1976 at littoral zone and vertically measured at st.CA. It fluctuated in the ranges of 7.68 (st.1) - 17.04 (st.10) mg / l in April, 7.60 (st.1) - 10.56 (st.11) mg / l in June, 7.46 (st.4) - 11.12 (st.10) mg / l in August and 5.43 (st.1) - 16.73 (st.10) mg / l in October at littoral zone. As for the vertical features, marked decreases with depth were found in stagnation period, June and August which was closely related to the fluctuation of the water temperature, and the dissolved oxygen became almost absent near the bottom. In October the dissolve oxygen was fairly uniformly distributed at all the depths.

V PHYTOPLANKTON

V.1. Horizontal distribution

V.1.1. Number of taxa (Table V.1.1.)

April, 1976 : Only Bacillariophyta and Chlorophyta were found, 12 and 4 taxa respectively.

June, 1976 : One taxon of Cryptophyta, 1 taxon of Bacillariophyta and 4 taxa of Chlorophyta appeared.

August, 1976 : Thirteen taxa were found including 1 taxon of Cryptophyta, 1 taxon of Chrysophyta, 6 taxa of Bacillariophyta and 5 taxa of Chlorophyta.

October, 1976 : One taxon of Cryptophyta and Chrysophyta and 3 taxa of Bacillariophyta were observed.

June, 1977 : One taxon of Cyanophyta, Euglenophyta and Cryptophyta and 6 taxa of Bacillariophyta and 5 taxa of Chlorophyta appeared.

Among these algae, Bacillariophyta and Chlorophyta contained many taxa in contrast with other phyla. Bacillariophyta markedly fluctuated with month, showing minimum in June 1976 (1 taxon) and maximum in April 1976 (12 taxa).

Comparing the data obtained by Ueno (1934) reporting 11 taxa, by Furuta (1964) reporting 31 taxa including 2 taxa of Cyanophyta and Dinophyta, 1 taxon of Chrysophyta, 17 taxa of Bacillariophyta and 9 taxa of Chlorophyta and by Hashizume (1975) finding 21 taxa including 1 taxon of Cryptophyta and Chrysophyta, 8 taxa of Bacillariophyta and 11 taxa of Chlorophyta, more abundant taxa composed of 37 taxa including 1 taxon of Cyanophyta, Euglenophyta and Cryptophyta, 2 taxa of Chrysophyta, 18 taxa of Bacillariophyta and 14 taxa of Chlo-

rophyta, were found in Lake Yunoko throughout the present 5 investigations with 46 samples.

More abundant taxa were found in Bacillariophyta and Chlorophyta, which agreed with the results of Furuta (1964) and Hashizume (1975) and the same tendencies were observed in Lake Ikeda, Lake Kakinuma, Unagi-ike Pond (Enviroment Agency Nature Conservation Bureau 1976), Lake Suwa (Aoyama et.al. 1973) and Lake Biwa (Negoro 1966).

V.1.2. Seasonal cycle of total cell number

April, 1976 : The water from 10 sampling stations were analysed and the cells in 1 ml of surface water were counted, which ranged from 4,200 (st.s) to 37,200 (st.A) and high cell numbers from 24,200 to 37,200 were found at 6 stations which were located in the southern half part of the lake or near the sewage works (Fig.V.1.1).

June, 1976 : Cell numbers at only 6 stations located in the central part of the lake were lower than those in April. They fluctuated between 500 (st.A) and 5,100 cells (st.e) and of these, from 1,300 to 3,600 cells were found at 4 stations (Fig.V.1.2).

August, 1976 : From 3,200 (st.A) to 22,700 (st.w) cells were counted at 9 stations. The cell numbers from 12,400 to 19,700 were found at 6 station at northwest corner which was considerably affected by the inflow of the sewage to southeast corner, from which the River Yukawa flowed. The standing crop in this season was high second to that in April (Fig.V.1.3).

October, 1976 : From 1,100 (st.w) to 53,000 (st.r) cells

were observed at 7 stations, among which 3 stations possessed high cell numbers ranging from 31,200 to 53,000 cells. In contrast with northwest corner, where a conspicuously high standing crop was observed, the standing crop was low at other stations. The high count in the northwest corner was possibly due to the high nutrients from the sewage effluent (Fig.V.1.4).

June, 1977 : At 17 stations, from 2,100 (st.b) to 10,900 cells (st.v) were counted. The highest standing crop was recognized at st.v in the northeast part of the lake where the effluent from a hot spring was discharged and many Cygnus cygnus inhabited. Low standing crop ranging from 2,100 to 4,500 cells was observed at 15 stations (Fig.V.1.5).

Though high populations of phytoplankton generally grow near the inlet of a lake and in a dammed lake (Whipple 1927, Yoshimura 1937 and Armitage & Simmons 1975), an inlet in Lake Yunoko scarcely develops and so high population of phytoplankton appeared near the inflow of the sewage and that of the effluent from the hot spring.

Both in June 1976 and 1977, remarkable decreases in the number of phytoplankton were observed. Low numbers in June were also reported by Aoyama & Kurasawa (1970). According to many workers, grazing is of less importance for a phytoplankton growth. Nauwerck (1963), however, has concluded that phytoplankton is of secondary importance as direct source of food for zooplankton. If so, zooplankton develops as the water becomes warm toward the end of the spring and their numbers become sufficient to have an appreciable effect on the

phytoplankton growth in Lake Yunoko. As to this point, high standing crop of zooplankton in June has been noted by Furuta (1964) and Aoyama & Kurasawa (1970) in Lake Yunoko. It is reasonable to assume that the growth of phytoplankton is followed by an increase of zooplankton which decreased the phytoplankton by grazing.

V.1.3. Seasonal variation of cell number classified by phyla (Table V.1.2)

During the 5 sampling occasions, 5 phyla of Cyanophyta, Cryptophyta, Chrysophyta, Bacillariophyta and Chlorophyta were observed.

April, 1976 : Almost all algal communities were occupied by Bacillariophyta and Chlorophyta by 97.2 and 2.8 % respectively.

June, 1976 : Cryptophyta was most abundant (71.9 %) followed by Chlorophyta (26.9 %) and Bacillariophyta (1.2 %).

August, 1976 : The phytoplankton was mainly composed of Bacillariophyta and Chlorophyta (33.5 %), and less were Chrysophyta (16.3 %) and Cryptophyta (3.1 %).

October, 1976 : Cryptophyta (28.6 %) was found next to Chrysophyta (69.4 %) and Bacillariophyta (1.5 %), and Chlorophyta rarely appeared.

June, 1976 : The main phytoplankton occurred was Bacillariophyta (53.3 %) and Cryptophyta (45.9 %), and both Cyanophyta (0.4 %) and Chlorophyta (0.4 %) seldom occurred. As to Cyanophyta, low population was found only in June 1977.

According to these results, Cryptophyta was inclined to profusely appear after the circulation periods in June and in October, when the water was rich in nutrients. Also, Chrysophyta was likely to begin to grow in summer and increase profusely in fall. Bacillariophyta had its high population in April and August 1976 and June 1977.

Water temperature is considered to be an important environmental factor for diatom growth. Kojima (1964 No.129) suggested that diatoms never show their active growth in summer except early in summer which is considered to be the prolongation of spring growth period. Sakai (Kojima 1964 No.110) pointed out that high concentrations of diatoms are found through November to early in April when the water temperature is below 15°C. In Lake Biwa the diatom growth was observed through winter to spring, and autumn (Kojima 1964 No.48 and 118), whereas in both the swamp Takasuka and Lake Kizaki, abundant growth of diatoms was observed throughout winter to spring (Kojima 1964 No.47 and 136). In the swamp Tatsunuma, diatom composed the main part of the phytoplankton in spring and autumn (Adachi et al. 1969). Round (1960) described that in some lakes of the English Lake District the major spring diatom outbursts occurred as the lake water was warmed up; in Windermere this was before the surface temperature reached 14°C and in Blelham, before 18°C and the spring growth phase ended during the early weeks of thermal stratification, but the reason for this was uncertain. He also found that the high water temperature in July to September coincided with low diatom numbers except two stations, and this exception

suggested that high water temperature was not detrimental to growth.

It has been stated that temperature is the most important factor affecting diatom growth, even more than nutrients, and that phytoplankton abundance varies directly with it (Patrick & Reimer 1966).

On the other hand, it has also been said that the temperature at which an organism is most abundant does not necessarily correspond to its optimum temperature (Fogg 1965) and that temperature is not so important for the diatom growth (Pearsall 1923, Daily 1938).

In Lake Yunoko, the diatoms predominated in August 1976 and occupied about 50 % of the total cell number. The water temperature of the surface at that time was 17.3°C which was not so high temperature as to conflict with the above described theory that considers the temperature as an important factor to control diatom population.

It was reported that silicates are essential substances for the diatom growth (Pearsall 1923) and diatoms require silicate in concentrations more than 0.5 mg / 1 for its growth (Pearsall 1932, Lund 1950). Lund (1954) found the development of the diatom was restricted when silicate concentration became less than 0.6 mg / 1 and Jørgensen (1957) also demonstrated the limitation of growth of diatoms by silicate concentrations of 0.5 mg / 1, confirming by both laboratory and field experiments. Nature Conservation Bureau of the Enviroment Agency reported that though the concentration of SiO_2 in Lake Yunoko was considerably low (approximately 15 mg / 1)in June

1971 caused by the spring outburst of phytoplankton, such low concentration was enough for algal growth, so SiO_2 could not be considered as a limiting factor in this time.

As to Chlorophyta, it appeared more conspicuously in June (26.9 %) and August (33.5 %) 1976 and was rarely found in other seasons. This result is coincident with a general feature that planktonic green algae in a lake profusely appear in summer (Godward 1937).

V.1.4. Diversity index (Table V.1.3)

Shannon's index of diversity (Shannon and Weaver 1963) was adopted to analyze the structure of algal community in this study. This index can be expressed by the formula : $H(S) = -\Sigma P_i \log_2 P_i$, where H(S) is the quantity of information, P_i is the ratio of individual number in ith species to total number and S is the number of species. So, H(S) may express the index of species diversity or stability.

Diversity index of phytoplankton in horizontal distribution is as follows.

April, 1976 : Diversity index, henceforth referred to simply as D.I., ranged from 1.06 (st.g) to 2.04 (st.s) and the difference between the maximum and the minimum exhibited a higher value compared with that in other seasons. Phytoplankton at st.g where showed the minimum D.I. value was mainly consisted of Stephanodiscus sp.(1) and Synedra acus and these two species occupied 98 % of the total cell number, whereas st.s showing the maximum D.I. value was dominated by the above described two species but they occupied

smallest parts (70 %) comparing with other stations.

June, 1976 : D.I. ranged from 0.23 (st.w) to 1.10 (st.d). St.d showed the highest value in this time and was dominated by Chlorella ellipsoidea and Cryptomonas sp. both of which occupied large part of the total cell number. In the case of st.e, almost the same part of the biomass as st.d was occupied by the above two species but one of these species surpassed the other, so this presumably led this station not to show the highest value as st.d.

August, 1976 : D.I. ranged from 1.50 (st.u) to 2.13 (st.w). At this time, the fluctuation of D.I. was small and each station showed similar values presumably because each dominant species almost equally appeared in each station. Compared with other seasons, D.I. took higher values in this time. This is supposed to be due to the more numerous taxa of dominant species (3 taxa) than those in other seasons.

October, 1976 : D.I. ranged from 0.80 (st.u) to 1.24 (st.f). There were no marked fluctuation through seven stations.

June. 1977 : D.I. ranged from only 0.90 (st.b) to 1.29 (st.r), although many stations (17 stations) were investigated.

The dominant species were composed of 2 taxa both in October 1976 and June 1977. At each station the ratio of these 2 taxa to the total cell number was similar in both seasons, hence difference in D.I. among each stations was probably small.

V.1.5. Dominant species

Through there are many methods to estimate dominant species, I adopted the count of cell number. This method regards such species that appear more often than the average frequency as dominant.

April, 1976 : The dominant species found at ten stations and the number of stations where certain species predominated were described as follows (Fig.V.1.1).

Stephanodiscus sp. (1) : Among all ten stations this species appeared as dominant and the frequency of appearance exceeded more than 50 % except st.s.

Synedra acus : This species predominated at eight stations except st.A and st.r. Following Stephanodiscus sp.(1), this species held the second rank, while this one ranked first at st.s

Synedra acus var. radians : This species dominated at 6 of the 10 stations. At 2 stations the frequency of occurrence was the second in rank and at 4 stations, the third in rank.

Chlamydomonas sp. : This species appeared at only st.r where this dominated second.

Synedra ulna var. danica : This species was observed predominantly at st.A where it ranked third.

June, 1976 : The following 2 species were observed as dominant (Fig.V.1.2).

Cryptomonas sp. : This species predominated at 5 stations except st.w, among which at 4 stations this one appeared frequently more than 50 % of the total biomass.

Chlorella ellipsoidea : This species predominated at 3 stations and exceeded 50 % in its frequency of appearance at st.w and st.d.

August, 1976 : The dominant species were composed of following 4 species at 9 stations among which only st.u had remarkably different dominant species (Fig.V.1.3).

Stephanodiscus sp.(s) : At all 9 stations this species was growing most abundantly and further more at 6 stations it predominated first.

Chlamydomonas sp. : Throughout all stations, this species was commonly dominant. Among these stations, at 3 stations it appeared first, at 4 stations second, and at 2 stations, third.

Dinobryon bavaricum : This species predominated at 8 stations among which it appeared third at 6 stations and second at 2 stations.

Cryptomonas sp. : This species appeared and was ranked third at only 1 station, st.u.

October, 1976 : The dominants were composed of 2 species both of which were observed at all 7 stations (Fig.V. 1.4).

Ochromonas sp. : This appeared 50 % or more at 4 stations.

Cryptomonas sp. : This species appeared 50 % or more at 2 stations.

June, 1977 : Two dominant species were found in this season (Fig.V.1.5).

Asterionella gracillima : This species appeared 50 % or more at 13 stations among 16 stations. Many workers have

noted that Asterionella usually occurs earliest in the spring. Pearsall (1932) believes this is due to the fact that Asterionella has a higher nutritive requirement than the succeeding species. On the other hand, in Lake Yunoko, this species occurred not in June 1976 but only in June 1977.

Cryptomonas sp. : At st.A and st.r, this species occupied 50 % or more.

Thus in summary, phytoplankton at each station consisted of less than 4 dominant species and as to the composition of the dominant species, at the same time, no difference was recognized through the stations and so the same dominant species were distributed throughout the lake. The characteristics of the location affecting the occurrence of the dominant species seem to influence the percentage in their appearance. The most remakable features of dominant species were found at st.r where water was affected by the sewage disposal and at the stations near the inflow of the waste water from hot spring.

As for the succession of the dominant species there seems to be no regular tendency since the mumber of the dominant greatly varied from season to season.

If the investigation had been carried out at short intervals over a long period of time, certain tendencies might have been found.

V.1.6. Measuring similarity between communities

Though there are many methods, which treat the similarity between communities, I used the similarity index of the C_λ

developed by Morishita (1959) to compare the composition of the phytoplankton communities. He proposed the index $C\lambda$ for measuring the degree of overlap of component species between two communities. This index is written as

$$C\lambda = \frac{2\sum^{\infty} x_1 x_2}{(\lambda_1 + \lambda_2)\, N_1 N_2}$$

where $$\lambda_1 = \frac{\sum^{\infty} x_1(x_1 - 1)}{N_1\,(N_1 - 1)}, \quad N_1 = \sum^{\infty} x_1,$$

$$\lambda_2 = \frac{\sum^{\infty} x_2(x_2 - 1)}{N_2\,(N_2 - 1)}, \quad N_2 = \sum^{\infty} x_2,$$

and x_1 is the number of individuals of a component species occurred in the sample 1 and x_2 that in the sample 2.

This method has the advantage that it is almost independent of sample size. The values of the index distribute from 0 to 1. The closer the value approaches 1, the more the communities are similar. The results in each season except st.A are shown in Fig.V.1.6. - 10, in which I estimate the values from 1.00 to 0.80 as showing high similarity, from 0.79 to 0.70 as slight one, from 0.69 to 0 as low one.

April, 1976 : Similarity matrix of the $C\lambda$ in Fig.V.1.6 shows high similarity except st.s where the first dominant species was Synedra acus and the second, Stephanodiscus sp. (1). Owing to the reversed sequence of the dominant species between st.s and another stations, the $C\lambda$ took low value.

June, 1976 : High similarity was found among st.e,q and x where Cryptomonas sp. commonly appeared as the first

dominant species. The similarity between st.d and st.w,q and x where Cryptomonas sp. commonly appeared as the first dominant species. The similarity between st.d and st.e, q and w was slight because the first dominant species was different between st.d and st.e, q and the ratio of the first dominant species to the total biomass was dissimilar at st.d and st.w, where both the first and the second dominant species devided almost the same part to the total at st.d while at st.w the second dominant species was not recognized nevertheless both stations had the same first dominant one. To compare st.w with other stations except st.d, $C\lambda$ shows low similarity. This is attributed to the dissimilarity of the first dominant species that occupied large part of the total biomass (Fig.V.1.7).

August, 1976 : Although the first dominant species were different between st.c, f, w and other five stations, all stations represent high similarity. At st.c, f and w the first dominant species was Chlamydomonas sp. and the second, Stephanodiscus sp. (s). The frequency of occurrence in these two species, however, was so similar that $C\lambda$ showed high similarity with other 5 stations where Stephanodiscus sp.(s) predominated first (Fig.V.1.8).

October, 1976 : All stations other than st.u represented high similarity. The reason for this among st.c, q, r and s was considered to be the appearance of the same first and second dominant species, Ochromonas sp. and Cryptomonas sp.respectively. Although at st.f and w where the same first and second diminant species occurred, the sequence of the dominant species was

reverse to those at the stations described above, there was no remarkable difference in their percentages and therefore Cλ of these 6 stations took high values. On the other hand, st.u showed low similarity to st.c, q, r and s owing to the reverse sequence of the dominant species and the difference in their percentages. The similarity was, however, high between st.u and st.w and between st.u and st.f because these stations have the same first dominant species regardless of a little difference in their percentages (Fig.V.1.9).

June, 1977 : All stations took high value, hence the communities of phytoplankton were very similar throughout all stations. The reason for this is that the first and second dominant species among all stations were composed of Asterionella gracillima which predominated first at 12 stations and Cryptomonas sp. that predominated at 5 stations. Also a great difference in the percentage was scarcely recognized between 2 species in addition (Fig.V.1.10).

Cλ has the close relation with the dominant species. In the present study high similarity was observed in the following situations.

The communities at two stations are composed of the same dominant species and when the dominant species occupy a large part of the total biomass, their sequence is an important factor. Furthermore, when the percentage of the common species has a negligible difference between two stations even if their sequence is different, Cλ is inclined to take high value.

Characteristic community occasionally developed in the vicinity of inflow of the sewage disposal or of that of waste water from the hot spring.

V.2. Vertical distribution

V.2.1. Vertical distribution of total cell number (Fig.V.2.1a,b.)

July, 1972 : The cell numbers ranged from 12,800 (1 m deep) to 632,100 cells (3 m deep) and the average was 255,200 cells which was the highest value throughout the period of investigations. The maximum algal density was observed in the layer more or less below the surface. Such a situation was also reported by Talling (1955).

October, 1972 : Five layers were studied where cell numbers of 6,800 (9 m) - 256,600 (1 m) were counted and the average was 93,200 cells. The rapid decrease with depth was observed below 5 m deep although it was the autumnal full circulation period. The optimal light intensity of the dominant species may be responsible for this fact.

December, 1972 : Among 8 layers comparatively high cell numbers following October 1972 were observed from the bottom to the surface and the average was 128,200 cells. As to the high density of phytoplankton in winter Fogg (1965) stated that light and temperature in winter are low, but the intensity and duration of light are sufficient to support some algal growth and abundant development of phytoplankton can frequently occur at temperatures approaching zero. An abrupt increase in number appeared at a depth of 9 m although Synedra which has been recognized as the characteristic species appearing

in the upper layers in Lake Yunoko (Ueno 1934, Furuta 1964) was dominant. This reason is uncertain.

April, 1976 : The cell numbers fluctuated from 9,500 (10 m) to 37,200 (0 m) among 6 layers and the average was 19,500 cells which was the highest value among 3 seasons in 1976. In this season water stagnation commenced to develop weakly and more abundant phytoplankton was observed at a depth of less than 4 m.

June, 1976 : Throughout the 5 layers investigated, the cell numbers ranged from 20 (10.5 m) to 900 (1 m) and the average was 400 which was considerably low comparing with other seasons. This reason has already shown in the former section (V.1.2).

August, 1976 : Comparatively low density of 200 (4 m) - 6,000 (1 and 2 m) was recorded at 6 layers and the average was 3,200 cells. Since the thermocline was developed at a depth of 2 - 3 m, more abundant population was observed at the upper layers of it. Such a tendency was common in the former two seasons.

In general appreciable growth occurred at the depths above 5 m except in December 1972, though obvious stagnation hardly developed in Lake Yunoko.

V.2.2. Seasonal variation of cell number classified by phyla (Table V.2.1.)

July, 1972 : No differences in the composition of the community were observed at each depth because Chlorophyta occupied 97 - 100 % of the total cell number at all depths

(0, 1, 3 and 6 m).

October, 1972 : Cyanophyta predominated at 1 m (about 90 %) and 9 m (about 50 %) deep, whereas at another depths it appeared from 19 to 36 % and Chlorophyta occupied large part of the total biomass instead.

December, 1972 : At all depths from 0 to 12 m, Bacillariophyta occurred from 99.5 to 100 % and so the distribution of the phytoplankton seemed to be horizontally uniform.

April, 1976 : Bacillariophyta had a frequency of more than 95 % through all depths; the remaining part consisting of Chlorophyta. This feature resembled that in December 1972.

June, 1976 : At upper three layers (0, 1 and 2 m) Chrysophyta appeared over 95 % and the remaining part was composed of Chlorophyta, whereas at a depth of 8 m Chrysophyta decreased to about 41 % and Chlorophyta increased to about 56 % instead and Bacillariophyta occurred about 3 %. At a deepest layer (10.5 m), Chrysophyta occurred about 69 % and almost 31 % consisted of Bacillariophyta.

August, 1976 : At depths of 0 and 1 m, Bacillariophyta appeared from about 57 to 64 %, Chrysophyta from 29 to 33 % and Chlorophyta from 7 to 10 %. Bacillariophyta occupied similar percentage of the total cell number at the depths of 2 and 4 m but Chrysophyta decreased to about 4 to 7 % and Chlorophyta increased from 34 to 49 %. At deeper layers, 8 and 9.5 m, almost all part (96 to 99.5 %) was occupied by Cyanophyta.

The composition of phytoplankton were vertically uniform in July, October and December 1972 and in April and June 1976 in

which season green algae abundantly occurred only at a depth of 8 m. This is considered to be due to the contamination of attached algae from the standing tree in the water in the neighborhood. The causes for this uniformity are considered as follows.

Since spring half stagnation period prolonged to July in 1972, the phytoplankton composition was nearly uniform though deeper layers were not investigated. October 1972 was the autumnal full circulation period showing a little difference of water temperature (1.3° C) between the surface and deeper layer, so the dominant species were composed of essentially the same ones. In December 1972, as water temperatures of the surface and deeper layer (11.5 m) were 2.5° C and 3.2° C respectively and its difference was only 0.7° C, it may be reasonable to regard this season as the circulation period. One of the reasons why the lake water was circulated despite that this season was originally the winter half-stagnation period, was supposed that Lake Yunoko was inclined to be strongly affected by wind action because it is a shallow lake and the lake water therefore, completely circulated.

The differences of water temperature between the surface and deeper layer in April and June 1976 were 3.1° C and 5.6° C respectively. So each season was considered as vernal half-stagnation period. Water of this lake, however, seemed to circulate quite moderately and this probably caused the uniformity.

In August 1976, remarkable difference in the dominant species was recognized between 0 - 4 m and 8 - 9.5 m owing to the

stagnation period in which the water temperature at the surface and a depth of 9.5 m was 17.3° C and 10.6° C respectively.

V.2.3. Diversity index (Table V.2.2.)

July, 1972 : D.I. showed a narrow range from 0.01 to 0.24 because of the exclusive dominance of Chlamydomonas sp.(A).

October, 1972 : D.I. ranged from 0.77 to 1.83 and its difference was 1.06. Though the percentage of the first dominant species showed low values as the depth increased except 2 m layer, D.I. took high values as the depth increased also except 2 m layer.

December, 1972 : D.I. fluctuated with small range (1.67 to 2.02) because of high domination of Melosira distans, M. italica f. curvata and Synedra acus with total average value 91.6 %.

April, 1976 : D.I. ranged from 1.25 to 1.71 with small fluctuation of 0.46 probably because there were no remarkable differences in the number of taxa composing dominant species and in their percentages between the depths.

June, 1976 : D.I. ranged from 0.11 to 1.35 with difference of 1.24. Although this range seems to be generally not so large , it is the highest value in this study due to the wide range of the distribution of the first dominant species (98.7 - 37.5 %).

August, 1976 : D.I. ranged from 0.07 to 1.46 with the difference of 1.39. Deeper layers showed comparatively low values as 0.35 at a depth of 8 m and 0.07 at that of 9.5 m because only one taxon Aphanothece sp. occupied large part

of the total biomass.

Throughout the investigations, the minimum and maximum values of D.I. were 0.01 and 2.02 respectively showing small differences. The reason for this is considered to be that only a few dominant species occurred in high percentage at almost all depths.

The relations between the depth of water and D.I. were summalized as follows.

1. D.I. took approximately constant values irrespective of the depth of water : July 1972, December 1972, April 1976.

2. D.I. took higher values as a depth increased : October 1972, June 1976.

3. D.I. took high values at the upper layers and low values at the deeper ones : August 1976.

Thus D.I. was strongly affected mainly by the percentage of the first dominant species.

V.2.4. Dominant species (Fig.V.2.1a, b)

The method to determine the dominant species is the same as that in horizontal distribution of phytoplankton.

July, 1972 : At all depths, although the investigation was carried out only to a depth of 6 m, only Chlamydomonas sp.(A) appeared.

October, 1972 : Aphanocapsa elachista var. planktonica predominated at a depth of 1 m, whereas Chlamydomonas sp.(B) and Aphanocapsa elachista var. planktonica appeared in order at the depth of 2, 4 and 6 m, and above-described two species appeared in reverse sequence at a depth of 9 m.

December, 1972 : At the surface Melosira distans predominated first and Synedra acus second, while at all other depths the first and the second dominant species appeared in reverse sequence except a depth of 6 m where Melosira italica f. curvata occurred as the second dominant one instead of Melosira distans which appeared as the third dominant species. Melosira italica f. curvata occurred third at the depth of 1, 3, 4, 9 and 12 m.

April, 1976 : Stephanodiscus sp. distributed as the first dominant species equally through all depths. Furthermore Synedra acus and S. acus var. radians was the second and the third dominant respectively except for the surface layer where the second and the third dominants were reversed.

June, 1976 : Only one taxon, Cryptomonas sp., commonly predominated through all depths except 8 m layer where Mougeotia sp. appeared first and Cryptomonas sp. did second.

August, 1976 : Stephanodiscus sp.(1) predominated first and Dinobryon bavaricum, second at upper layers (0, 1 and 2 m deep). At a depth of 4 m Chlamydomonas sp.(A) appeared as the first dominant species and Stephanodiscus sp.(1) did as the second. Aphanothece sp. exclusively occupied a large part of the total biomass at the depths of 8 and 9.5 m.

Thus, in summary there were no significant differences in the vertical composition of the dominant species except in August 1976 in which dominant species showed great differences between upper layers and lower ones owing to the complete stagnation period. On the other hand, the order of the dominant species sometimes changed. As the dominant species

of phytoplankton was composed of only one to three taxa and they occupied considerably large part, the composition of the community in Lake Yunoko was considered to be simple.

V.2.5. Measuring similarity between communities

July, 1972 : High similarity was observed between 4 layers because the first dominant species was common at 4 layers and their percentages were considerably high showing the values from 96.9 to 100 %(Fig.V.2.2).

October, 1972 : As Fig.V.2.3 shows, the community at a depth of 1 m was different from the communities of other depths because the community at this depth was composed of only one taxon, Aphnocapsa elachista var. planktonica which was the second dominant species at the depth of 2, 4 and 6 m, and it showed high percentage (87.2 %). High similarity was found among 2, 4 and 6 m layers where the same dominant species appeared in the same order.

December, 1972 : Fig.V.2.4 shows high similarity throughout all depths. Even though the order of the dominant species was different there was no great difference in their percentages. The dominant species were of course composed of the same ones. These facts presumably lead the high similarity.

April, 1976 : This season also represented high similarity except the layers between 0 m and 10 m where the second and the third dominant species were different and in addition the first dominant one occupied different percentage (Fig.V.2.5).

June, 1976 : High similarity was observed between all depths except for the 8 m layer where represented dissimilar communities by the sudden appearance of Mougeotia sp. (Fig.V.2.6).

August, 1976 : High similarity was observed between upper 3 layers (0 – 1 – 2 m) and between deeper 2 ones (8 – 9.5 m). The significant dissimilarity between the upper and deeper layers was due to the difference of the dominant species, while at a depth of 4 m, as the first dominant species differed from that in the upper and deeper layers though the second one at this depth was the same as the first one in the upper layer, this layer showed greater dissimilarity to the deeper layers than the upper layers (Fig.V.2.7).

VI. BENTHIC ALGAE IN THE LIMNETIC ZONE

VI.1. Live cell

VI.1.1. Seasonal cycle of total cell number

July, 1972 : Samples were collected at 12 stations. Cell numbers per mm^2 of the sediment surface range from 1,800 (10 m) to 331,600 cells (1 m). Marked decrease in number appeared between 4 and 5 m (Fig.VI.1).

October, 1972 : From 300 (course C,12 m deep, henceforth simply expressed as C 12) to 211,400 cells (C 1) were counted among 28 stations and the rapid decrease was observed between 1 and 2 m (Fig.VI.2).

December, 1972 : The maximum count, 876,800 cells were found at A 1.5 and the minimum one, 6,700 cells at A 10 among 27 samples. The cell numbers decreased markedly at 2 m in course A and increased again at 3 m. Such trend was also observed in Windermere by Round (1961) who showed that the mean population at 2 m seems always to be less than at 1 m, and also less than that at some depth greater than 2 m. He furthermore stated that the flora rapidly declines below 6 m. It, however, occurred below 4 m in Lake Yunoko. On the contrary, the maximum count was observed at 2 and 2.3 m in course C and the numbers sharply reduced below 7 m (Fig.VI. 3).

April, 1976 : The cell numbers ranged from 5,700 (C 11) to 331,300 (A 1.3). Little growth occurred below 1.8 m and the great difference in algal growth among the stations below 1.8 m was hardly found both in course A and C, whereas rapid decrease in number was observed at depths greater than 6 m in

course C which is in agreement with the data of Round (1961) (Fig.VI.4).

June, 1976 : The cell number fluctuated between 4,900 (CA 11) and 181,700 cells (A 5) among 21 samples. As Round (1961) showed, the cell numbers rapidly dropped at 6 m in course A, while in course C little growth was observed at 9 m and 11 m (CA) (Fig.VI.5).

August, 1976 : The maximum number of cells 218,600, was found at 2 m (course A) and the minimum 8,200 cells at 11 m (course C) among 18 stations. The marked decrease in numbers occurred below 4 m but a little recovery was observed at 9 and 10 m in course A, while in course C appreciable increase in numbers occurred at 5 m and above, but few were observed at 11 m (C 11 and CA 11) (Fig.VI.6).

October, 1976 : The greatest number(262,300 cells) was found at 1.5 m (course C) and the least 8,400 cells at 10 m (course A). Though a little increase occurred at 9 m, the cell number decreased from 4.5 m in course A, whereas the standing crop showed a steady decrease from shallow to deep water in course C (Fig.VI.7).

In general, the maximum numbers were frequently found at shallower stations and the minimum at the deepest or its adjacent stations in Lake Yunoko though there was some variation of the depth where a sharp reduction was observed, from season to season and from course to course. Fig.VI.8 shows the vertical distribution of the number of live cells per 1 mm^2, averaging those at different stations with almost the same depths.

The cell numbers showed a tendency to decrease as the depth increased except in June. Round (1961) pointed out that the most favorable depth in some lakes of the English Lake District is 3 m in regard to the optimal photosynthesis of the diatoms whereas shallower depths appear to be somewhat less favorable because of a partial inhibition of photosynthesis (Talling 1957 a, b) and little growth occur below 6 m. In Lake Yunoko the maximum growth was rarely observed at 3 m and the significant decrease at 6 m was found only in April (course C), June (course A) and October (course A) 1976. One of the main reasons for these disagreements with Round's data may be the difference of species composition between Lake Yunoko and lakes in the English Lake District. Gruendling (1971) reported from his study on the epipelic algae in the shallow Marion Lake where the mean depth is 2.4 m that the maximum standing crop is usually found at 2 m and the decrease is found at 0.5, 1.0, 3.0 and 4.0 m. He pointed out that the reduction of light is probably responsible for the decrease in the standing crop at 3.0 and 4.0 m while other factors such as grazing by animals and light inhibition of photosynthesis are acting to reduce it at 0.5 and 1.0 m. The maximum standing crop was observed at 2 m only in December 1972 and August 1976 in Lake Yunoko. Since the optimal light intensity of the algal growth is different in each algal species and the light penetration is influenced by the amount of suspended particles, it is difficult to find out general feature of the standing crop in relation to the water depth. Moreover, the characteristics of physical and chemical factors such as wave action

and the nature of sediment are different in each lake, so that they may induce complexities of the depth distribution.

VI. 1.2. Seasonal variation of cell number classified by phyla

Table VI.1a,b shows seasonal variation of the live cell numbers classified by phyla. It is clear that the diatoms significantly predominated, percentages of which varied from a low of 87.5 and to a high of 100 %. The frequency of occurrence of the algae other than diatoms was less than 1 % at almost all stations and so the benthic algae in Lake Yunoko almost entirely consisted of the diatoms.

Round (1964) reported that blue-green algae in Windermere range deeper than diatoms and suggested that they are less sensitive to light. Hutchinson (1967) pointed out that the usual members of the deepest littoriprofundal algae taxocene are blue-green algae, with a few special members of other groups such as the red alga Hildenbrandia, and that the blue-green algae found in the deep zone often show some chromatic adaptation, producing pink forms. On the other hand, it is suggested that the types of lake sediments and the overlying waters have strong controlling influences on the types of epipelic flora that will develop and on the size of the standing crop of each species. In this point, Round (1957) has shown that for many of the English lakes the diatoms and the green algae favor high organic sediments. From this suggestion, it might be expected that the high organic sediments in Lake Yunoko was responsible for the dominance of diatoms in the benthic algal flora.

Gruendling (1971) observed that temperature and light quantity appear to be the most important variable influencing the blue-green algal standing crop and their growth did not begin until the water temperature approached 20.0°C.
It was noted by Hashizume (1975) that the blue-green algae have never appeared in Lake Yunoko in the summer season because of low water temperature, although it is strongly eutrophicated lake. Actually the water temperature seldom exceeded 20°C throughout a year, so that the low water temperature might be responsible for the low growth of blue-green algae in Lake Yunoko.

VI.1.3. Dominant species

July, 1972 : The most significant species as a dominant was Fragilaria pinnata followed by Fragilaria spp. which appeared at the deeper zones (Fig.VI.1).

October, 1972 : The main dominant species were Fragilaria pinnata, Fragilaria spp. and F. pinnata var. lancettula (Fig. VI.2)

December, 1976 : Fragilaria pinnata, F. pinnata var. lancettula and F. capucina var. mesolepta were the main dominant members of the flora (Fig.VI.3).

April, 1976 : Fragilaria pinnata appeared most frequently as the first dominant species and the other species such as Melosira distans, F. construens, F. construens var. binodis and Stephanodiscus sp. were also dominant (Fig.VI.4).

June, 1976 : At many zones, Fragilaria pinnata predominated first whereas Melosira distans which often appeared at deeper zones ,F. construens and F. construens var. binodis were

important dominant species (Fig.VI.5.).

August, 1976 : The distribution of the first dominant species Fragilaria pinnata was limited at 7 stations among 17 in this season. F. construens often predominated first at 5 stations. Other species such as Melosira distans, F. crotonensis, F. construens var. binodis and F. pinnata var. lancettula were found as the first dominant species at a few stations (Fig.VI.6).

October, 1976 : Fragilaria pinnata predominating first at 7 stations among 17 was followed closely by F. construens. F. construens var. binodis and Melosira distans also predominated first at several stations (Fig.VI.7).

From these investigations it was clear that Fragilaria pinnata predominated first at almost all zones, though the extent of dominance by this species was more limited in 1976 than in 1972 and the other species especially Melosira distans also predominated at comparatively deeper zones.

Regarding the compensation depth as about 1 % of relative light intensity, it is approximately 6 m during the circulation period and to the bottom during the stagnation period and thus the euphotic zone is considered to be 6 m, more or less throughout a year in Lake Yunoko (Yamaguchi & Ichimura 1970). So it is clear from this investigation that algal production was found below the euphotic zone in Lake Yunoko. A similar phenomenon was observed in Lake Biwa where Stephanodiscus carconensis and Melosira solida grew on profoundal lake sediment (Tsuda 1965).

Hutchinson (1967) pointed out that the benthic algal commu-

nities are in general confined to the euphotic zone and there may, however, be species present in the feebly illuminated transitional littoriprofundal zone that are at least partially heterotrophic. Lund (1954) reported from the inspection of diatom periodicity that diatoms are possessed of ability to remain alive on and in the deposits in the dark and under anaerobic conditions. Fogg (1965) noted that many algal species are capable of growth in the dark if given a suitable organic substrate. Rodhe (1955) found indications of growth of nannoplankton in a sub-arctic lake during the winter under circumstances in which virtually no light could have been available and he supposed chemotrophic growth. The chemo-trophic growth was also suggested by Bernard (1963) who observed that nannoplankton algae are often as numerous in samples taken from considerable depth in the sea as they are in the photic layer. Fischer (1977) stated that the ability to grow heterotrophically as mixotrophy is obviously a common feature in diatoms.

Although a large number of taxa appeared as phytoplankton and benthos, the live cells on the bottom at the limnetic zone were confined to several species.
Stockner and Armstrong (1971) found that Fragilaria pinnata which was one of the main dominant taxa in Lake Yunoko, occurs more abundantly at deeper stations because its optimal light intensity for growth is low. In addition, as to Fragilaria, they were not considered to derive from plankton since throughout the studied period they had never composed main part of the phytoplankton.

As to Melosira distans which often appeared as dominant species in Lake Yunoko, Gruendling (1971) found the largest standing crop of this species consistently at the deeper stations (2.0, 3.0 and 4.0 m). Lund (1954) reported that Melosira italica subarctica passed to the deposits in summer and there remains alive forming resting stage in the dark anaerobic conditions. It may be possible to assume that generally Melosira is able to survive in such conditions by forming resting stage.

These observations may suggest that some of the prevailing benthos appearing at the deeper zone in Lake Yunoko would have an ability of growing or living at low light intensity or dark and further living heterotrophically.

VI.1.4. Measuring similarity between communities

The similarity index of the $C\lambda$ designed by Morishita (1959) was used to compare the composition of the communities in benthic algae at two different stations.

(A) In the case of two neighboring stations in the same course (Fig.VI.9a,b)

July, 1972 : High similarity was found between shallower zones above 6 m deep and between 12 m zones where the first dominant species were common.

October, 1972 : In course B, almost all stations above 6 m deep showed high similarity, while low one was recognized in deeper stations.

In the case of course C, the similarity between stations above 10 m showed a high value because of the commonness of the first (Fragilaria pinnata) and frequently the second

dominant species.

December, 1972 : The algal composition at all stations represented high similarity. The first dominant species was occupied by Fragilaria pinnata at many stations whereas at some stations F. pinnata var. lancettula and F. pinnata dominated first and second respectively without significant difference in their percentages. A strong resemblance was observed between shallower stations above 4 m deep and it was hardly observed between deeper stations below 4 m because of the difference of the first dominant species in course B.

In course C, Cλ values showed high similarity from 1 to 11 m (st.C 11a), because of the common appearance of the first dominant species or that of the first or the second dominant one with similar percentages. The composition of the main species at st.11.5 m was dissimilar to neighboring stations.

April, 1976 : The six stations from 1.3 to 6 m were investigated in course A and high similarity was observed throughout all stations, owing to the same first dominant species Fragilaria pinnata. High similarity was recognized at upper 6 stations above 8 m in course C. F. pinnata dominated first from 1.8 to 5 m, while apart from their order, the first to the third dominant species were composed of the same ones without significant difference in their percentages at 5 and 6 m. The first dominant species was common at 6 and 8 m. The dissimilarity below 8 m was supposed that each station had a different first dominant species, which occupied large part of the community.

June, 1976 : Among 10 stations in course A, upper stations above 8 m with the same first dominant species showed high similarity. The similarity between 8 and 9 m was low due to their different first dominant species.

In course C, the stations above 8 m showed high similarity because Fragilaria pinnata prevailed commonly as the first or the second dominant species, and moreover a great difference on the percentage between the first and the second was hardly appreciated. Though the first dominant one was different at 7 and 8 m, $C\lambda$ value showed comparatively high because of the appearance of the common second dominant one with similar percentage to the first one.

August, 1976 : In course A, high similarity was observed only at upper 4 stations where Fragilaria construens appeared as the first or the second dominant species and in this case the first and the second ones represented similar percentage. Fragilaria construense appeared as the first dominant one at 4 and 5 m, and their similarity, however, was low presumably because of the difference in the second and the third dominant species. There appeared low similarity below 5 m owing to the difference in the first and the second dominant ones.

In course C, comparatively low similarity was obtained between 2 - 3 m, 5 - 11 m (st.CA 11) and st.C 11 - CA 11. The first dominant species at 2 and 3 m were common but their percentages were different. The low similarity between the other stations was presumably attributed to the difference in the first and the second dominant species.

October, 1976 : In course A, high similarity was found

only between 2 - 3 m, 3 - 3.5 m and 4.5 - 5.8 m owing to the common appearance of the first dominant species except 4.5 - 5.8 m where the dominant species consisted of three taxa, of which two taxa occupying almost 50 % together were common though the first dominant one which occupied less than 50 % was different. Except for the similarity between 5 and 10 m (st.CA 10) where the first to the third dominant species were entirely different, the similarity highly resembled in course C where Fragilaria construence and F. pinnata commonly appeared as the first or the second dominant.

On a general survey from these data, high similarity between two neighboring stations was observed up to 4 m or at 10 m in course A, while in course C it was observed up to 5 m or 11 m. At the same sampling time high similarity appeared up to deeper zones in course C than in course A.

The relation between depth limitation and seasonal variation in the similarity of algal communities has not been clear.

Considering high similarity as 0.80 and above in $C\lambda$ value, the following situation may be the cause for it.

(1) The two communities have the same first dominant species which occupied a large part of the total biomass. In this case, higher values are obtained when the first dominant holds almost 50 % (e.g. st.D 4.5 - D 6 in July 1972), but there seems to be exception when a great disparity in their percentages is recognized (e.g. st.C 2 - C 3 in August 1976).

(2) The order of the first and the second dominant species

in two communities coincides with each other and their totals attain almost 50 %.

(3) The totals of the first and the second dominants exceed 50 % in two communities even when the order of them inversely arranged (e.g. st.A 4 - A 5, st.A 6a - A 6b, st.C 1 - C 2.5 in December 1972, st.C 6 - C 8 in April 1976 and st.C 2 - C 3, st.C 3 - C 4, st.C 4 - C 5 in June 1976).

(4) The total frequency of occurrence of the first , the second and the third dominants exceeds 50 % when the members of them in two communities are common even though their orders are different (e.g. st.C 3.5 - C 5, st.C 5 - C 6, st.C 6 - C 8 in April 1976 and st.C 3 - C 3.8 in October 1976).

(B) In the case of two stations with similar depth in the different course or station (Fig.VI. 10a,b)

October, 1972 : The similarity was low between st.B 2. - C 2.5, st.C 5 - B 5b, st.B 7 - C 7, st.CA 10.5 - B 10 and st.CA.10.5 - C 10, and slight between st.B 1 - C 1b. But high similarity was frequently found in 13 intervals among 19.

December, 1972 : High similarity was found in 12 intervals among 17.

April, 1976 : Low similarity is hardly recognized although 2 intervals between st.A 1.3 - C 1.8 and st.A 6 - C 6 showed slight similarity.

