Effects on Phytoplankton Biomass, Succession and Composition in Lake 223 as a Result of Lowering pH Levels from 7.0 to 5.6. Data from 1974 to 1979

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EFFECTS ON PHYTOPLANKTON BIOMASS, SUCCESSION AND COMPOSITION IN LAKE 223 AS A RESULT OF LOWERING pH LEVELS FROM 7.0 TO 5.6. DATA FROM 1974 to 1979

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ABSTRACT

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This report summarizes the effect on the phytoplankton community in Lake 223 (Experimental Lakes Area) of lowering the pH from 7.0 to 5.6. It discusses changes in total biomass, succession and diversity over the four years of acidification and 2 years prior to treatment (1974 to 1979). Also included are 6 figures showing total biomass and accumulative percent composition for Lake 223 and Lake 224 (a control lake).

Key words: phytoplankton; acidification; Experimental Lakes Area; biomass; succession; diversity.

RESUME

Findlay, D. L. and G. Saesura. 1980. Effects on phytoplankton biomass, succession and composition in Lake 223 as a result of lowering pH levels from 7.0 to 5.6. Data from 1974 to 1979. Can. MS Rep. Fish Aquat. Sci. 1585: iv + 16 p.

Le présent rapport résume les effets de l'abaissement du pH de 7.0 à 5.6 sur le phytoplancton dans le lac 223 (région des lacs expérimentaux). On y examine les variations de la biomasse totale, la succession et la diversité en quatre ans d'acidification et deux ans ans avant le traitement (de 1974 à 1979). Il comprend également six figures montrant la biomasse totale et la composition en pourcentage des substances accumulées dans l'eau du lac 223 et du lac témoin 224.

Mots cles: phytoplancton; acidification; région des lacs expérimentaux; succession; diversité.

INTRODUCTION

In 1976, a whole-lake acidification experiment was initiated on Lake 223 in the Experimental Lakes Area, northwestern Ontario. Sulfuric acid was used to lower the pH of epilimnion water from a pre-acidification value of 7.0 (Beamish et al. 1976) to 6.7-7.0 in 1976, to 6.0-6.2 in 1977, to 5.7-5.9 in 1978 (Schindler et al. 1980) and 5.4-5.7 in 1979 (Schindler, unpublished data). The pH was lowered early in each ice-free season. Weekly additions of acid were necessary throughout the summer to maintain the pH near the predetermined value. Schindler et al. (1980) describe the experiment in greater detail.

This report presents pre-acidification data (1974 and 1975) and discusses the effects of acidification on the phytoplankton community in the first four years of acidification, 1976 to 1979.

LITERATURE REVIEW

Acid precipitation has become the major ecological problem facing eastern North America in the last decade (Conroy et al. 1975; Schofield 1976; Gorham 1976; Dillon et al. 1978).

The phytoplankton communities are one of the biological components affected by acidification (Johnson et al. 1970; Almer 1974; Kwiatkowski and Roff 1976; Yan and Stokes 1978). Although the effects of acidification on the phytoplankton community have been studied, most of the data presented refer to effects which occur at low pH values (5.0-3.5). In the literature there are several suggestions as to how the biomass is affected. Conroy et al. (1975) suggest that biomass decreases in acidic waters, while Hörnström et al. (1973) suggest there are no significant changes from pre-acidification estimates until extremely low pH levels occur.

Species diversity and succession are other parameters which have been discussed. It is generally agreed that diversity decreases as pH decreases, with 5.6 to 5.9 being the level at which it is first noticeable (Almer et al. 1974). As for acidification effects on species succession, Cyanophyceae, Diatomeae and Chrysophyceae were found to be absent or very low in acidic lakes (Johnson et al. 1970) with Peridineae or Chlorophyceae dominating (Almer et al. 1974; Yan and Stokes 1978).