June, 1976 : Five of 9 intervals showed high similarity and the rest represented low one.

August, 1976 : In this season, $C\lambda$ values were considerably low except for one of 8 intervals.

October, 1976 : High similarity was observed in only 2 of 8 intervals. Of the other 6 intervals 4 showed low similarity and 2 slight one.

Throughout the seasonal obsevations described above, high similarity was frequently found in 4 occasions October and December 1972 and April and June 1976, but in two occasions, August and October 1976, low similarity was obtained in many intervals because of the discrepancy of the first dominant species.

According to the analyses of the similarity on the basis of the water depth, shallower zones above 3 m often exhibited low similarity. This is presumably due to the difference of the first dominant species or to that of their percentages when the first ones were common at two stations. It is assumed that these differences resulted from the enviromental complexities such as heterogeneous spatial distribution of aquatic higher plants which were composed of Elodea, flourishing in shallower parts of the lake, and the difference of the sediment between course A and C, where the sediment was mixed with gravels.

VI.2. Dead cell

VI.2.1. Seasonal cycle of total cell number

April, 1976 : The cell numbers varied from a low of 123,000 at a depth of 4.5 m to a high of 449,000 at 3 m in course A. There was no significant correlation between the cell density and the water depth.

Comparing the composition of the dead cells with that of

the live cells in course A, the former surpassed the latter except at 1.3 m.

In course C, the very low cell number, 24,000, was obtained at 2 m and the high one, 831,000, was obtained at 10 m. The dead cells showed larger numbers than the live cell at 6 stations except at 1.8 m, 2 m and 11 m (st.CA 11).

June, 1976 : The cell numbers were from 95,000 at 7 m to 401,000 at 4 m in course A, while comparatively higher cell density, from 299,000 at 9 m to 1,000,000 at 2 m, was observed in course C. The number of the dead cells was larger than that of the live cells at all stations both in course A and C.

August, 1976 : The cell numbers fluctuated from 152,000 at 8 m to 585,000 at 9 m in course A and from 129,000 at 11 m to 442,000 at 3 m in course C. At all stations the dead cells surpassed the live cells in their density.

October, 1976 : The cell numbers ranged from 154,000 at 2 m to 619,000 at 4 m in course A and from 322,000 at 12 m to 1,060,000 at 2.5 m in course C. Higher cell density was observed in the dead cells than in the live cells at all stations. A vast number of the frustules of dead diatoms were found on the bottom surface of the lake. Generally the dead cells were more abundant than the live ones and a great difference was found in the species compositions between the live and dead cells.

There were little correlations between the cell density and the water depth or season.

VI.2.2. Seasonal variation of cell number classified by phyla

No benthic algae other than Bacillariophyta were found as the dead cells on the sediment of the lake bottom. Although it is generally possible to detect the cell wall of Scenedesmus, Pediastrum and many taxa belonging to Chrysophyta from the sediment of the lake bottom, the cell wall of such species was hardly observed perhaps owing to the sparse occurrence of such species as plankters in Lake Yunoko.

VI.2.3. Dominant species

April, 1976 : (Fig.VI.4.)

Course A --- Melosira distans was the first dominant species at all stations except 1.3 m and Fragilaria capucina var. mesolepta, Stephanodiscus sp., M. italica f. curvata, F. pinnata and Synedra acus commonly appeared as the dominant although their ranks varied according to the water depth.

Course C --- Such species took the first rank as Melosira italica f. curvata at 4 stations, M. distans at 3 and Fragilaria pinnata at 2. The main species ranking under the second were composed of Asterionella formosa, Stephanodiscus sp., Synedra acus and the first ranked species described above.

There were no great differences in the dominant species between two courses, but the first dominant species was more stable in course A than in course C.

June, 1976 : (Fig.VI.5.)

Course A --- Melosira distans contributed as the

first dominant species except at 9 m and the other dominant species were the same as those in April.

Course C --- The first dominant species were composed of Melosira distans at 5 stations, M. italica f. curvata at.3, Fragilaria pinnata, Stephanodiscus sp. and Asterionella formosa at 1. The other dominant species were almost the same as those in April.

The dominant species other than the first one in course A were analogous to those in course C, whereas the first dominant species in course C were more complex than those in course A, showing the same tendency as the case in April.

August, 1976 : (Fig.VI.6.)

Course A --- The first dominant species were composed of Melosira distans at 6 of the 10 stations, M. italica f. curvata and Stephanodiscus sp. at 2 stations respectively. The dominant species under the second were almost the same as those in April and June.

Course C ---At 5 of the 7 stations, Melosira distans appeared as the first dominant species and at another 2 stations, Fragilaria pinnata and M. italica f. curvata predominated first, whereas the dominant ones under the second were almost the same as those in April and June with less numbers of species than in the preceding two seasons.

Comparing the dominant species in this season with those in April or June, the first dominant species were comparatively stable in this season and also the dominant ones under the second were composed of less numbers of species. It would be

unreasonable to assume that these differences resulted from the marked changes in the species composition of the dead cells during a short period. So, the slight difference of the sampling stations probably caused such differences.

October, 1976 : (Fig.VI.7.)

Course A --- Melosira distans predominated first at 7 of the 10 stations and Stephanodiscus sp. did first at 2 stations, and another 1 station was predominated by Fragilaria pinnata. The dominant species under the second were similar to those in April, June and August.

Course C --- Melosira distans held the highest rank at 5 stations among 7 and Stephanodiscus sp. and Fragilaria pinnata predominated first at 1 station.

The dominant species other than the first were similar to those in the preceding 3 seasons. Both in April and June, the first dominant species differed between course A, where M. distans took the first rank at almost all stations, and course C, where it predominated first at limited few stations. In August and October M. distans took the first rank with similar frequency at both courses. So, the first dominant species closely resembled between April and June and between August and October. The component species of the dominant under the second presented high resemblance, regardless of their ranks at any season.

VI.2.4. Measuring similarity between communities

(A) In the case of two neighboring stations in the same course (Fig.VI.9b)

April, 1976 :

Course A --- High similarity was observed at almost all intervals except 1.3 - 2 m.

Course C --- The half of the all intervals represented high similarity.

June, 1976 :

Course A --- All intervals from 2 to 10 m showed high similarity.

Course C --- Ten intervals from 2 to 12 m were investigated , among which high similarity was observed between 6 - 7 m and 7 - 8 m and slight one between 4 and 5 m.

August, 1976 :

Course A --- Low similarity was found between 1 - 2 m and 2 - 3 m and 8 - 9 m, slight one between 2 - 3 m, 5 - 6 m, 7 - 8 m and 9 - 10 m, and high one between 4 - 5 m and 6 - 7 m.

Course C --- All stations showed high similarity in this season.

October, 1976 :

Course A --- The 9 intervals from 2 to 10 m were examined among which 2 intervals, 2 - 3 m and 9 - 10 m, took low similarity,1 interval slight, and 6 intervals high.

Course C --- Low similarity was found in 2 intervals, 1.5 - 2.5 m and 5 - 9 m, and slight one in 1 interval 9 - 11 m, and the other 3 intervals took high one.

No definite tendency was recognized in the relation between the water depth and similarity, although low similarity was often found at shallower zones. On the other hand, the simi-

larity of the live cells at shallower zones represented high.

It is assumed that the benthic flora of the dead cells at the deep zone was apt to be affected directly by phytoplankton association which comparatively uniformly distributed in the lake, while that at shallower zone was markedly different from location to location. So, it is conceivably possible that Cλ between two neighboring stations at shallower zones took the lower value than that at deeper ones.

(B) In the case of two stations with similar depth in the different course (Fig.VI.10a,b)

April, 1976 : Among 5 intervals, the similarity was low in 3 intervals and slight in 1 interval.

June, 1976 : Low similarity was found at st.A 2 - C 2, st.A 5 - C 5 and st.A 9 - C 9, slight one at st.A 4 - C 4, and high one at st.A 3 - C 3, st.A 6 - C 6, st.A 7 - C 7, st.A 8 - C 8 and st.A 10 - C 10.

August, 1976 : The 4 intervals, st.A 2 - C 2, st.A 3 - C 3, st.C 11a - 11b and st.C 11a - CA 11, showed low similarity and 3 intervals, st.A 4 - C 4, st.A 5 - C 5 and st.CA 11 - C 11b, showed high similarity.

October, 1976 : Low similarity was recognized in 2 intervals between st.A 2 - C 2.5 and st.C 1.5 - C 2.5, while high one was frequently observed in 8 intervals between st.A 2 - C 1.5, st.A 3 - C 2.5, st.A 3.5 - C 3, st.A 3 - C 3, st.A 3 - C 3.5, st.A 4 - C 3.8, st.A 4.5 - C 5 and st.A 10 - CA 10.

Though shallower zones such as 2 m and 3 m were inclined to show low similarity, the definite tendency was hardly ob-

served between water depth and $C\lambda$ values. In the case of the live cells, the intervals which showed low similarity reached 56 % of the total intervals.

(C) Comparison between the live and the dead cells in the same station

As Fig.VI.11 showes, high similarity was found at only 1 station among total 36 stations in course A, and also 1 station among total 34 stations in course C. So it is clear that the significant difference was found in the composition of the community between the live and the dead cells. The reason for this is considered as follows. The community of the live cells was composed of actually growing species, planktonic species which deposited on the lake bottom with significant amount, and accidental species derived from the littoral periphyton which probably less affected the composition of the community in benthic flora because of their small quantities.

Though there are very few detailed reports which refer to the survival of the phytoplankton deposited on the lake sediment, Lund (1954) pointed out the possibility of the existence of the planktonic species in forming a resting stage on the sediment for a considerably long period.

It is said that the prerequisite of motility for the epipelic flora means that few planktonic species could survive on the sediment (Round 1964). So, the live cell on the sediment, derived from the plankton, might undergo severe selection and only several planktonic species and benthic one, which can grow in reduced light intensity or

sometimes in the dark with anaerobic condition, can survive on the sediment.

In the case of the dead cells, they mainly originate from the decomposition of the benthic living algae and planktonic species which have accumulated for a long term since the commencement of lake formation. Although Merilainen (1969) pointed out the occurrence of the resolution in the diatom frustule in certain cases, the loss resulted from such phenomenon is considered to be negligible. On the other hand, the deposition of the dead cells is occasionally mixed up by the movement of Chironomus spp. and this might cause the vertically uniform distribution of the algal communities, while the living cells could grow for a comparatively short time and might never compose thicker layer than the dead cells and the influence of Chironomus spp. was negligible.

Because of the abovementioned features, the flora might be different between the dead the the live cells.

VI.3. Comparison between phytoplankton and benthic algae

VI.3.1. Limnetic zone

Considering that phytoplankton assemblage consisted of a total of 22 species, of which 8 belonged to the diatoms, the dominant species other than the diatoms frequently appeared throughout the investigation, while the dominant benthic community in the limnetic zone was composed of a tatal of 10 species, all of which were belonged to the diatoms, especially Fragilaria pinnata. So, there was a recognized significant difference in the composition of the dominant

species between phytoplankton and benthic algal community.

As to the benthic community of the dead cells, the first dominant species was Melosira distans followed by Asterionella formosa, Fragilaria capucina var. mesolepta, F. construens var. binodis, F. crotonensis, F. pinnata var. lancettula, M. italica f. curvata, Stephanodiscus sp. and Synedra acus, all of which are considered to be the planktonic species. A large part of the dead community might be derived from plankton because such species that occupied a large part of the dead benthos were hardly detected from the dominant species of the living benthos except a few species and could be found as the main plankter, as observed by many workers until that time (Fig.VI.12).

The living dominant species were significantly different from the dead ones and mainly composed of Fragilaria, occationary accompanied by Melosira distans. Concerning several species of Fragilaria, they can grow both as planktonic and benthic, but I have never recognized that they grew profusely as a plankter throughout the period of observation and never found any reports that they appeared as the dominant plankter except Fragilaria crotonensis in Lake Yunoko. So, the main living benthic community, Fragilaria, is considered to proliferate on the sediment of the lake bottom. In regard to Melosira distans, which often predominated as plankton, it is generally tolerant of severe enviroment and Round (1957) found this species in the dystrophic water. Fukushima & Ko-Bayashi (1978) observed that it profusely flourishes as plankton in strongly acidic water, containing abundant

ferric substances. Considering from the high tolerance of this species, it would be reasonable for this species to grow on the bottom sediment in Lake Yunoko although it rarely appeared as the living dominant species. The high density of this species as benthic dead cells was assumed to derive from the plankton. Hashizume (1974) reported an outburst of this species as plankton in November 1973.

VI.3.2. Littoral zone close to shore line.

The samples of phytoplankton and benthic algae were taken from the littoral zone close to the shore line at st.2 and st.4 in June 1977 and examinations were attempted. The benthic samples were separately collected from two different substrates, stone and sand, at the distances of 1 m (10 cm deep), 3 m (26 cm deep), 5 m (36 cm deep) at st.2 and 1 m (10 cm), 2 m (20 cm) and 3 m (36 cm) at st.4 from the shore, while the samples for the estimation of phytoplankton were collected from the surface water and from the water immediately above the substrates except at the shallowest places at both stations.

(A) Number of taxa (Fig.VI.13)

Benthic algae : The numbers of taxa on the stone ranged 16 - 18 at st.2 and 24 - 36 at st.4, while that on the sand ranged 6 - 10 at st.2 and 11 - 16 at st.4. So, the composition of the community was more simple at st.2 than at st.4, and on sand than on stone. As it is generally observed that the epipelic algae in a lake are mainly composed of motile species (Round 1953, 1964), it is reasonable that the flora of the sand lacks variety.

Phytoplankton : The numbers of taxa at the upper layers were 12 and 17 at st.2 and 15 - 27 at st.4 and those in the lower layers were 12 and 18 at st.2 and 27 and 31 at st.4. The communities at st.4 were more variable than those at st.2 in the same manner as the benthos, and those in the lower layers at st.4 showed more diversity than those in the upper layers, but marked difference in the standing crop was hardly observed between two layers.

(B) Standing crop (Fig.VI.13)

Benthic algae : The standing crop of algae on the stone expressed by cell numbers per mm^2 ranged 7×10^3 - 19×10^3 at st.2 and 10×10^3 - 22×10^3 at st.4, whereas that on the sand ranged 43×10^3 - 283×10^3 at st.2 and 109×10^3 - 238×10^3 at st.4 (Fig.VI.13). Great differences in the standing crop were not observed between st.2 and st.4 and the density of algal cells on the sand was several times higher than that on the stone. On the contrary, Moore (1979) referred to the quantitative relation among epilithic, epipelic, epiphytic and epipsamic algae and pointed out the minority of the epipsamon with respect to the number of taxa and standing crop. More study is needed to explain this discrepancy.

Phytoplankton : The cell numbers in the surface water were 2.6×10^3 - 15.9×10^3 at st.2 and 3.4×10^3 - 5.2×10^3 at st.4 and those at near-bottom layers ranged 4.0×10^3 - 12.4×10^3 at st.2 and 2.6×10^3 - 2.7×10^3 at st.4.

(C) Dominant species

Benthic algae (Fig.VI.14) : Fragilaria pinnata predominated

first on the sand and stone at both stations, especially at st.2 where it occupied the major portion of the total biomass, and it had a tendency to occupy more highly the sand than the stone. Fragilaria pinnata var. lancettula frequently appeared as the second dominant species in 9 of 12 samples.

There were no significant differences of the dominant species between the stone and the sand. The composition of the communities on the stone was more complicated than that on the sand with respect to the number of the dominant species. Furthermore, more diversified communities were found at st.4 probably because st.2 was close to the boat house and the turbulence by boats simplify the algal flora at st.2. Round (1964) pointed out that the epipelic is essentially a subcommunity of motile forms since motility is necessary to enable the algal cells to move to the surface after disturbance of the sediment and furthermore he showed that the exceptions to this "role of motility" are Melosira varians, Fragilaria intermedia, F. virescens and other rarer Fragilaria species among the diatoms. Round's observations are coincident with the appearance of diatoms in Lake Yunoko. In addition, the dominant species of the epipelic both at littoral and limnetic zones were commonly composed of Fragilaria species.

Phytoplankton (Table VI.2) : The first dominant species at the surface layer was Asterionella gracillima followed by Fragilaria sp. or Cryptomonas sp. The other member of the dominant was F. pinnata. In the case of more distant stations such as st.2-5m and st.4-3m, the dominant species consisted

of the same species as those in limnetic zone, namely A. gracillima and Cryptomonas sp. without Fragilaria. In this context, Ilmavirta et al. (1977) reported that phytoplankton in the pelagic and littoral zones have a similar species composition at all seasons. On the other hand, the first dominant species, just above the bottom sediment, were A. gracillima or F. pinnata (st.2-3m) followed by Cryptomonas sp. or A. gracillima (st.2-3m). It is clear that comparing the communities near the bottom layer with those at the surface one the benthic species had larger proportion in the bottom layer community if Fragilaria species and Scenedesmus species were considered to derive from benthic flora.

As to the communities at the surface layers, the proportion of the planktonic species to the total biomass increased as the distance from the shore increased. So, the littoral phytoplankton was more or less influenced by the benthic flora, especially at shallower zone or at immediately above the bottom in Lake Yunoko.

(D) Measuring similarity between communities by means of C_λ

(a) Measuring similarity according to the distance from the shore

Benthic algae : As Fig.VI.15b shows, except for the samples on the stone between st.4-1m and st.4-3m there were no real differences between two communities growing at different distances from the shore both on the sand and on the stone because of the similar species composition.

Phytoplankton : As Fig.VI.15d shows, significant differences were not recognized in the case of the surface communities both at st.2 and st.4, while low or slight similarity was occasionally found only at st.2 probably because of the unstable condition of the bottom sedimant caused by human activities.

(b) Measuring similarity of the benthos according to the different substrata, stone and sand

$C\lambda$ values (Fig.VI.15a) showed high similarity at st.2 in each depth, but slight or high similarity was observed at st.4. So, the differences of algal communities resulted from the substrata on which they grew were observed at st.4, but not at st.2 presumably owing to the turbulence by boats.

There are many reports on the relationship between algal communities living on different kinds of substrata and there is a divergence of conclusiton for this problem. Some workers reported from their glass plate results that the glass is not selective as far as diatoms are concerned (Patrick et al. 1954) or that the attached material on glass plates is quite similar to that on the rock substrata except several epilithic species belonging to the green algae (i.e., Ulothrix aequalis and Cladophora fracta) (Castenholz 1960).
Stockner & Armstrong (1971) found the greater relative abundance of Cyclotella stelligera and Synedra delicatissima on the glass slides than on the natural rock substrata.
They also stated that the diatom taxa on glass slides are basically similar to those observed on the natural rock substrata. It is supposed that the difference of the algal

communities due to the substrata is caused by the environmental factors and time factor, how long the substrata are exposed to the circumstances.

(c) Measuring similarity of phytoplankton, living two different layers

As Fig.VI.15c shows, there were no great differences of the phytoplankton communities between two layers. The phytoplankton in the littoral zone showed vertically uniform distribution.

(d) Measuring similarity between benthos and phytoplankton

C_λ showed very low values both at st.2 and st.4 except at st.2-3m where Fragilaria pinnata appeared in large proportions both in benthos and plankton (Fig.VI.15e). This is due to the differences of the dominant species between two samples. Ilmavirta et al. (1977) compared the species compositions of littoral and pelagic plankton communities and pointed out less than 20 % of the littoral plankton species are the same as occurred in epipelic communities. It seems that the littoral plankton was composed of the algae derived from both epipelic and phytoplanktonic communities, and that the proportion of epipelic algae was greatest at shallow parts of the littoral region where wave action caused water currents and turbulence (Kairesalo 1977). The same phenomenon was observed in Lake Yunoko but no species, considered to derive from phytoplankton, was observed as dominant benthic species. So, the species composition between benthos and phytoplankton has a little correlation in Lake Yunoko.

VII. BENTHIC ALGAE IN THE LITTORAL ZONE

VII.1. Environmental features of the sampling stations

Station 1 : This station was at the northeastern corner of the lake and the pump shed of Chuzenzi spa source was situated near this station. The water temperature was always high because the spa was flowing out, and it was a sunny place. In June 1976 Elodea sp. and Spirogyra sp. were found, and decayed Elodea sp. was found in October 1976.

Station 2 : This station was situated at the edge of the lake on the line that connected the southern corner of Namma Hotel and the Usagijima peninsula. It was a sunny place and at its western side a little stream was flowing into the lake. Because of the accumulating sand which was carried by the stream, the lake near this station was shallow to some distance from the shore. The surface of the lake was covered with snow in March 1973. Its thickness was about 7 cm at st.2-2 and 15 cm at st.2-5 (the number following station number means the distance from the shore, expressed by meters). Elodea sp. was growing at the distance of 6 m in August and 8 m in October 1976 from the shore.

Station 3 : This station was in front of the mountain cottage and at its eastern side the waste of the spa was flowing into the lake. This station was sunny. In March 1973, the ice of 5 mm thick covered the lake and, moreover, snow lay on it 15 cm deep at st.3-4. In August 1976, Elodea sp. was floating around this station.

Station 4 : It seemed that water near this station was

polluted by the organic substances, because at the side of this station there was sewage works and the treated water entered the lake. This station was quite sunny. The sediment there was composed of sand. Chironomos sp. was occasionally found. In March 1973, snow lay 9 cm, 10 cm and 15 cm deep at st.4-1, 4-2 and 4-3 respectively, and especially at st.4-3 ice of 1 cm thick lay below the snow. Elodea sp. and sometimes Spirogyra sp. (June 1976) abundantly grew a little far from st.4 in 1976 and 1977.

Station 5 : This station was situated at the north-western corner of the lake, and as the trees (mostly Tsuga diversifolia) were very thick, it was not a sunny place. It seemed that spring gushed from near this station. Batrachospermum sp. was found at st.5-3 in March 1973. In June 1976, a mass of Spilogyra sp. and Elodea sp. attached by Sphaerotilus sp. was found. A great amount of Elodea sp. flourished in August 1976.

Station 6 : This station was situated in the depths of the cove which was on the opposite side of the southern corner of the Usagijima peninsula and this station was not sunny because of the thick trees. Water froze at a thickness of 2.5 cm and Spirogyra sp. was found in December 1968. In March 1973, snow lay 8 cm deep and its surface froze at st.6-1 and it lay 12 cm deep at st.6-2. Elodea sp. and Spirogyra sp. were found in June 1976 and Ephydatia sp. was also found at st.6-2. In August 1976, Elodea sp. grew abundantly in the region 1 m distant from the shore and Acellus sp. was occasionally found.

Station 7 : This station was almost at the middle between st.6 and the southwestern corner of the lake. As the trees (e.g. Tsuga diversifolia) were also thick there, it was not a sunny place. In December 1968, water froze 2.5 cm thick and Nostoc sp. was found. Ephydatia sp. lived at st.7-2 in September 1972. In March 1973, water froze at a depth of 17 cm or less.

Station 8 : The location of this station was the southwestern corner of the lake. The trees (composed of Betula sp. and Pterocarya rhoifolia) were thick and it was a shady place. Water froze 2 cm thick in December 1968 and 2.5 cm in December 1972. Ice of 14,20 and 38 cm thick was found with comparatively deep snow cover (95, 60 and 37 cm deep at st.8-1, 8-3 and 8-5 respectively) in March 1973. Nostoc sp. was found in October 1968 and in August and October 1976.

Station 9 : This station was the southeastern corner of the lake and in the shade of the trees. In December 1972 water froze 2.5 cm thick. Elodea sp. grew abundantly in August and October 1976.

Station 10 : This station was near the southeastern corner of the lake and was sunny. In July 1967, a great number of Chara sp. dashed on the shore were found. Water froze 1 and 2 cm thick at st.10-4 and st.10-7 respectively in December 1972 and snow lay 60, 55, 54.5 and 71 cm deep at st.10b-1, 10b-2, 10b-4 and 10b-7 respectively in March 1973. As a spring gushed from near st.10a in March 1973 water was open, while st.10b was a little distant from

st.10a and water temperature was lower than that at st.10a and thick snow lay. Nostoc sp. was frequently observed in October and December 1968 and in June, August and October 1976. Chara sp. occasionally appeared at st.10-7 in September 1972 and October 1976. Batrachospermum sp. was found in December 1972 and at st.10b-4 in March 1973. A small amount of Elodea sp. were observed at st.10-1 in September 1976.

Station 11 : This station was located nearly at the middle between the southeastern corner of the lake and the base of the Usagijima peninsula and near the head of a little projecting land. As this station was in the shade of Tsuga diversifolia, it was not so sunny. The surroundings of this place froze and many Asellus sp. was found in December 1972. In March 1973, water froze 21 cm deep. Nostoc sp. was often observed in October and December 1968 and in April, June, August and October 1976. Asellus sp. appeared in December 1972 and in June 1976. In October 1976, Spirogyra sp.was also observed.

Station 12 : This station was at the southern side of the base of the Usagijima peninsula and a sunny place. A spring flowed near this station, so there were no ice and snow in March 1968 and 1973, and in December 1972. A great amount of Elodea sp. floated in April and June 1976 and it decreased in August 1976. Decayed Elodea sp. and Spilogyra sp. were found in October 1976.

Station 13 : This station was located at the northern side of the Usagijima peninsula and was somewhat sunny.

VII.2. Seasonal cycles of total cell number

Fig.VII.2.1 - VII.2.6 shows the total cell counts per 1 mm^2 of the surface of substrate in each station.

When the stations are arranged in cell numbers the following order is obtained, st.2 > st.4 > st.1 > st.12 > st.3 > st.5 > st.6 > st.9 > st.7 > st.8 > st.10 > st.11. The first 5 stations showed considerably high standing crops, more than 20×10^3 cells / mm^2. Comparatively low standing crops, less than 10×10^3 cells / mm^2 were observed at the rest of the stations. Except for st.12 the stations which showed high standing crop were located at the northwest side of the lake where was considerably affected by inflow of the sewage from Yumoto Town or the treated water from the sewage works. It was reported that the springs in Lake Yunoko contains high concentration of NO_3-N (Tochigi Pref. 1975). The high standing crop at st.12 might be due to this feature. The inflow of the treated water from the sewage works and nutrient rich water from springs were responsible for the comparatively high standing crop at st.5. It was reported that average standing crops of benthic algae in Japanese rivers are ordinarily 2×10^3 - 5×10^3 cells / mm^2 (Fukushima and Ko-Bayashi 1971). Comparing the standing crops in Lake Yunoko with those in the rivers, it appears that the value in Lake Yunoko was so large. Only two stations, st.10 and st.11, showed smaller values. Fig.VII.2.7 shows the average and the range of cell numbers in each season. This figure reveals a great difference between the maximum and the minimum cell numbers, because the standing crop sharply

fluctuated from station to station and the stations in the northern half of the lake showed higher cell numbers than those in the southern half.

When seasons are arranged in cell numbers, the following order is obtained, March > December > April > June > September > October > August > July. High standing crops were observed in early spring and winter, while low ones were observed in summer. Round (1960) reported that the benthic epipelic diatom community undergoes distinct seasonal changes and he summarized this change as low winter growth, high spring growth, variable (sometimes negligible) summer growth and moderate autumn growth periods. The high standing crops of a winter in Lake Yunoko contrasted with his data. Why he attributed the low growth in winter to decreasing light intensity is considered to be the high latitudes of his fields, while Lake Yunoko is located at the temperate regions and so light could not be the limiting factor of algal growth in winter. On the other hand, the wave action may wash off a large numbers of periphytic algae and this caused the low standing crop. So, it is considered that the high production of epipelic and epilithic algae during winter or early spring may partly be caused by a physical stability as decrease of wave action, which resulted from the partial freezing of lake water.

VII.3. Seasonal variation of cell number classified by phyla (Table VII.3.1.- VII.3.3.)

The main components at st.1 were the diatoms and the

blue-green algae in March and July 1967 and in March 1968, but from December 1968 on the algal communities were mainly composed of the diatoms. The occurrence of the blue-green algae corresponded with the abundant effluent from the hot spring near this station. The diatoms prevailed at st.2, 3,4,12 and 13, all of which were the sunny places. At st.5, the diatoms prevailed and the blue-green algae joined the dominant species with the diatoms since June 1976.
The blue-green algae, mainly Homoeothrix janthina, replaced the diatoms as the first dominant since June 1976 at st.6, 7, 8, 9, 10 and 11, which were in the shade of trees except st.10.

In contrast to the diatoms which inclined to prevail at sunny places, the blue-green algae profusely grew at the shadowy ones, but the definite correlation between the occurrence of the green algae and enviromental situations was hardly observed. In general, the blue-green algae abundantly grow in the season of high water temperature in the most of Japanese rivers (Fukushima and Ko-Bayashi 1971), but such a general feature was not observed in Lake Yunoko. Except at st.6, 7, 8, 9, 10 and 11 from June 1976 on, the diatoms composed the significant part of the epilithic and epipelic communities.

VII .4. Dominant species

VII .4.1. Analysis of dominant species according to the sampling dates

March 1967 : Among 4 stations, the blue-green algae

predominated first only at st.1 where the organisms with a tolerance to pollution such as Synechococcus eximius and Nitzschia palea grew abundantly. Fragilaria pinnata was observed predominantly at st.2 and this species is considered to be the typical periphyton of the lake. Melosira italica f. curvata which is regarded as a planktonic species and Fragilaria spp. prevailed at st.3 and st.5 (Fig.VII .4.1).

July 1967 : The blue-green algae took comparatively high rank at st.1, 8, 9 and 11, among which Synechococcus eximius, regarded as having a strong tolerance to pollution, hold the first rank at st.1 and st.11.

Fragilaria pinnata, which widely distributed at the lake bottom, predominated first at st.2.

St.3,5 and 12 had the same dominant species, Fragilaria spp.

Gomphonema intricatum took the first rank at st.8 which was located near the water fall, and G. clevei var. javanica ranking the second and Homoeothrix ranking the third are generally considered to be the lotic species. The lotic species G. clevei var. javanica constituted a large part of the community at st.9 just above the water fall.

Homoeothrix janthina was commonly found at st.8, 9, 10 and 11, among which it predominated first at st.10.

Asterionella formosa widely distributed at all stations other than st.5. It is assumed that this species derived from the deposition of the plankton on the basis of such concept that only Asterionella is conclusively euplanktonic among diatoms (Hutchinson 1967) (Fig.VII .4.2).

March 1968 : The main components of the communities

were diatoms and blue-green algae. The latter predominated only at st.1 (Synechococcus eximius) and st.9 (Homoeothrix janthina). The commonest diatoms were Achnanthes japonica, Diatoma elongatum and Melosira varians. The lotic species Homoeothrix janthina and Gomphonema tetrastigmata constituted the main part of the community at st.9 which had the lotic condition (Fig.VII,4.3).

October 1968 : The diatoms significantly prevailed through almost all stations except st.6 where the green algae Chaetophora sp. predominated, and the blue-green algae were scarcely found as the first dominant species in this season.

Fragilaria pinnata which distributed widely on the sediment of deeper lake bottom was commonly found at st.2,3 and 13. At st.5 where a spring gushed out, Melosira varians, which is considered to be the typical spring species, predominated. The lotic species, Homoeothrix janthina and Gomphonema clevei var. javanica wich profusely grew at st.7, took the second and the third ranks at st.9.

Cymbella microcephala hold a large part of the community at st.9, 10 and 11, while Achnanthes lineariformis commonly appeard as the first dominant species at st.8 and st.12 (Fig.VII .4.4).

December 1968 : The diatoms commonly took a large part of the communities and the blue-green algae predominated first at only one station, st.10 (Homoeothrix janthina), while the green algae took comparatively high rank at st.6 (Ulothrix sp.).

The diatom Achnanthes exigua was present in a large number instead of the blue-green algae which predominated in the former three seasons.

Similar to the situation in October, Fragilaria pinnata commonly predominated at st.2,3 and 13. Achnathes lanceolata, which could not show the strong tolerance to water pollution, lived in a large number at st.5.

Melosira italica f. curvata distributed commonly at 8 of 11 stations, among which it predominated first at st.6 and st.12. The first dominant species Achnanthes lineariformis was common in both October and December 1968 at st.8.

The st.9 supported the lotic species as Gomphonema angustatum var. producta, A. lineariformis and G. clevei var. javanica.

In contrast to the dominant species in October, the first and the second dominant changed their ranks at st.10; so Homoeothrix janthina took the first rank and Cymbella microcephala the second without significant difference in their percentage occurrences. C. microcephala also constituted a large part of the biomass at st.11 (Fig.VII .4.5).

September 1972 : Both the diatoms and the blue-green algae were dominantly present and the diatoms ranked first at northwestern half of the lake (st.1 - st.6).

The blue-green algae and the green algae took the first rank more frequently than the diatoms at another half part of the lake (st.7 - st.12). The commonest diatom was Fragilaria pinnata at 7 of the 32 stations followed by Homoeothrix janthina and Stigeoclonium sp.

There was little correlation between the first diminant

species and the water depth, owing to the difference of distances from the shore at the same stations, at st.1, 2, 4, 6, 7 and 12, all of which were located almost at the northern half of the lake. In this season, no lotic species were recongized at st.9.(Fig.VII .4.6).

December 1972 : The diatoms widely predominated first and the blue-green alga Homoeothrix janthina ranked first only at st.11-1. The commonest diatom was Melosira distans at 12 of the 32 stations and its distribution was limited at the southern half of the lake such as at st.6, 7, 8, 9, 10, 11 and 12. Fragilaria pinnata was widely present, following M. distans,but its distribution was confined to st.2, 3 and 4. The other common species as the first dominant were H.janthina, Achnanthes austriaca, A. exigua, A. lineariformis, Amphola ovalis var. pediculus, Cymbella leptoceros, Gomphonema tetrastigmata, Rhoicosphenia curvata and Synedra acus.

As regard to the first dominant species of the different depths at the same station, little difference was found at st.1 (Achnanthes exigua), st.2 and st.4 (Fragilaria pinnata), st.5 (Amphola ovalis var. pediculus) and st.6, 7 and 8 (Melosira distans). These stations were localized at the northwest and southwest sides of the lake.

The lotic species such as H. janthina, A. lineariformis, G. clevei var. javanica, G. tetrastigmata and S. ulna were frequently found at st.8, 9 and 10 which were located near the water fall (Fig.VII .4.7).

March 1973 : The diatoms occupied a large part of the first dominant species, especially Melosira distans which

commonly lived at the southern half of the lake, followed by Fragilaria pinnata which specifically distributed at the sandy stations as st.2 and st.4. Diatoma hiemale var. mesodon, which generally grew abundantly in a cold lotic water, was found at st.5 presumably because a great amount of the spring gushed out near this station.

The significant difference in the depth distribution of the first dominant species at the same stations was hardly observed at the northern to northwestern stations such as st.1 (Achnanthes exigua), st.2 and st.4 (F. pinnata), st.5 (Diatoma hiemale var. mesodon)and st.6 (Melosira distans) (Fig.VII .4.8).

April 1976 : The blue-green algae were present at 7 of the 32 stations as the first dominant species and the diatoms accounted for the remainder. The commonest diatom was Fragilaria pinnata which appeared at the northern half of the lake such as st.2, 4, 5 and 12, followed by Stephanodiscus sp. which was localized at st.9, 10 and 11, the southeast part of the lake. Homoeothrix janthina locally predominated at 7 stations in the southern part of the lake. Synedra rumpens var. fragilarioides produced a large population at highly eutrophicated stations which were located in the northern part of the lake.

The occurrence of F. pinnata var. lancettula was parallel with that of F. pinnata, although the latter was mostly present in following seasons (Fig.VII .4.9)

June 1976 : The commonest and widely distributing species was Homoeothrix janthina. It appeared in the southern

half of the lake and constituted a large part of the community. Fragilaria pinnata was present in large numbers at the northern stations,especially at sandy ones. The other first dominant species were Fragilaria spp., which predominated at 3 stations, Synedra rumpens var. fragilarioides and F. pinnata var. lancettula (Fig.VII .4.10).

August 1976 : The commonest alga was Homoeothrix janthina at 17 of 32 stations, although its distribution was localized at the southern half of the lake, where the floras were very simple because it constituted considerably large part of the community. The other important first dominant species was F. pinnata which appeared almost at all stations other than such stations where H. janthina was found (Fig.VII .4.11).

October 1976 : In regard to the occurrence of the first dominant species the same tendency as that in August 1976 was observed in this season, although Chamaesiphon africanus var. minimus replaced H. janthina at st.10 and st.11 (Fig.VII .4.12).

The most significant first dominant species over 4 seasons in 1976 were Homoeothrix janthina and Fragilaria pinnata. The distribution of H. janthina was limited at several stations in April, while it predominated at the most stations which were located in the southern half of the lake in June, after which it declined owing to the replacement of the first dominant one by another algae in August and October. Although this species is considered to be the cold-water species in Europe, it has been observed in many rivers in Japan that the higher the water temperature became, the

more widely it distributed. So, there would be some correlations between the water temperature and its distribution in Lake Yunoko. The relation between the number of stations where F. pinnata predominated first and the season was reverse to the case of H. janthina, and their distribution seldom overlapped each other.

VII.4.2. Analysis of dominant species according to the sampling stations

Station 1 : The common diatoms were Synechococcus eximius, Achnanthes exigua and Fragilaria pinnata. It is difficult to find out a regular seasonal succession in the dominant species.

Station 2 : F. pinnata frequently dominated first in almost all seasons.

Station 3 : No definite seasonal succession in the dominant species was observed.

Station 4 : F. pinnata and F. pinnata var. lancettula were present in all seasons.

Station 5 : Some species, which grew characteristically in the spring, occasionally appeared, but regular seasonal succession was hardly observed.

Station 6 : Melosira distans usually grew under the ice in December 1972 and in March 1973, while Homoeothrix janthina abundantly appeared in June 1976 and it subsequently predominated since that time.

Station 7 : The commonest diatom under the ice in December 1972 and in March 1973 was M. distans. H. janthina occupied large part of the community in and after April 1976.

Station 8 : The algal communities were frequently composed of lotic species throughout all seasons. H. janthina predominated in and after April 1976.

Station 9 : The main algal communities were strongly affected by planktonic and lotic species. The simple flora since June 1976 was a reflection of the abundant occurrence of Homoeothrix janthina.

Station 10 : Planktonic and lotic species were frequently found in the algal communities and H. janthina predominated since June 1976.

Station 11 : The blue-green algae were often observed, but significant seasonal succession was hardly recognized.

Station 12 : Fragilaria species commonly appeared in all seasons except in December 1972 and in March 1973.

Regarding the dominant species, it is difficult to recognize regular seasonal succession within epilithic and epipelic assemblage throughout all stations. At st.2 and st.4, Fragilaria pinnata was commonly present in most of the time and it predominated first over the studied period except in March 1968. This species was usually found at stations characterized by a higher nutrient content in a similar way as F. construens (Hickman 1974) and F. construens var. venter (Round 1957).

Melosila distans was frequently observed under the ice. Considering from this feature in addition to the fact that it was present on comparatively deeper lake bottom, it is supposed that this species can grow over a wide range of a light intensity.

It was observed that the species, which were considered to be derived from plankton,showed appreciable growth as a component of the littoral benthic communities in certain season, but they were never detected as a number of the dominant in the following season, while other benthic algae could be often found in the following season. So, it is assumed that plankton-origin species can not remain as a periphyton for a long period.

Homoeothrix janthina was present in large numbers since April 1976 and more studies are need to explain this appearance.

VIII DISCUSSION

The commonest benthos in the limnetic zone was Fragilaria which also occurred always as the littoral benthic algae ; especially at st.2 and st.4 it prevaild over the studied period and tended to distribute at the north shore (e.g. st.1, 2, 3, 4, 5 and 13) which was strongly affected by polluted water, and at deeper part of the inlet, st.12. It may be possible to consider that Fragilaria, especially F. pinnata, have the wide range of tolerance for pollution and of light intensity in which it might grow, since they showed appreciable growth on the deeper lake bottom with high organic content.

In general, many algae are able to utilize organic substrates, such as sugars and organic acid, to maintain growth in complete darkness or as the sole source or a supplementary source of carbon in the light. The algae able to grow in darkness are derived mainly from soil, heavily contaminated water, or littoral marine habitats (Lewin 1963).
It has been suggested that the pennate diatoms may have more heterotrophic species in comparison with the centric diatoms which are predominantly photoautotrophic(Lewin 1963 ; Lylis & Trainor 1973). This seems logical because the pennates are usually closely associated with the organic bottom substrata. The greatest number of heterotrophic species are found in the pennata diatoms. Lylis and Trainor (1973) found that Pinnularia sp., Eunotia sp., Gomphonema parvulum, Navicula molha and Nitzschia palea grew heterotrophically.

To ascertain the heterotrophic capability of Fragilaria

pinnata including F. pinnata var. lancettula, the batch culture was attempted. The diatoms used in this study were isolated from the benthos growing on the lake bottom, 10 m deep. Cultures were maintained in Fogg's liquid medium (1956) to which sterile vitamin B_{12} (3.0 μg / l) was added instead of soil extract. Samples containging approximately 1.2 - 1.5 x 10^4 cells / ml were cultured for 24 hr in total darkness or in continuous light of 100 or 2000 lux. The water temperature was kept at about 11°C. Glucose (10.0 mg / l) was used as carbon source. Sterility was checked by inoculating nutrient broth. Growth of F. pinnata (including F. pinnata var. lancettula) was determined by the chlorophyll concentration (Fig.VIII.1) and by cell counts. The results for growth on the basis of cell numbers are presented in Table VIII.1. Growth as determined by increase in the cell number and chlorophyll concentration indicated that glucose supported the heterotrophic growth. When glocose in cencentration of 10 mg / l was provided, a moderate increase of cells was observed in the dark or in weakly illuminated cultures. However, in continuous light (2000 lux), the growth was not enhanced if glucose was provided. Similarly, in the case of Cyclotella cryptica it has no ability to take up glucose when grown at high light intensities, but when cells are incubated at lower light intensities or in complete darkness, the glucose transport capacity increases (Hellebust 1971). It is likely that light conditions control the uptake of glucose.

Fogg (1965) suggested that an organic substrate may enable

an alga ot attain a higher relative growth rate than would be possible without the substrate in the light condition. In the case of Scenedesmus constulatus var. chlorelloides it attained a maximum value for the relative growth constant, k, which could not be increased by supplying glucose, at saturating light intensities, while at limiting light intensities k was increased by a supply of glucose but never to a value more than that attained at saturating light intensity (Roach 1928). Such enhancement of growth by glucose under the dim light or complete darkness occurs with the benthic diatom F.pinnata in Lake Yunoko. Fogg and Belcher (1961) also observed similar tendency in the planktonic Chlorella pyrenoidosa.

These results suggest that F. pinnata (including F. pinnata var. lancettula) may heterotrophically survive in weakly illuminated or complete dark conditions, although the growth was slow.

The fact that the dead cells which predominated as plankters in the previous season increased at the lake bottom and the composition of the dominant species in the dead benthic communities suggests that the dead cells in benthic communities were mostly derived from the plankton.

Simultaneous sampling of both littoral benthos and plankton was made in October and November 1972 and in April, June, August and October 1976. The dominant planktonic species in October 1972 were Chlamydomonas sp. and Aphanocapsa elachista var. planktonica. The former occasionally appeared with a very small amount at a few littoral stations, but

it was impossible to detect the latter species in the littoral benthic community.

Melosira distans, Synedra acus and M. italica f. curvata were present in large numbers as plankton in December 1972. M. distans and S. acus widely distributed at the littoral stations while M. italica f. curvata was scarcely present.

Stephanodiscus sp., S. acus var. radians, Chlamydomonas sp. and S. ulna var. danica achieved a significant percentage occurrence as plankton in April 1976. Stephanodiscus sp. prevailed as the littoral benthos only at the southern part of the lake and S. acus also composed one of the dominant benthic algae at the littoral, while S. acus var. radians less frequently predominated. In contrast to the three taxa described above, Chlamydomonas sp. was present in very small numbers at several littoral stations and S. ulna var. danica was never found.

The dominant planktonic species, Cryptomonas sp. and Chlorella ellipsoidea, were never observed as the littoral benthos in June 1976.

In August 1976, the dominant phytoplankton was composed of Stephanodiscus sp., Dinobryon bavaricum and Chlamydomonas sp. at the upper layers and Aphanothece sp. at the lower ones. They were hardly observed as littoral benthos. This might be due to the fact that the strong wind gererally blows from the south in summer season, therefore, the surface water was drifted to the northern shore which was directly affected by polluted water. Thus, it would be difficult for certain plankton to flourish at such region as benthos.

In addition, the sediment at the north side shore was subjected to more marked physical disturbance caused by wind or human activities, and this might sweep away such loosely attached periphyton as phytoplankton-derived species.