METHODS

Phytoplankton sampling was done in conjunction with primary production sampling. A 4.5 L water sample was taken from three stratum (epilimnion, metalimnion, hypolimnion) using an integrating sampler (Shearer 1978). The thickness of the stratum to be sampled was determined from temperature, light, and chlorophyll profiles (DeClercq et al. 1977). The sampler was lowered and raised through the stratum allowing the bottle to fill. The sample was then brought to the laboratory where 125 mL were removed and preserved with Lugol's solution[1] for counting at a later date.

For counting and identification, 10 to 20 mL aliquots were allowed to gravity settle from 12 to 24 hours, depending on the density of the phytoplankton. After settling, the sample was examined using a Zeiss inverted microscope. Most of the counting and identification was done at 125x, 400x and 1000x with phase contrast illumination. The counting procedure used was the Utermöhl technique as modified by Nauwerck (1963). To convert the cell/L counts to biomass values, it was necessary to approximate the volume of cells of various species. Volume estimates were made using geometric shapes which most closely resembled those of the cells (Vollenweider 1969). Duplicate samples were counted and all data presented are averages of two individual counts.

Index of diversity (d) was calculated using

$$d = \frac{S - 1}{\log_e N}$$

(Margalef 1958) where S = number of species present and N = number of individuals counted.

RESULTS

1974-1975 PRE-ACIDIFICATION YEARS

Epilimnion (Fig. 1): In 1974 and 1975 the epilimnion in Lake 223 had a pH value of 7.0 (Beamish et al. 1976) and was dominated by Chrysophyceae throughout the entire sampling season. The major chrysophycean species present were *Chromulina* sp., *Chrysochromulina* spp., *Dinobryon sertularia*, *Dinobryon bavaricum* var. *Vanhoeffenii*, *Dinobryon crenulatum*, *Chrysosphaerella multispina*, and *Chrysococcus* sp. Populations of Cyanophyceae, Chlorophyceae, Diatomeae, Cryptophyceae and Peridineae occurred at various times but rarely represented more than 15% of the total standing crop. Biomass values in 1974 and 1975 averaged 825 mg/m^3 and 650 mg/m^3 respectively, with maximum values of 1400 mg/m^3 in 1974 and 1100 mg/m^3 in 1975 recorded in late spring.

Hypolimnion (Fig. 3): In 1975 the hypolimnion was dominated by chrysophycean species *Dinobryon sertularia*, *Dinobryon bavaricum* var. *Vanhoeffenii*, *Chrysochromulina* spp., *Chrysosphaerella multispina*, *Uroglena americana*, *Chromulina* sp., *Chrysococcus* sp. Populations of Chlorophyceae, Cryptophyceae, and Peridineae were also present throughout the sampling season but contributed very little to the total standing crop. Biomass values fluctuated between 950 mg/m^3 to 2100 mg/m^3 throughout the sampling season.

ACIDIFICATION YEARS

1976

Epilimnion (Fig. 1): In 1976 the pH of the epilimnion ranged from 6.7-7.0 ($\bar{x}$ 6.79) (Schindler et al. 1980). Chrysophyceae dominated the standing crop for the full ice-free season. *Chrysococcus* sp., *Chromulina* sp., *Uroglena americana*, *Dinobryon cylindricum*, *Dinobryon bavaricum* var. *Vanhoeffenii*, *Ochromonas* sp., and *Chrysosphaerella multispina* were the

[1] 10 g KI in 20 mL H_2O + 5 g I_2, completely dissolved. Add 50 mL H_2O + 5 g Na acetate. Dissolve.

most common chrysophytes. Throughout the sampling season small populations of chlorophytes (*Monoraphidium setiforme, Monoraphidium* sp., *Dictyosphaerium simplex*), diatoms (*Cyclotella glomerata, Synedra acus, Rhizosolenia eriensis, Asterionella formosa, Tabellaria fenestrata*), and cryptophytes (*Rhodomonas minuta, Cryptomonas* spp., *Katablepharis ovalis*) were also present. Biomass values ranged from 550 mg/m^3 to 1250 mg/m^3.