The dominant planktonic species Ochromonas sp. and Chryptomonas sp. in October 1976 were never present at littoral stations.

Throughout these observations, the dominant planktonic species were never observed at st.1, 2, 4 and 5, where the benthic communities represented distinctly different species composition from the plankton. Since these stations other than st.5 were characterized by a higher nutrient content, only such species as those having the affinity to a higher nutrient status could grow abundantly, while at st.5 where the spring flowed out, the dominant species reflected some characteristics of the spring. In addition, these stations were subjected to considerable water movement which might cause the removal of loosely attached algae. The abovementioned facts might be partly due to the absence of plankton-derived species at several northern littoral stations.

Thus, the phytoplankton communities produce variable effects upon the littoral benthic communities. The extent of their effects is attributed in part to the physico-chemical enviromental conditions at littoral stations and the characteristics of each phytoplankton species such as the tolerance for highly eutrophicated condition and adaptability of living in different habitat as epipelic or epilithic algae.

In regard to the origin of phytoplankton, there is a

concept that benthos becomes plankton. In this case, the plankton falls onto the sediment and forms resting spores, and floats again into the water when conditions become favorable. So, there is a steady build-up of plankton on the sediments (Wesenberg & Lund 1908, Nauman 1927). Lund (1954) indicated that planktonic species of Melosira become benthos, when condition is unsuitable for their growth and turbulence is insufficient to keep them afloat, and survive on the sediment forming resting spores until they move again into plankton. Stockner and Armstrong (1971) observed that Cyclotella stelligera, which is common in the littoral periphyton, is rapidly removed and becomes common in the phytoplankton.

Interaction between the plankton and periphyton was also studied by Brown and Austin (1973) paying attention to the occurrence of species common to both habitats, and it was clearly observed that a decrease in cell numbers and percent abundance in planktonic populations coincided with an increase in the periphyton.

On the other hand, there are also many evidences to show that benthos-origin plankton is generally an erroneous concept in moderate to large lakes. Round's works (1964) show that there is never any conspicous build-up of plankton on the sediments before a large plankton bloom.

As to Asterionella Lund (1949) concluded that the live cells of this species always survive at low population levels as plankters and are able to increase in numbers when conditions are suitable for them. It is proposed that the planktonic diatoms are not tychoplankton and the planktonic diatom

populations exist which react independently of the epiphytic and epipelic populations, suggesting the presence of genetic difference (Clerk & Runnels 1975).

Considering from these observations it is assumed that the main components of the phytoplankton communities never originated from the benthos except in small or shallow lakes, although it was reported that Melosira resuspends from the lake bottom due to the isothermal mixing currents, while it is possible that the plankton with a small numbers derives from the resuspension of benthos by water turbulence and it may never becomes the main plankton but accidental one. Whereas littoral and profundal deposits receive cells from the plankton and these deposits are not returned to the plankton except some species. The "inoculum" for phytoplankton may always be present in the open water even though below the level of detection, and it can develop and become integral constituent of the plankton if sufficient nutrients, light and water temperature are available.

IX SUMMARY

Phytoplankton and benthic algae in Lake Yunoko have been studied from ecological and physiological points of view.

The horizontal standing crops of phytoplankton as measured by cell numbers represented high level in the spring and remained at a relatively low level during the summer before the autumnal second maximum, although the standing crop differed with sampling stations even in the same sampling season. The phytoplankton communities were dominated by less than 4 taxa and these taxa were fairly evenly distributed throughout all stations, but the percentage occurrences of each taxa were different at each station.

In regard to the succession of the dominant species, no regular tendency was observed since the member of the dominant greatly varied from season to season. Probably because this lake is shallow and subjected to marked water turbulence caused by wind, there were no significant differences in the vertical composition of the dominant species except in August 1976 in which the lake stratified completely.

In regard to the standing crop and the succession of the benthos at the limnetic zone, the maximum standing crop was frequently found at shallower regions, while the minimum at the deepest or its adjascent regions. The live cells on the bottom sediments were confined to species such as *Fragilaria pinnata* which predominated first at almost all regions and *Melosira distans* which also predominated at comparatively deeper ones.

As to *F. pinnata* including *F. pinnata* var. *lancettula*

which were collected from the deeper lake sediments (10 m), they grew heterotrophically in complete darkness or weakly illuminated condition (100 lux), when glucose in concentration of 10 mg/l was provided. However, in continuous light(2000 lux) growth was not enhanced if glucose was provided. It is likely that these species might grow heterotrophically on the sediment of relatively deep lake bottom.

No benthic algae other than Bacillariophyta were found as dead cells on the sediment of the lake bottom. The component species of the dominant dead cells slightly differed with seasons, whereas their percentages varied from season to season and from station to station. The main components of the dead cells were plankton-derived diatoms and partly benthic diatoms growing at the same place.

A significant difference was found in the composition of the communities between the live and the dead cells and between phytoplankton and benthic communities living in the limnetic zones.

In regard to the composition of the dominant species in the littoral benthic communities, considerable variation occurred from station to station among the 12 or 13 stations and from season to season. This is in sharp contrast with the phytoplankton communities in which marked differences were rarely found in the dominant species composition. The standing crops of the littoral benthic algae represented wide range variation in each season and at each station, whereas appreciable growth of Fragilaria species especially F. pinnata frequently occurred and comparatively high standing crop

was observed at highly eutrophicated northern half side of the lake.

Considering from the species composition of benthic algal communities at both limnetic and littoral zones it is unlikely that dominant phytoplankton originated from the benthic communities.

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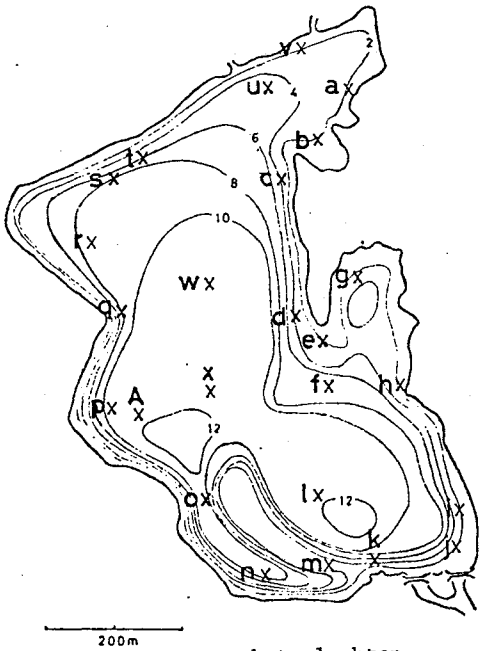
1972 VII			1972 X			1972 XII			1976 IV			1976 VI			1976 VIII			1976 X		
course	depth (m)			(m)			(m)			(m)			(m)			(m)			(m)	
A	1	mud	B	1	mud	A	1	mud	A	1.3	mud	A	2	mud	A	1	mud	A	2	mud
	2	mud		2	mud		1.5	mud		2	mud		2.5	mud		2	mud		3	mud
	3.5	mud		3	mud		2	mud		3	mud		3	mud		3	mud		3.5	mud
B	7	mud		3.5	mud		3	mud		4	mud		4	mud		4	mud		4	mud
	9	mud		4	mud		4	mud		4.5	mud		5	mud		5	mud		4.5	mud
C	12	mud		5	mud		5	mud		6	mud		6	mud		6	mud		5.8	mud
D	4.5	mud		6	mud		6	mud	C	1.8	sandy mud + gravel		7	mud		7	mud		7	mud
	6	mud		7	mud		10	mud		2	sandy mud + gravel		8	mud		8	mud		8	mud
E	9	mud		8	mud	B	1.2	mud		3.5	mud		9	mud		9	mud		9	mud
				9	mud		3	mud		5	mud		10	mud		10	mud		10	mud
				10	mud		4	mud		6	sandy mud	C	2	mud	C	1	mud	C	1.5	mud
			C	1	mud + gravel		5	mud		8	mud		3	mud		2	mud		2.5	sandy mud
				2.5	mud		6.5	mud		10.5	mud		4	mud		3	mud		3	mud
				4	mud		8	mud		11	mud		5	mud		4	mud		3.8	mud
				5	mud	C	1	mud + gravel					6	mud		5	mud		5	mud
				6	mud + gravel		2	sandy mud + gravel					7	mud		11	mud		10	mud
				7	mud		2.5	sandy mud + gravel					8	mud					12	mud
				10	mud		3	mud + gravel					9	mud						
				10.5	mud		4	mud + gravel					10	mud						
				11	mud		5	mud					11	mud						
				12	mud		7	mud					12	mud						
			D	3	mud		10	mud												
			G	8	mud		11	mud												
							11.5	mud												
						F	9.5	mud												

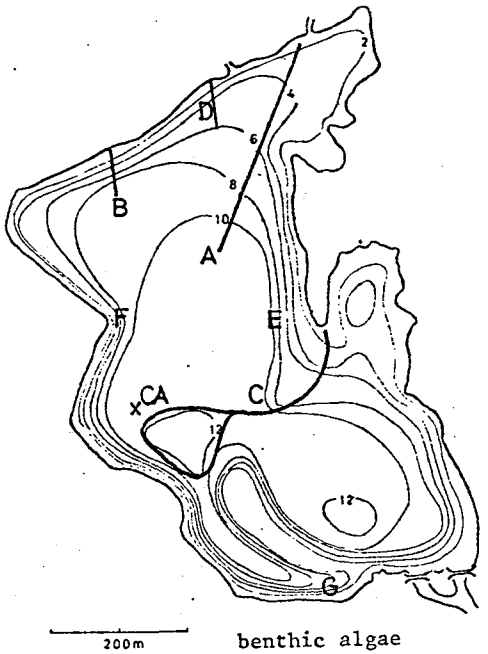
Table III.1 A granular variation of superficial sediment at each depth in Lake Yunoko.

測深図

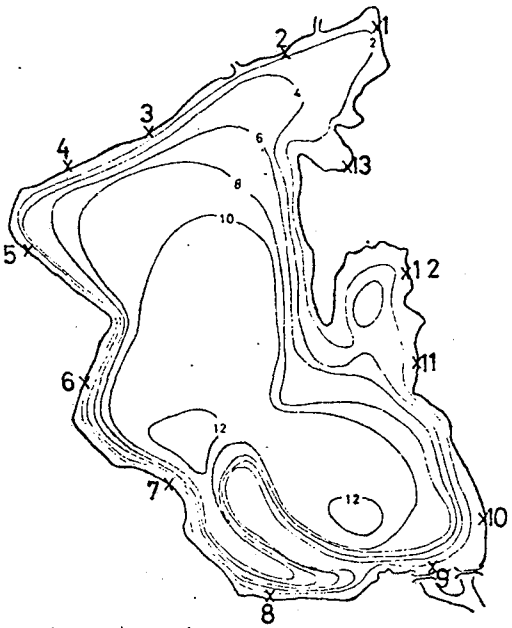
Fig.III.1. Bathymetric map of Lake Yunoko.
The sampling station is indicated with x .



phytoplankton

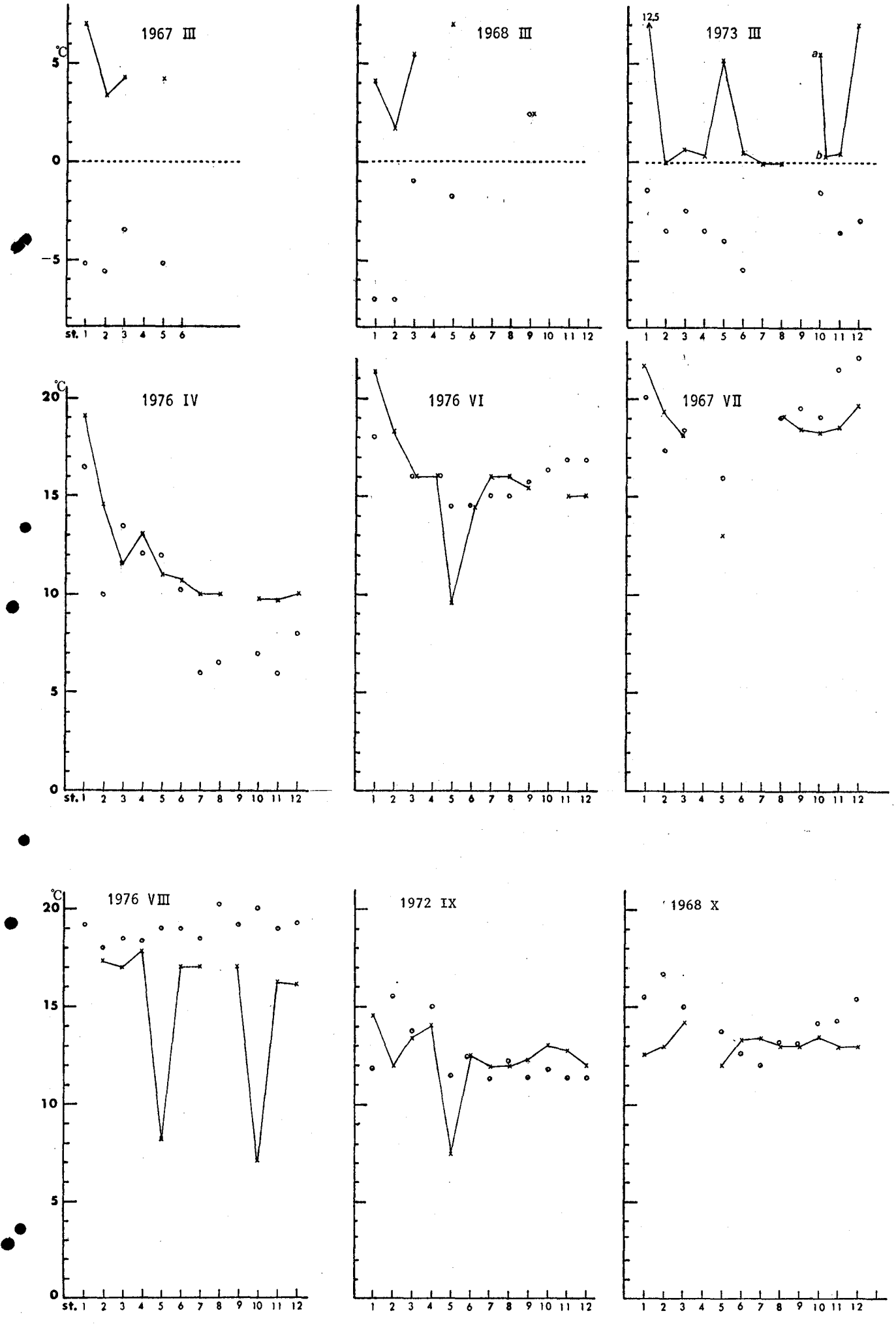


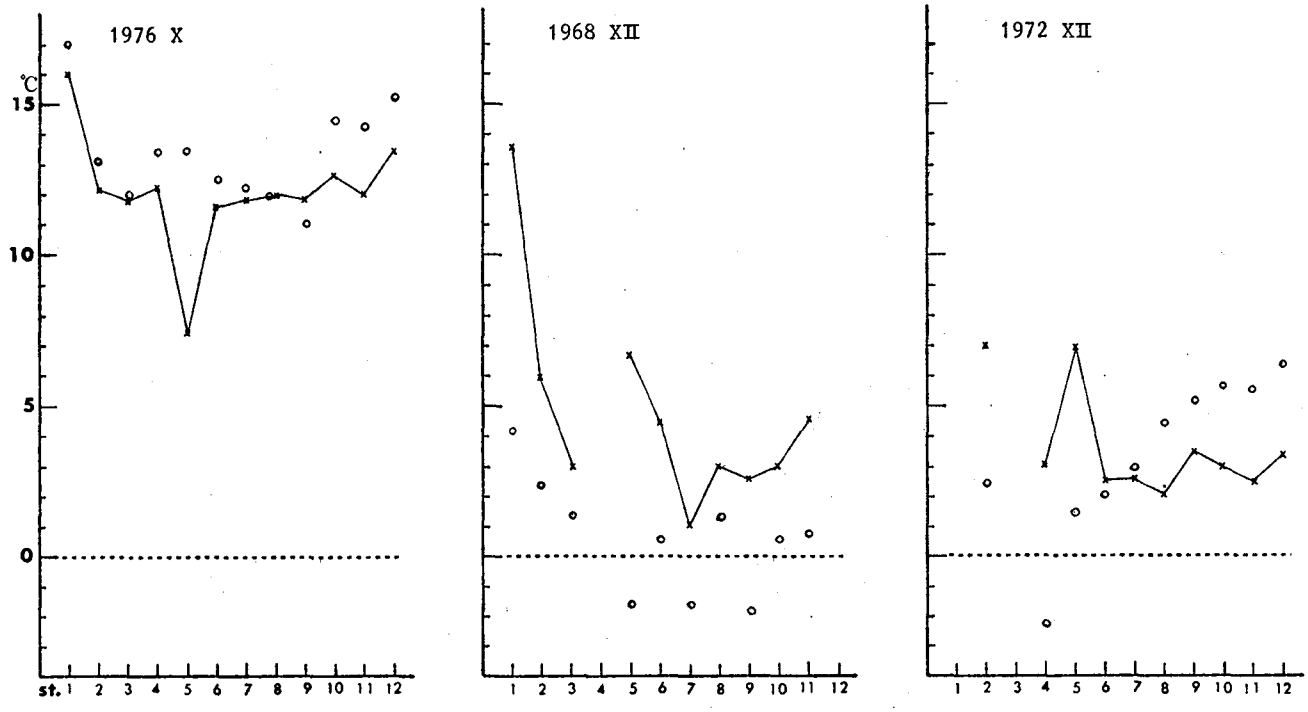
benthic algae



benthic algae at littoral zone

Fig.IV.1. Water temperature (×) and air temperature (∘) in each station.




1976 X
1968 XII
1972 XII
°C
15
10
5
0
st. 1 2 3 4 5 6 7 8 9 10 11 12
1 2 3 4 5 6 7 8 9 10 11 12
1 2 3 4 5 6 7 8 9 10 11 12

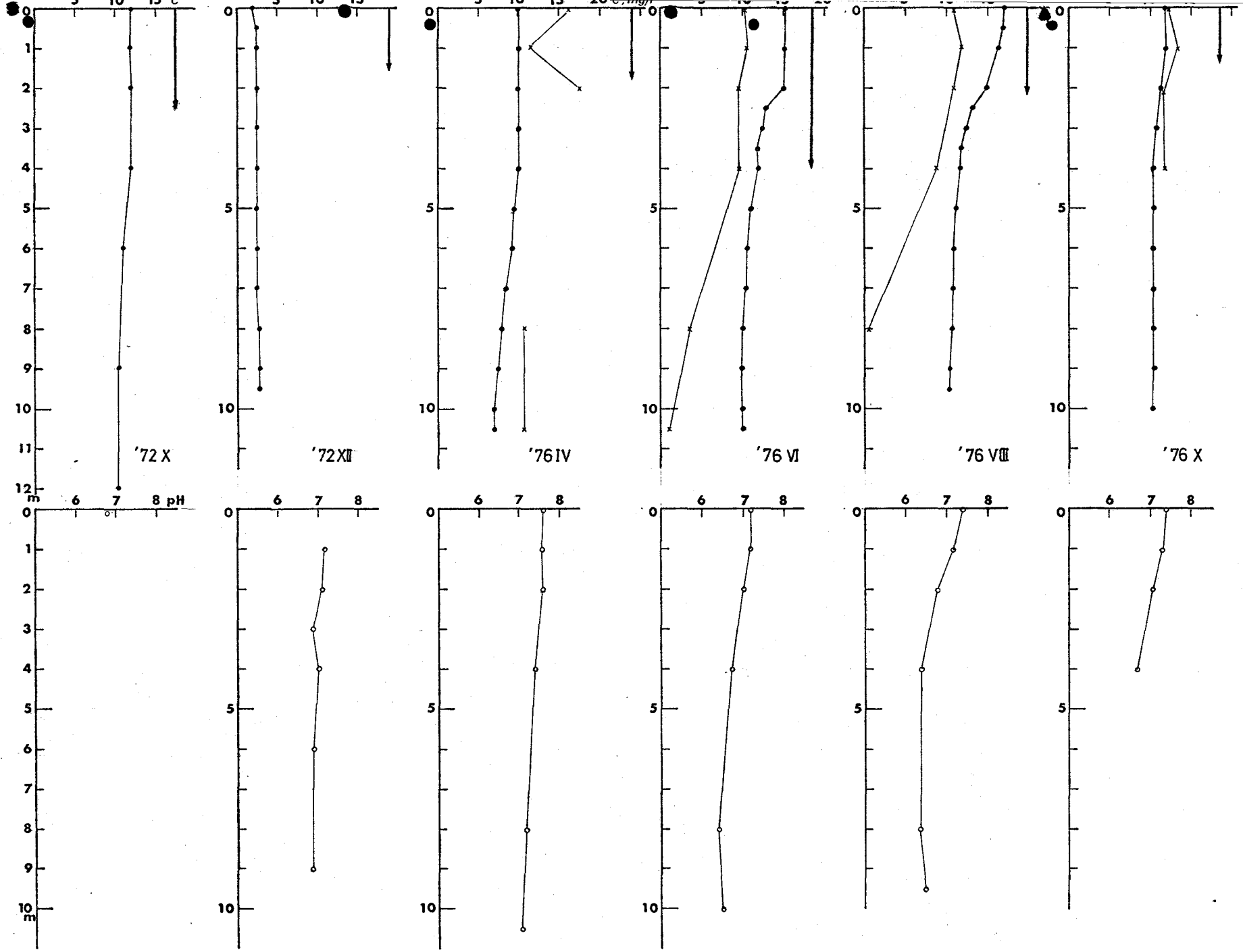


Fig.IV.2. Vertical distributions of water temperature, dissolved oxygen and pH. • water temperature × dissolved oxygen ○ pH ↓ secchi depth

Table V.1.1. Seasonal variation of phytoplankton taxa in horizontal distribution.

date		no. of samples	Cyano-phyta	Eugleno-phyta	Crypto-phyta	Chryso-phyta	Bacilla-riophyta	Chloro-phyta	total
1976	IV	9	0	0	0	0	12	4	16
	VI	5	0	0	1	0	1	4	6
	VIII	8	0	0	1	1	6	5	13
	X	7	0	0	1	1	3	3	8
	total	29	0	0	1	2	15	9	27
1977	VI	17	1	1	1	0	6	5	14
grand total		46	1	1	1	2	18	14	37

Table V.1.2. Relative abundance of phytoplankton in horizontal distribution.

date		Cyano-phyta	Crypto-phyta	Chryso-phyta	Bacilla-riophyta	Chloro-phyta
1976	IV	0%	0	0	97.2	2.8
	VI	0	71.9	0	1.2	26.9
	VIII	0	3.1	16.3	46.9	33.5
	X	0	28.6	69.4	1.5	0.5
1977	VI	0.4	45.9	0	53.3	0.4

Table V.1.3.
A comparison of diversity index values at each station.

Date & Station		Value of Diversity Index
1976 IV	d	1.51
	g	1.06
	m	1.55
	n	1.56
	o	1.47
	p	1.41
	q	1.60
	r	1.22
	s	2.04
1976 VI	d	1.10
	e	0.68
	q	0.37
	w	0.23
	x	0.31
1976 VIII	c	1.99
	f	1.86
	l	1.69
	q	1.65
	r	1.62
	s	1.73
	u	1.50
	w	2.13
1976 X	c	0.95
	f	1.24
	q	1.08
	r	0.97
	s	0.84
	u	0.80
	w	1.15
1977 VI	a	1.01
	b	0.90
	c	1.05
	e	1.04
	g	1.00
	h	1.14
	i	1.08
	j	1.06
	k	0.99
	n	1.05
	p	0.97
	q	0.94
	r	1.29
	s	0.97
	t	1.03
	u	1.04
	v	1.01

Fig.V.1.1. **Cell numbers and dominant species of phytoplankton**

1976 IV

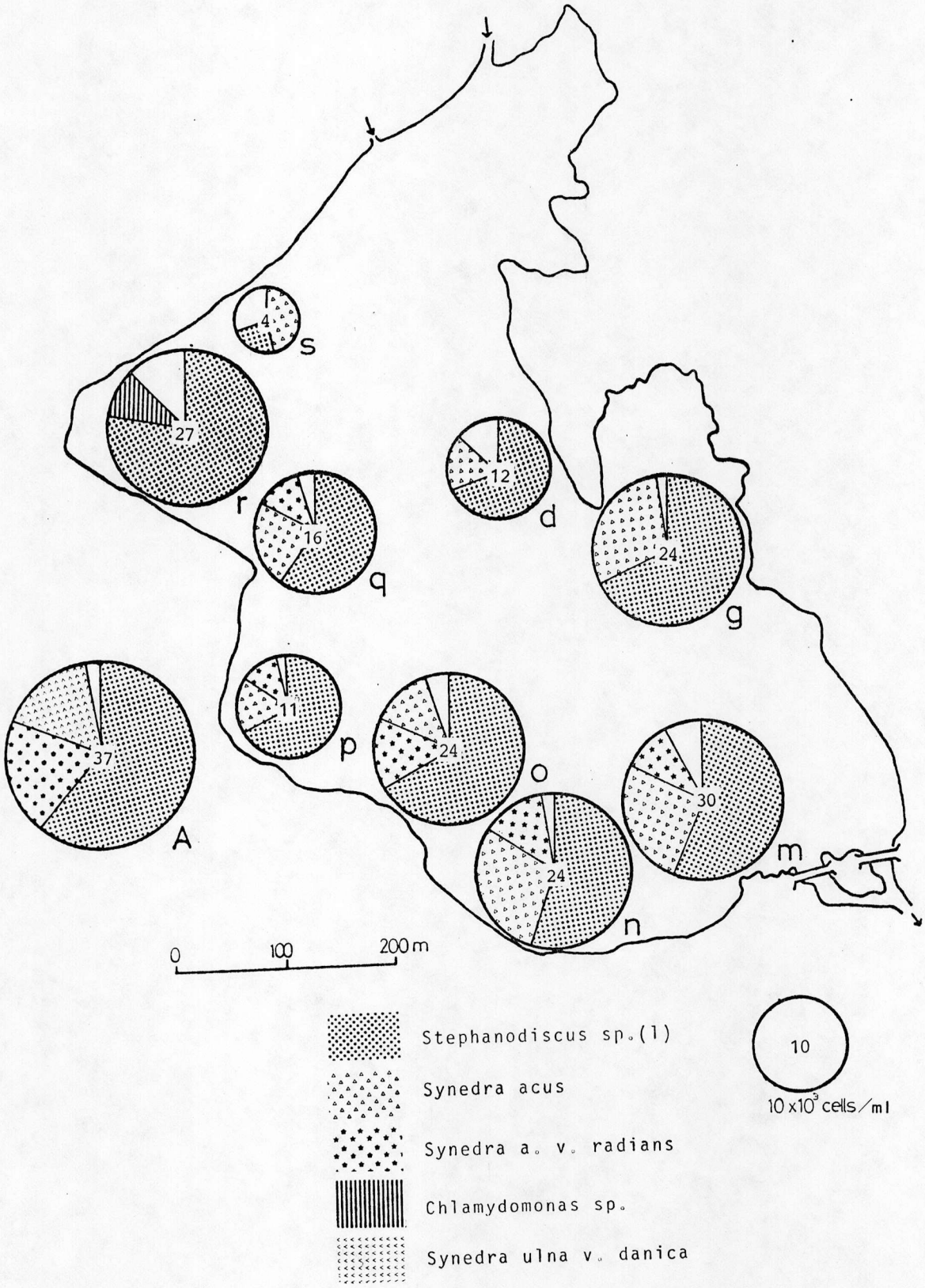


Fig.V.1.2. **Cell numbers and dominant species of phytoplankton**

1976 VI

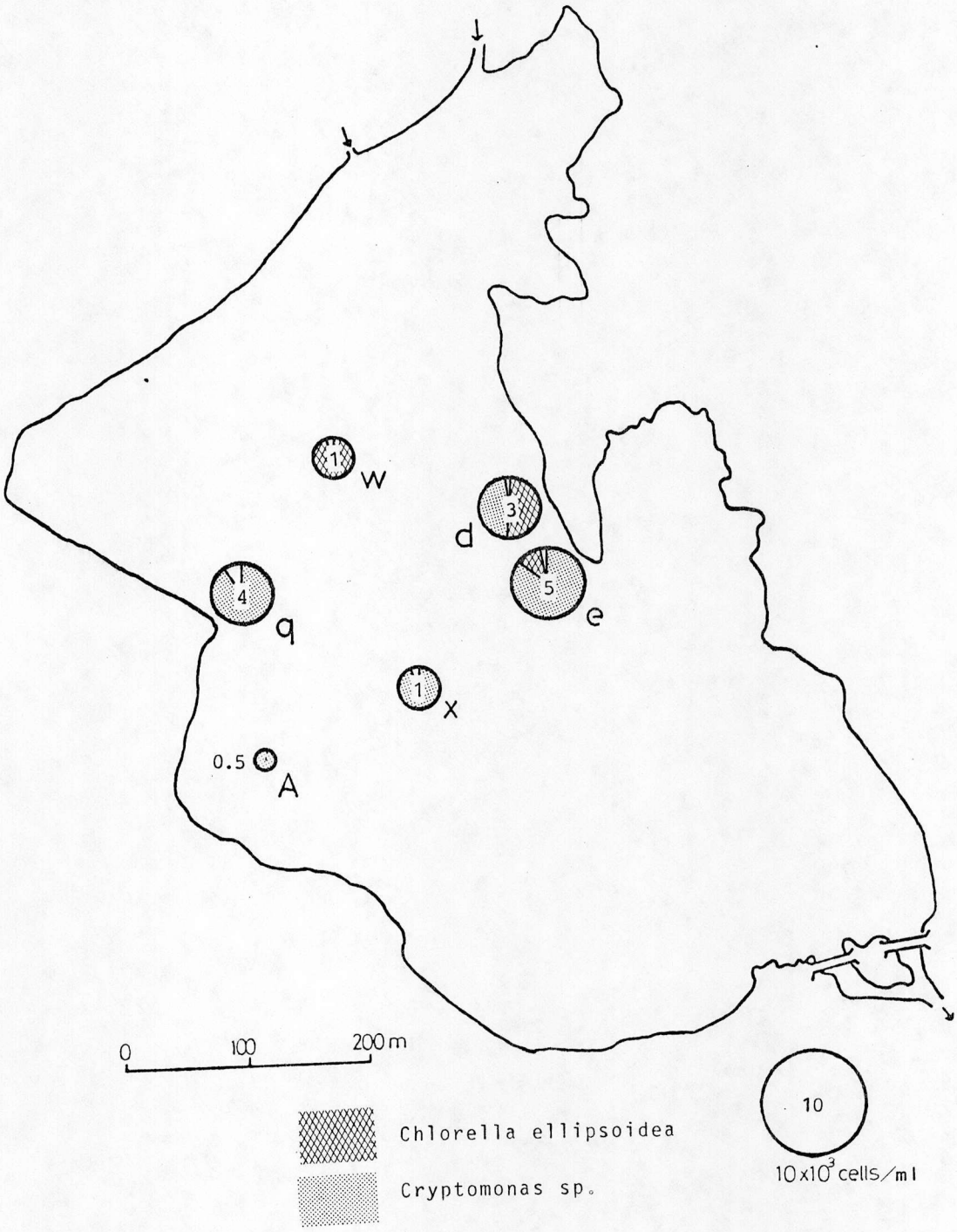


Fig.V.1.3. Cell numbers and dominant species of phytoplankton

1976 VIII

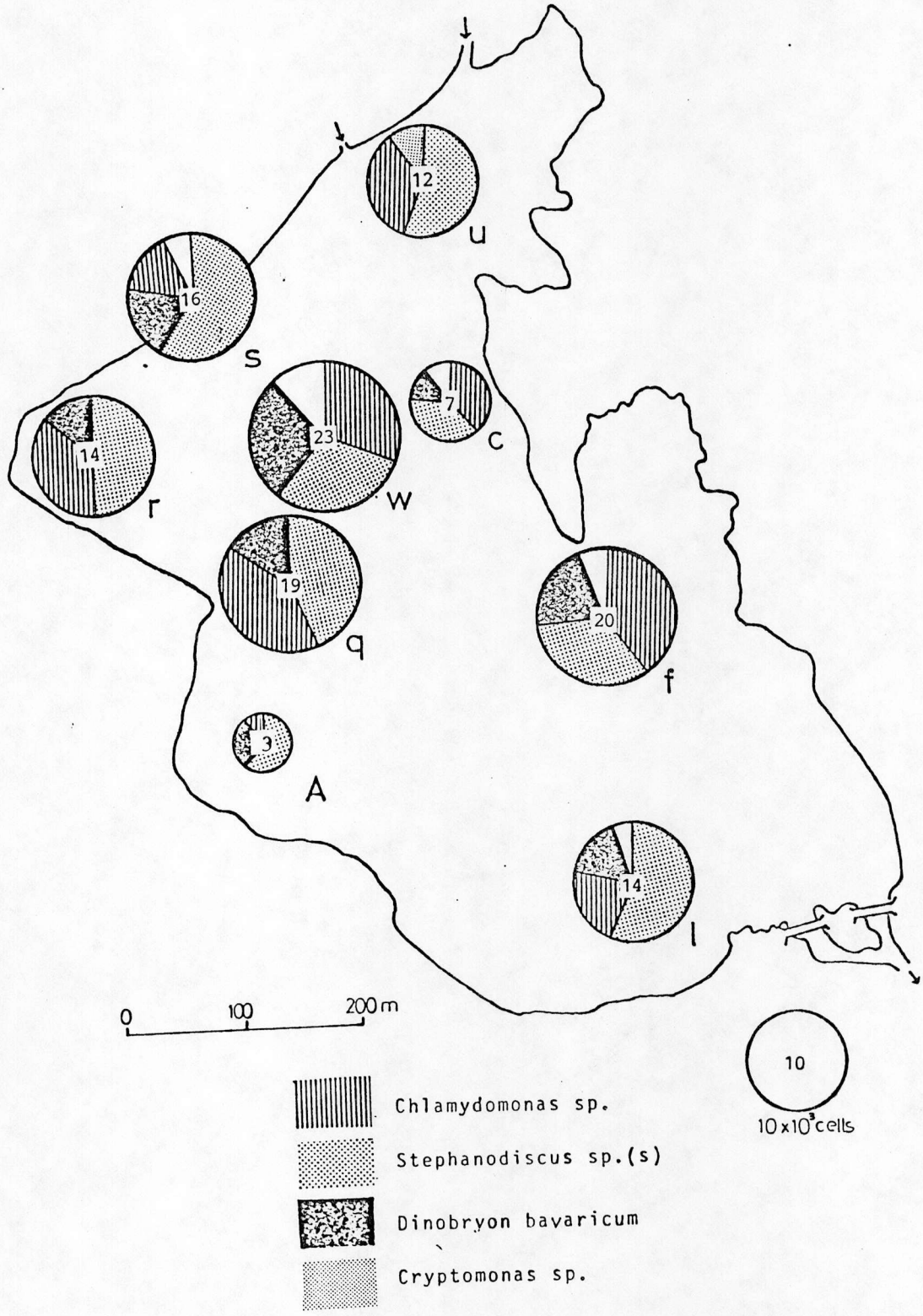


Fig.V.1.4. Cell numbers and dominant species of phytoplankton

1976 X

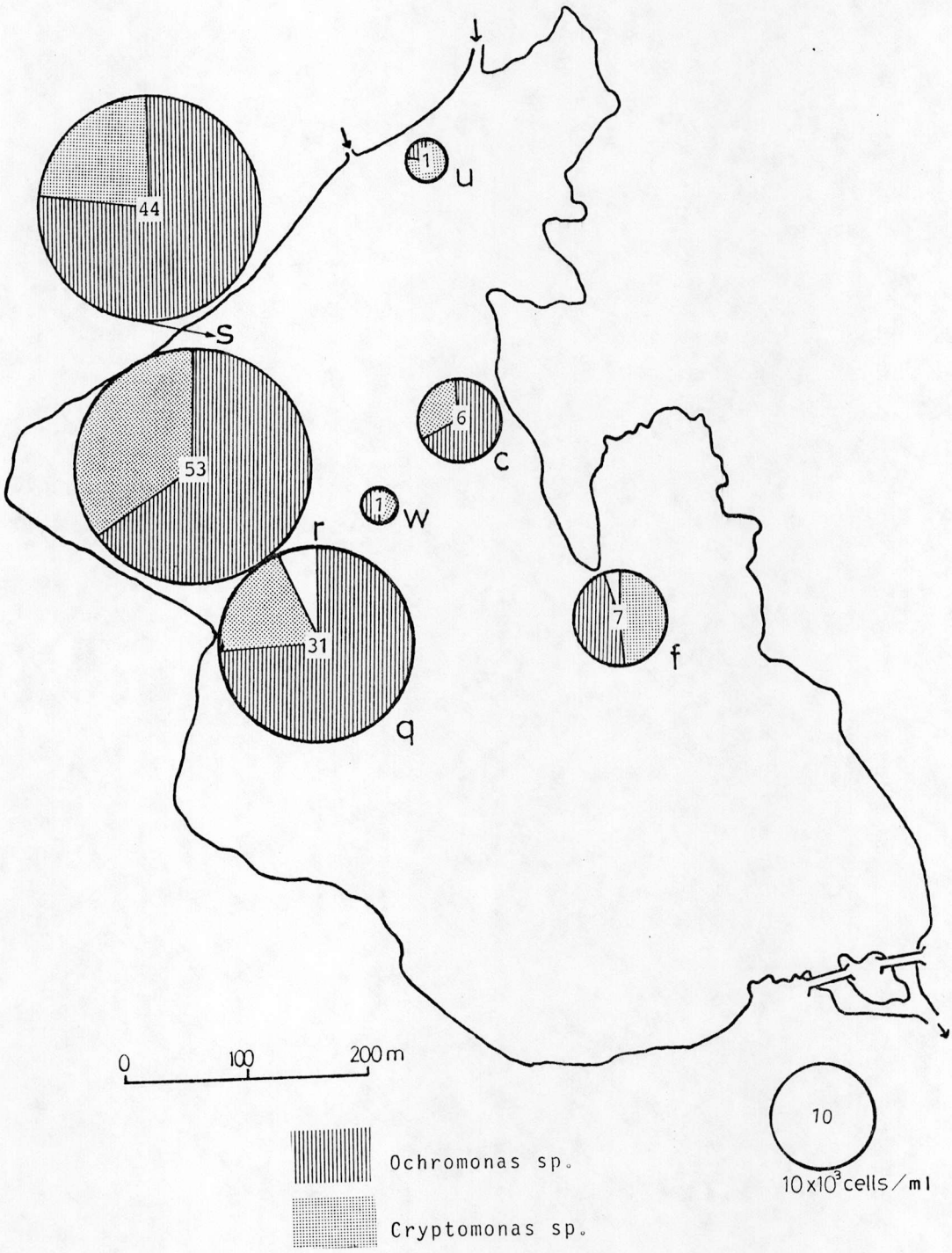


Fig.V.1.5. Cell numbers and dominant species of phytoplankton

1977 VI

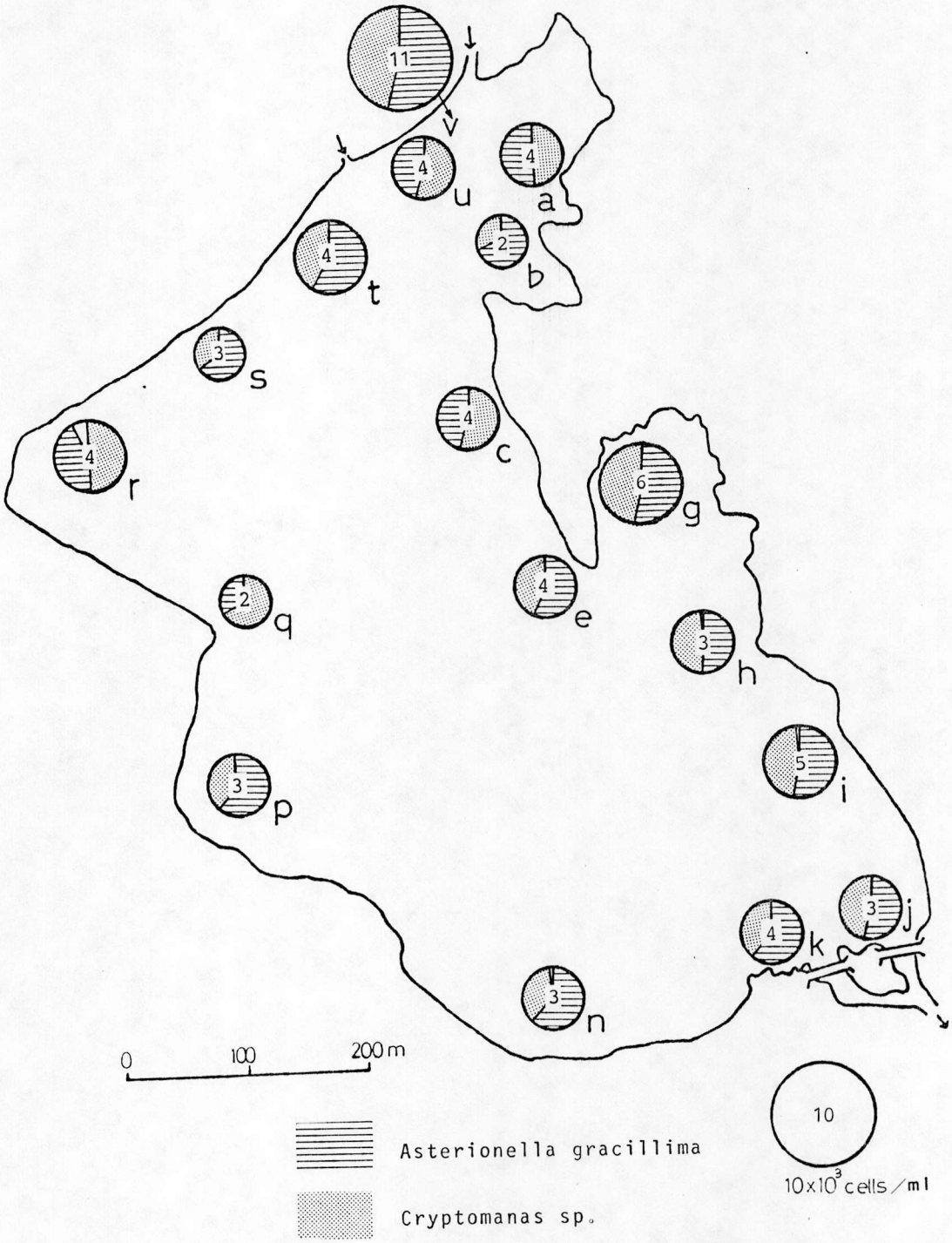
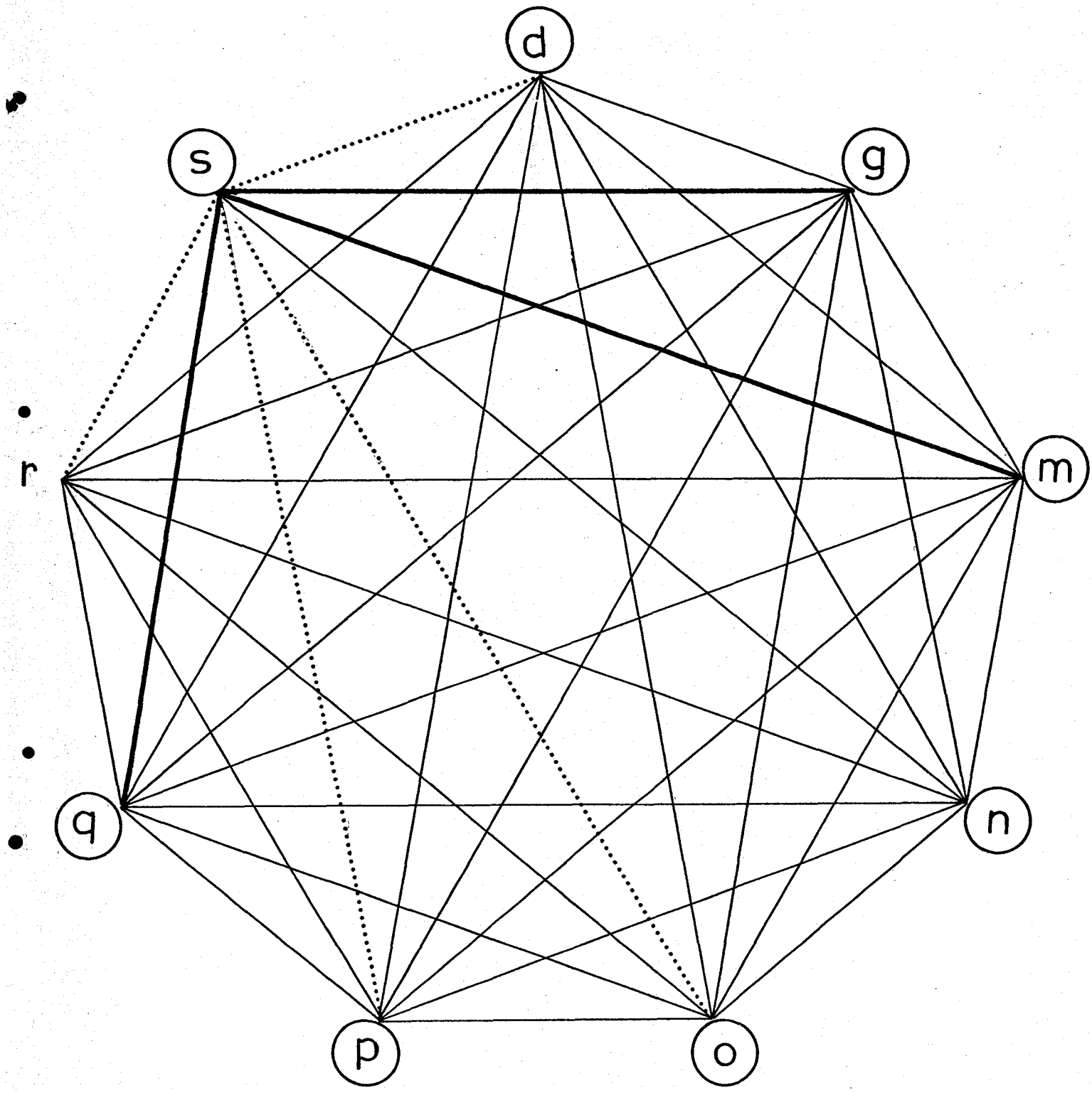


Fig.V.1.6. Cλ Values of phytoplankton in horizontal distribution 1976 IV



This figure shows the Cλ values between two communities at each sampling station, which is indicated the alphabet, by means of three different lines. The values distribute from 0 to 1. The closer the value approaches 1, the more the communities are similar. I estimate the values from 1.00 to 0.80 as showing high similarity (thin line), from 0.79 to 0.70 as slight one (thick line), from 0.69 to 0 as low one

——— 1.00 - 0.80

▬▬▬ 0.79 - 0.70

..... 0.69 - 0.00

Fig.V.1.7. C_λ Values of phytoplankton in horizontal distribution

1976 VI

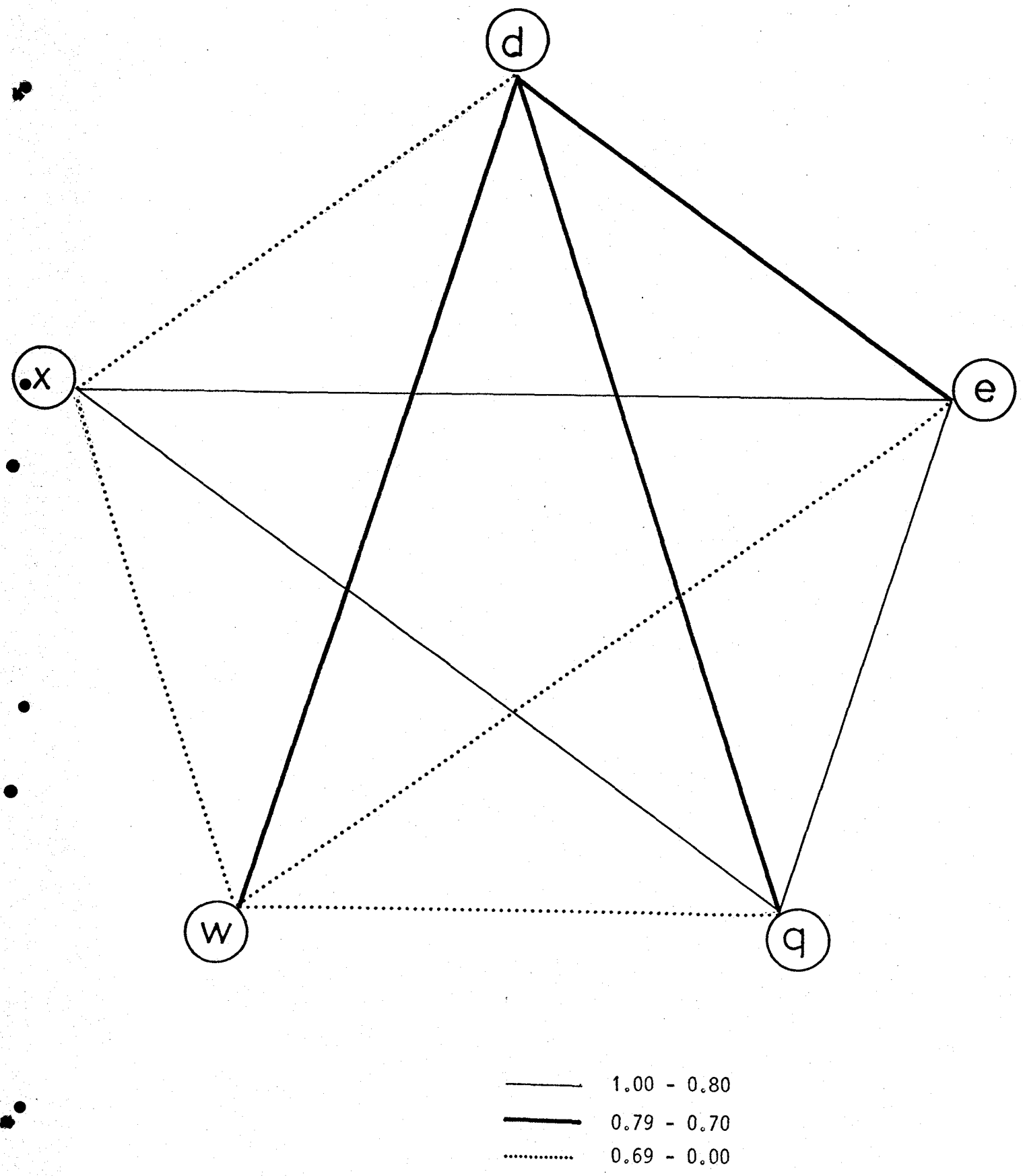


Fig.V.1.8. Ca Values of phytoplankton in horizontal distribution

1976 VIII

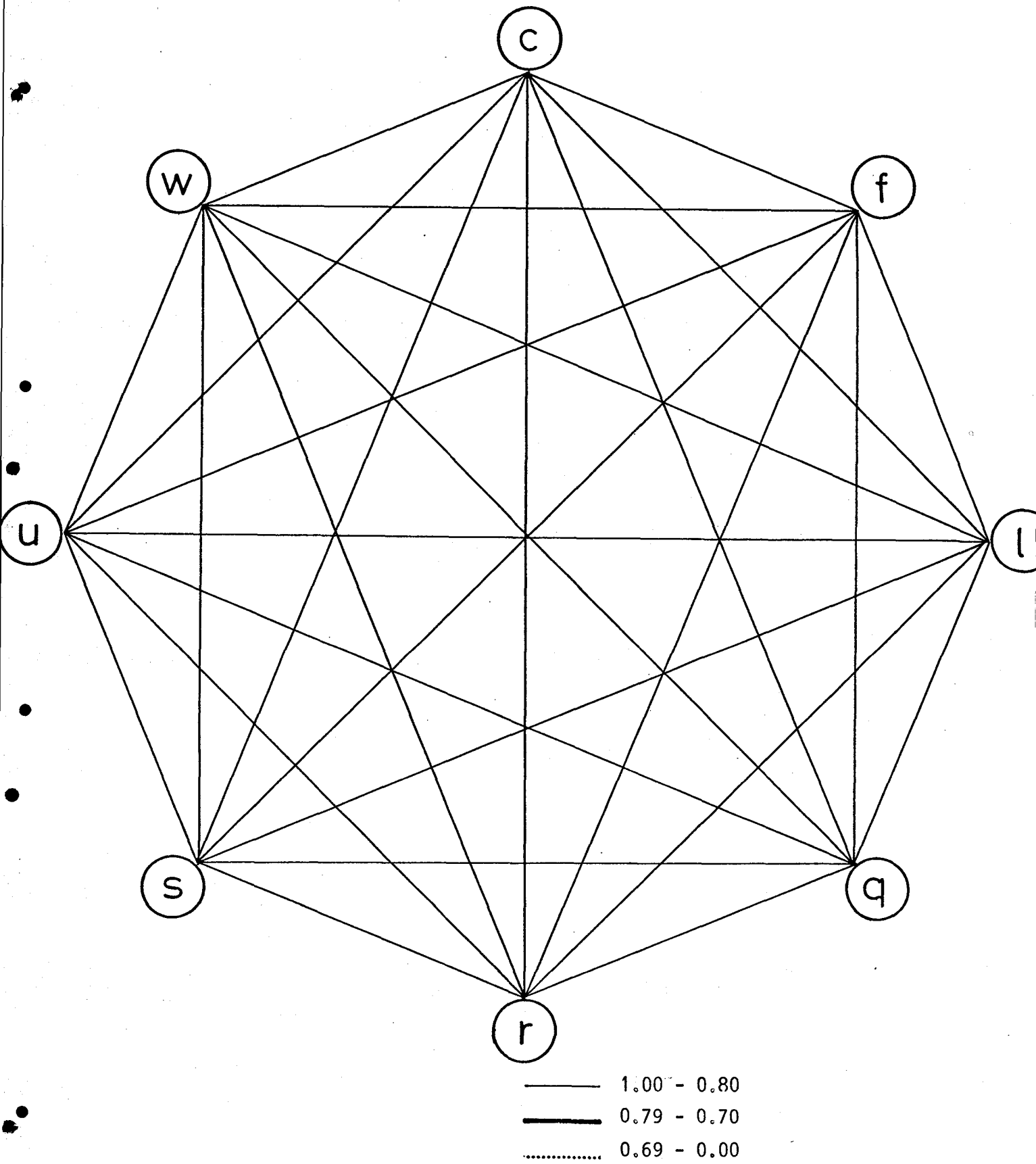
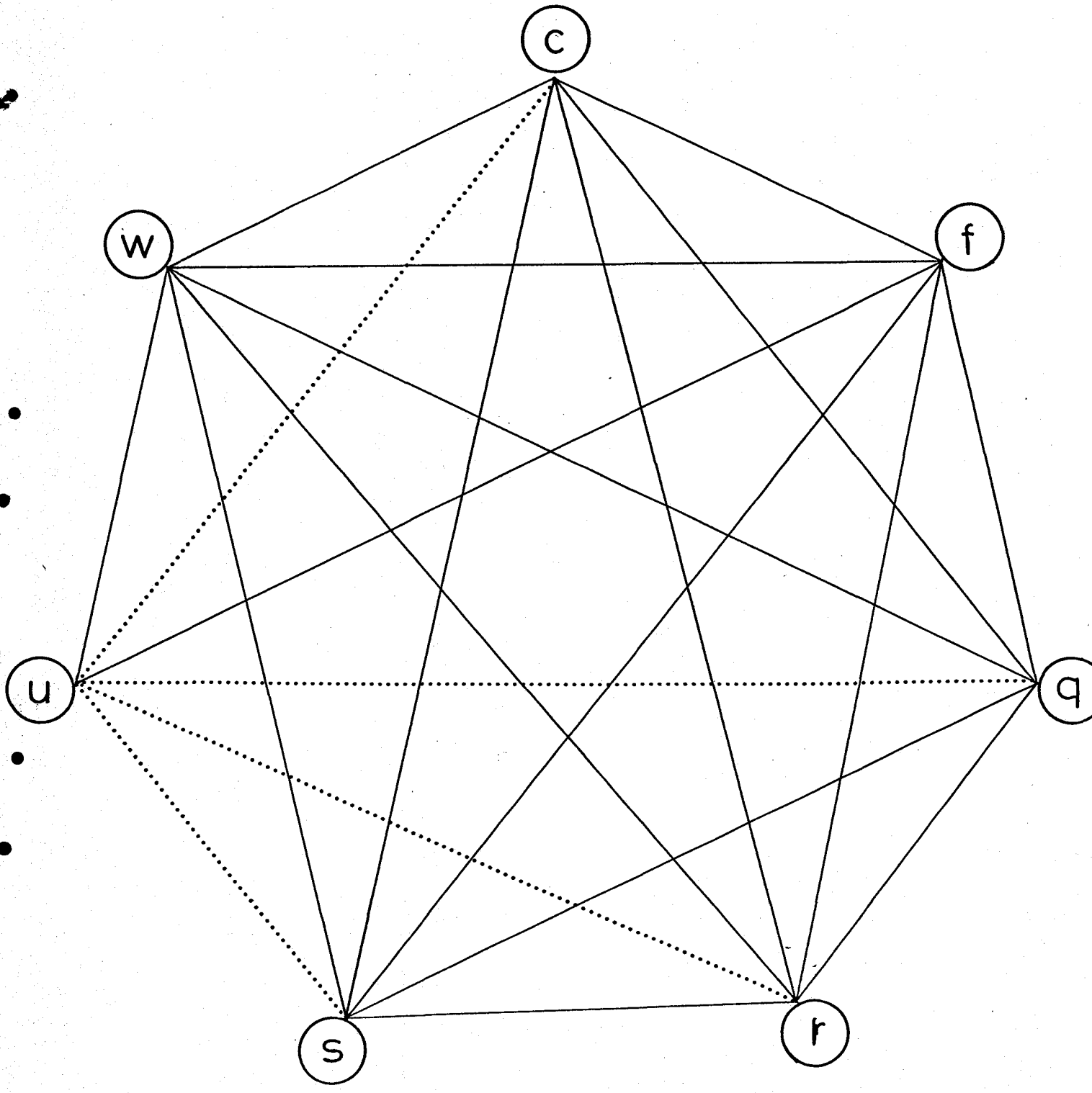


Fig.V.1.9. Cλ Values of phytoplankton in horizontal distribution

1976 X



1.00 - 0.80

0.79 - 0.70

0.69 - 0.00

Fig.V.1.10. C_λ Values of phytoplankton in horizontal distribution

1977 VI

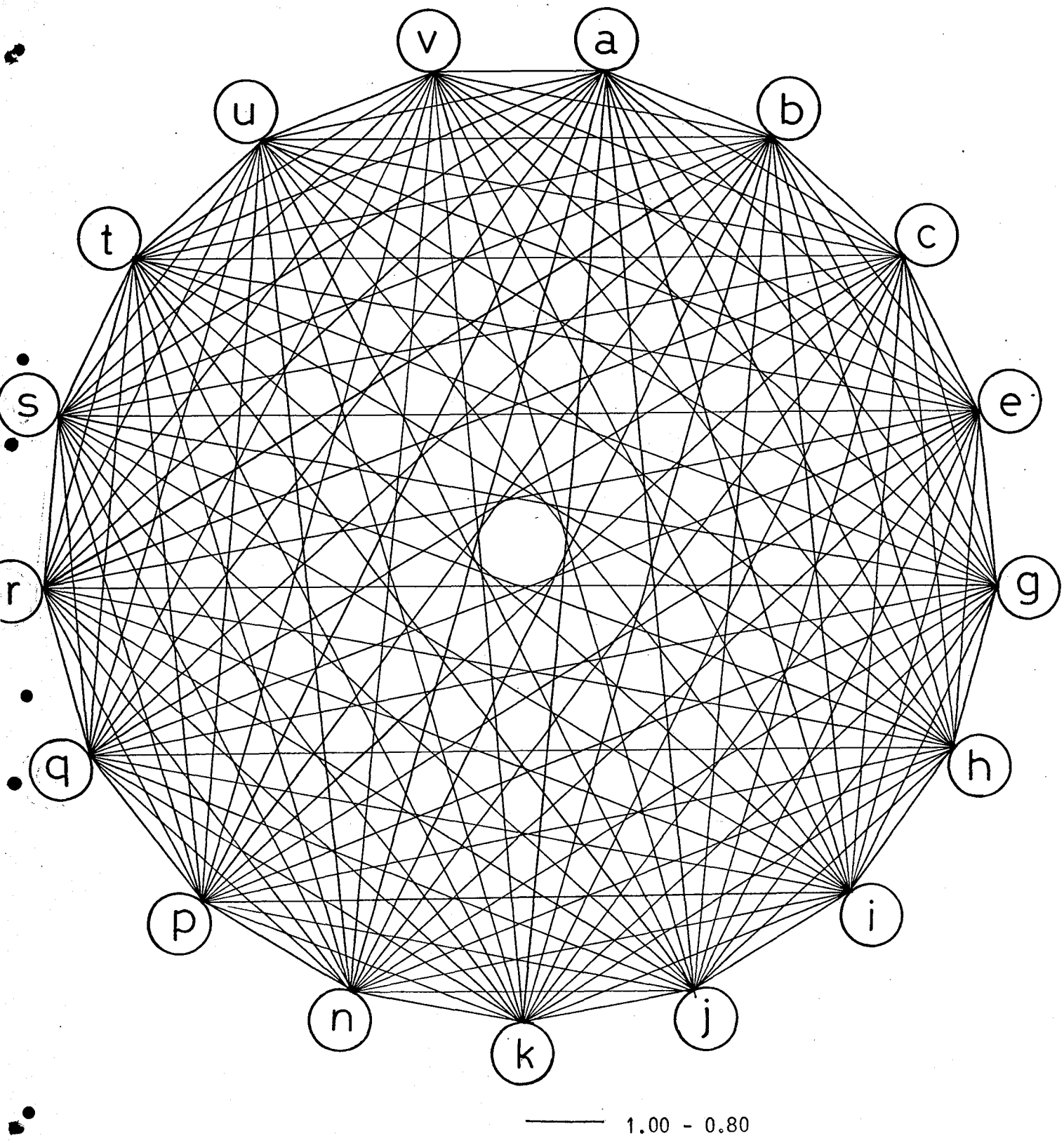


Table V.2.1. Relative abundance at each depth.

date		depth \ phylum	Cyano-phyta	Eugleno-phyta	Crypto-phyta	Chryso-phyta	Bacilla-riophyta	Chloro-phyta
1972	VII	0 m	0 %	0.1 %	0 %	0.1 %	0.9 %	98.9 %
		1	0	0	0	2.1	0.7	97.2
		3	0	0	0	0	0	100.0
		6	0	0	0	1.4	0	98.6
1972	X	1	87.1	0	0	0.2	0.2	12.5
		2	36.3	0.1	0	0	1.7	61.9
		4	18.7	0.1	0	0	1.8	79.4
		6	27.2	3.3	0	0	0.3	69.2
		9	50.0	2.4	0	0	4.4	43.2
1972	XII	0	0	0.1	0	0	99.5	0.4
		1	0	0	0	0	99.9	0.1
		2	0	0.2	0	0	98.7	1.1
		3	0	0	0	0	99.5	0.5
		4	0	0	0	0	99.6	0.4
		6	0	0	0	0	99.7	0.3
		9	0	0	0	0	100.0	0
		12	0	0	0	0	99.5	0.5
1976	IV	0	0	0	0	0	97.2	2.8
		1	0	0	0	0	100.0	0
		2	0	0	0	0	95.4	4.6
		4	0	0	0	0	95.2	4.8
		8	0	0	0	0	100.0	0
		10	0	0	0	0	100.0	0
1976	VI	0	0	0	98.7	0	0	1.3
		1	0	0	96.9	0	0	1.9
		2	0	0	95.1	0	0	4.9
		8	0	0	41.3	0	2.9	55.8
		10.5	0	0	69.2	0	30.8	0
1976	VIII	0	0	0	0	28.7	64.4	6.9
		1	0	0	0.4	32.5	56.7	10.3
		2	0	0	0	7.0	59.2	33.8
		4	0	0	0	4.3	47.0	48.7
		8	95.8	0	0	0	4.2	0
		9.5	99.5	0	0	0	0.3	0.2

Table V.2.2.

A comparison of diversity index values at each station.

Date & Station		Value of Diversity Index
1972 VII	0 m	0.09
	1	0.24
	3	0.01
	6	0.11
1972 X	1 m	0.77
	2	1.29
	4	1.25
	6	1.61
	9	1.83
1972 XII	0 m	1.67
	1	1.89
	2	1.74
	3	1.75
	4	1.69
	6	1.84
	9	1.82
	12	2.02
1976 IV	0 m	1.46
	1	1.69
	2	1.71
	4	1.68
	8	1.25
	10	1.63
1976 VI	0 m	0.11
	1	0.23
	2	0.28
	8	1.35
	10.5	1.35
1976 VIII	0 m	1.42
	1	1.46
	2	1.41
	4	1.34
	8	0.35
	9.5	0.07

Fig.V.2.1a Cell numbers and dominant species of phytoplankton in vertical distribution.

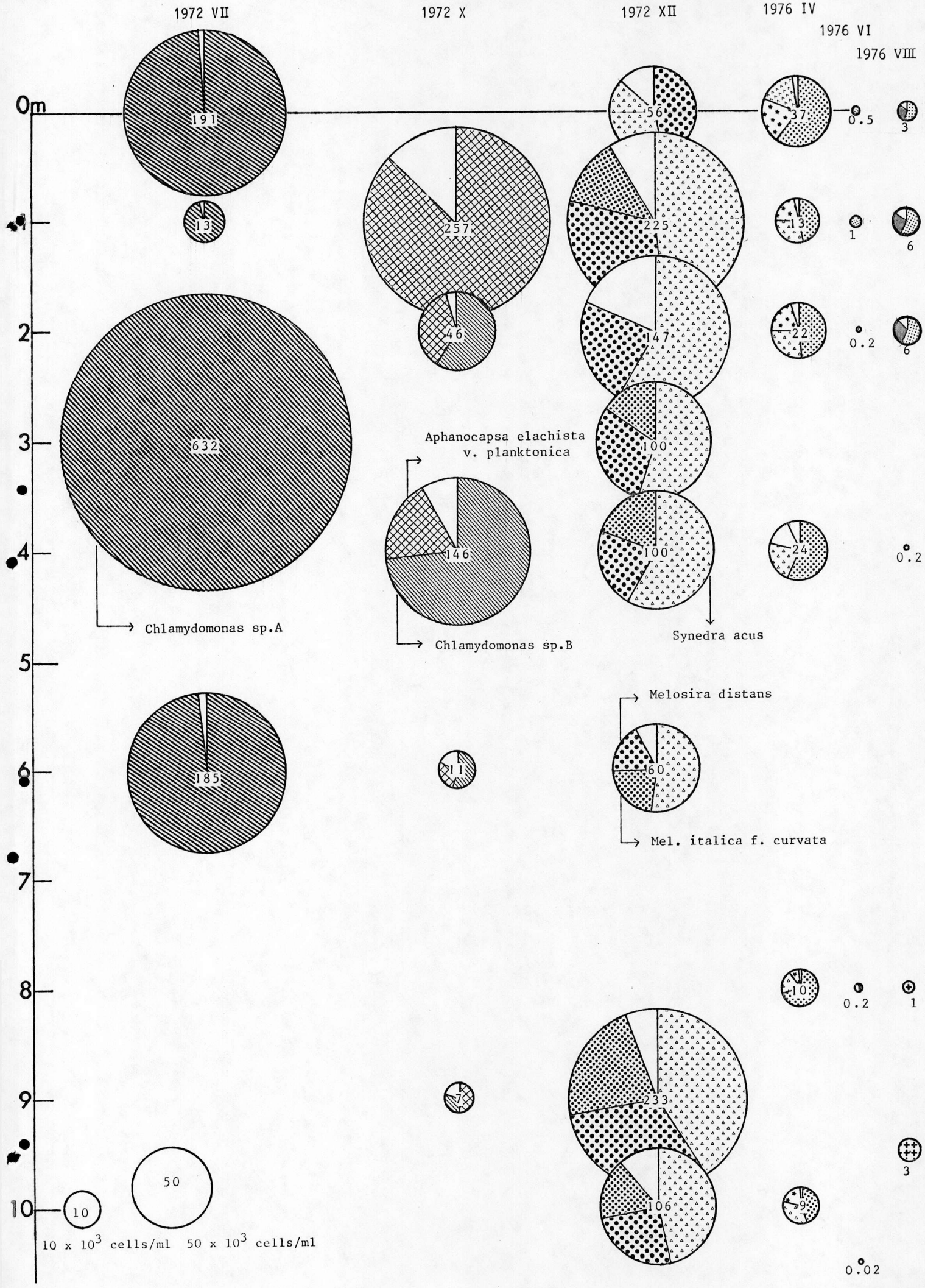


Fig.V.2.1b Cell numbers and dominant species of phytoplankton in vertical distribution.

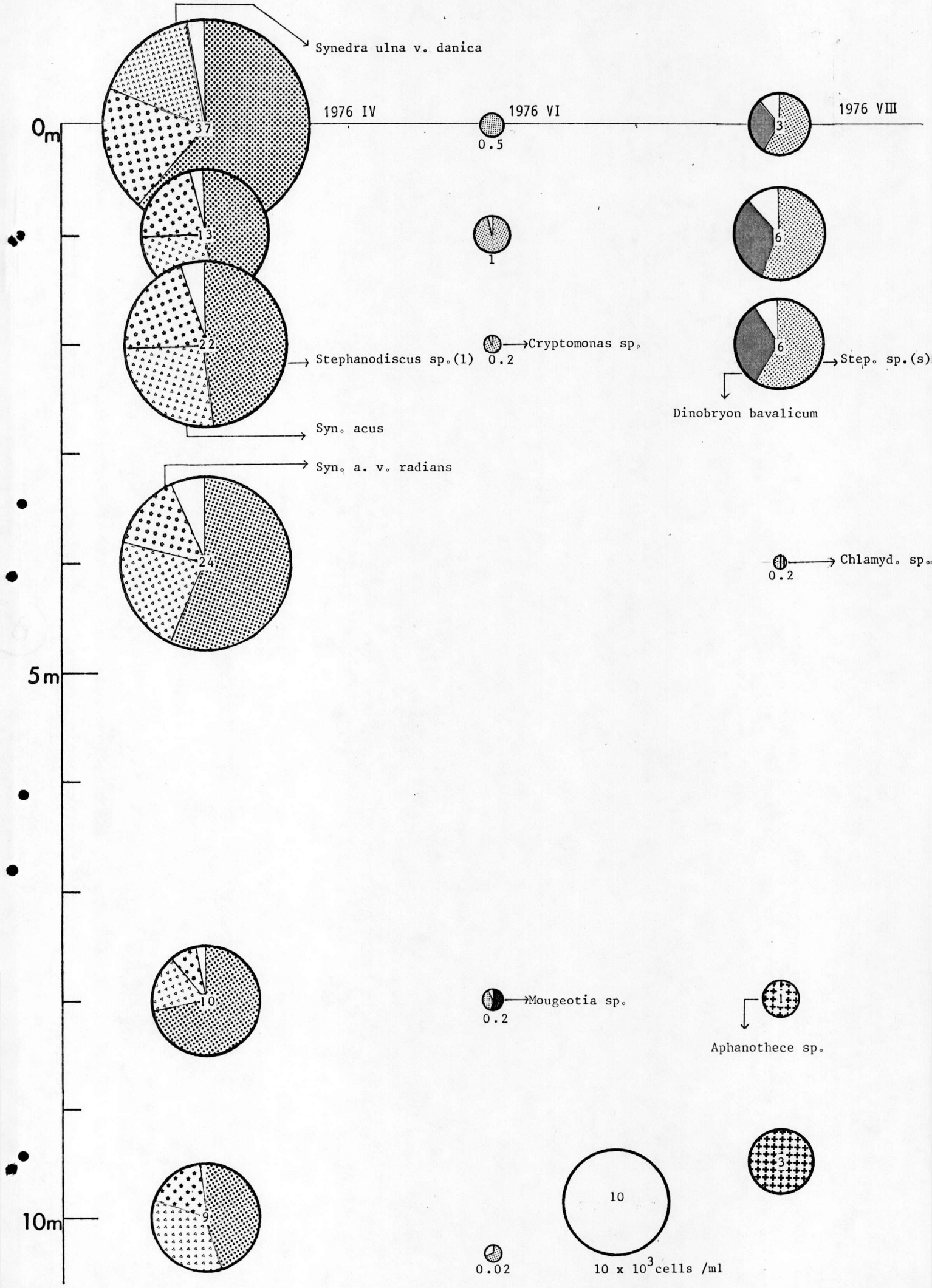
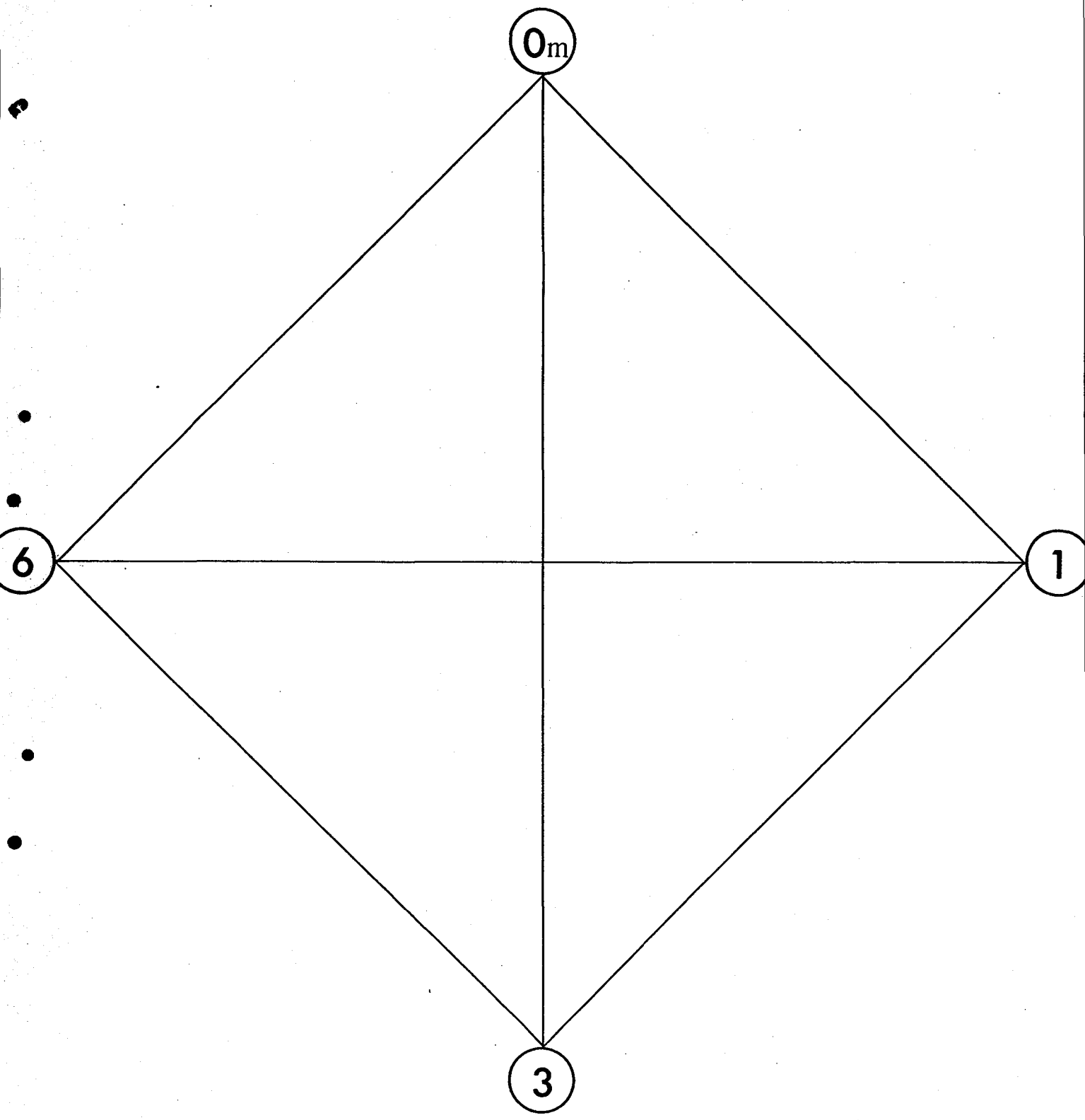


Fig.V.2.2. Cλ Values of phytoplankton in vertical distribution

1972 VII



This figure shows the Cλ values between two communities at each depth by means of three different lines. The thin line indicates high similarity, the thick line, slight one and the dotted line, low one.
The number shows the water depth of the sampling station (st.A).

——— 1.00 - 0.80
▬▬▬ 0.79 - 0.70
..... 0.69 - 0.00

Fig.V.2.3. C_λ Values of phytoplankton in vertical distribution

1972 X

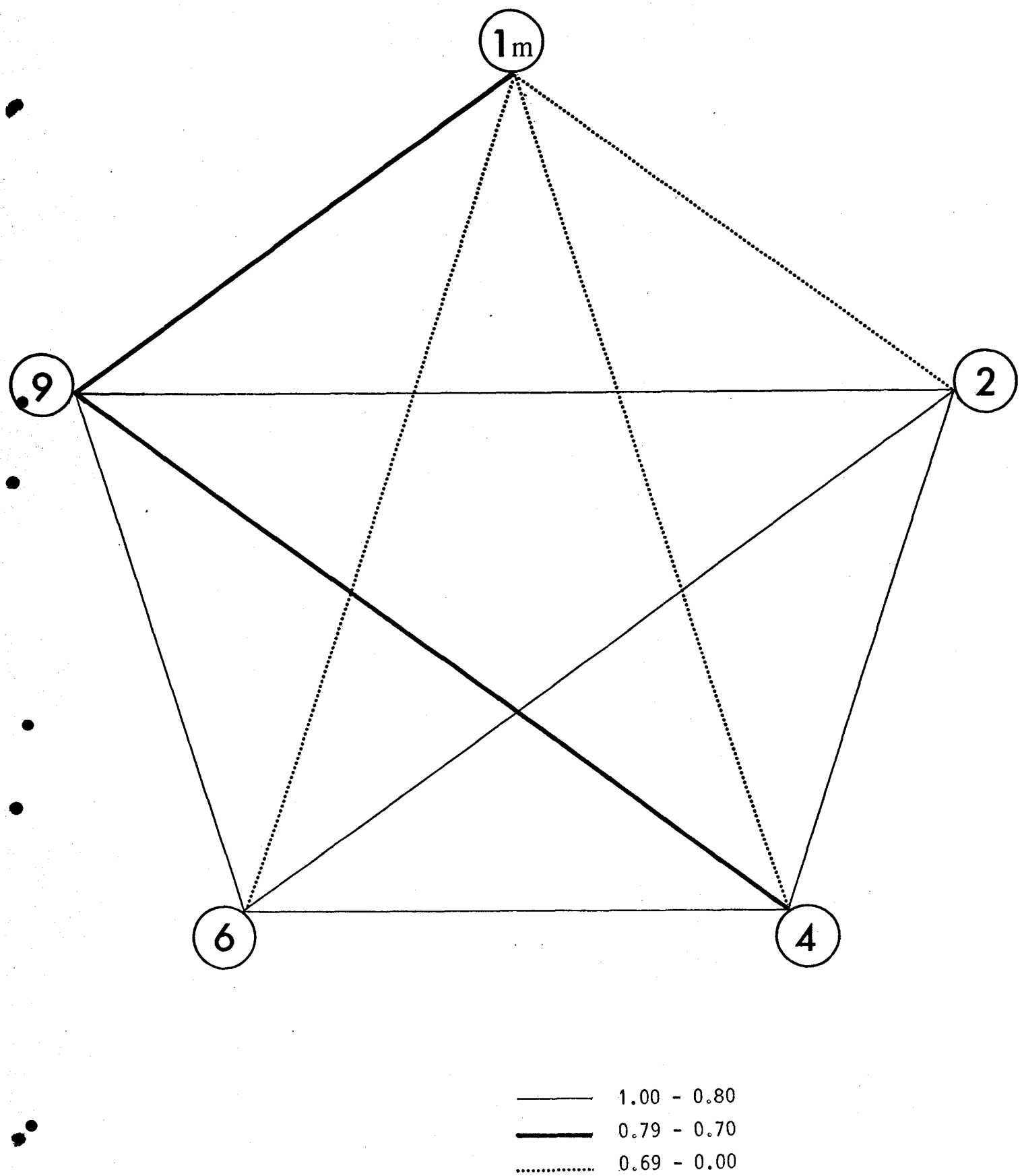
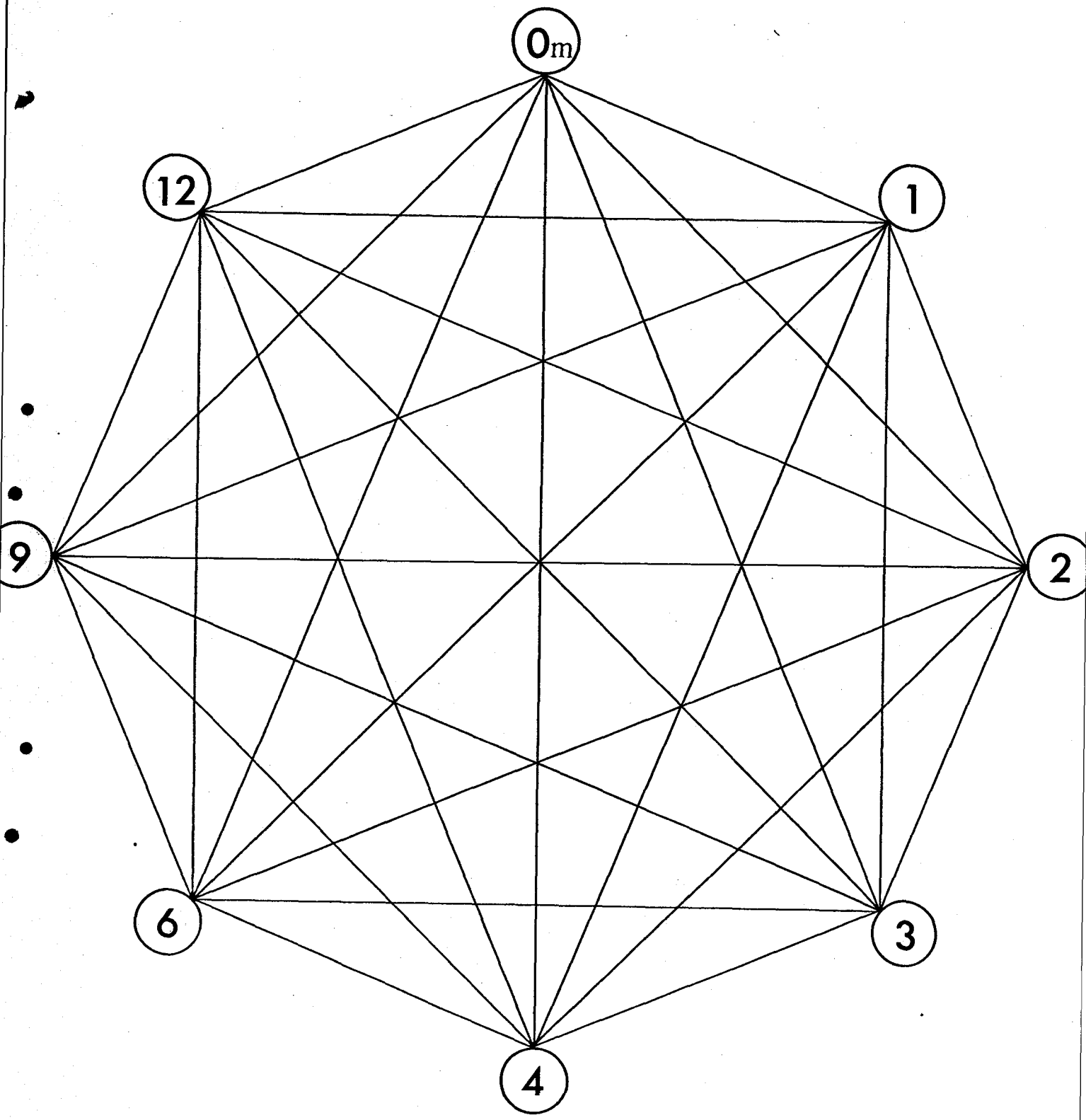