Metalimnion (Fig. 2): The metalimnion in 1976 was dominated by chrysophycean species for the entire sampling season. Those chrysophytes found to be most common were *Dinobryon bavaricum, Dinobryon bavaricum* var. *Vanhoeffenii, Dinobryon cylindricum, Dinobryon sertularia*, and *Chrysosphaerella multispina*. Chlorophyeae and Cryptophyceae were present through the season while a small population of Cyanophyceae occurred in mid-June until late July. The major chlorophytes were *Chlamydomonas* sp., *Staurastrum paradoxum*, and *Monoraphidium* sp. with *Rhodomonas minuta* and *Cryptomonas* spp. representing the cryptophycean populations. *Oscillatoria Redekei, Oscillatoria limnetica*, and *Merismopedia glauca* were the cyanophytes which appeared in mid-summer.

Biomass values ranged from 600 mg/m^3 to 1420 mg/m^3 during this period. Sampling of the metalimnion ceased in early September due deepening of the thermocline.

Hypolimnion (Fig. 3): Chrysophyceae dominated the hypolimnion with *Stichogloea Doederleinii, Uroglena americana, Dinobryon bavaricum, Dinobryon bavaricum* var. *Vanhoeffenii, Dinobryon cylindricum, Dinobryon sertularia* and *Synura* sp., for the entire sampling season. *Synura* sp. was found only in early August at which time it constituted 61% of the standing crop. Chlorophyceae, Diatomeae, and Cryptophyceae were also present, with those species found in the metalimnion being the major contributors, while *Oscillatoria Redekei* (a cyanophyte) appeared in mid-August comprising 16% of the biomass.

There were two noticeable peaks in the biomass estimates. The first was in late spring when biomass values increased from 800 mg/m^3 to 2700 mg/m^3. The second peak occurred in mid-July to late August. Biomass increased from 970 mg/m^3 to 3750 mg/m^3. Sampling was terminated in late August with the onset of fall turnover and deepening of the thermocline.

1977

Epilimnion (Fig. 1): In 1977 the pH of the epilimnion in Lake 223 ranged from 6.0-6.2 ($\bar{x}$ 6.08) (Schindler et al. 1980). Sampling commenced in early May at which time a biomass value of 2542 mg/m^3 was recorded. Chrysophyceae dominated with *Uroglena americana* and *Chrysochromulina* sp. being the major species. Peridineae (*Gymnodinium* sp. and *Amphidinium* cf *luteum*) represented 11% of the biomass. Biomass decreased in mid-May to 1100 mg/m^3 and Diatomeae (*Synedra acus* and *Rhizosolenia eriensis*) became co-dominant with the already dominant chrysophycean species. By late May to early June these diatoms decreased, giving way to populations of chlorophytes (*Oocystis submarina* var. *variabilis* and *Chlorella* cf *mucosa*) and dinoflagellates (*Peridinium inconspicum* and *Gymnodinium* sp.). Biomass at this time decreased to 600 mg/m^3. By mid-June biomass values increased to 1560 mg/m^3 at which time it was represented by 75% Chrysophyceae (*Stichogloea Doederleinii* and *Dinobryon bavaricum* var. *Vanhoeffenii*), 14% Chlorophyceae, and 5% Peridineae. In early July *Merismopedia glauca*, a cyanophyte, appeared constituting 30% of the biomass and Chrysophyceae decreased to 45%. In late July chrysophytes were 46% (*Chromulina* sp., *Chrysochromulina* spp., *Uroglena americana* and *Chrysococcus* sp.), cyanophytes were 23% (*Merismopedia glauca*), and chlorophytes were 20% (*Spondylosium planum* and *Monoraphidium* sp.) of the total biomass (570 mg/m^3). Chlorophyceae (*Oocystis lacustris*) increased in August and constituted 33% of the standing crop. Chrysophytes continued to increase throughout August. By early September, dominance of Chrysophyceae was re-established with *Chrysochromulina* sp., *Chrysococcus* sp., and *Dinobryon bavaricum* var. *Vanhoeffenii*. Chrysophyceae continued to represent more than 60% of the biomass for the remainder of the ice-free season with the occurrence of a cryptophycean pulse in late October (*Cryptomonas* sp.).