Fig.V.2.4. Cλ Values of phytoplankton in vertical distribution

1972 XII



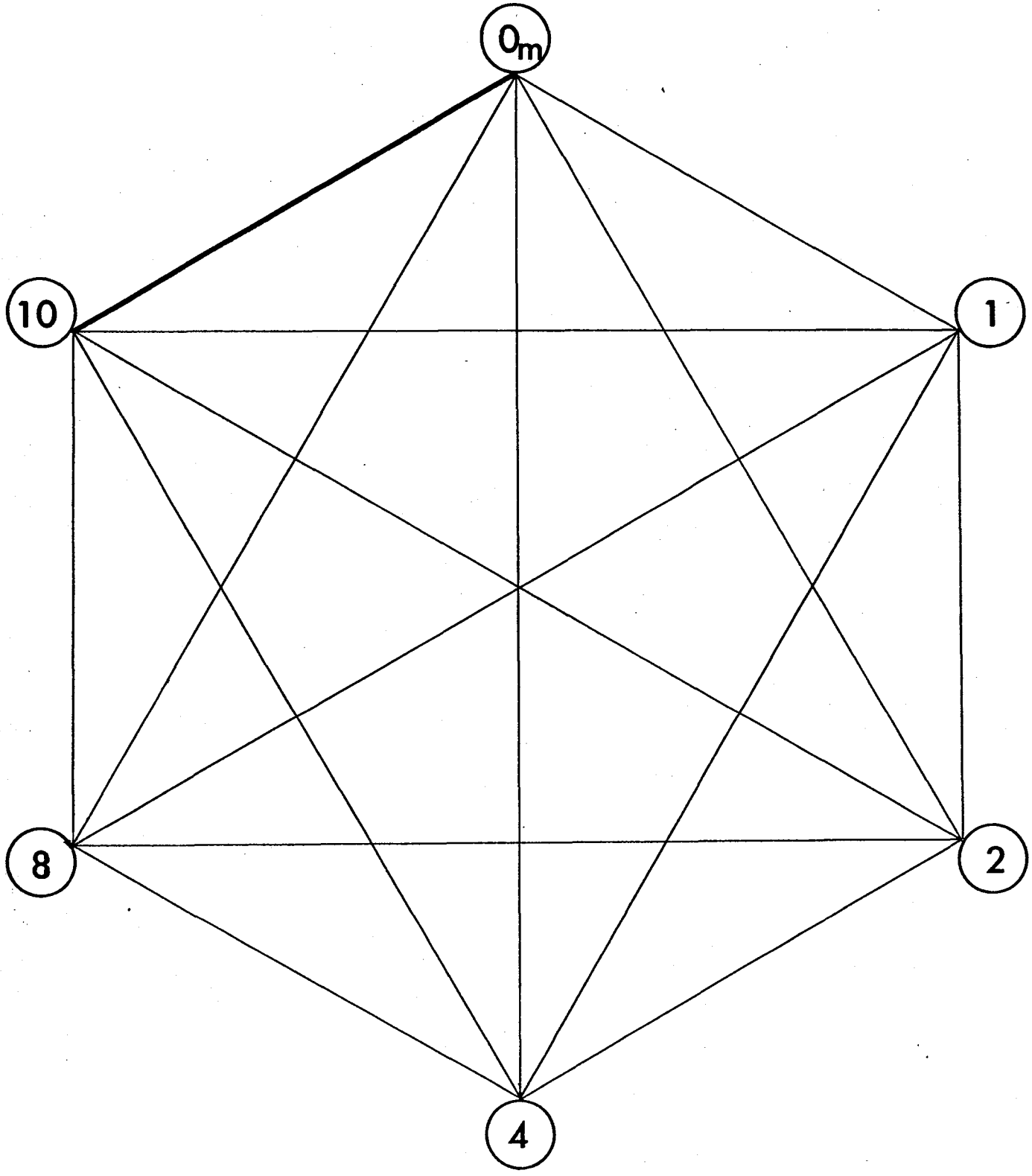
1.00 - 0.80

0.79 - 0.70

0.69 - 0.00

Fig.V.2.5. C_λ Values of phytoplankton in vertical distribution

1976 IV



1.00 - 0.80

0.79 - 0.70

0.69 - 0.00

Fig.V.2.6. C_λ Values of phytoplankton in vertical distribution

1976 VI

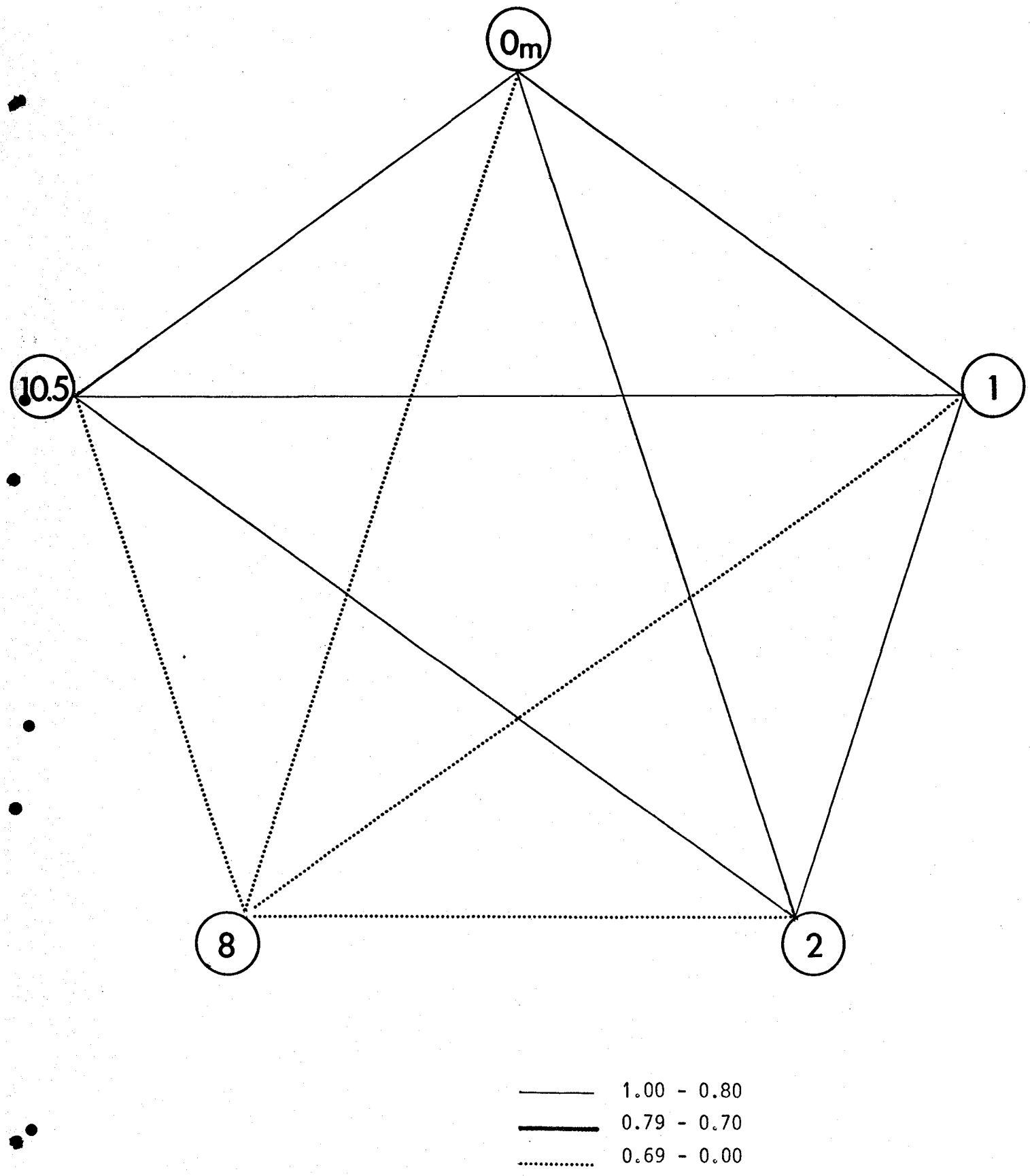
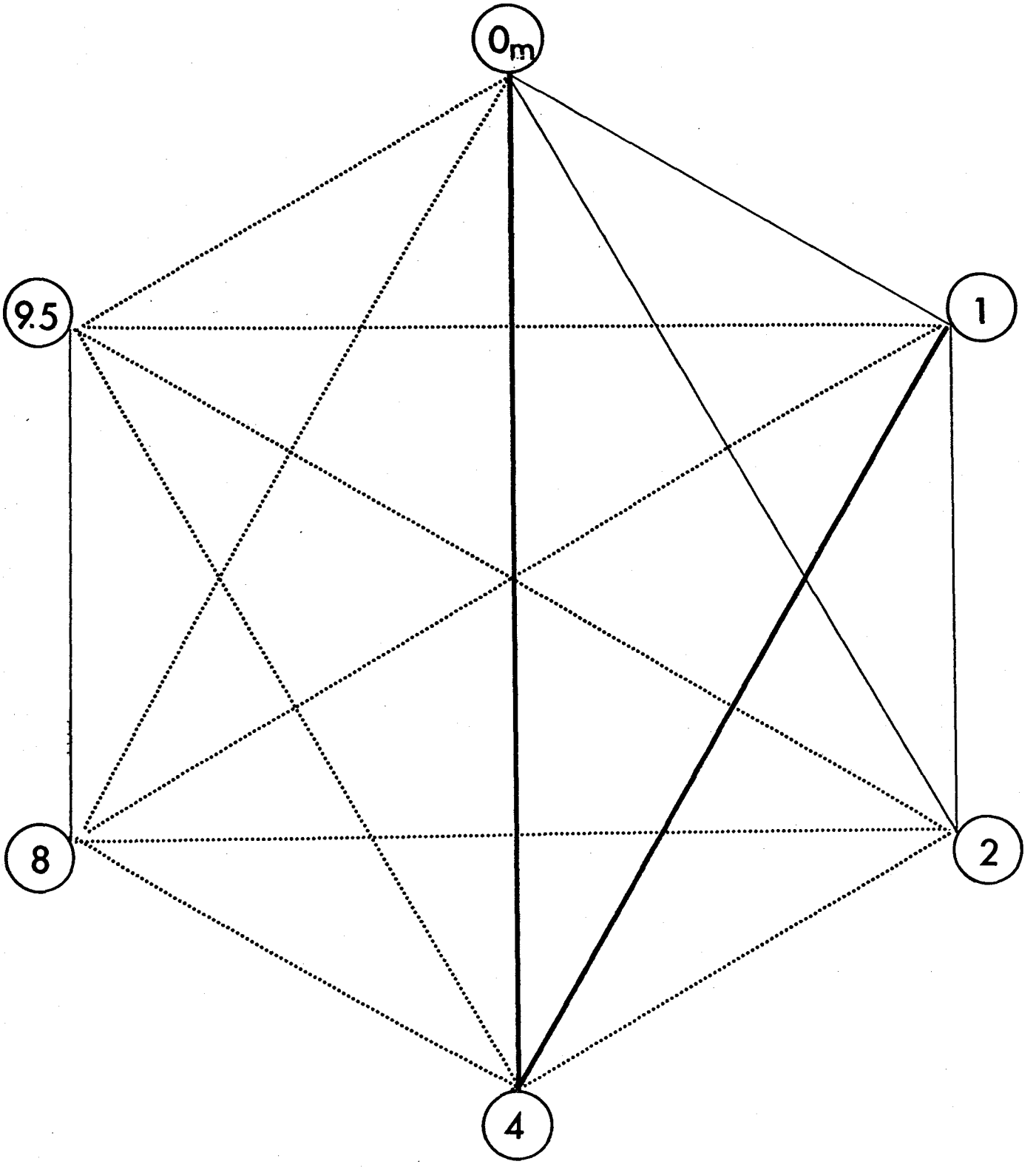


Fig.V.2.7. Cλ Values of phytoplankton in vertical distribution

1976 VIII



1.00 - 0.80

0.79 - 0.70

0.69 - 0.00

Table VI.1a.
Relative abundance of benthic algae

date	station	Cyano-phyta	Euglenophyta	Chrysophyta	Bacillariophyta	Chlorophyta
1972 VII	A 1	0	0	0	100	0
	A 2	0	0	0	100	0
	A 3.5	0	0	0	100	0
	B 7	0	0	0	100	0
	B 9	0	0	0	100	0
	C 10	0	0	0	100	0
	C 12a	0	0	0	100	0
	C 12b	0	0	0	100	0
	D 4.5	0	0	0	100	0
	D 6	0	0	0	100	0
	E 9	0	0	0	100	0
1972 X	B 1	0	0	0	100	0
	B 2	0	0	0	100	0
	B 3a	0.2	0	0	97.8	2.0
	B 3b	0.3	0	0	98.6	1.1
	B 3.5	0	0.2	0	99.8	0
	B 4	0	0	0	100	0
	B 5a	0.7	0	0	99.3	0
	B 5b	0	0.4	0	98.7	0.9
	B 6a	0.2	0.7	0	99.1	0
	B 6b	0	0	0	100	0
	B 7	0	0	0	100	0
	B 8	0	0	0	100	0
	B 9	12.5	0	0	87.5	0
	B 10	1.3	0	0	95.2	3.5
	C 1a	0	0	0	100	0
	C 1b	0	0	0	100	0
	C 2.5	0	0.7	0	98.7	0.6
	C 3	0	0.2	0	99.5	0.3
	C 4	0.6	0.6	0.1	98.0	0.7
	C 5	0	0	0	100	0
	C 6	0	0	0	100	0
	C 7	0	0.4	0	99.6	0
	C 10	0	0.6	0	99.4	0
	CA10.5	0	0	0	100	0
	C 11	0	0.1	0	99.9	0
	C 12a	0	0	0	100	0
	C 12b	0	0	0	100	0
	G 8	0	0.7	0	99.3	0
1972 XII	A 1	0	0	0	99.8	0.2
	A 1.5a	0	0	0	100	0
	A 1.5b	0.1	0	0	99.9	0
	A 2	0.6	0	0	99.4	0
	A 3	0	0	0	100	0
	A 4	0	0	0	100	0
	A 5	0.2	0	0	99.2	0
	A 6	0	0	0	100	0
	A 10	0	0	0	100	0
	B 1.2	0.3	0	0	98.9	0.8
	B 3	0	0	0	100	0
	B 4	0	0	0	99.5	0.5
	B 5	0.3	0	0	98.5	1.2
	B 6.5	0.3	0	0	99.7	0
	B 8	0	0	0	99.1	0.9
	C 1	0	0	0	99.7	0.3
	C 2	0	0	0	99.8	0.2
	C 3	0	0	0	100	0
	C 4	0	0	0	99.6	0.4
	C 5	0.1	0	0	99.7	0.2
	C 7	0.3	0	0	98.4	1.3
	C 10	0	0	0	94.0	6.0
	C 11a	0	0	0	100	0
	C 11b	0	0	0	100	0
	CA11.5	0	0	0	100	0
	F 9.5	0	0	0	99.7	0.3

Table VI.1b.
Relative abundance of benthic algae

date	station \ phylum	Cyano-phyta	Euglenophyta	Chrysophyta	Bacillariophyta	Chlorophyta
1976 IV	A 1.3	0	0	0	100	0
	A 2	0	0	0	100	0
	A 3	0	0	0	100	0
	A 4	0	0	0	100	0
	A 4.5	0	0	0	100	0
	A 6	0.3	0	0	99.7	0
	C 1.8	0	0	0	99.0	1.0
	C 2	0	0	0	100	0
	C 3.5	0	0	0	100	0
	C 5	0	0	0	99.0	1.0
	C 6	0	0	0	100	0
	C 8	0	0	0	100	0
	C 10	0	0	0	100	0
	CA10.5	0	0	0	100	0
	C 11	0	0	0	100	0
1976 VI	A 2	0	0	0	100	0
	A 2.5	0.4	0	0	99.6	0
	A 3	0	0	0	100	0
	A 4	0	0	0	100	0
	A 5	0	0	0	100	0
	A 6	0	0	0	100	0
	A 7	0	0	0	100	0
	A 8	0	0	0	100	0
	A 9	0	0	0	100	0
	A 10	0	0	0	100	0
	C 2	0	0	0	100	0
	C 3	0	0	0	100	0
	C 4	0	0	0	100	0
	C 5	0	0	0	100	0
	C 6	0	0	0	100	0
	C 7	0	0	0	100	0
	C 8	0	0	0	100	0
	C 9	0	0	0	100	0
	C 10	0	0	0	100	0
	CA11	0	0	0	100	0
1976 VIII	A 1	0	0	0	100	0
	A 2	0	0	0	100	0
	A 3	0	0	0	100	0
	A 4	0	0	0	99.9	0.1
	A 5	0	0	0	100	0
	A 6	0	0	0	100	0
	A 7	0	0	0	100	0
	A 8	0	0	0	99.0	1.0
	A 9	0	0	0	100	0
	A 10	0	0	0	100	0
	C 1	0	0	0	98.7	1.3
	C 2	0	0	0	100	0
	C 3	0	0	0	100	0
	C 4	0	0	0	100	0
	C 5	0	0	0	100	0
	C 11a	0	0	0	100	0
	C 11b	0	0	0	100	0
	CA11	0	0	0	100	0
1976 X	A 2	0	0	0	100	0
	A 3	0	0	0	100	0
	A 3.5	0	0	0	100	0
	A 4	0	0	0	100	0
	A 4.5	0	0	0	100	0
	A 5.8	0	0	0	100	0
	A 7	0	0	0	100	0
	A 8	0	0	0	100	0
	A 9	0	0	0	100	0
	A 10	0	0.6	0	99.4	0
	C 1.5	0	0	0	100	0
	C 2.5	0	0	0	100	0
	C 3	0	0	0	100	0
	C 3.8	0	0	0	100	0
	C 5	0	0	0	100	0
	CA10	0	0	0	100	0
	C 12	0	0	0	100	0

1976 IV				1976 VI				1976 VIII				1976 X			
course	depth (m)	d.c.	l.c.		(m)	d.c.	l.c.		(m)	d.c.	l.c.		(m)	d.c.	l.c.
A	1.3	38.0	0.7	A	2	70.9	6.8	A	1	37.9	0.3	A	1	51.0	1.3
	2	78.5	6.6		2.5	73.3	10.9		2	64.4	3.1		2	76.6	0.8
	3	65.9	12.7		3	82.3	2.5		3	87.2	14.7		3	81.3	23.0
	4	62.2	15.8		4	79.5	23.8		4	79.0	9.7		4	93.7	12.1
	4.5	80.8	10.8		5	89.6	13.6		5	94.1	57.9		5	83.5	25.8
	6	89.1	27.3		6	89.6	10.7		6	96.9	59.2		6	91.4	14.4
					7	77.9	19.5		7	91.0	37.5		7	96.0	29.0
					8	94.2	11.9		8	98.0	66.7		8	96.5	29.1
					9	94.3	47.9		9	94.1	55.0		9	98.2	36.4
					10	96.1	47.2		10	98.4	82.9		10	93.6	48.6
C	1.8	31.3	2.1	C	2	30.5	0.3	C	1	46.1	1.3	C	1.5	35.9	1.2
	2	25.9	2.4		3	88.0	14.6		2	72.5	1.5		2.5	80.2	2.4
	3.5	73.4	5.3		4	73.2	13.9		3	65.0	28.8		3	74.3	4.3
	5	86.4	20.5		5	85.6	13.4		4	90.1	23.4		3.8	93.1	25.1
	6	96.4	33.8		6	89.2	15.2		5	93.1	19.3		5	86.8	13.3
	8	99.1	51.2		7	92.8	17.7		11	96.5	34.2		10	97.0	42.6
	10	78.1	81.8		8	98.6	35.5						12	96.3	62.9
	10.5	92.9	14.8		9	93.1	6.7								
	11	95.8	73.2		10	98.0	52.4								
					11	92.9	4.8								
					12	93.0	58.3								

Table VI.2 Relative abundance of planktonic species appearing in benthic micro algae on the basis of cell numbers.

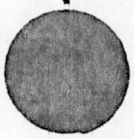
d.c. : dead cell communities

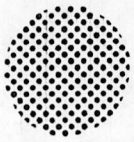
l.c. : live cell communities

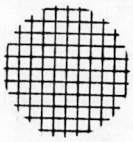
Table VI. 3 Relative abundance of the dominant phytoplankton at surface (s) and near bottom (b) layers.

stations / name of species	2-1	2-3		2-5		4-1	4-2		4-3	
	(s)	(s)	(b)	(s)	(b)	(s)	(s)	(b)	(s)	(b)
Cryptomonas sp.		7.4%		35.7	27.5	18.1	15.6	17.3	44.6	14.5
Asterionella gracillima	52.2	55.3	25.5	57.2	39.5	35.9	54.7	51.9	50.0	52.6
Fragilaria construens v. binodis								7.8		
F. pinnata		8.1	43.3		14.6	8.3				5.0
F. pin. v. lancettula								4.3		6.2
F. sp.	36.4	20.3	21.3		7.5	26.9	16.0	5.1		10.6
Scenedesmum armatus v. chodati					6.6					

Asterionella formosa

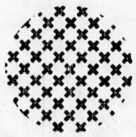

Fragilaria pinnata


Mel.italika f. curvata


Synedra acus

Diatoma elongatum

Melosira distans


Stephanodiscus sp.

Fpl	Fragilaria pinnata v. lancettula
Fc	F. construens
Fcb	F. const. v. binodis
Fcs	F. const. v. subsalsa
Fcv	F. const. v. venter
Fcm	F. capucina v. mesolepta
Fcr	F. crotonensis
Fspp	F. spp
Cpm	Cocconeis placentula v. mesolepta

Fig.VI.1. The dominant species and cell numbers of benthic micro algae on the lake sediment 1972 VII

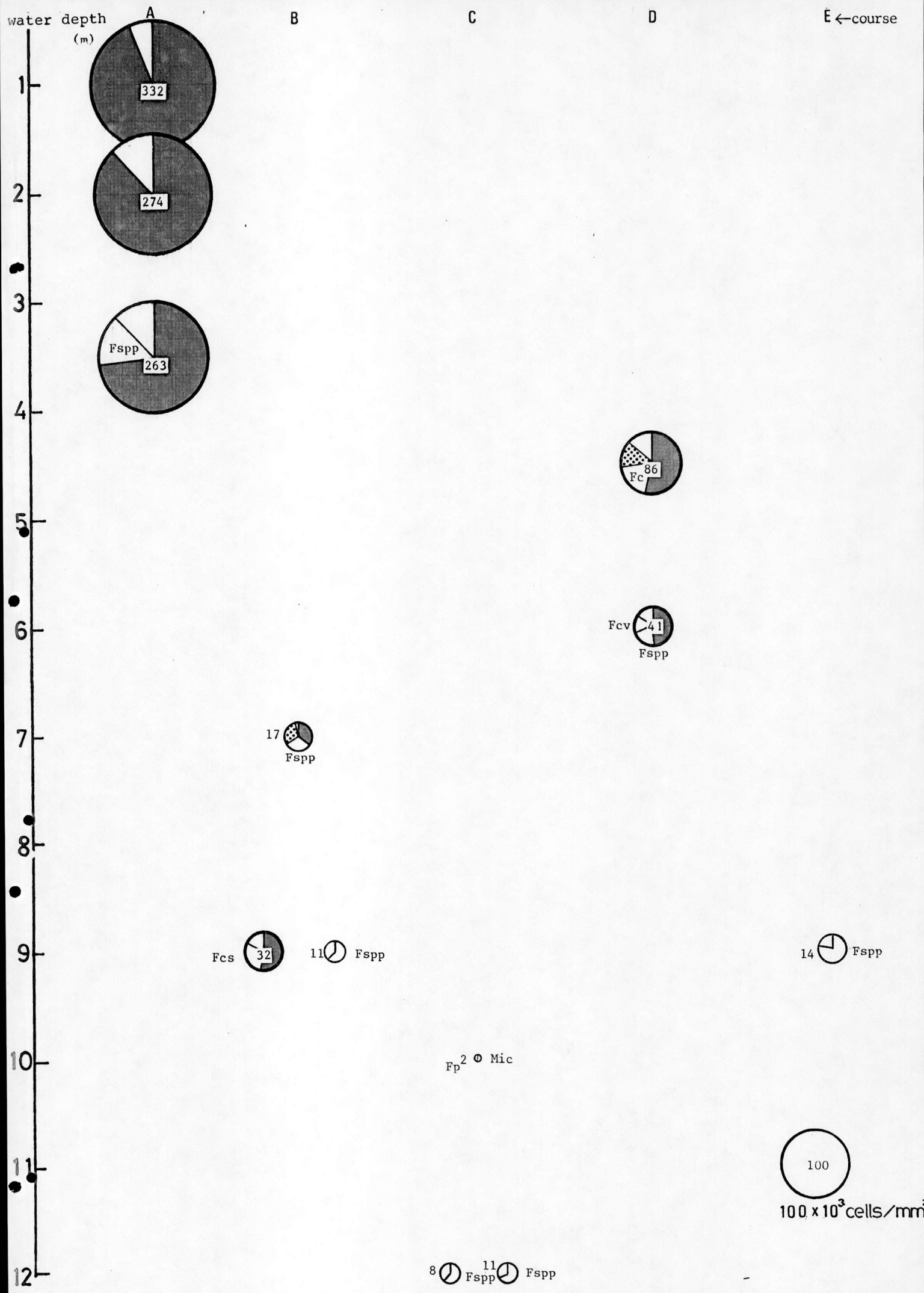


Fig.VI.2. The dominant species and cell numbers of benthic micro algae on the lake sediment 1972 X

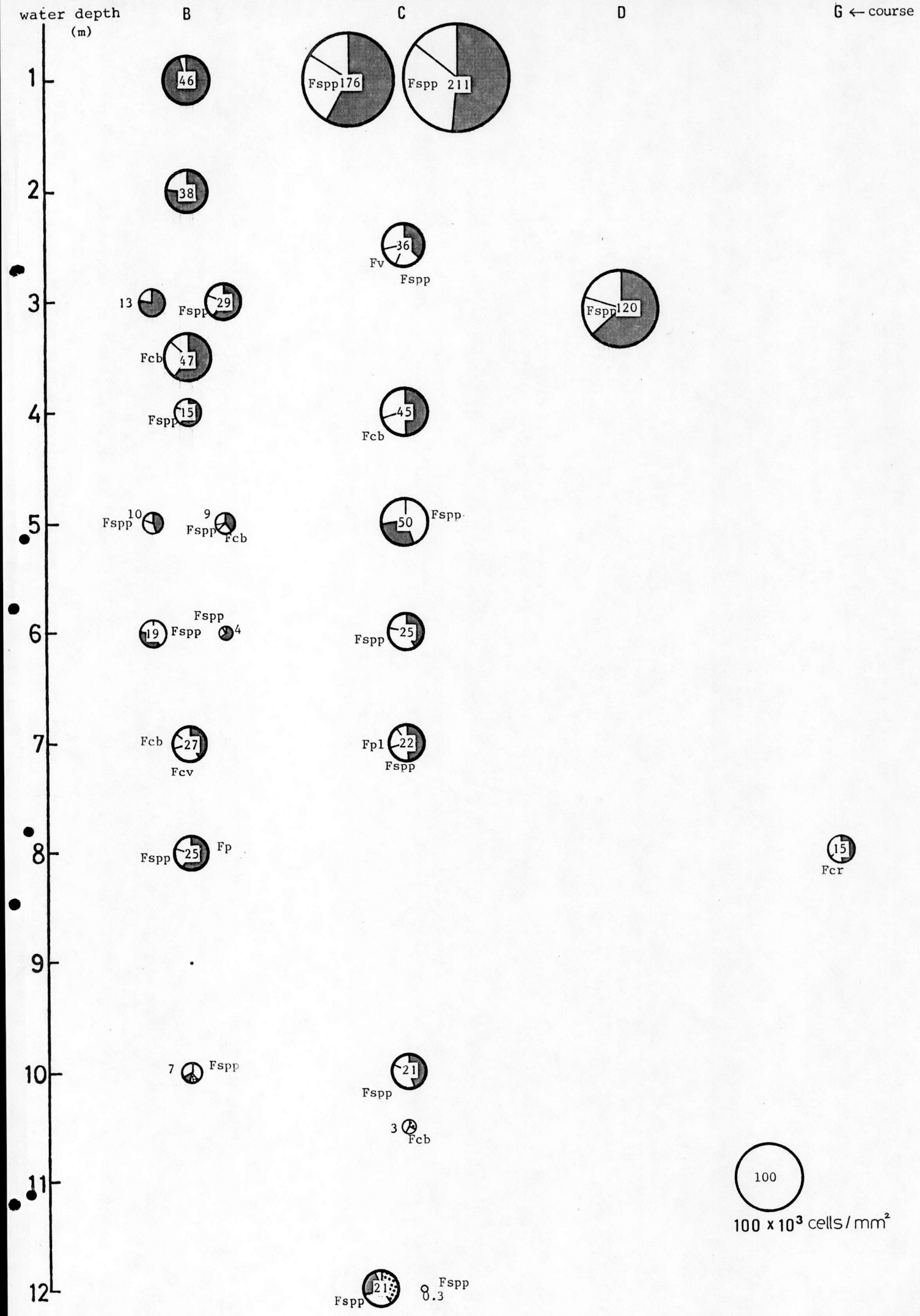


Fig.VI.3. The dominant species and cell numbers of benthic micro algae on the lake sediment 1972 XII

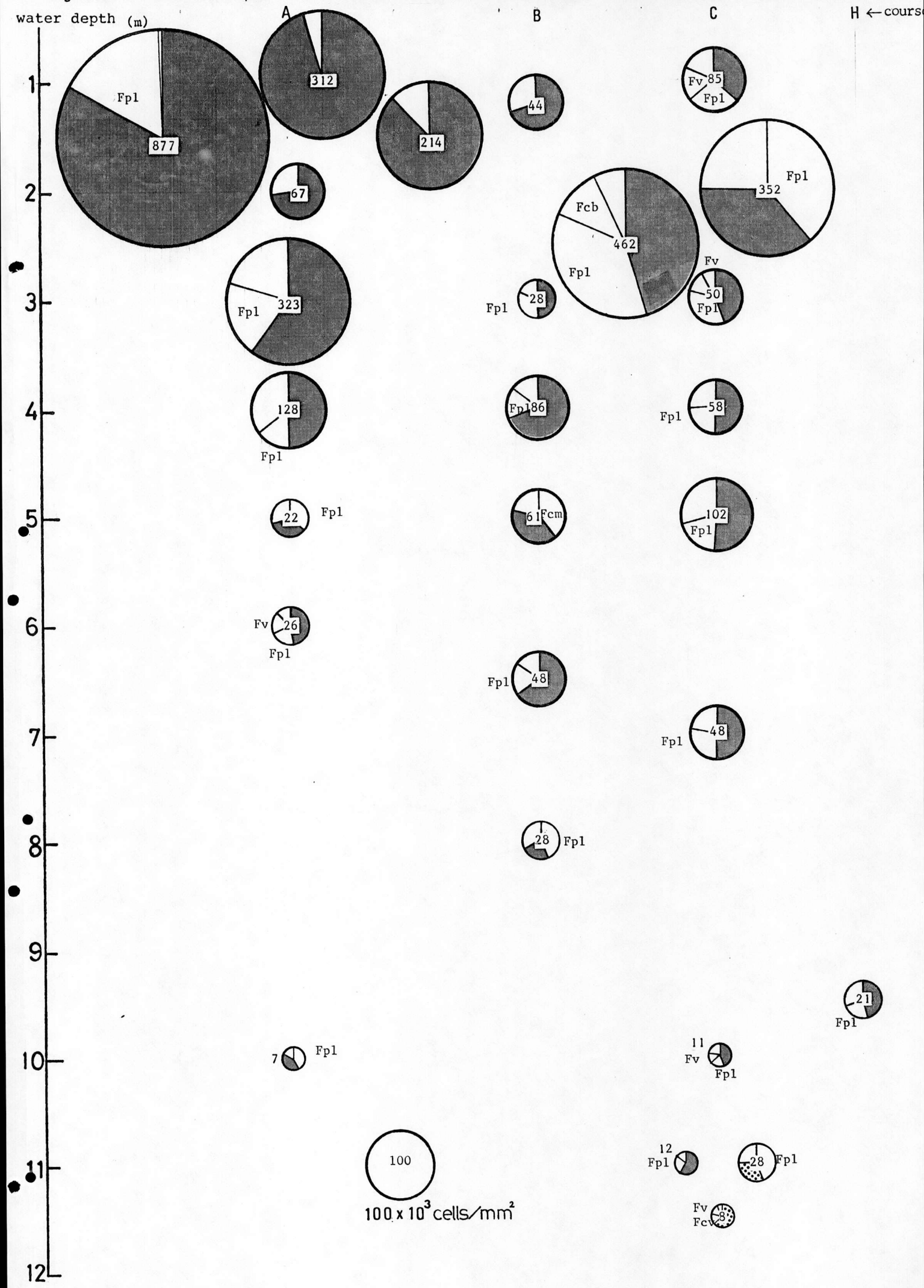


Fig.VI.4. The dominant species and cell numbers of benthic micro algae on the lake sediment 1976 IV

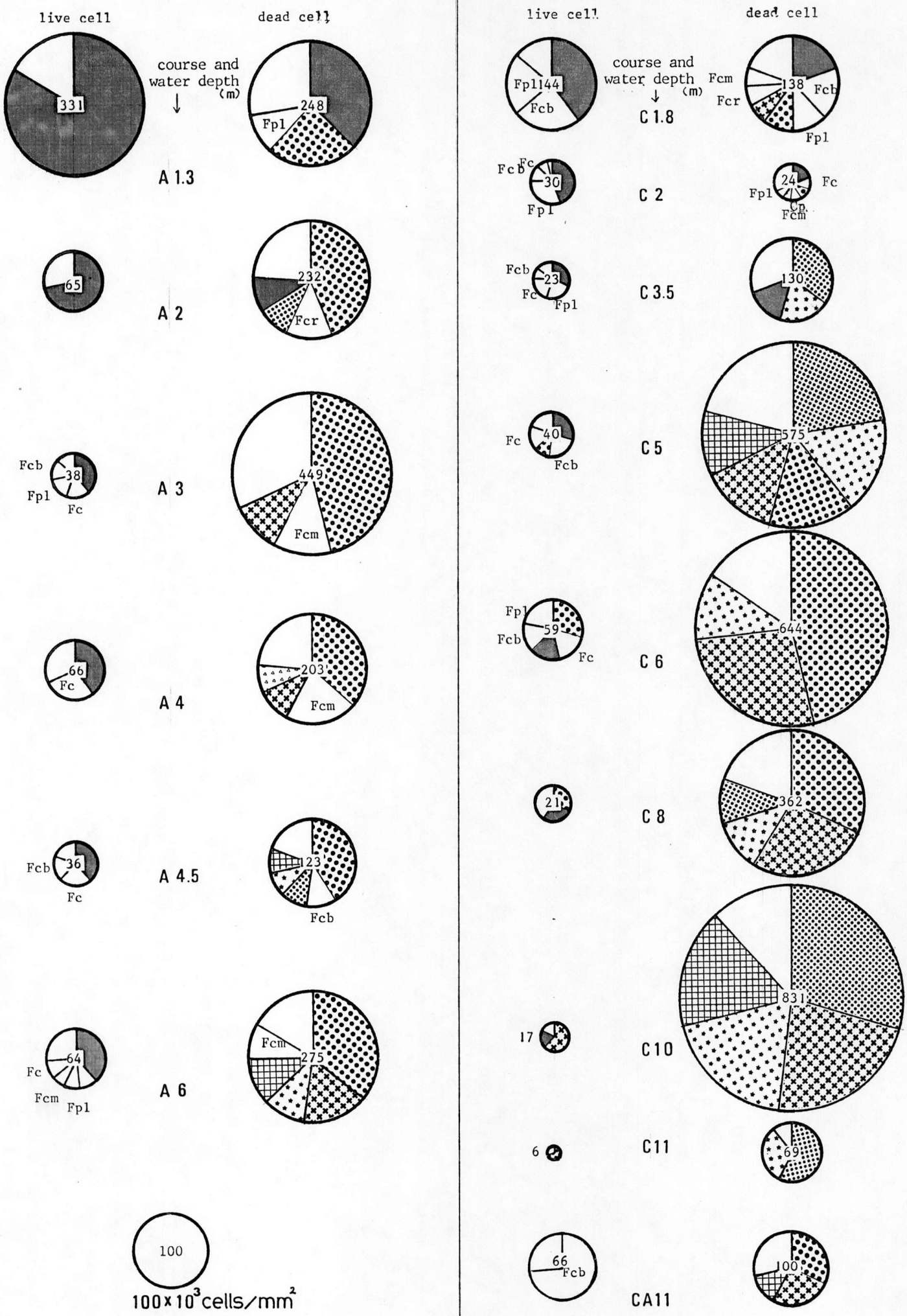


Fig.VI.5. The dominant species and cell numbers o ben hic micro algae on the lake sediment 1976 VI

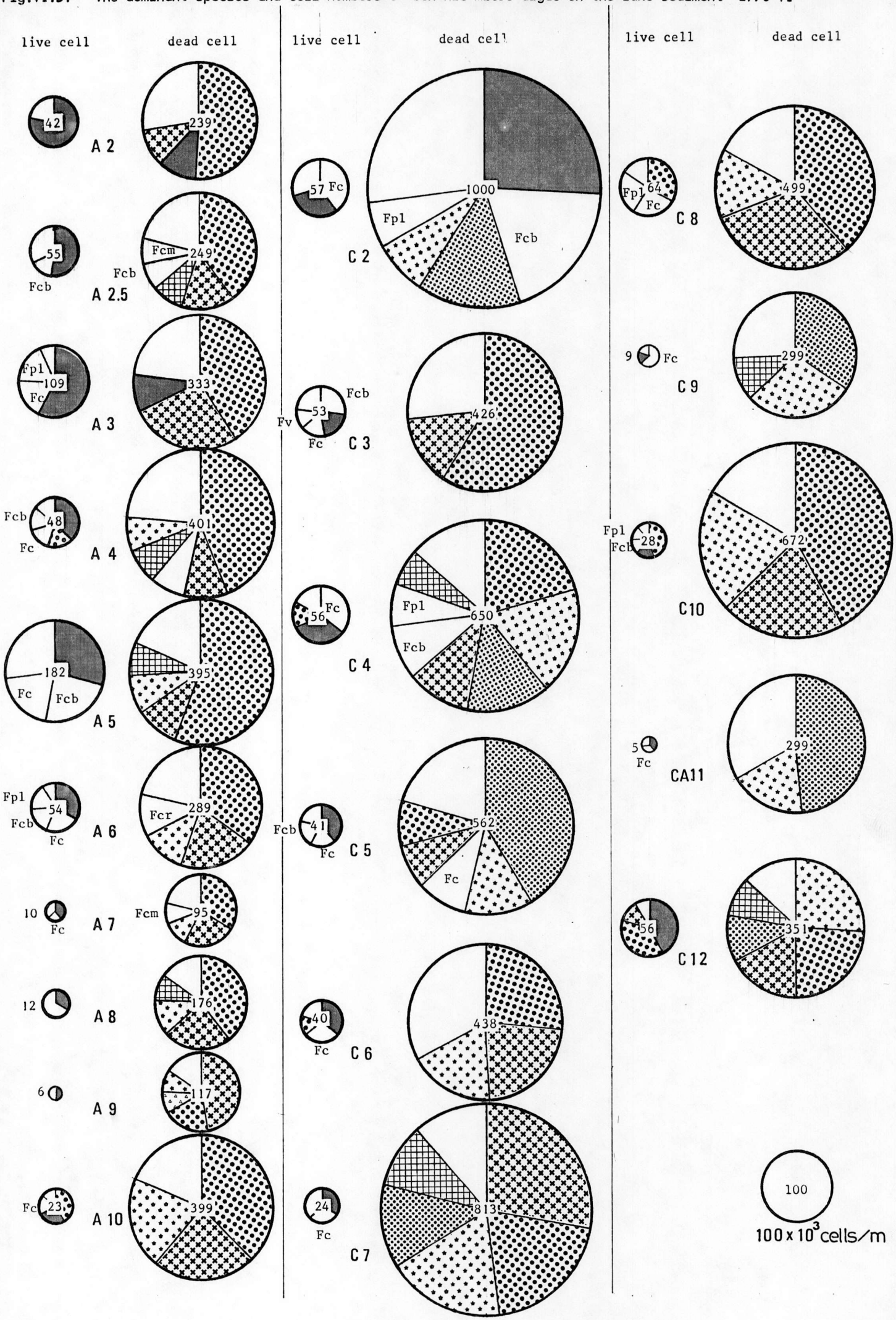


Fig.VI.6. The dominant species and cell numbers of benthic micro algae on the lake sediment 1976 VIII

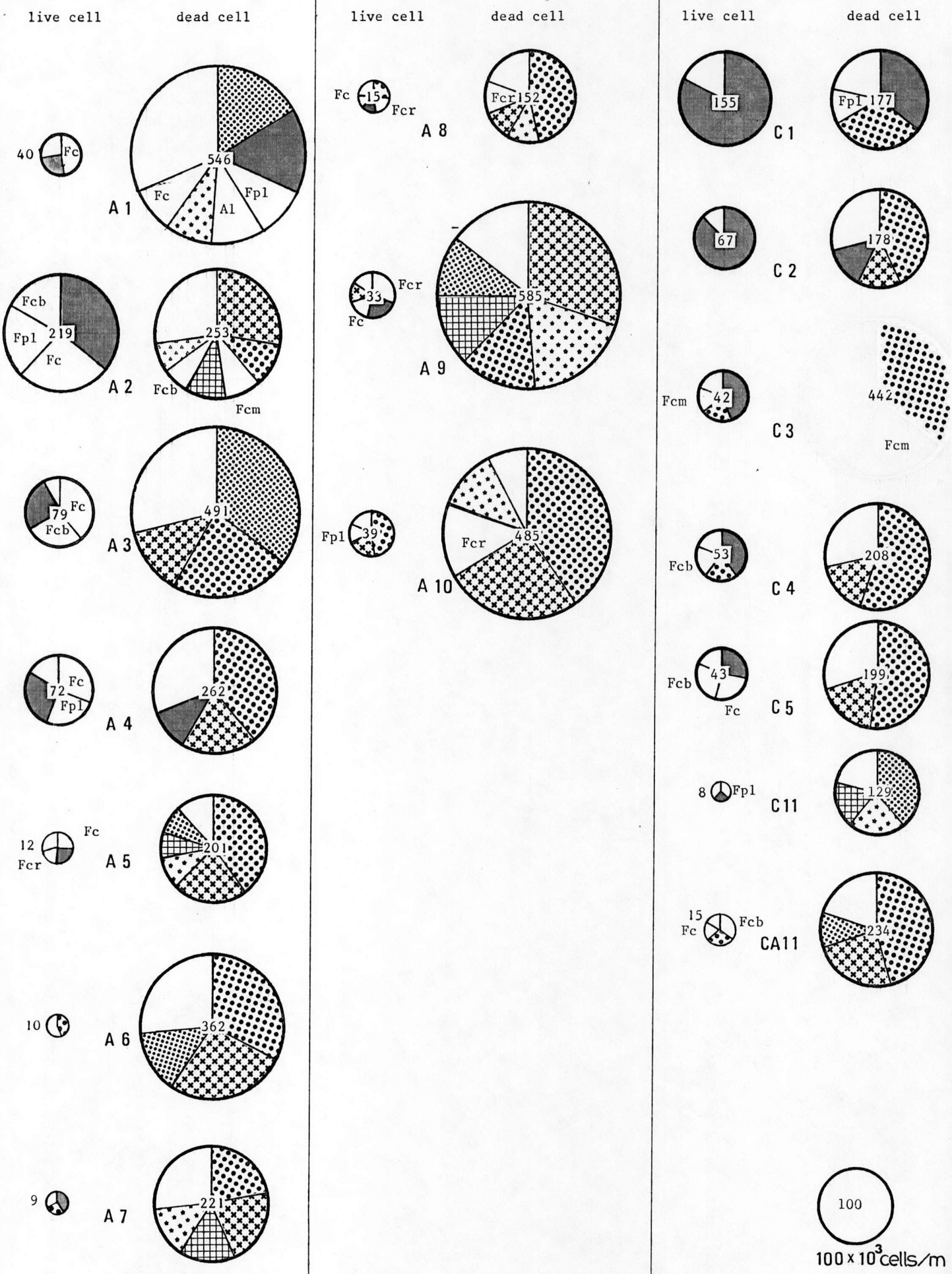


Fig.VI.7. The dominant species and cell numbers of benthic micro algae on the lake sediment 1976 X

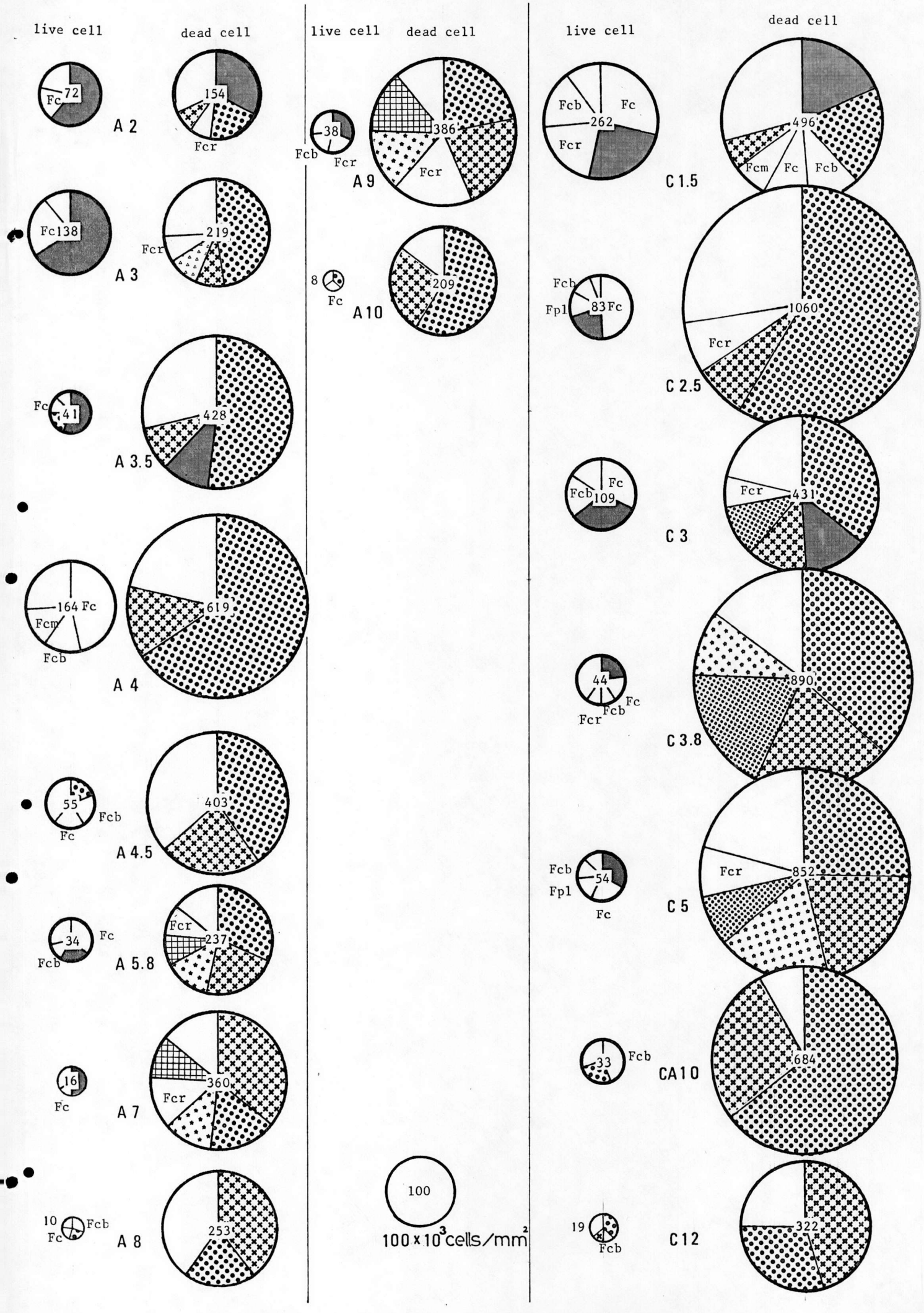


Fig.VI-8. Vertical distribution of cell numbers in benthic micro algae averaging those at different stations with the same or near depths.

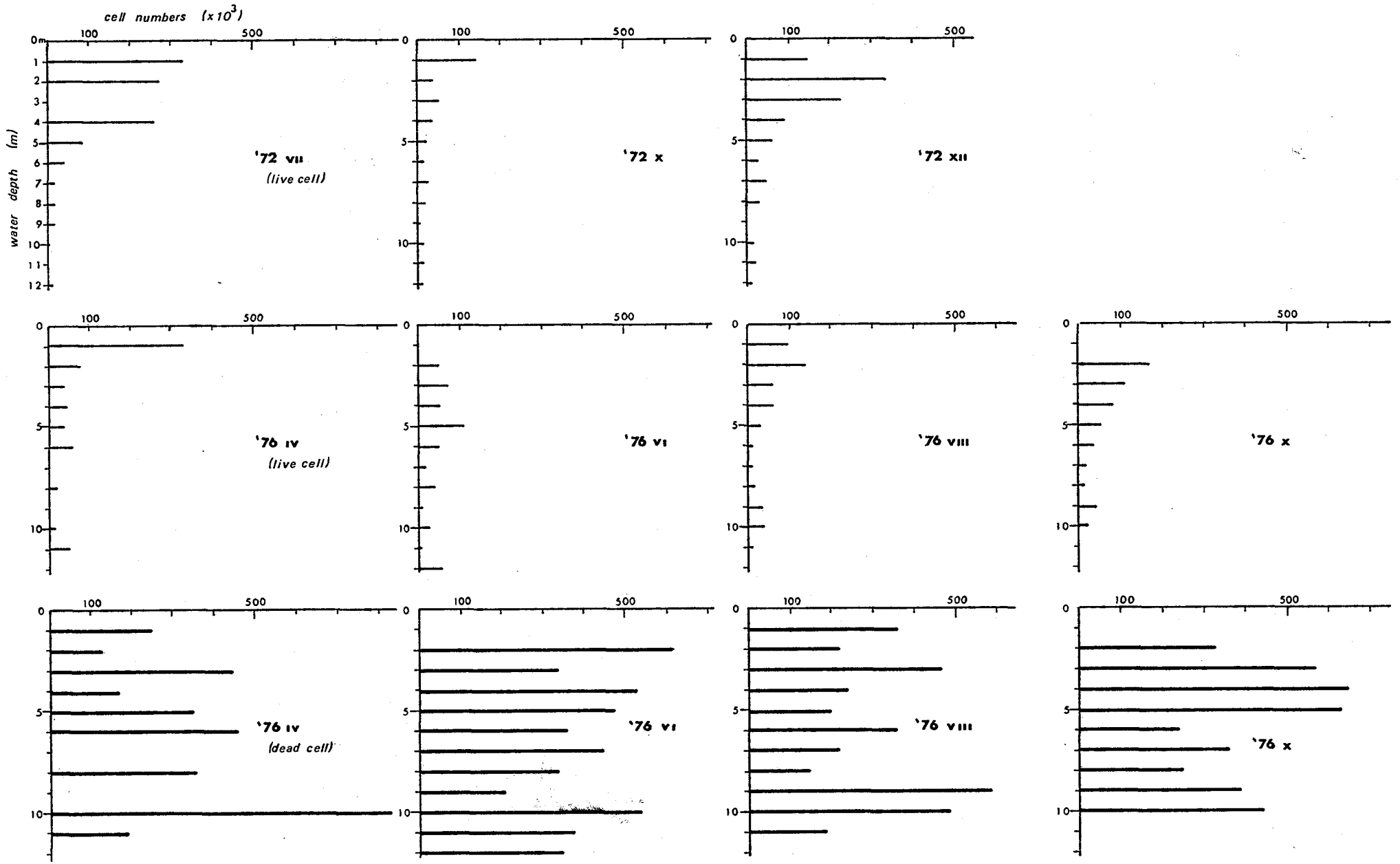
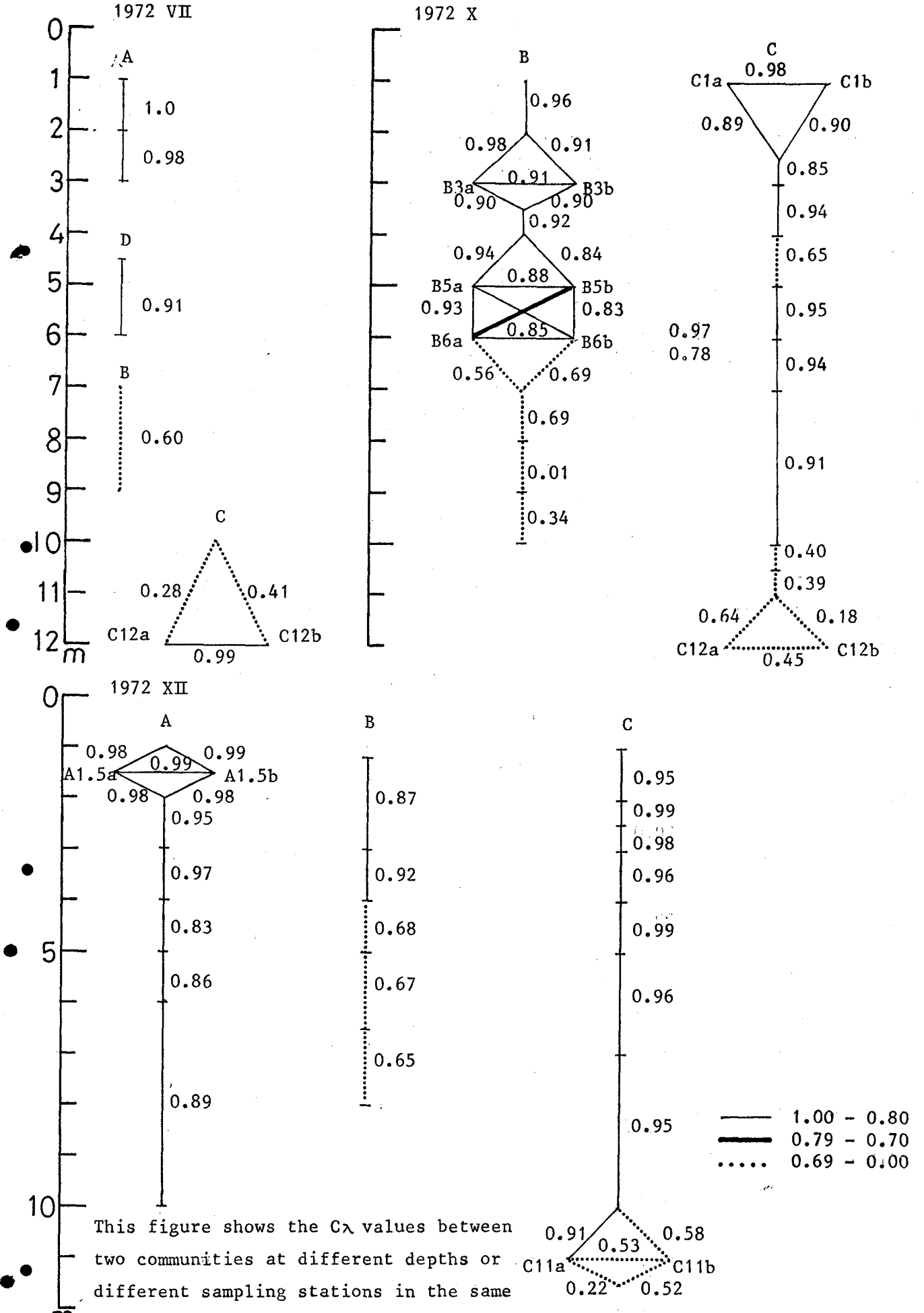


Fig.VI.9a. C_λ values of benthic microalgae between neighboring stations



This figure shows the C_λ values between two communities at different depths or different sampling stations in the same course. The values distribute from 0 to 1. The closer the value approaches 1, the more the communities are similar. I estimate the values from 1.00 to 0.80 as showing high similarity (thin line), from 0.79 to 0.70 as slight one (thick line), from 0.69 to 0 as low one (dotted line).

ig.VI.9b Cλ values of benthic micro algae between neighboring stations

( ) dead cell

left line - live cel
right line- dead cel

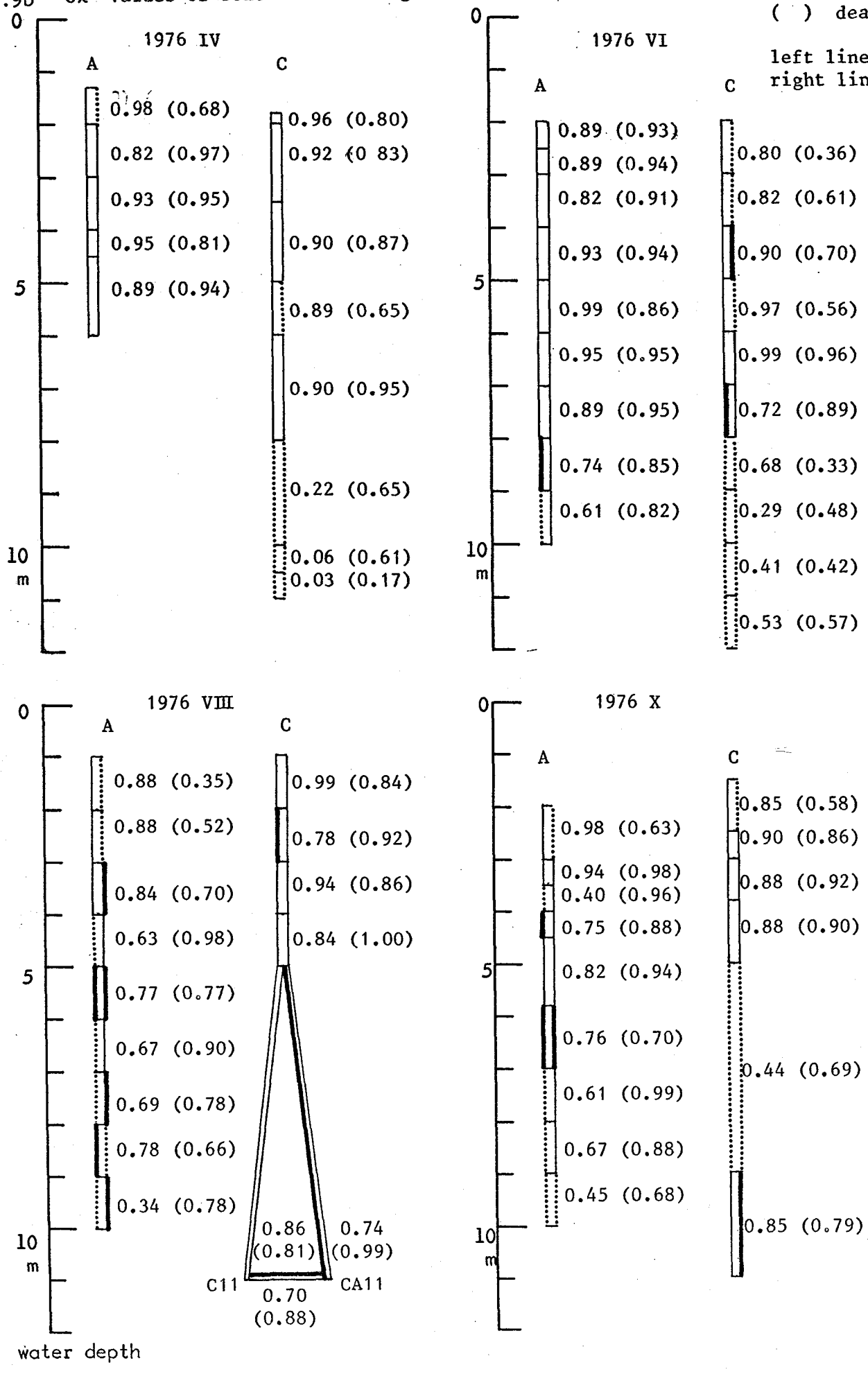


Fig.VI.10a C_λ values of benthic micro algae between same or the nearest depth in different stations

( ) dead cell

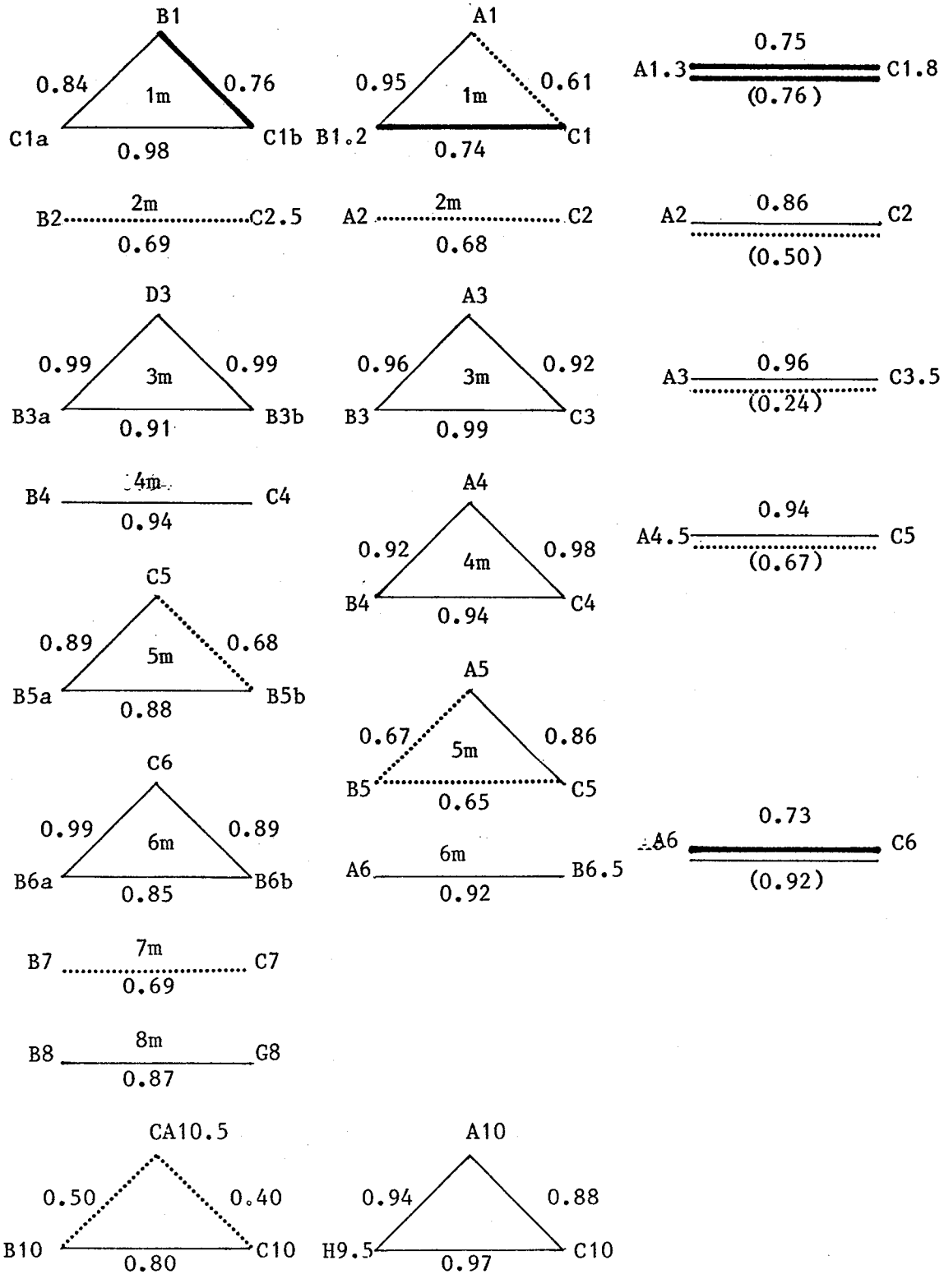
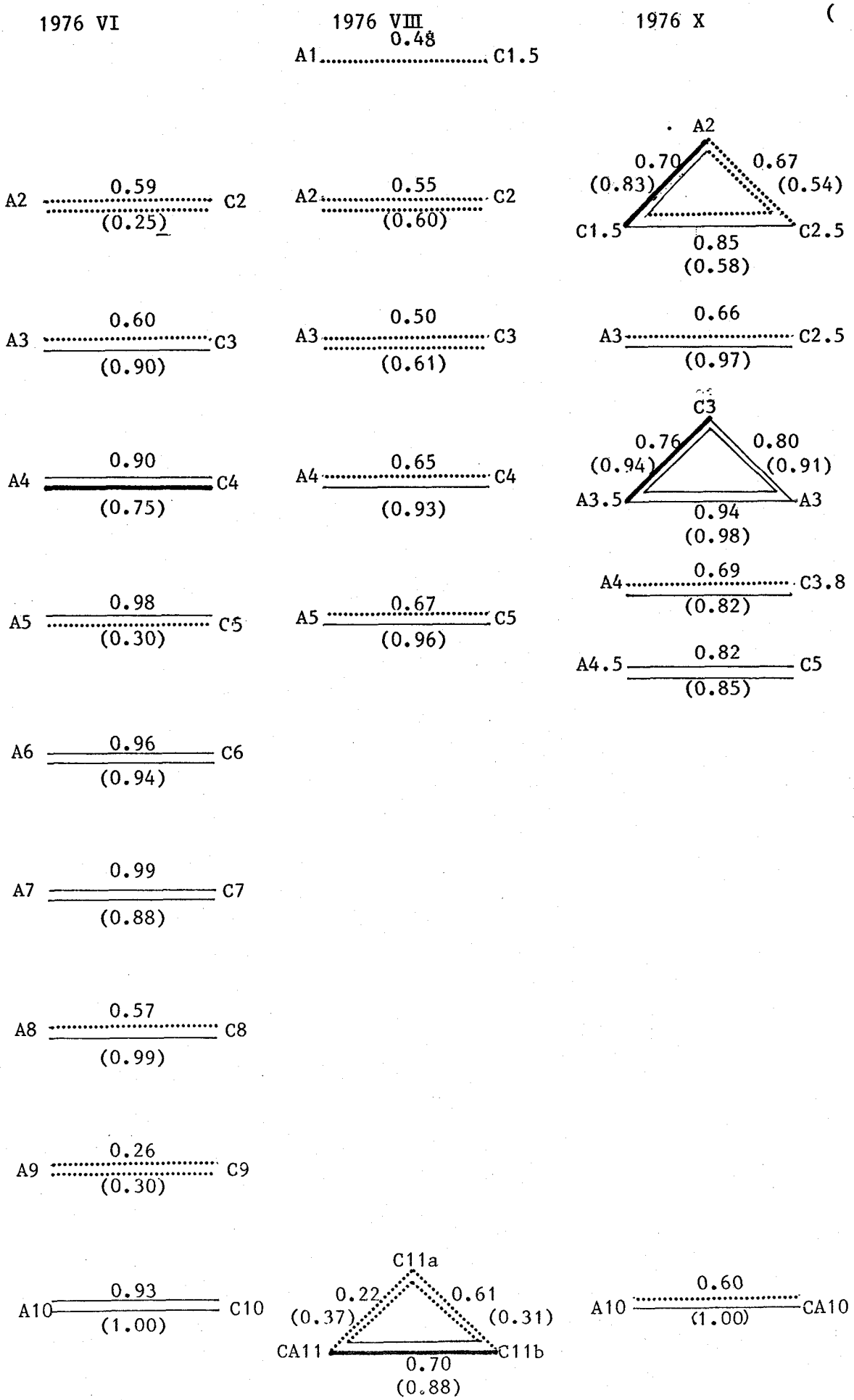


Fig.VI.10b

C_λ values of benthic micro algae between same or the nearest depth in different stations

( ) dead cell



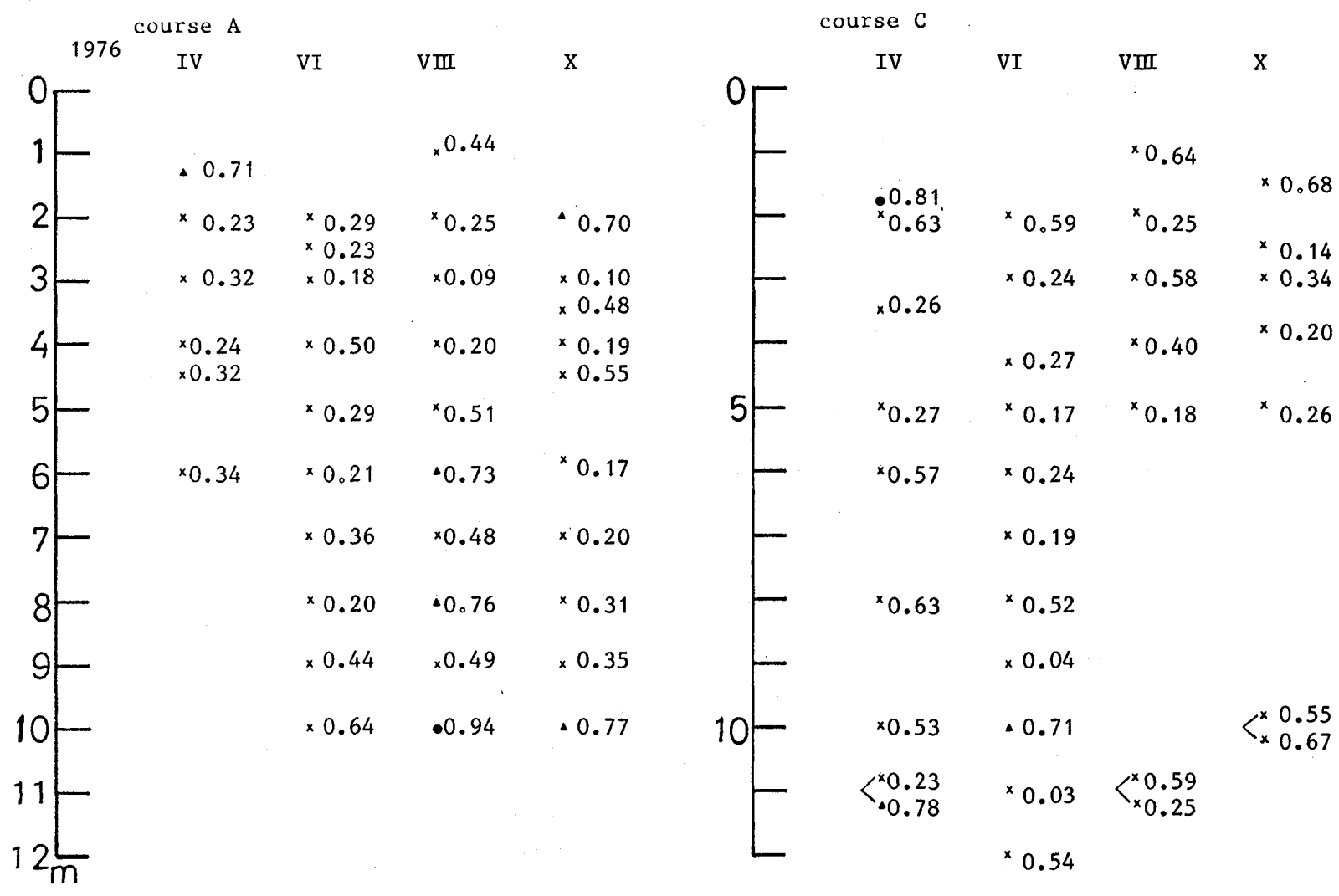


Fig.VI.11. C_λ values between live cells and dead cells at same stations

● 1.00 - 0.80
▲ 0.79 - 0.70
× 0.69 - 0.00

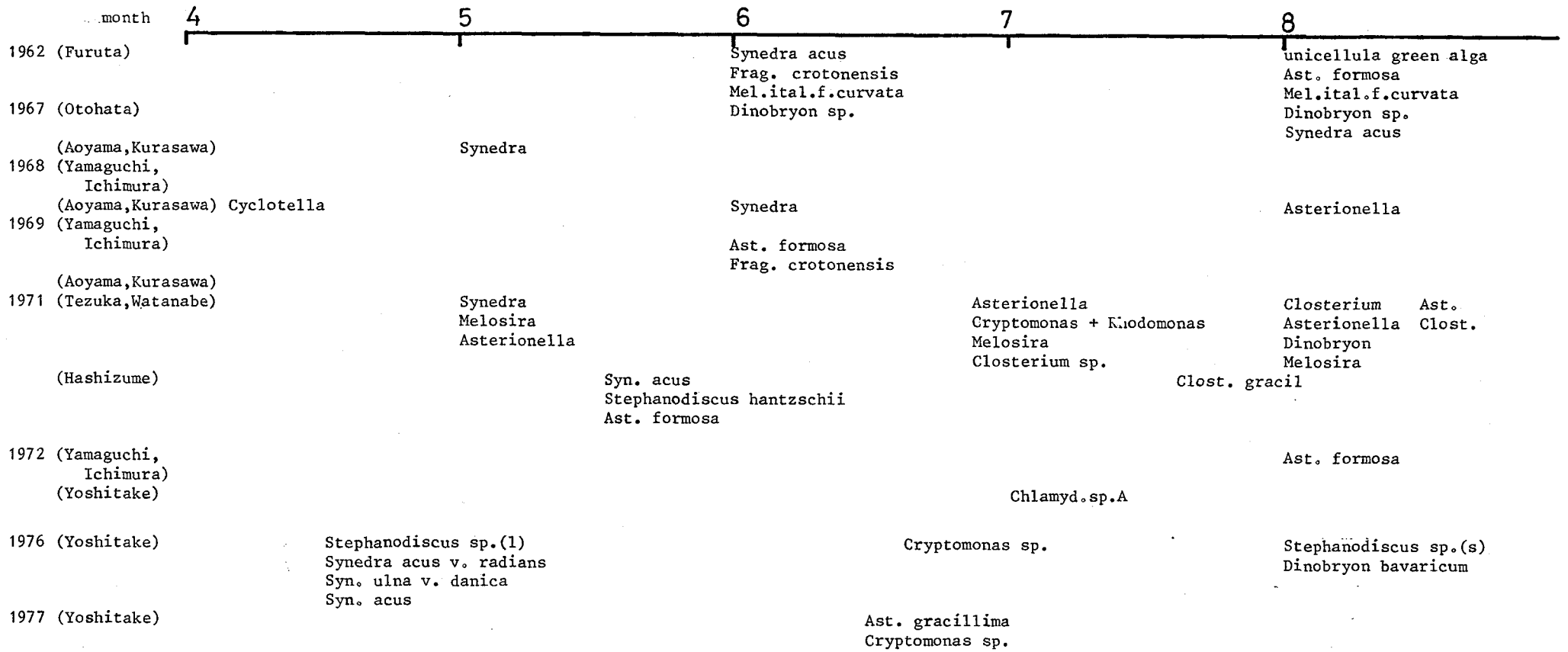


Fig.VI.12 Seasonal succession of phytoplankton during past 15 years observed by many workers in Lake Yunoko.

month 9 10 11 12 1

Ast. formosa
Glenodinium ?

Asterionella

from fall to spring Mel. ital. subsp. subarctica f. curvata, Mel. ital.sub. subarctica

Melosira

Mel. italica

Melosira

Synedra
Asterionella

Cryptomonas + Rhodomonas

Cryptomonas + Rhodomonas
Melosira
Asterionella
Dictyosphaerium

Stephano. hantzschii
Ast. formosa

Cryptomonas erosa
Dictyosphaerium pulchellum
Ast. formosa

Frag. crotonensis
Syn. sp.

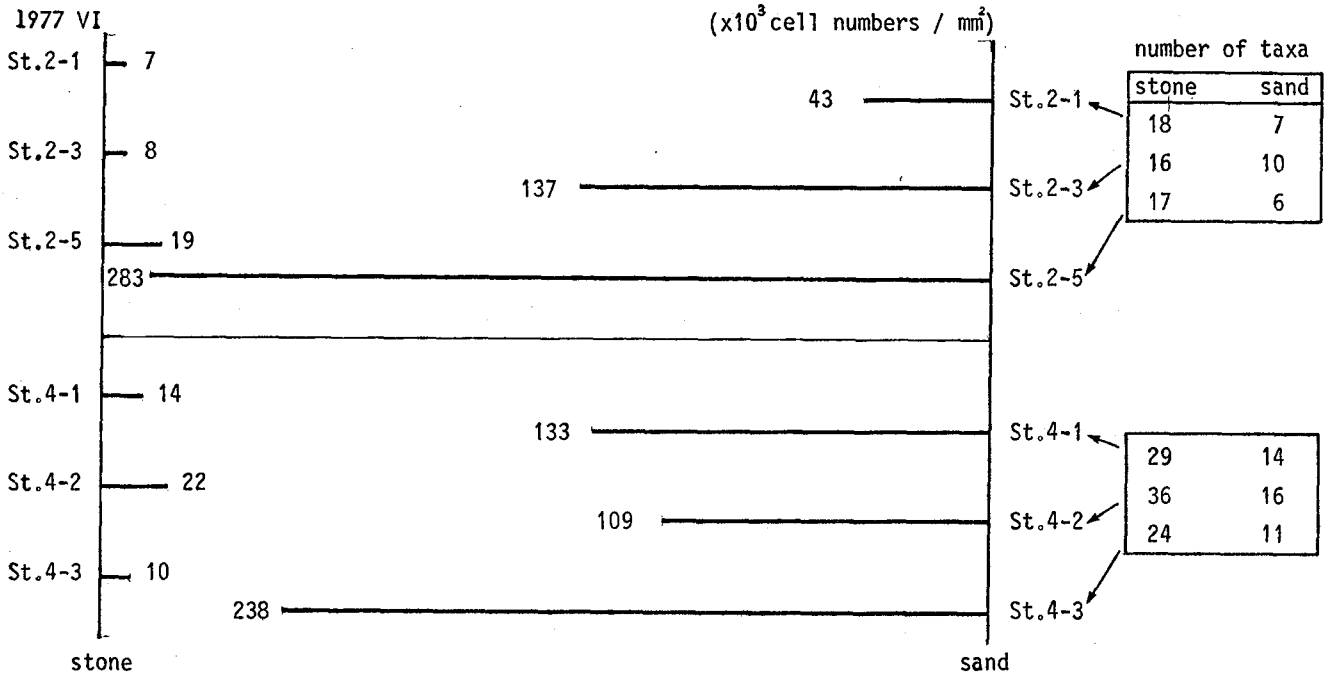
Aphanocapsa elachista v. planktonica
Chlamyd sp. B

Mel. distans
Syn. acus
Mel. ital.f.curvata

Ochromonas sp.
Cryptomonas sp.

Fig.VI.13.

Cell numbers in two different substrates,stone and sand.



Cell numbers of the phytoplankton at two different layers.

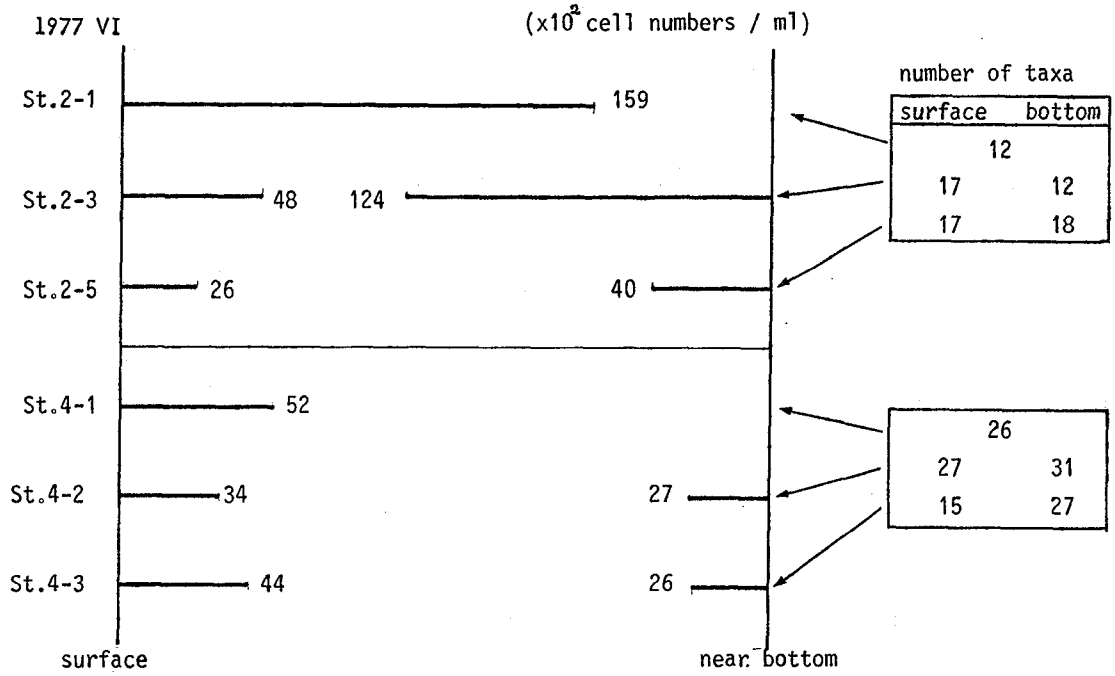
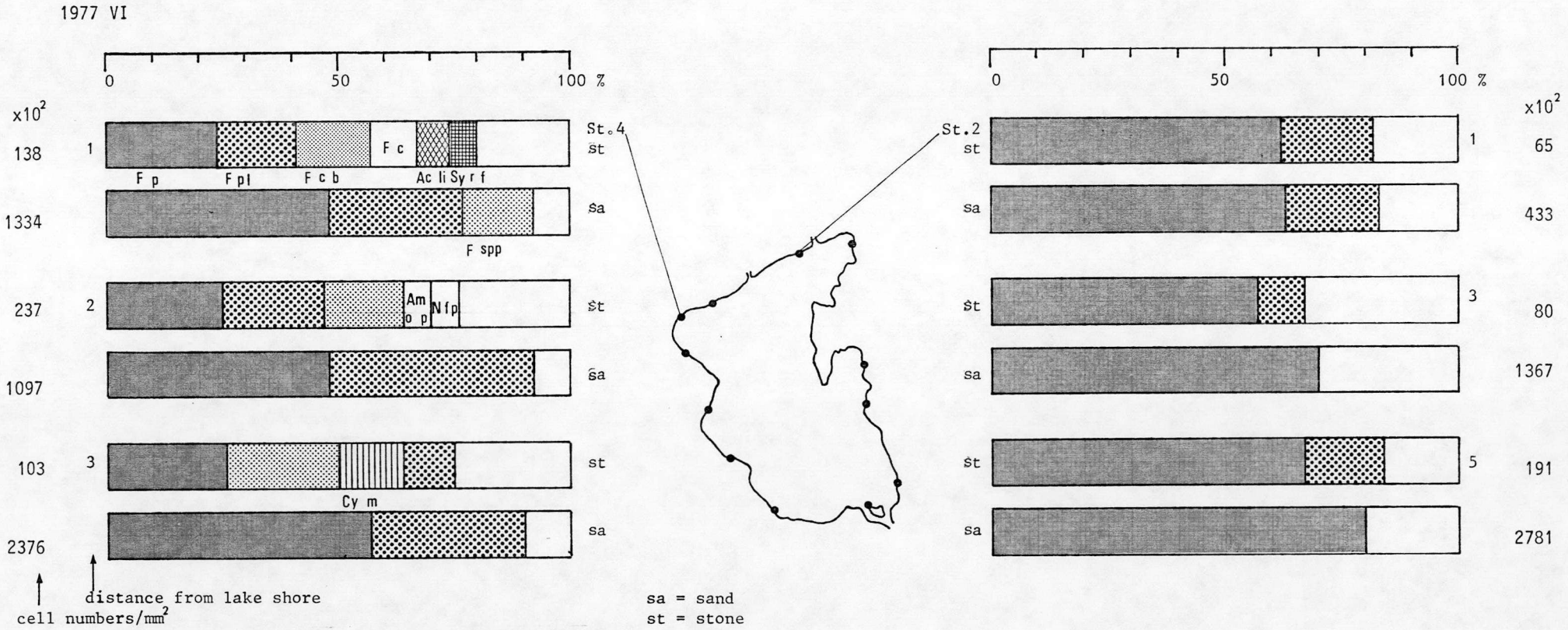


Fig.VI.14.

Relative abundance of dominant species and total counts of epipelic or epilithic micro algae in each littoral station.



Ac li	Achnanthes lineariformis
Am o p	Amphola ovalis v. pediculus
Cy m	Cymbella microcephala
F c	Fragilaria construens
F c b	F. con. v. binodis
F p	F. pinnata
F p l	F. pin. v. lancettula
N f p	Nitzschia frustulum v. perpusilla
Sy r f	Synedra rumpens v. fragilarioides

Fig.VI.15a. Cλ values between benthos in two different substrates, stone and sand.

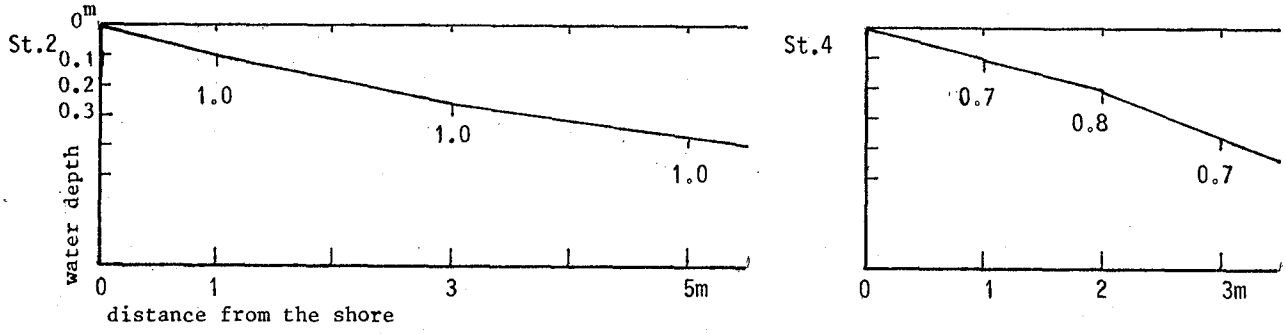


Fig.VI.15b. Cλ values between benthos in different distances from the shore bracket : sand no bracket : stone

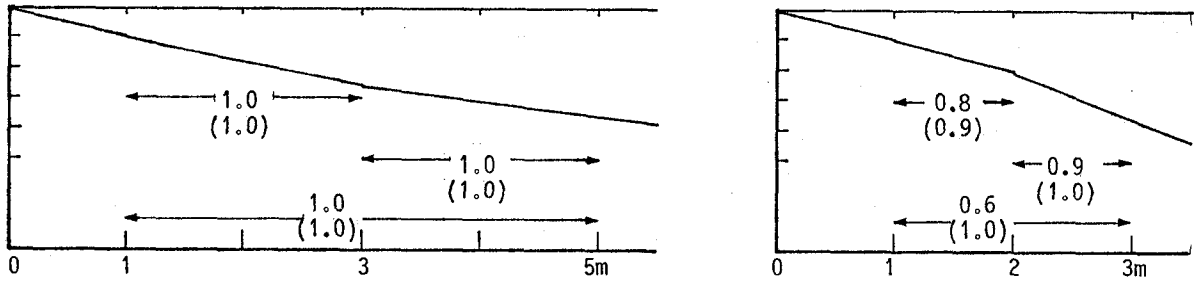


Fig.VI.15c. Cλ values of the phytoplankton between surface and near bottom layers.

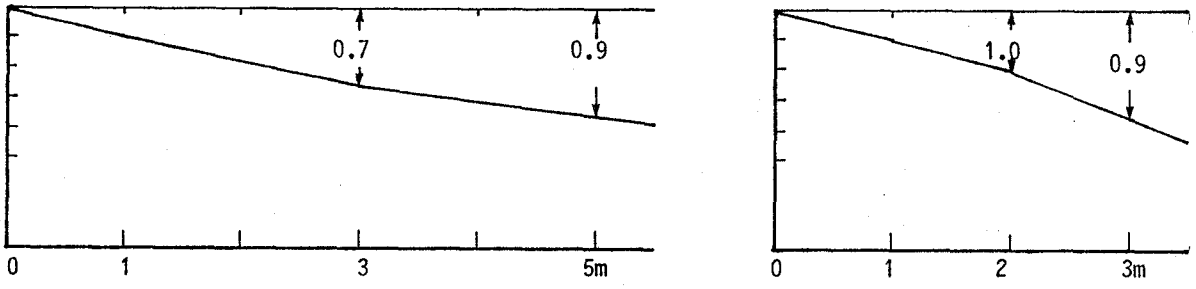


Fig.VI.15d. Cλ values of the phytoplankton between different distances from the shore. bracket : near bottom
no bracket : surface

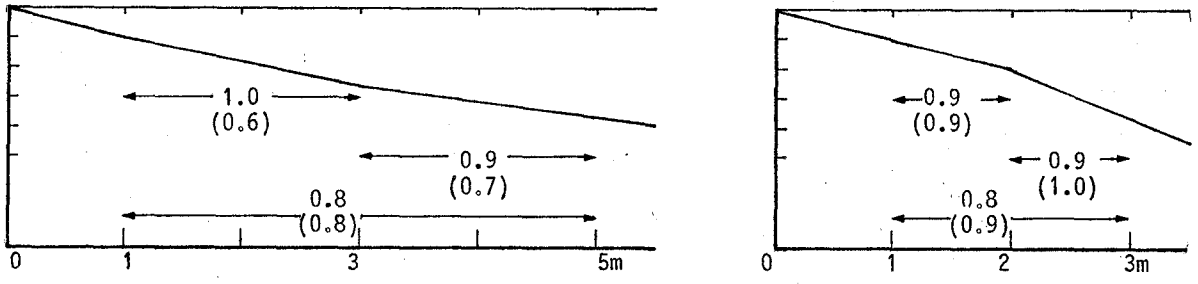
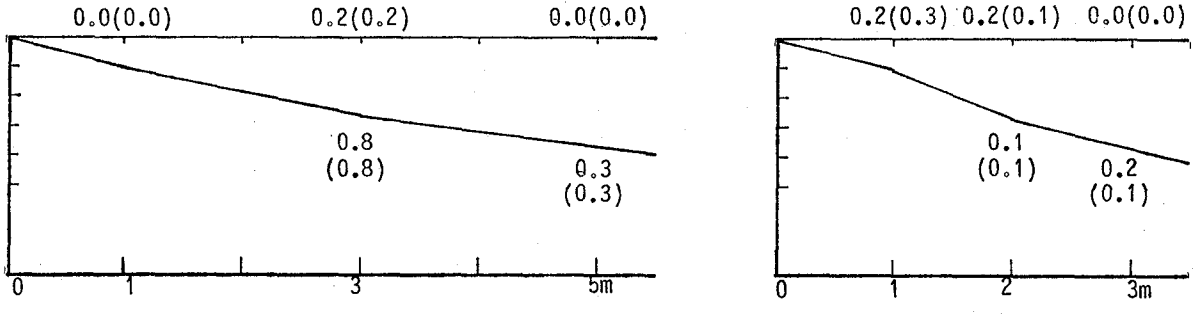


Fig.VI.15e. Cλ values between benthos and phytoplankton at the same station. Upper and under values show the similarity between benthos and phytoplankton at the surface or near bottom layers respectively.
bracket : sand no bracket : stone



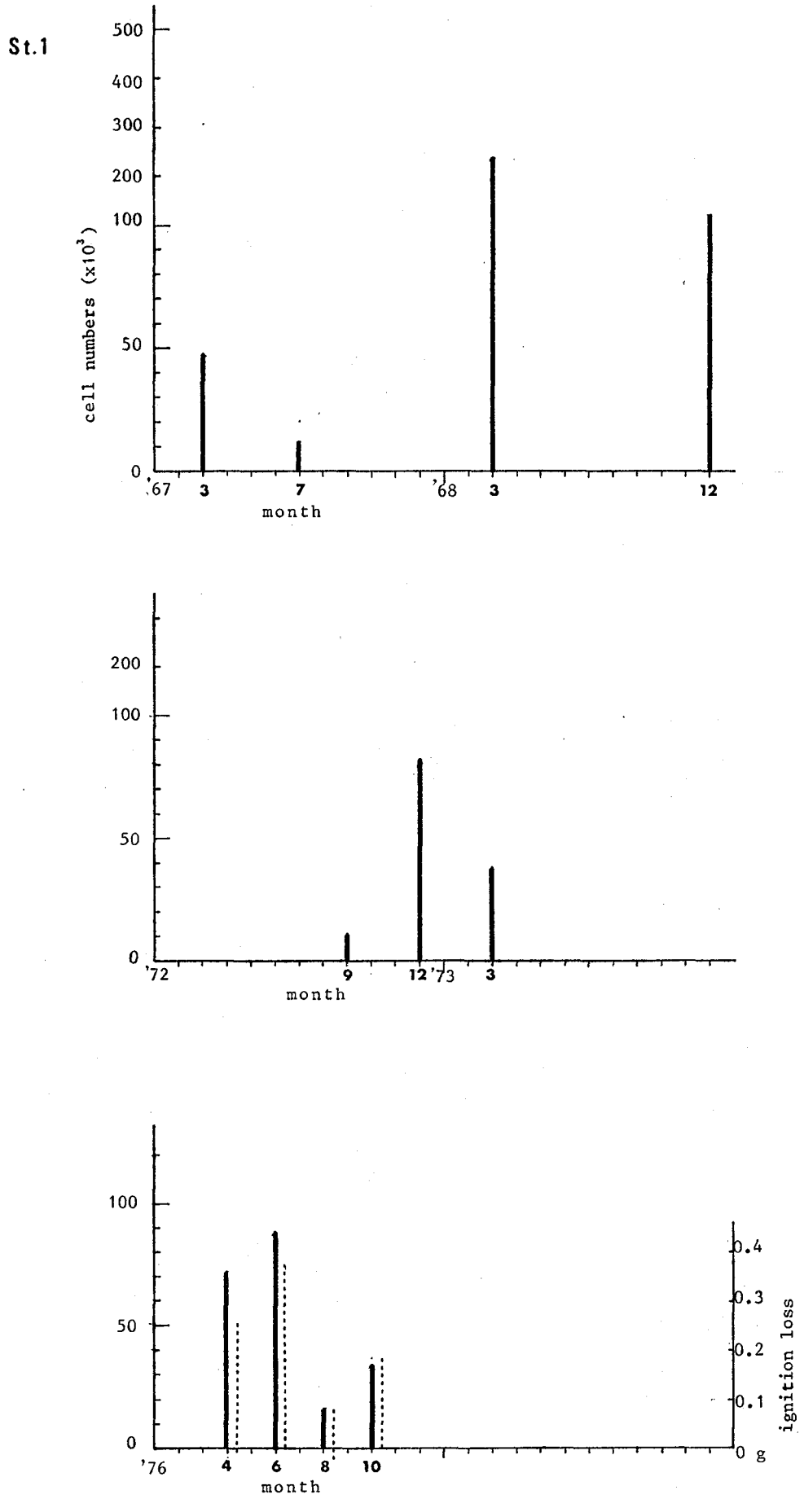


Fig.VII .2.1.
The seasonal counts of benthic micro algae from littoral zones in Lake Yunoko.