Metalimnion (Fig. 2): During 1977, the early spring biomass in the metalimnion was 1651 mg/m^3. Chrysophyceae (*Chrysochromulina* sp., *Uroglena americana*, and *Dinobryon* spp.) and Diatomeae (*Synedra acus* and *Rhizosolenia eriensis*) were co-dominant, each representing 34% with an additional 15% Peridineae and 10% Chlorophyeae. By late May, Chrysophyceae had become dominant with the appearance of *Stichogloea Doederleinii* in addition to the previously mentioned species. Biomass increased to 2630 mg/m^3 in mid-June and then decreased throughout late June and early July to 1100 mg/m^3. *Dinobryon bavaricum* var. *Vanhoeffenii* was present in large numbers during this time. In late July biomass increased to 3500 mg/m^3 of which Chlorophyceae (*Dictyosphaerium simplex*) constituted 30% and Chrysophyceae 52%. In late August biomass increased to 4440 mg/m^3, a yearly metalimnetic maximum. The chlorophyte *Dictyosphaerium simplex* continued to increase throughout August, and by late August, was the dominant species, representing 55% of the total biomass with a live cell estimate of 24 x 10^6 cell/L. By late September Chrysophyceae (*Chromulina* sp., *Chrysochromulina* spp., *Uroglena americana*, and *Chrysococcus* spp.) had re-established dominance being 56% of the total. Sampling ceased at this time due to deepening of the thermocline.

Hypolimnion (Fig. 3): In 1977, Lake 223's hypolimnion was dominated by Chrysophyceae throughout the entire sampling season. The major chrysophycean species were *Chrysochromulina* spp., *Dinobryon bavaricum* var. *Vanhoeffenii, Uroglena americana, Chrysococcus* sp., and *Chromulina* sp. Populations of Chlorophyceae, Cryptophyceae and Diatomeae were also present throughout the season with *Chlamydomonas* spp., *Dictyosphaerium pulchellum, Dictyosphaerium simplex*, and *Monoraphidium setiforme* being the more common chlorophytes. *Cryptomonas* sp. and *Katablepharis ovalis* represented the cryptophytes and *Synedra acus, Tabellaria fenestrata*, and *Rhizosolenia eriensis* were important diatom species. Biomass increased from 3600 mg/m^3 in mid-May to 6960 mg/m^3 in late July.

1978

Epilimnion (Fig. 1): The epilimnetic pH in Lake 223 during 1978 was lowered to a range of 5.7-5.9 ($\bar{x}$ 5.84) (Schindler et al. 1980).

Chrysophyceae dominated for the entire ice-free season, consistently representing 60-80% of the standing crop. In early spring *Chrysochromulina* sp., *Chromulina* sp., *Chrysococcus* sp., *Salpingoeca frequentissima*, and *Chrysosphaerella multispina* were the major chrysophytes. *Dinobryon bavaricum* and *Dinobryon sertularia* dominated the epilimnion in June and July. In early August *Uroglena americana* was the major species and remained such for the remainder of the ice-free season. Chlorophyceae (*Chlamydomonas* sp., *Ankistrodesmus falcatus*, *Oocystis lacustris*, *Monoraphidium setiforme*, and *Spondylosium planum*), Cryptophyceae (*Cryptomonas* sp.), and Diatomeae (*Synedra acus*, *Rhizosolenia eriensis*, and *Cyclotella comta*) were also present throughout the season. Biomass fluctuated from 630 mg/m to 1550 mg/m^3 averaging 1100 mg/m^3 for the ice-free season.