(cells/mm²)

cell number
ignition loss

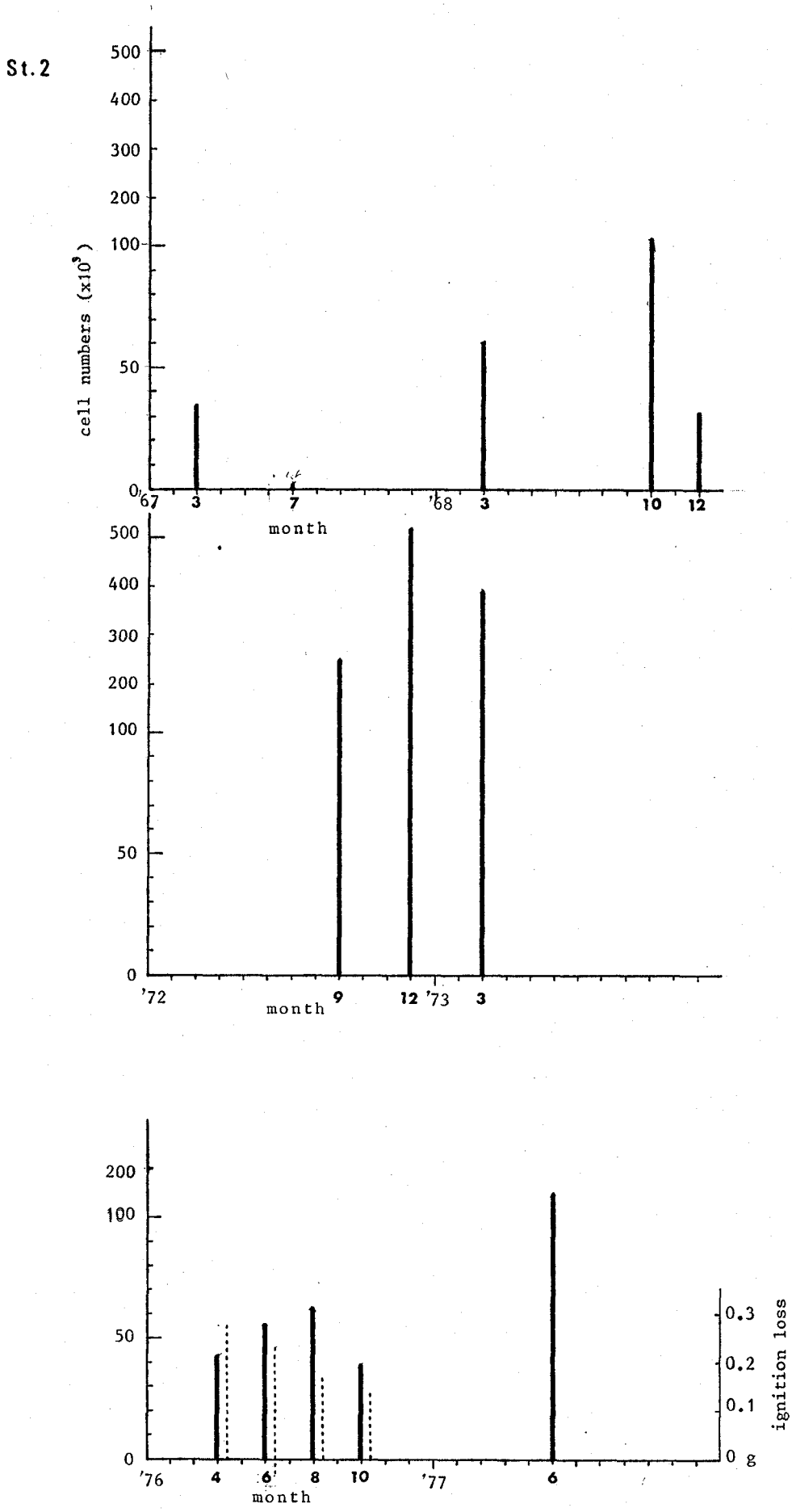


Fig.VII .2.2.

The seasonal counts of benthic micro algae from littoral zones in Lake Yunoko.

(cells / mm^2)

cell number

ignition loss

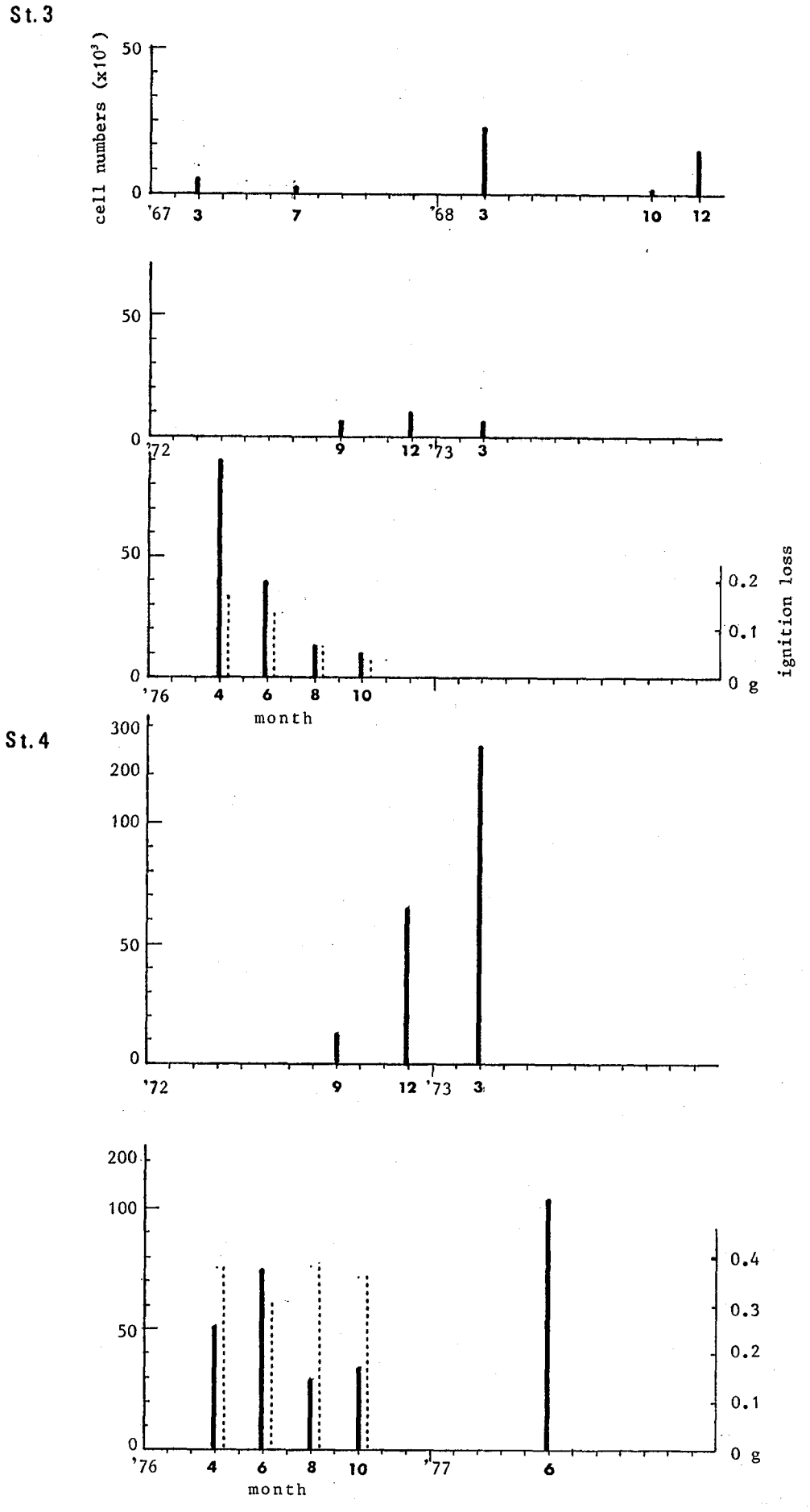


Fig.VII .2.3.

The seasonal counts of benthic micro algae from littoral zones in Lake Yunoko.

(cells / mm^2)

——— cell number

..... ignition loss

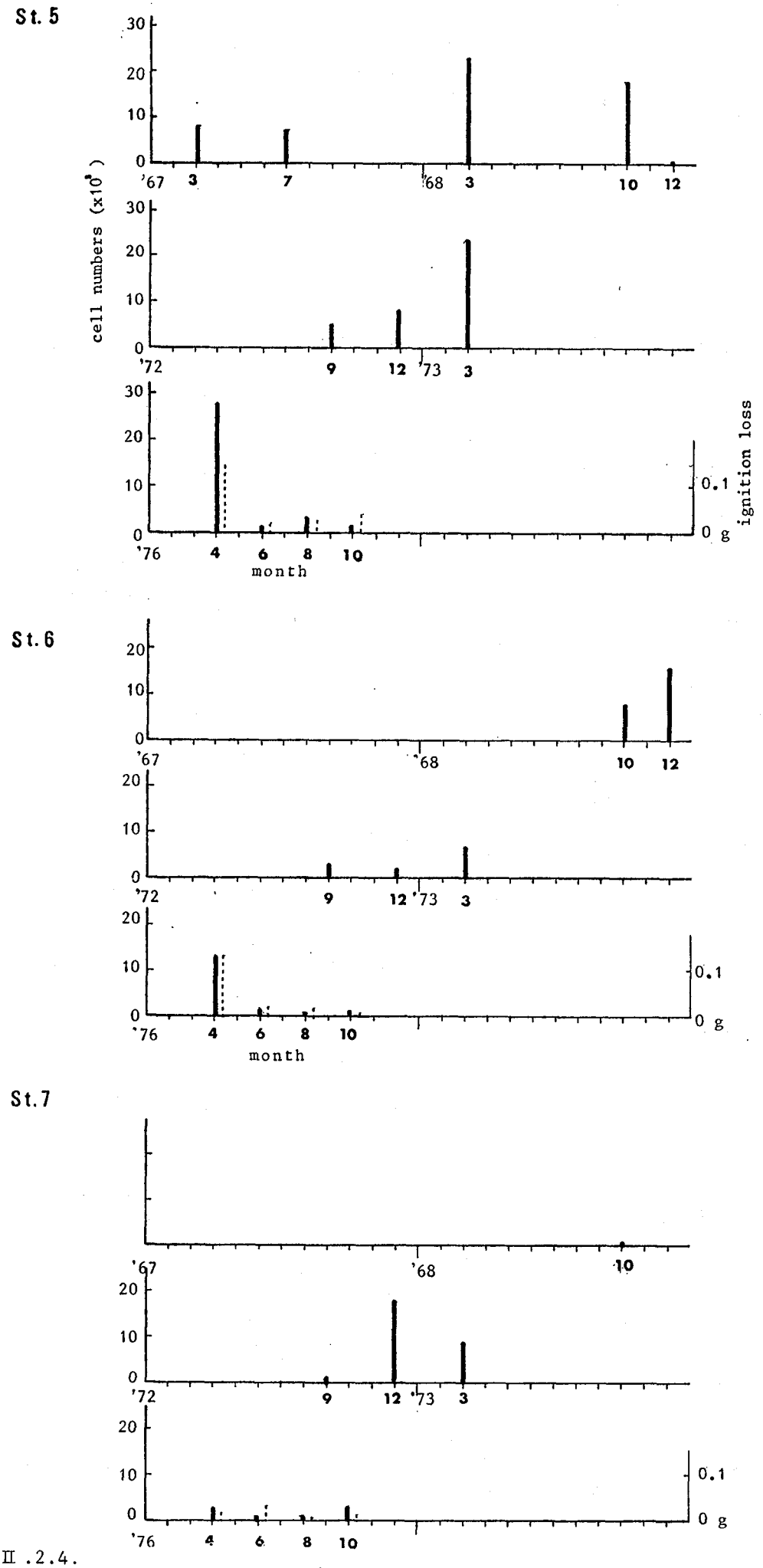


Fig.VII .2.4.

The seasonal counts of benthic micro algae from littoral zones in Lake Yunoko.

(cells / mm^2)

cell number

ignition loss

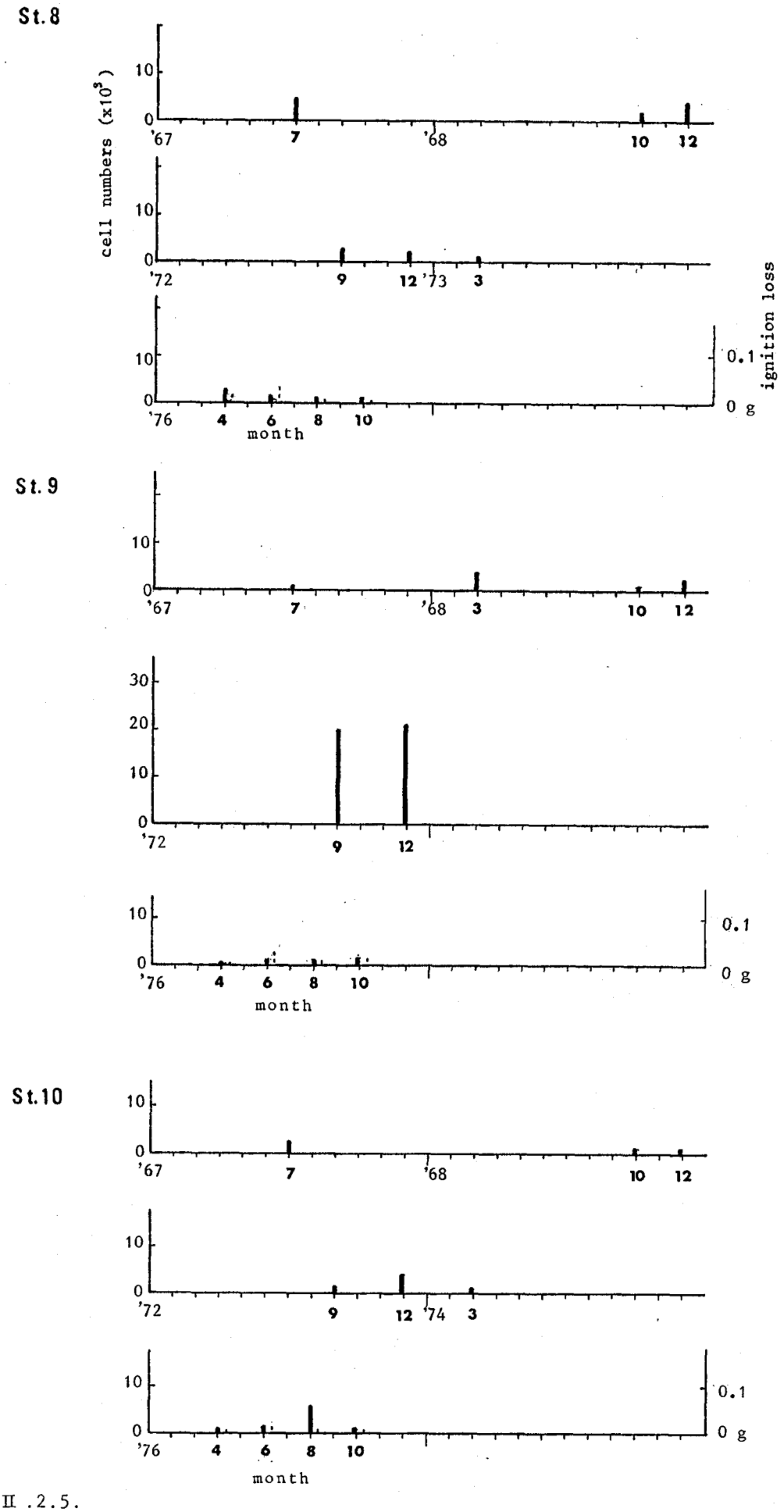


Fig.VII .2.5.

The seasonal counts of benthic micro algae from littoral zones in Lake Yunoko.

(cells / mm^2)

cell number

ignition loss

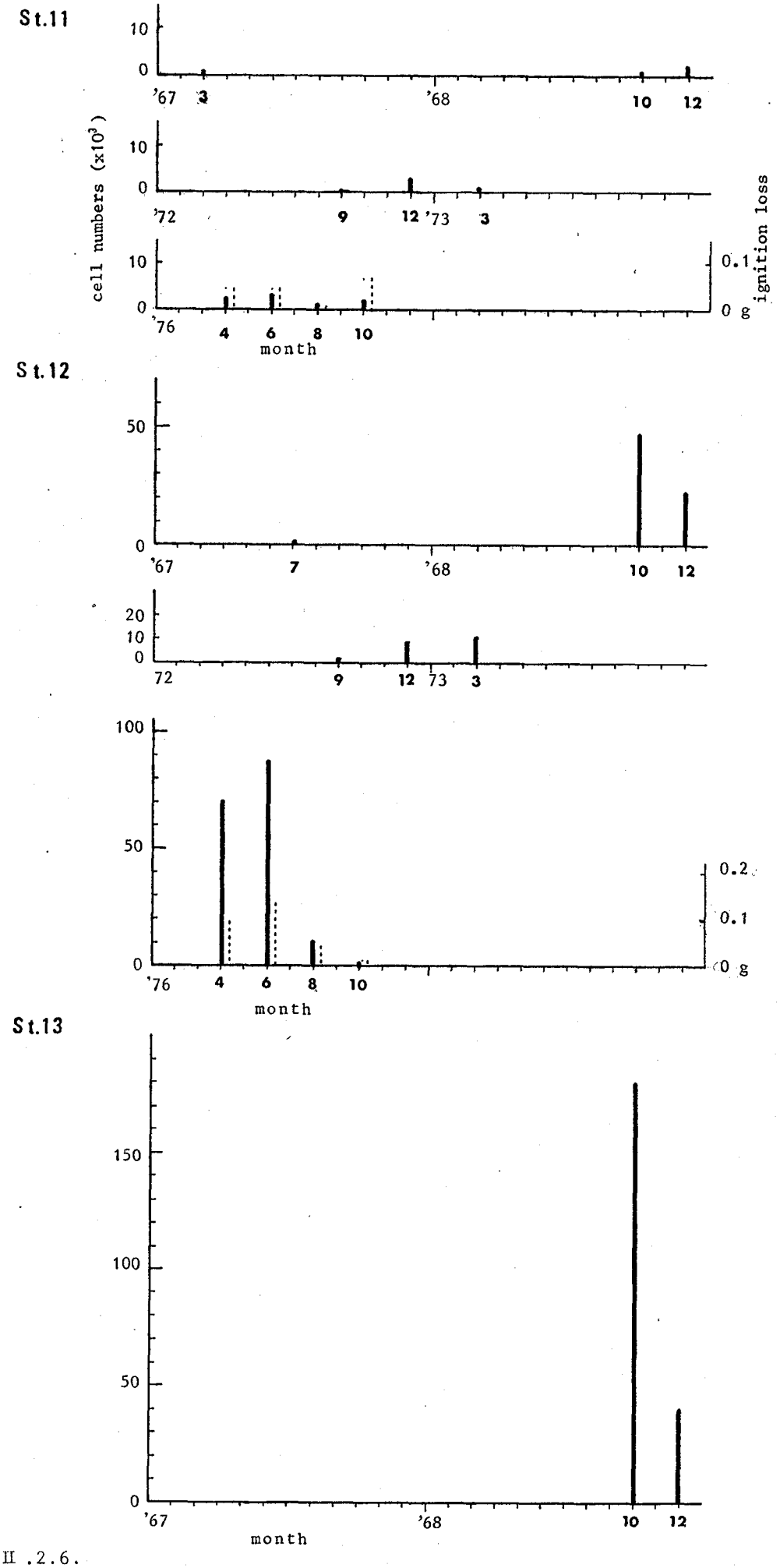


Fig.VII .2.6.

The seasonal counts of benthic micro algae from littoral zones in Lake Yunoko.

(cells / mm²)

cell number

ignition loss

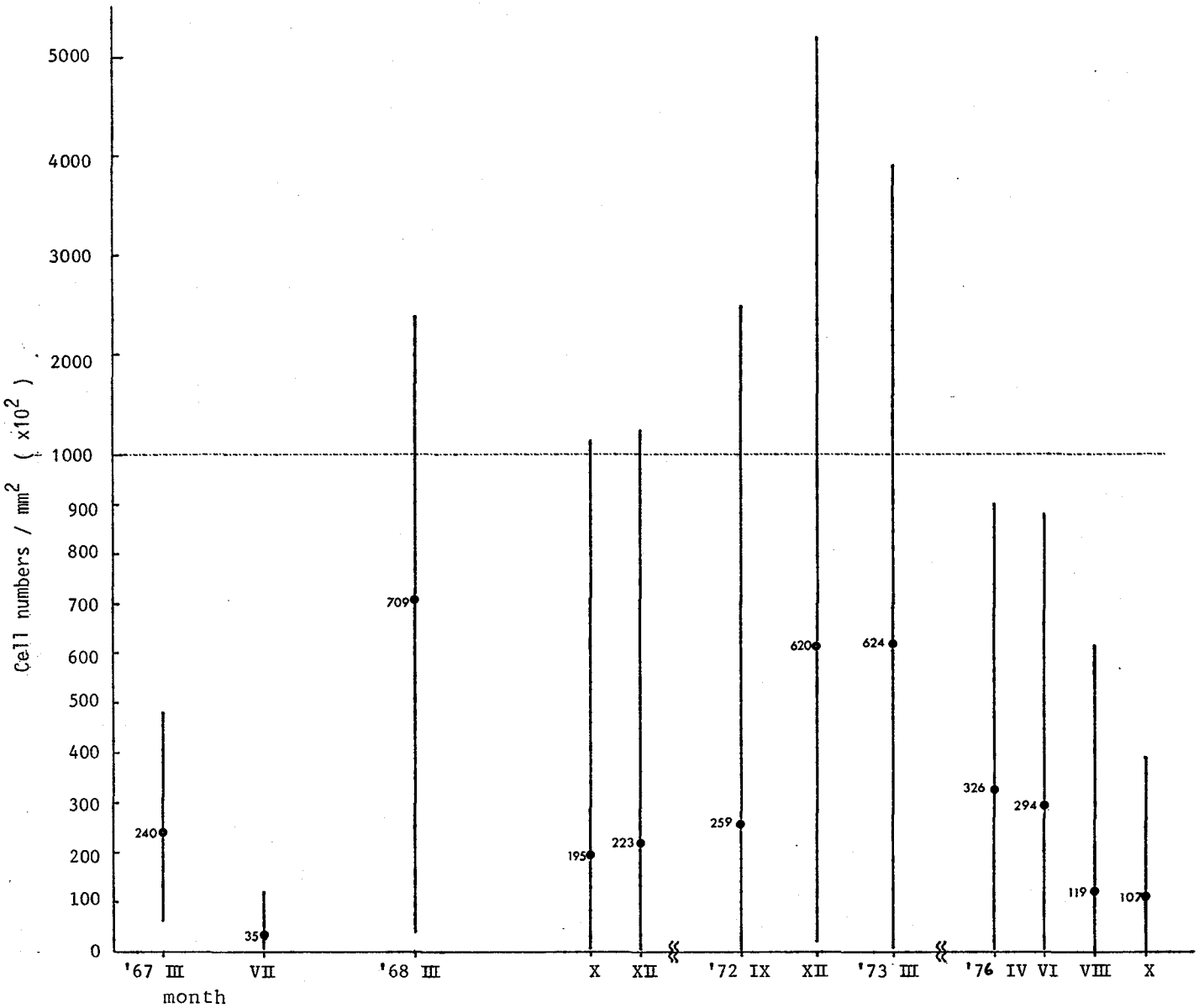


Fig.VII .2.7 Seasonal change in variable range and its average of cell numbers in benthic micro algae from littoral zones in Lake Yunoko.

Table VII.3.1. Relative abundance of littoral benthic algae

date	station	Cyano-phyta	Bacilla-riophyta	Chloro-phyta
1967 III	1	45.5	54.5	0
	2	0.2	99.7	0.2
	3	0.2	95.9	3.9
	5	1.2	97.2	1.6
1967 VII	1	51.3	47.3	1.4
	2	0.2	95.8	4.0
	3	0.1	99.3	0.6
	5	4.8	92.0	3.2
	8	15.0	84.2	0.8
	9	15.6	84.4	0.0
	10	37.8	62.2	0.0
	11	29.0	70.5	0.5
	12	2.1	96.4	1.5
1968 III	1	70.1	29.9	0.0
	2	7.7	91.5	0.8
	3	0.1	98.5	1.4
	5	7.3	88.4	4.3
	9	34.1	65.5	0.4
1968 X	2	0.0	98.5	1.5
	3	0.2	93.1	6.9
	5	0.0	100.0	0.0
	6	0.0	58.1	41.9
	7	18.0	80.4	1.6
	8	19.7	70.3	10.0
	9	19.7	80.3	0.0
	10	14.9	85.1	0.0
	11	8.2	91.8	0.0
	12	0.0	100.0	0.0
	13	26.3	73.7	0.0
1968 XII	1	19.2	80.8	0.0
	2	0.0	100.0	0.0
	3	0.0	98.6	1.4
	5	1.0	89.6	9.4
	6	7.4	76.4	16.2
	8	2.4	94.6	3.0
	9	7.1	88.6	4.3
	10	35.4	64.6	0.0
	11	0.0	100.0	0.0
	12	0.0	99.4	0.6
	13	10.7	89.3	0.0

date	station	Cyano-phyta	Bacilla-riophyta	Chloro-phyta
1972 IX	1-0.5	15.7	81.0	3.3
	1	1.8	97.3	0.9
	2-2	0.0	100.0	0.0
	5	0.0	100.0	0.0
	8	0.0	100.0	0.0
	3-1	0.0	100.0	0.0
	2	0.0	98.0	2.0
	4	0.0	98.5	1.5
	4-1	0.0	85.9	14.1
	2	0.0	77.8	22.2
	3	0.0	85.0	15.0
	5-1	0.0	91.5	8.5
	2	1.6	86.0	12.5
	6-1	0.0	100.0	0.0
	2	0.0	99.1	0.9
	7-1	24.2	41.0	34.8
	2	0.0	77.2	22.8
	8-1	96.8	3.5	0.0
	3	24.0	61.7	14.4
	5	15.7	58.4	25.9
	9-1	12.9	83.9	3.2
	2	2.7	97.3	0.0
	3	63.0	36.5	0.5
	10-1	22.7	68.8	8.5
	2	51.5	48.5	0.0
	4	30.1	68.9	0.9
	7	68.8	26.5	4.7
	11-1	3.4	72.6	23.9
	2	1.4	74.7	24.0
	3	16.2	73.0	10.8
	12-0.5	44.5	55.5	0.0
	1	49.4	50.6	0.0
1972 XII	1-0.5	11.5	88.5	0.0
	1	3.6	92.5	3.8
	2-2	0.0	100.0	0.0
	5	0.0	100.0	0.0
	8	0.0	100.0	0.0
	3-1	0.0	72.3	27.7
	2	0.3	98.1	1.5
	4	0.0	99.6	0.4
	4-1	0.0	89.7	10.3
	2	0.0	96.2	3.8
	3	0.0	76.2	23.8
	5-1	1.5	95.3	3.2
	2	4.2	92.4	3.4
	6-1	6.9	88.8	4.3
	2	41.5	56.0	2.4

date	station	Cyano-phyta	Bacilla-riophyta	Chloro-phyta
1972 XII	7-1	1.5	94.9	3.5
	2	1.2	88.6	10.2
	3	1.1	86.9	11.9
	8-1	10.2	89.8	0.0
	3	31.6	67.8	0.6
	9-1	16.4	83.6	0.0
	2	31.7	68.0	0.3
	3	8.0	82.9	9.1
	10-1	8.9	91.1	0.0
	2	11.9	88.1	0.0
	4	11.8	88.2	0.0
	7	13.6	85.7	0.6
	11-1	40.8	58.4	0.7
	2	35.7	61.1	3.2
	3	10.9	88.3	0.8
	12-0.5	21.4	69.9	8.7
	1	13.9	83.3	2.8
1973 III	1-0.5	7.1	86.0	6.9
	1	15.2	84.4	0.3
	2-2	0.0	100.0	0.0
	5	0.0	100.0	0.0
	3-1	0.0	76.6	23.4
	2	0.4	98.8	0.8
	4	0.0	100.0	0.0
	4-1	0.0	94.1	5.9
	2	0.0	94.6	5.4
	3	0.0	97.3	2.7
	5-1	4.4	95.6	0.0
	2	2.5	91.1	6.3
	3	0.5	95.8	3.7
	6-1	0.0	100.0	0.0
	2	26.4	73.6	0.0
	7-1	0.2	99.8	0.0
	2	0.0	98.8	1.2
	3	30.3	64.2	5.5
	8-1	9.5	90.5	0.0
	3	14.7	82.5	2.8
	5	1.3	96.8	1.9
	10a-1	15.9	82.0	2.0
	2	48.8	51.2	0.0
	10b-1	1.6	98.4	0.0
	2	20.9	79.1	0.0
	4	10.9	84.8	4.3
	7	0.0	100.0	0.0
	11-2	23.7	76.3	0.0
	12-0.5	4.9	94.1	1.0
	1	7.5	72.1	20.5

Table VII.3.2. Relative abundance of littoral benthic algae

date	station	Cyanophyta	Bacillariophyta	Chlorophyta
1976 IV	1-1	10.5	85.1	4.4
	2	13.3	84.7	1.9
	2-2	0.3	84.8	14.9
	5	0.1	82.8	17.1
	8	0.0	97.7	2.3
	3-1	1.6	98.4	0.0
	2	0.5	98.5	1.0
	4	0.0	98.2	1.8
	4-1	0.0	91.7	8.3
	2	0.0	97.0	3.0
	3	0.0	96.5	3.5
	5-1	2.7	88.4	8.9
	2	1.2	96.2	2.6
	6-1	1.3	95.2	3.6
	2	0.0	100.0	0.0
	7-1	60.3	38.6	1.1
	2	36.2	48.1	15.7
	3	64.0	34.8	1.2
	8-1	58.1	41.6	0.3
	3	57.3	41.7	1.0
	9-1	0.0	72.7	27.3
	2	4.3	86.3	9.3
	3	0.0	66.7	33.3
	10-1	30.8	69.2	0.0
	2	10.7	89.3	0.0
	4	6.4	93.6	0.0
	7	4.4	95.6	0.0
	11-1	34.6	64.3	1.0
	2	65.7	34.0	0.4
	3	75.6	24.4	0.0
	12-0.5	1.2	95.2	3.5
	1	5.9	93.5	0.6
1976 VI	1-0.5	2.8	97.2	0.0
	1	11.8	87.4	0.7
	2-2	0.0	88.4	11.6
	5	0.0	96.5	3.5
	3-1	0.0	94.0	6.0
	2	0.0	98.6	1.4
	4	0.0	99.4	0.6
	4-1	0.0	97.3	2.7
	2	0.0	94.0	6.0
	3	0.0	96.1	3.9
	5-1	92.8	4.8	2.4
	2	53.1	46.9	0.0
	6-1	91.5	6.2	2.3
	2	89.5	7.3	3.2

date	station	Cyanophyta	Cryptophyta	Chrysophyta	Bacillariophyta	Chlorophyta
1976 VI	7-1	90.6	0.0	0.0	8.3	1.0
	2	98.7	0.0	0.0	1.3	0.0
	3	94.8	0.0	0.0	5.2	0.0
	8-1	92.6	0.0	0.0	7.4	0.0
	3	71.6	0.0	0.0	24.9	3.6
	9-1	94.5	0.0	0.0	4.2	1.2
	2	76.3	0.0	0.0	23.7	0.0
	3	87.0	0.0	0.0	13.0	0.0
	10-1	86.0	0.0	0.0	14.0	0.0
	2	84.3	0.0	0.0	15.7	0.0
	4	97.7	0.2	0.0	2.1	0.0
	11-1	74.5	0.0	0.0	25.5	0.0
	2	79.6	0.0	0.0	18.4	1.9
	3	81.2	0.0	0.0	16.9	1.9
	12-0.5	0.0	0.0	0.0	99.4	0.6
	1	0.7	0.0	0.0	96.8	2.6
1976 VIII	1-0.5	26.2	0.0	0.0	70.9	2.9
	1	2.7	0.0	0.0	89.9	7.3
	2-2	0.0	0.0	0.0	97.2	2.8
	5	0.0	0.0	0.0	98.4	1.6
	3-1	0.0	0.0	0.0	99.7	0.3
	2	0.0	0.0	0.0	100.0	0.0
	4	0.0	0.0	0.0	99.7	0.3
	4-1	12.0	0.0	0.0	85.5	2.6
	2	0.0	0.0	0.0	97.8	0.6
	3	0.0	0.0	0.0	100.0	0.0
	5-1	49.3	0.0	0.0	50.7	0.0
	2	42.9	0.0	0.0	56.1	1.1
	6-1	3.4	0.0	0.0	95.7	1.0
	2	96.4	0.0	0.0	3.6	0.0
	7-1	93.4	0.0	0.0	6.4	0.2
	2	85.9	0.0	0.0	11.9	2.2
	3	88.2	0.0	0.0	11.0	0.9
	8-1	69.8	1.6	0.0	21.2	7.5
	3	76.9	0.0	3.3	19.6	0.2
	5	86.7	0.0	0.3	13.0	0.0
	9-1	49.9	0.0	1.7	37.4	11.1
	2	81.6	0.0	0.0	18.3	0.2
	3	70.9	0.0	0.0	27.1	2.0
	10-1	85.6	0.0	6.6	7.8	0.0
	2	81.1	0.0	4.3	14.3	0.3
	4	76.1	0.0	0.2	9.6	14.2
	7	95.6	0.0	0.4	4.0	0.0
	11-1	59.1	0.0	0.0	26.7	14.2
	2	83.8	0.0	3.2	11.9	1.1
	3	77.0	0.0	0.6	22.3	0.0
	12-0.5	0.3	0.0	0.0	99.4	0.3
	1	0.0	0.0	0 0	100.0	0.0

Table VII .3.3. Relative abundance of littoral benthic algae

date	station \ phylum	Cyano-phyta	Eugleno-phyta	Crypto-phyta	Chryso-phyta	Bacilla-riophyta	Chloro-phyta
1976 X	1-0.5	4.6	0.0	0.0	0.0	92.1	3.3
	1	8.2	0.0	0.0	0.0	89.8	2.0
	2-2	0.0	0.0	0.0	0.0	99.4	0.6
	5	0.0	0.0	0.0	0.0	97.7	2.3
	3-1	3.1	0.0	0.0	0.0	94.8	2.1
	2	3.9	0.0	0.0	0.0	92.9	3.3
	4	0.0	0.0	0.0	0.0	96.3	3.7
	4-1	0.0	0.0	0.0	0.0	91.6	8.4
	2	5.8	0.0	0.0	0.0	90.0	4.2
	3	0.0	0.0	0.0	0.0	96.5	3.5
	5-1	54.3	0.0	0.7	0.0	45.0	0.0
	2	64.1	0.0	0.4	0.0	34.0	1.5
	6-1	73.7	0.0	2.7	0.0	21.8	1.9
	2	90.7	0.0	0.0	0.0	9.3	0.0
	7-1	95.0	0.0	0.0	0.0	4.0	1.0
	2	96.2	0.0	0.0	0.0	3.8	0.0
	3	96.2	0.0	0.0	0.0	3.8	0.0
	8-1	57.1	0.0	1.6	1.6	20.3	19.2
	3	92.7	0.0	0.0	0.0	6.3	1.0
	5	88.7	0.0	0.0	0.0	10.5	0.8
	9-1	86.5	0.0	0.4	0.0	11.3	1.7
	2	73.2	0.0	0.0	0.0	26.1	0.7
	3	16.5	0.0	0.0	0.0	77.5	6.1
	10-1	68.2	5.6	0.0	0.0	25.4	0.8
	2	73.5	0.0	0.0	0.0	26.1	0.4
	4	68.2	0.0	0.0	0.0	31.8	0.0
	7	69.8	0.0	0.0	0.0	30.2	0.0
	11-1	97.0	0.0	0.0	0.0	3.0	0.0
	2	90.4	0.0	0.0	0.0	9.6	0.0
	12-0.5	22.5	0.0	0.0	0.0	72.8	4.8
	1	0.4	0.0	0.0	0.0	98.2	1.4
1977 VI	2-1 st	1.2	0.0	0.0	0.0	92.5	6.3
	sa	0.0	0.0	0.0	0.0	94.1	5.9
	3 st	7.4	0.0	0.0	0.0	84.4	8.2
	sa	0.1	0.0	0.0	0.0	93.1	6.8
	5 st	0.3	0.0	0.0	0.0	94.2	5.5
	sa	0.0	0.0	0.0	0.0	97.2	2.8
	4-1 st	0.0	0.0	0.0	0.0	97.3	2.7
	sa	0.0	0.0	0.0	0.0	96.6	3.4
	2 st	3.8	0.0	0.0	0.0	93.8	2.4
	sa	0.0	0.2	0.0	0.0	98.8	1.0

Anabaena sp.	An sp
Aphanocapsa delicatissima	Ap d
Aphanocapsa elachista v. planktonica	Ap e p
Aphanothece nidulans	
Chamaesiphon africanus v. minimus	
Cham. cylindricus	Ch c
Cham. rostafinskii	Ch r
Homoeothrix hansgirgi	H h
Hom. janthina	
Phormidium sp.	P sp
Synechococcus eximius	S e
Synechocystis aquatilis v. minor	Syc a m
Achnanthes austriaca	Ac a
Ach. exigua	Ac e
Ach. japonica	Ac j
Ach. lanceolata	Ac l
Ach. lineariformis	
Ach. spp.	Ac spp
Amphora ovalis v. pediculus	Am o p
Asterionella formosa	As f
Ceratoneis arcus v. vaucheriae	C a v
Cyclotella spp.	Cyc sp
Cymbella leptoceros	Cy l
Cym. microcephara	
Cym. prostlata	Cy p
Cym. ventricosa	Cy v
Diatoma elongatum	D e
Diat. hiemale v. mesodon	D h m
Fragilaria brevistriata	F b
Frag. capucina v. gracilis	F cp g
Frag. cap. mesolepta	F cp m
Frag. construens	F c
Frag. con. v. binodis	
Frag. con. v. venter	F c v
Frag. crotonensis	F cr
Frag. pinnata	
Frag. pin. v. lancettula	
Frag. spp	

Gomphonema angustatum	G a
Gom. ang. v. producta	G a p
Gom. clevei	G cl
Gom. clevei v. javanica	
Gom. constrictum	G cn
Gom. intricatum	G i
Gom. parvulum	G p
Gom. par. v. micropus	G p m
Gom. tetrastigmata	
Melosira italica f. curvata	M i c
Mel. varians	M v
Mel. distans	
Navicula cryptocephala	Na c
Nav. radiosa c. minutissima	Na r m
Nitzschia acicularis	N ac
Nitz. amphibia	N a
Nitz. dissipata	N d
Nitz. frustulum	N f
Nitz. frus. v. perpusilla	N f p
Nitz. microcephala	N m
Nitz. palea	N p
Nitz. paleacea	N pc
Nitz. romana	N r
Rhoicosphenia curvata	R c
Stephanodiscus sp.	
Synedra acus	
Synedra acus v. radians	Sy a r
Syn. rumpens v. fragilarioides	
Syn. rumpens v. scotica	Sy r s
Syn. ulna	Sy u
Chaetophora sp.	Cht sp
Chlamydomonas sp.	Chl sp
Dictyosphaerium ehrenvergianum	Dc e
Geminella minor	Gm m
Scenedesmus spp	Sc spp
Spilogyra sp.	Sp sp
Stigeoclonium sp.	St sp
Ulothrix oscillarina	U o
Ulot. sp.	U sp

Fig.VII 4.1.

Relative abundance of dominant species and total counts of epipelic or epilithic micro algae in each littoral station.

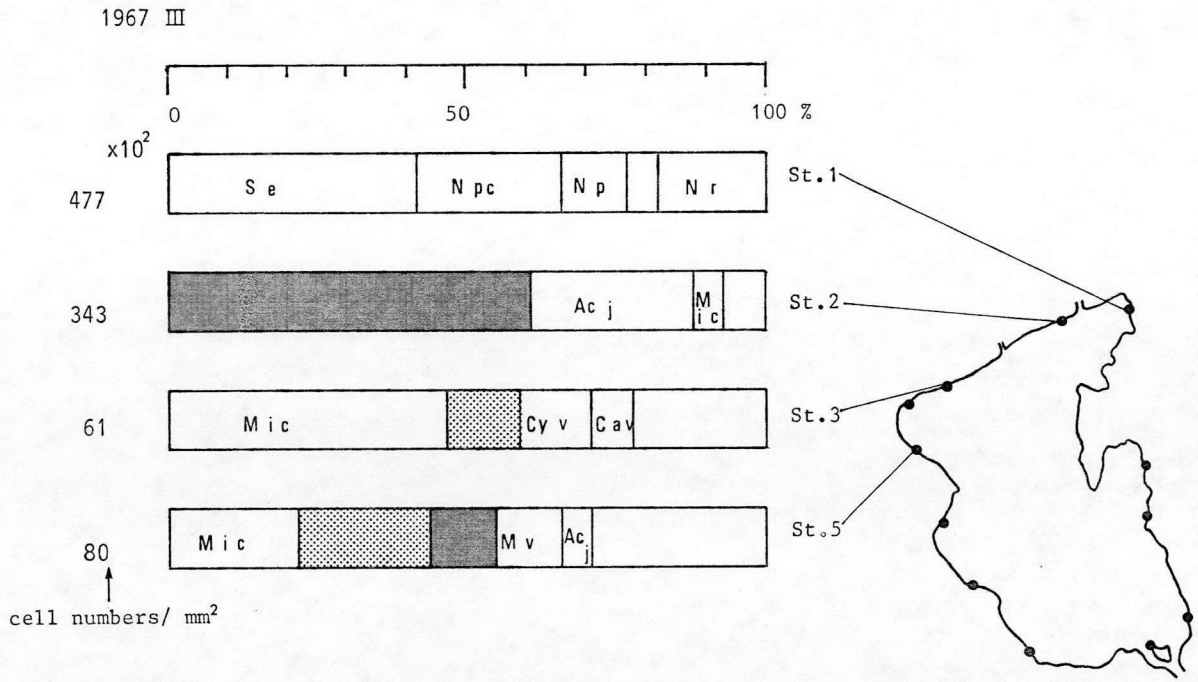


Fig.VII.4.2. Relative abundance of dominant species and total count of benthic micro algae in each littoral station.

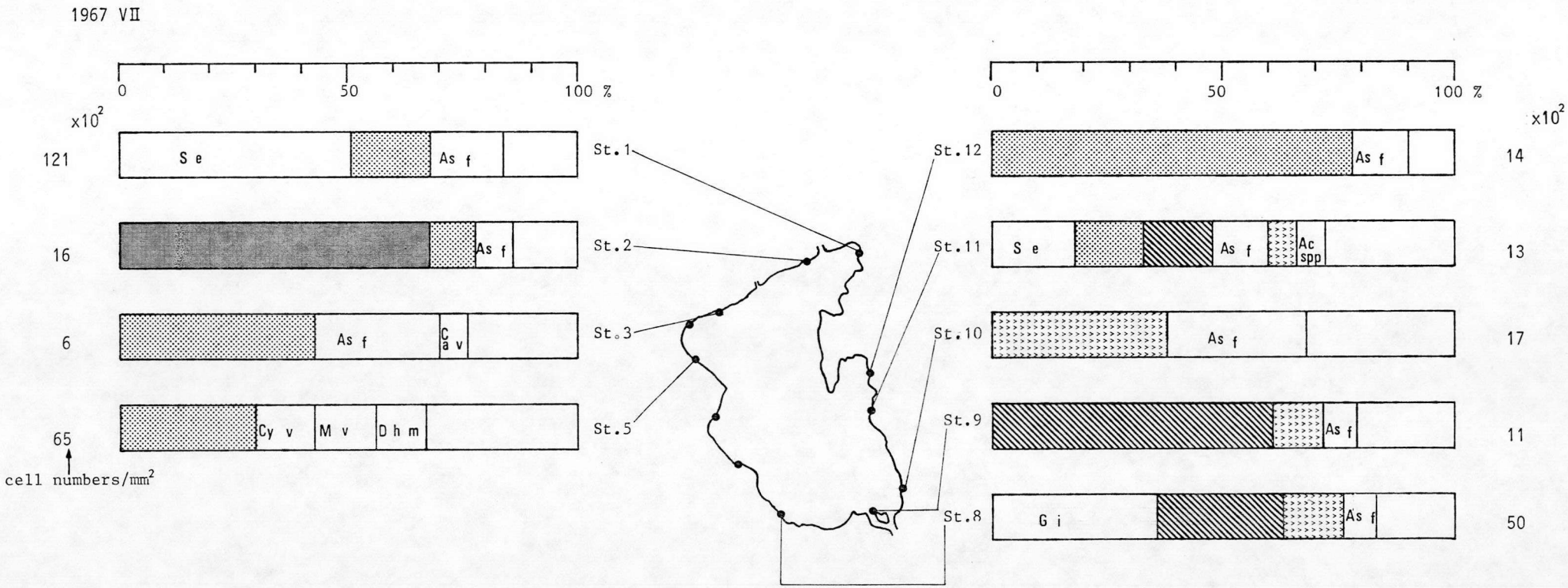


Fig.VII.4.3 Relative abundance of dominant species and total count of benthic micro algae in each littoral station.

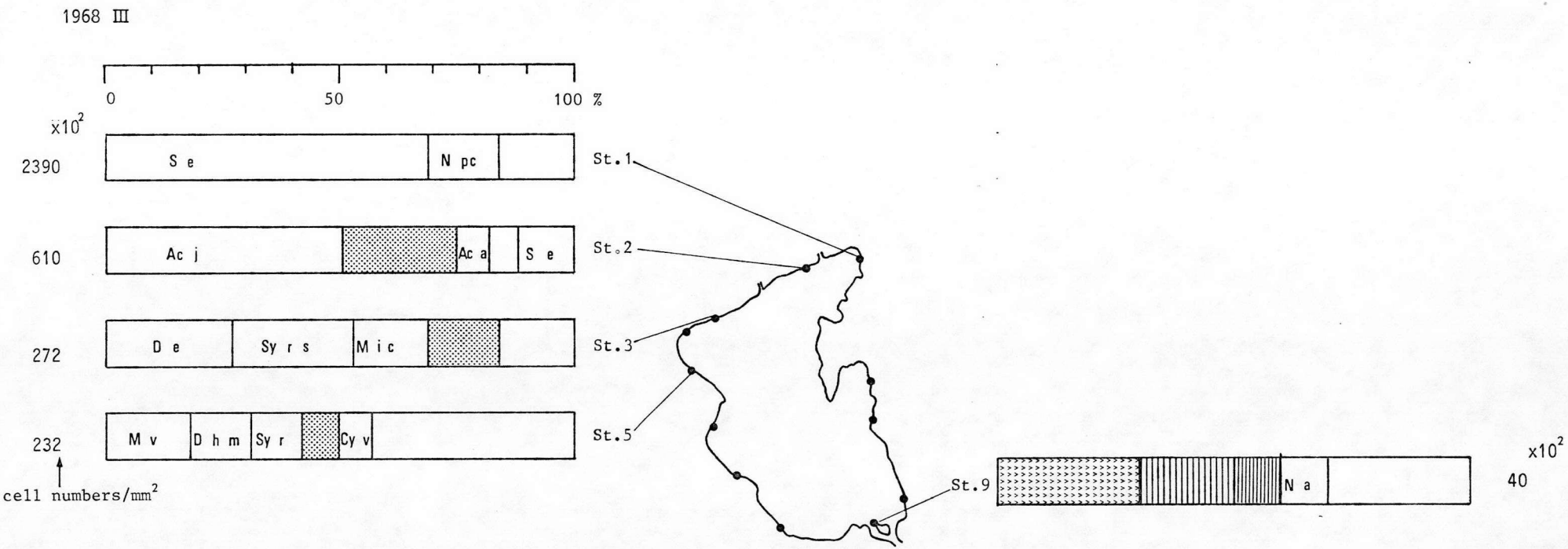


Fig.VII.4.4. Relative abundance of dominant species and total count of benthic micro algae in each littoral station.

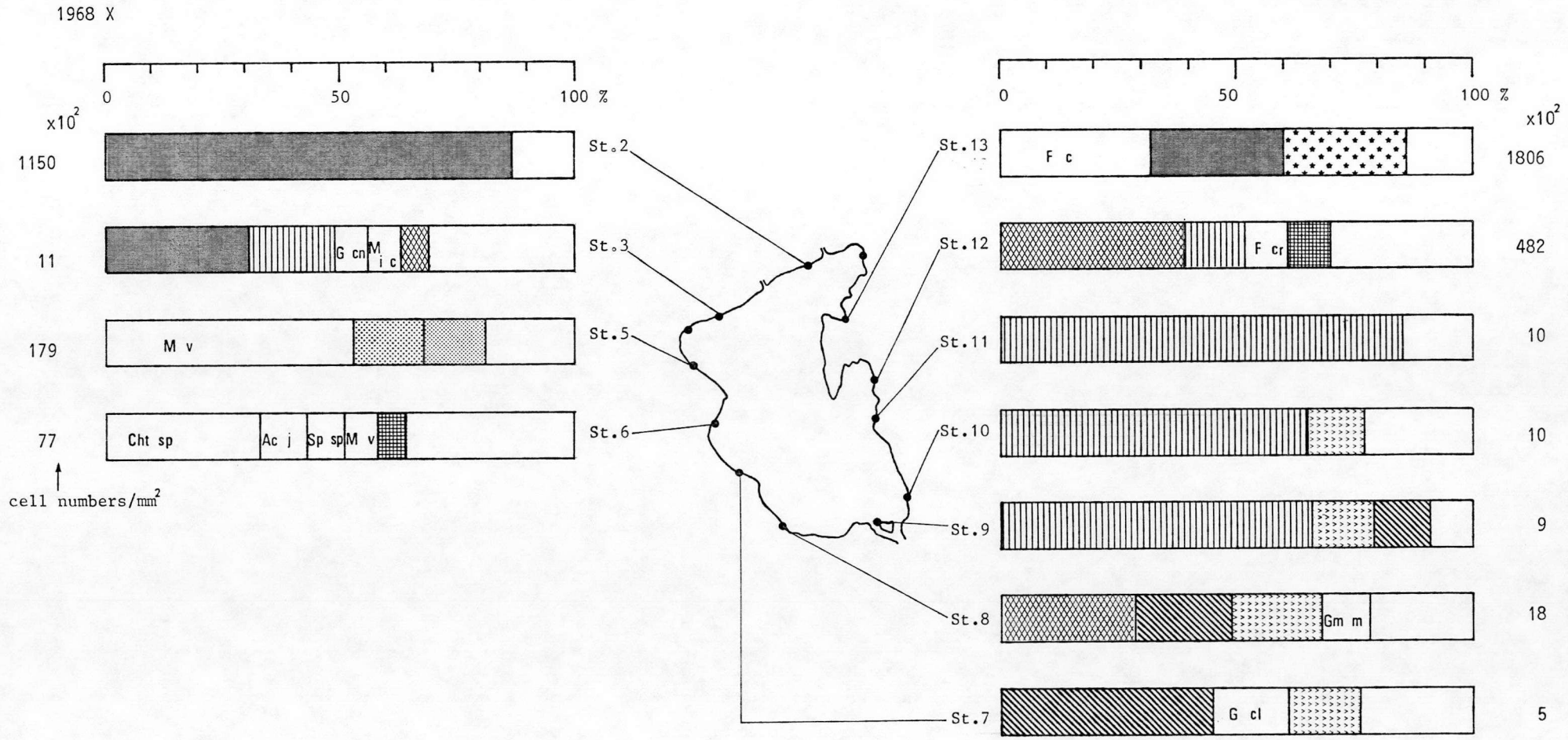
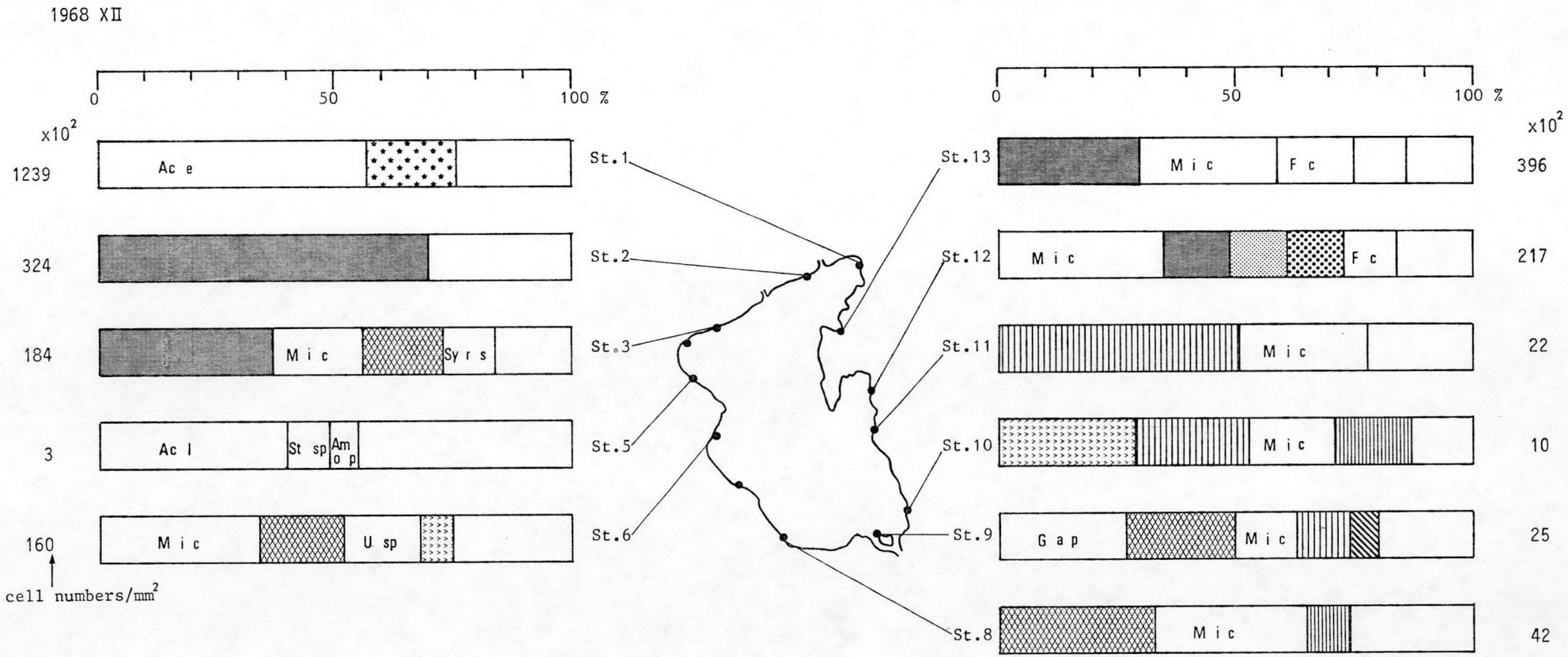


Fig.VII.4.5. Relative abundance of dominant species and total count of benthic micro algae in each littoral station.



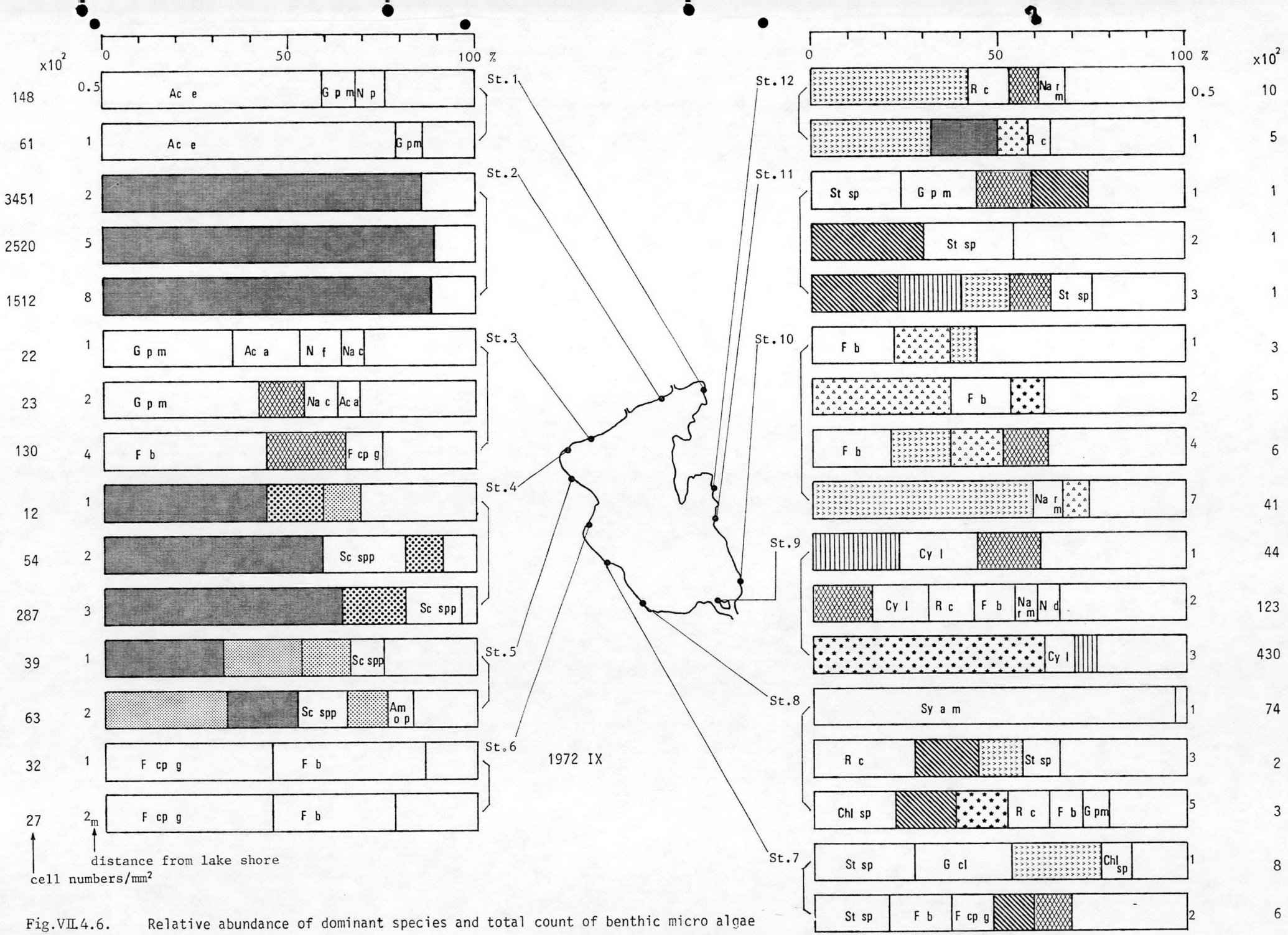


Fig.VII.4.6. Relative abundance of dominant species and total count of benthic micro algae in each littoral station.

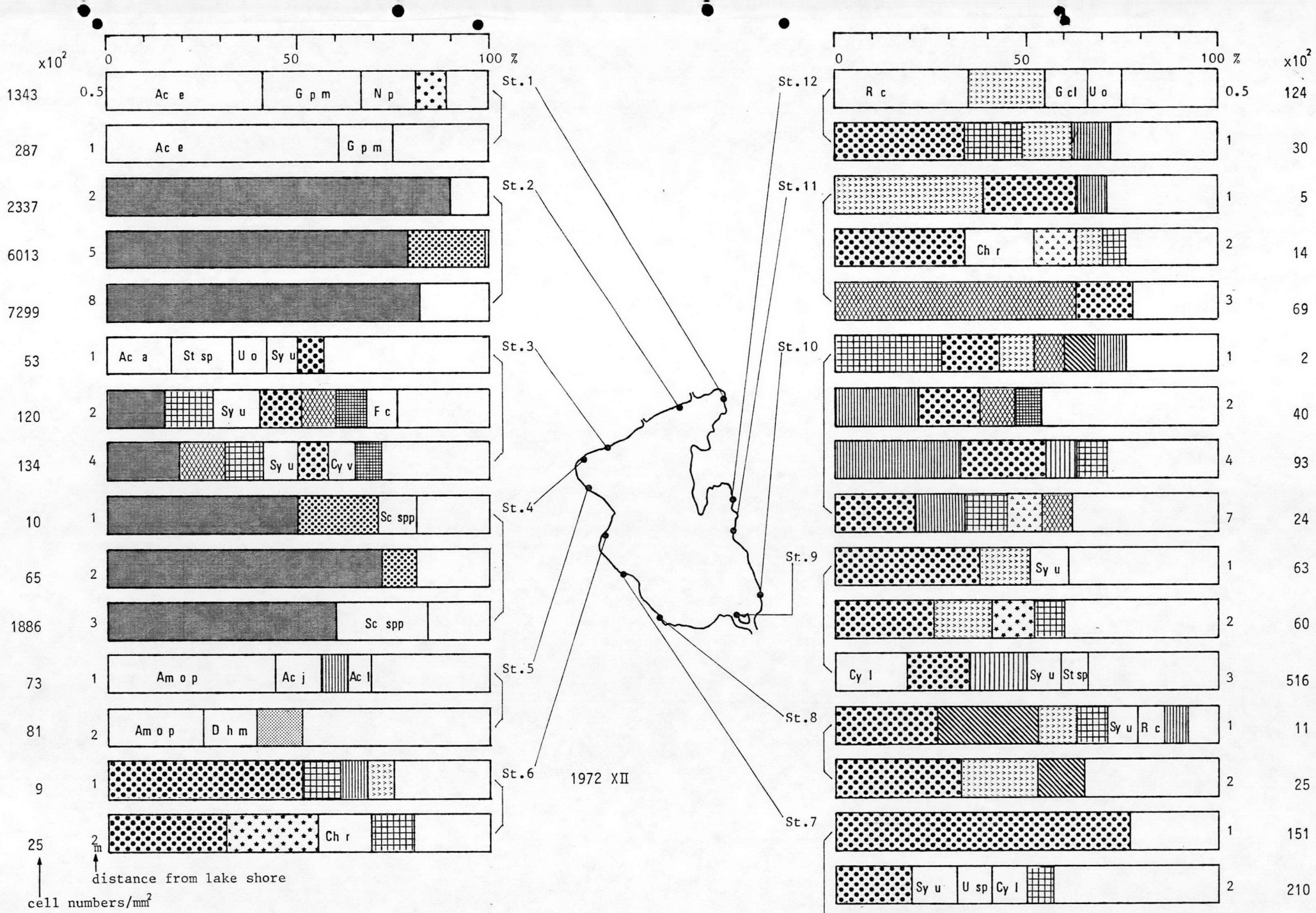


Fig.VII.4.7. Relative abundance of dominant species and total count of benthic micro algae in each littoral station.

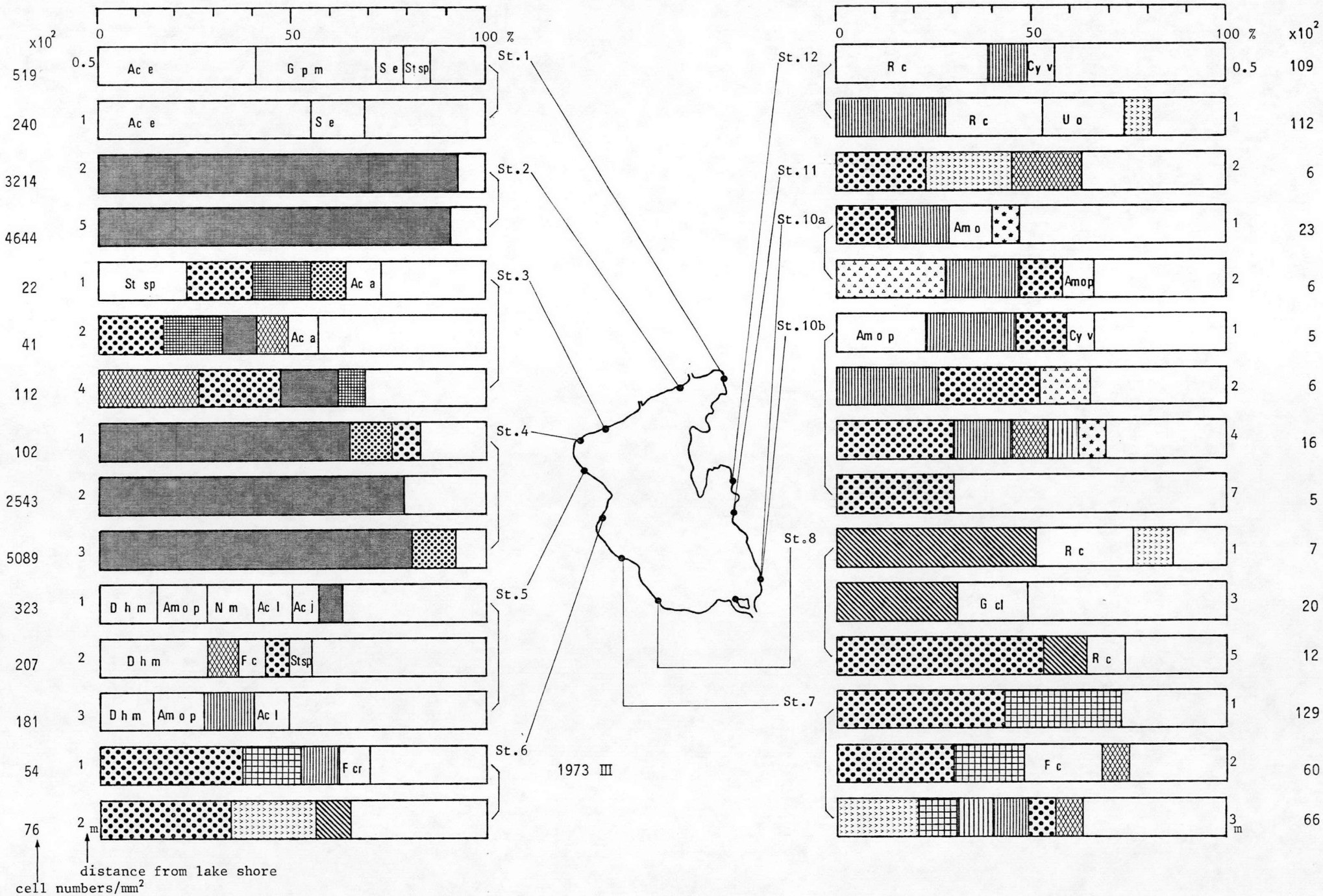


Fig.VII.4.8. Relative abundance of dominant species and total count of benthic micro algae in each littoral station.

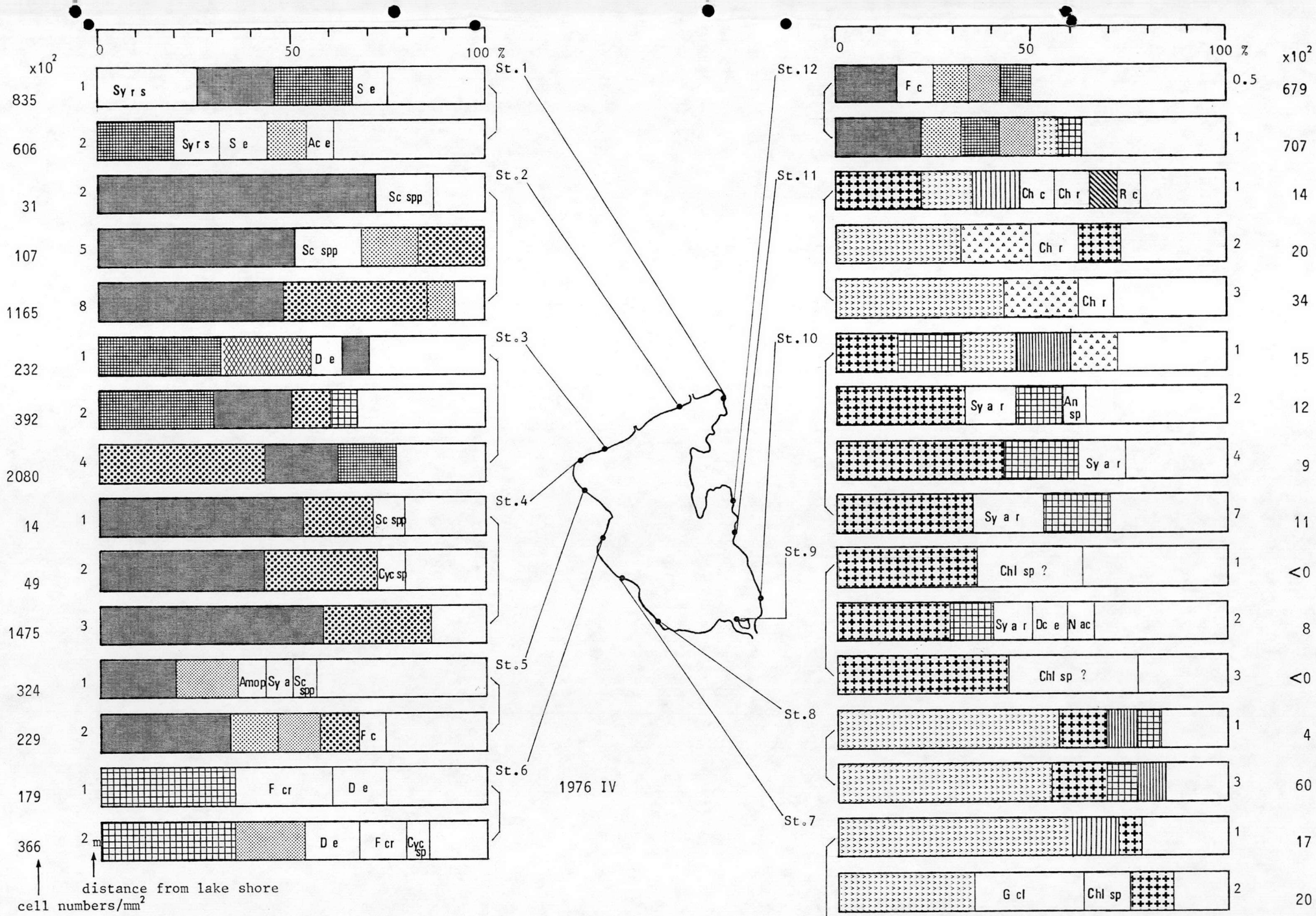


Fig.VII.4.9. Relative abundance of dominant species and total count of benthic micro algae in each littoral station.

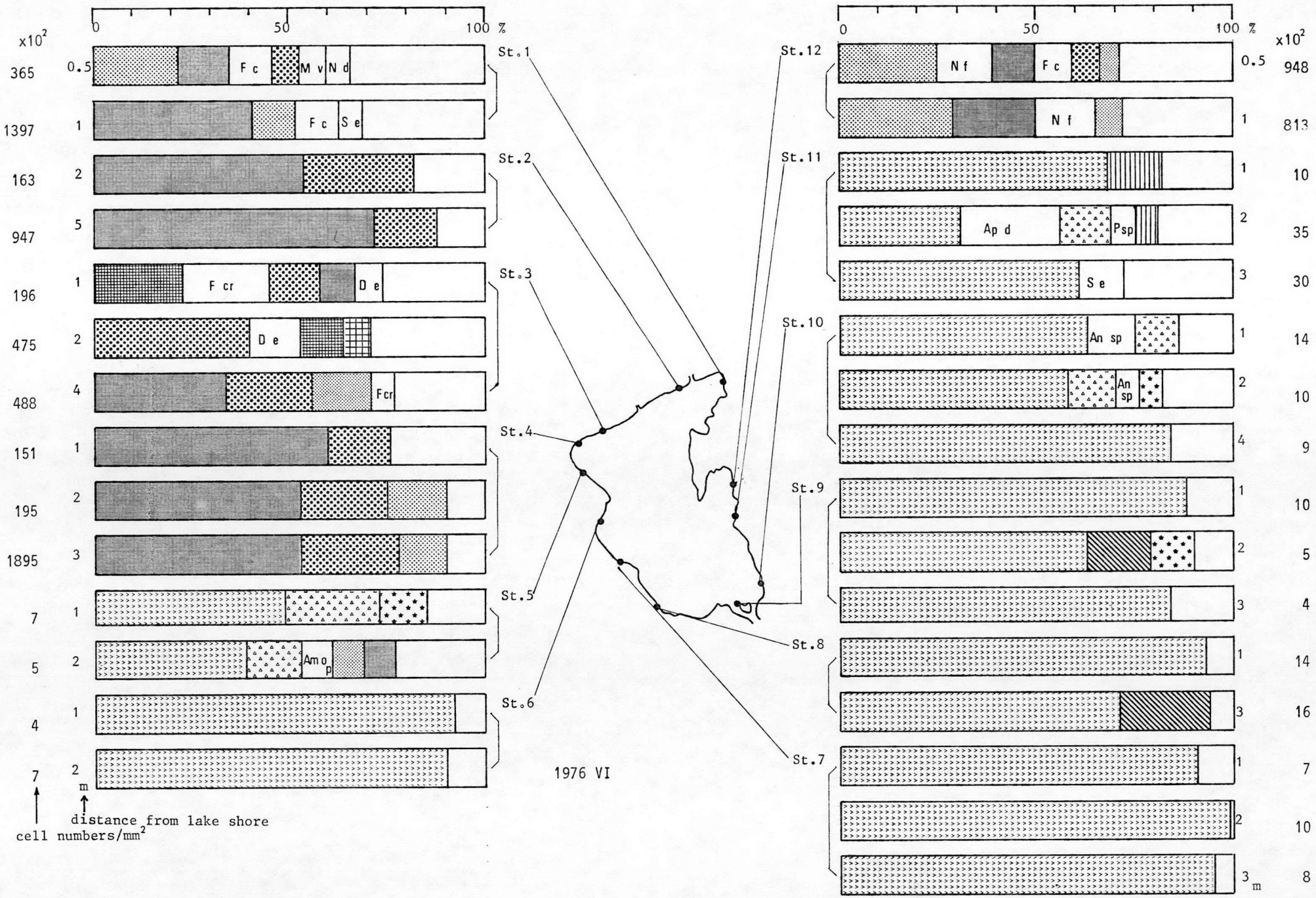


Fig.VII.4.10. Relative abundance of dominant species and total counts of benthic micro algae in each littoral station.

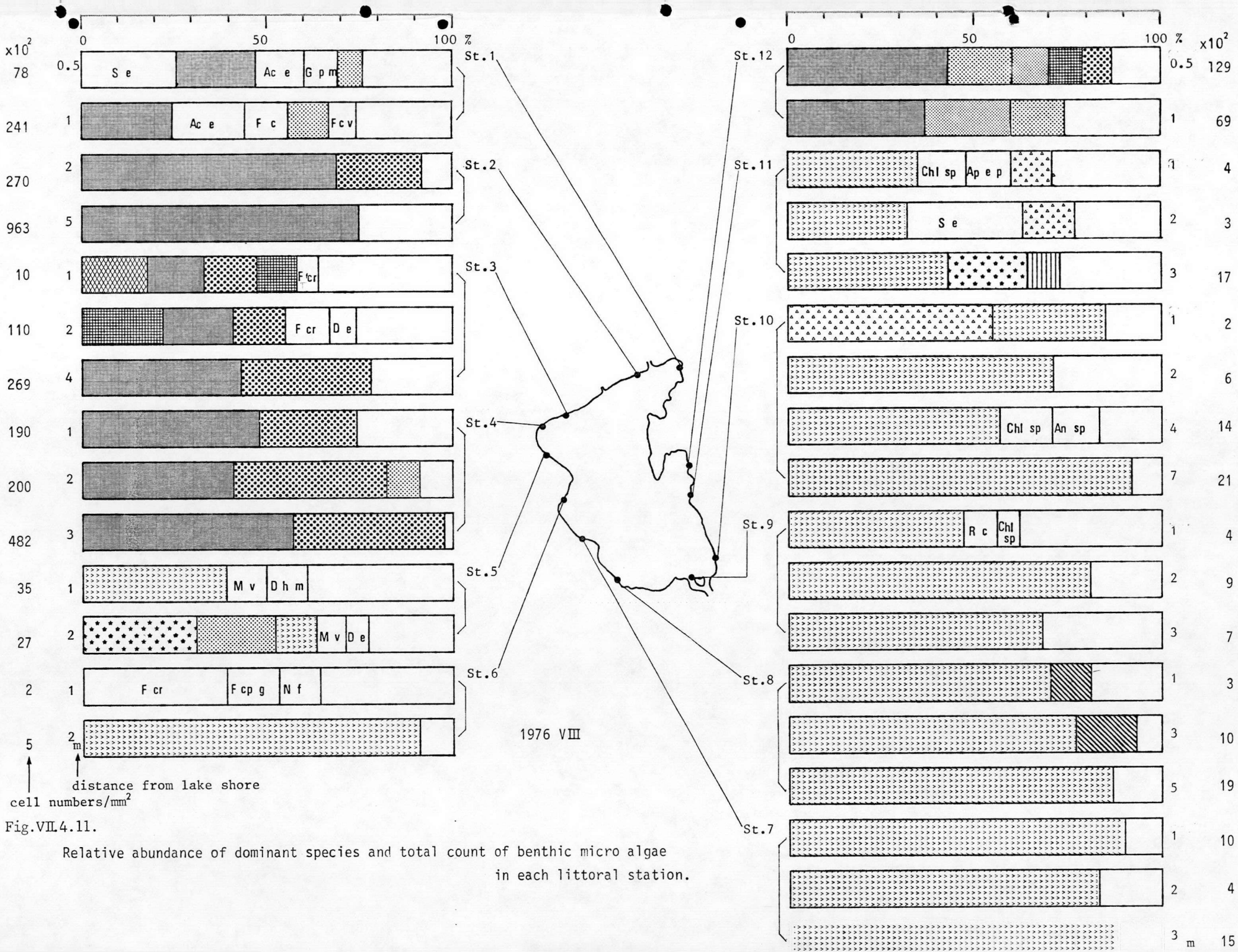


Fig.VII.4.11.

Relative abundance of dominant species and total count of benthic micro algae in each littoral station.

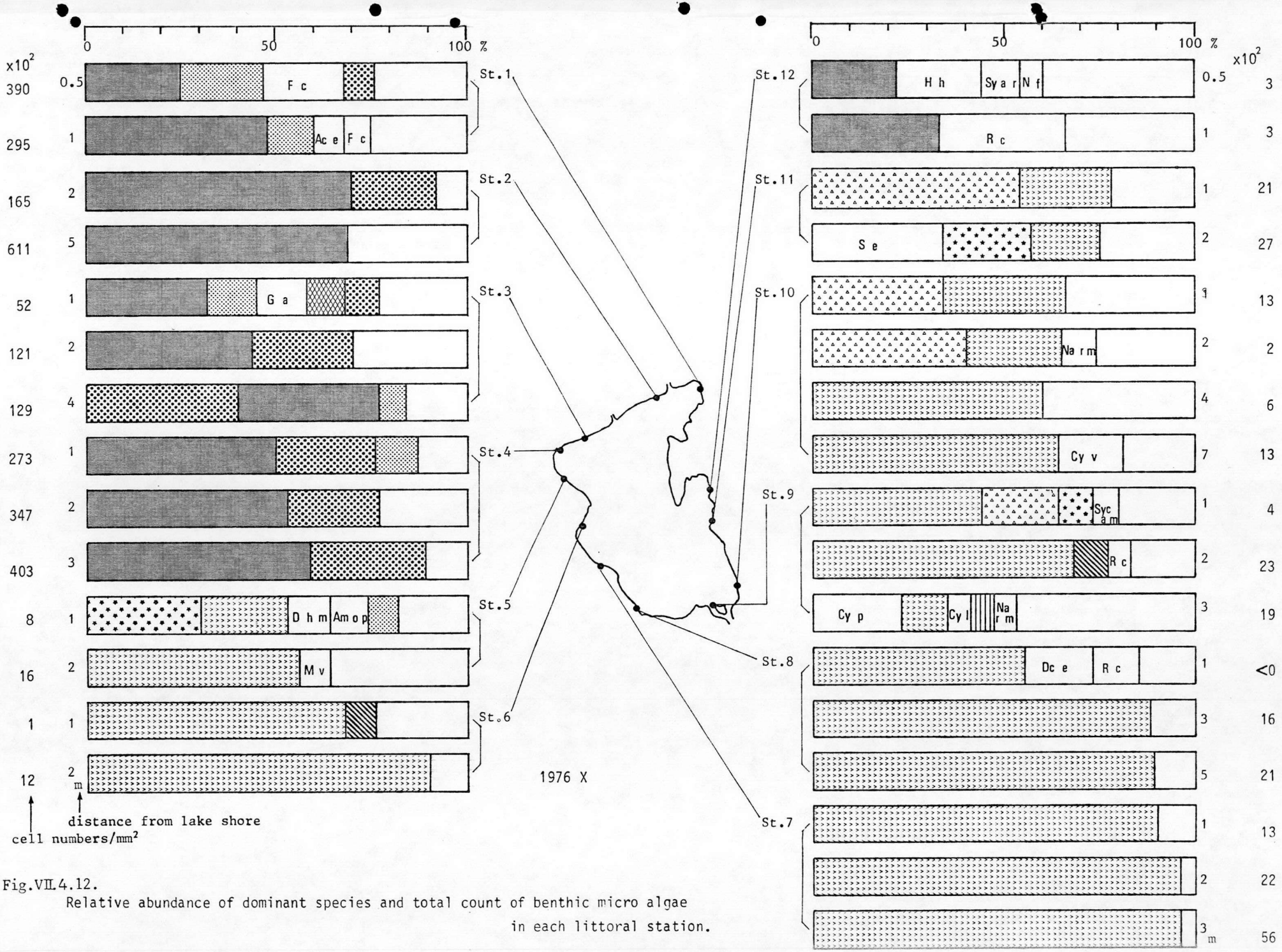


Fig.VII.4.12.
Relative abundance of dominant species and total count of benthic micro algae in each littoral station.

Table VIII.1 Growth of *Fragilaria pinnata* (including *F. pinnata* v. *lancettula*) and growth indexes based on cell numbers under different light intensities.

Glucose (mg / l)	light intensity (lux)	Day 0		Day 5		Day 10		Day 15	
		Cell number (10^4)	G.I.	Cell number (10^4)	G.I.	Cell number (10^4)	G.I.	Cell number (10^4)	G.I.
0	2000	1.5	1.0	4.5	3.0	18.5	12.3	34.3	22.9
	100	1.3	1.0	1.2	0.9	2.0	1.5	2.6	2.0
	0	1.2	1.0	1.2	1.0	1.1	0.9	1.1	0.9
10	2000	1.2	1.0	3.5	2.9	14.4	12.0	26.4	22.0
	100	1.3	1.0	1.7	1.3	3.4	2.6	4.2	3.2
	0	1.4	1.0	2.0	1.4	3.1	2.2	3.5	2.5

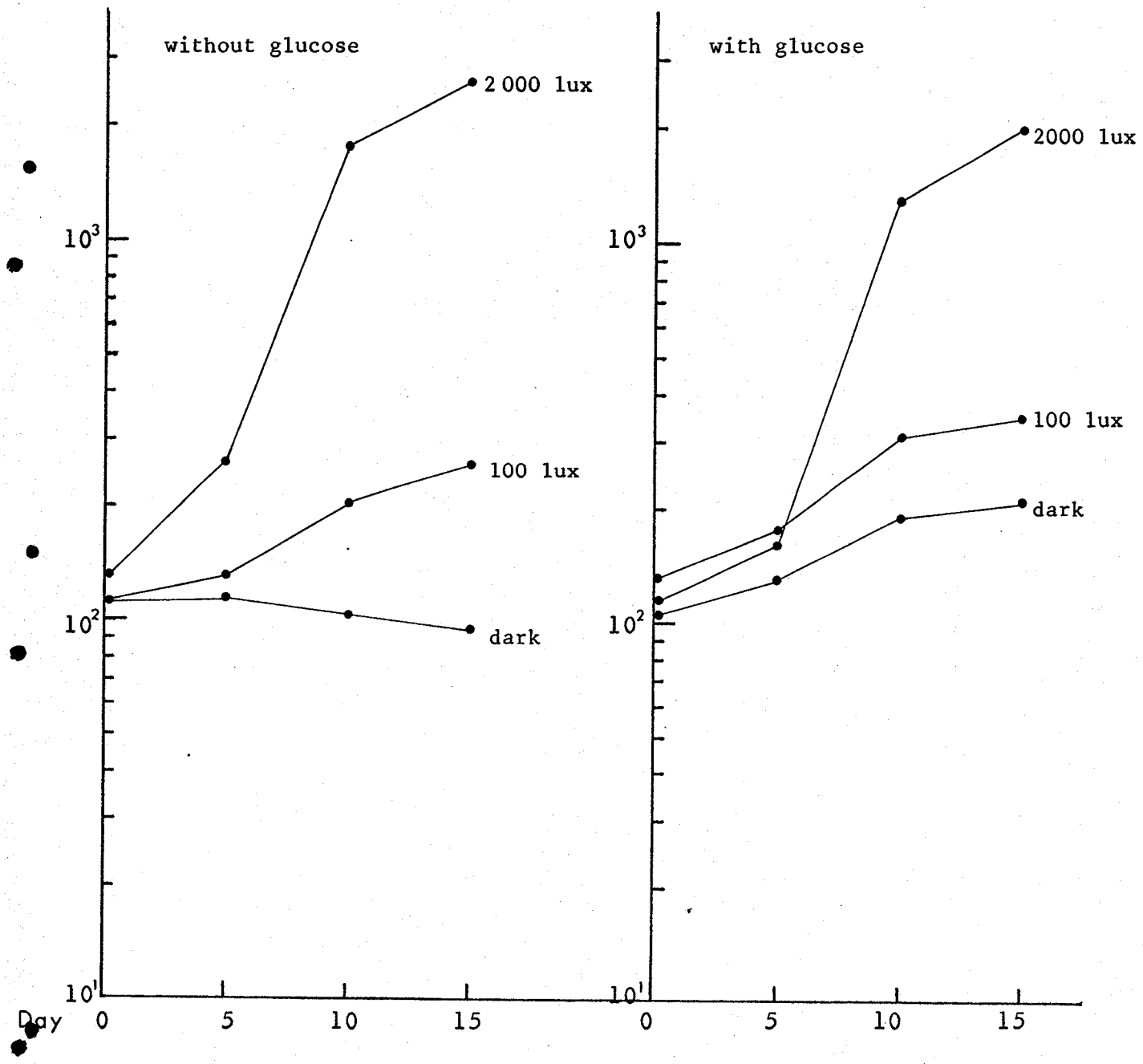



Fig.VIII.1 Growth of F. pinnata (including F. pinnata v. lancettula) in different light intensities, with and without glucose. (Semilog plot of µg chlorophyll a / l)