Metalimnion (Fig. 2): The metalimnion in Lake 223 was dominated by chrysophycean species *Uroglena americana*, *Chrysochromulina* sp., and *Chrysococcus* sp. in mid-May. Biomass at this time was 1333 mg/m^3. Biomass by early June decreased to 1000 mg/m^3 and the standing crop was represented by 54% Chrysophyceae (those species previously reported in the epilimnion), 26% Chlorophyceae (mainly *Dictyosphaerium simplex*), and 13% Cryptophyceae. By July biomass increased to 1800 mg/m^3 and Chrysophyceae constituted 81% of the biomass, with *Dinobryon sertularia* and *Stichogloea Doederleinii* representing 71% of the chrysophytes. By late July biomass increased to 1978 mg/m^3 and Chrysophyceae decreased to representing 54% of the standing crop. Chlorophyceae increased to 24% with *Dictyosphaerium simplex* being the major chlorophyte. In mid-August the standing crop was represented by 70% Chrysophyceae (*Dinobryon sertularia* and *Stichogloea Doederleinii*), 11% Diatomeae, and 11% Chlorophyceae and biomass decreased to 1759 mg/m^3. In early September biomass decreased to 1400 mg/m^3. *Uroglena americana* and *Stichogloea Doederleinii* constituted the dominant chrysophytes while *Spondylosium planum*, *Monoraphidium setiforme*, and *Oocystis submarina* var. *variabilis* represent the chlorophytes which were 24% of the standing crop. Sampling of the metalimnion stopped in early September due to fall mixing.

Hypolimnion (Fig. 3): In 1978 the hypolimnion was sampled on a monthly basis from mid-May until early September. In early May a biomass of 1590 mg/m^3 was recorded. Chrysophyceae represented 69% of the biomass (*Chrysosphaerella multispina*, *Chrysococcus* sp., and *Uroglena americana*) and Chlorophyceae 14% (*Chlamydomonas* sp., *Ankistrodesmus falcatus*, and *Monoraphidium setiforme*). In June, Chrysophyceae decreased to 54%, at which time an increase in *Cryptomonas* spp. was recorded. Biomass increased in late July to 7658 mg/m . This increase is due to an increase in several chrysophycean species (*Mallomonas caudata*, *Dinobryon sertularia*, *Stichogloea Doederleinii*, and *Chrysococcus* sp.) and chlorophycean species (*Dictyosphaerium simplex* and *Monoraphidium setiforme*). In mid-September biomass decreased to 1770 mg/m at which time the standing crop consisted of 55% chrysophytes, 20% chlorophytes, 12% cryptophytes, and 11% diatoms. Sampling ceased at this time due to deepening of the epilimnion beyond the 1% light level.

1979

Epilimnion (Fig. 1): In 1979 the pH of the epilimnion ranged between 5.4-5.7 ($\bar{x}$ 5.60) (Schindler, unpublished data). In mid-May, the standing crop was represented by 49% Chlorophyceae, 35% Chrysophyceae, 7% Cryptophyceae, and 5% Diatomeae. *Chlorella* cf *mucosa* (a chlorophyte) was the dominant species, constituting 40% of the total standing crop; *Chrysococcus* sp. was the major chrysophyte. Biomass averaged 1309 mg/m^3. Throughout May biomass increased then decreased in early June. Chlorophyceae increased to 52% of the biomass of which 45% was *Chlorella* cf *mucosa*. In late June dominance shifted to Chrysophyceae (*Dinobryon bavaricum*, *Uroglena americana*, *Chrysochromulina* sp., and *Chrysococcus* sp.), while chlorophytes decreased to 13% of the standing crop. Throughout June and July biomass decreased reaching 466 mg/m^3 in mid-July. Chrysophyceae dominated with *Mallomonas* sp. being the major species. During August *Chrysosphaerella multispina*, *Mallomonas* sp., and *Uroglena americana* constituted the dominant chrysophycean species with biomass fluctuating between 872 mg/m^3 and 750 mg/m^3. In mid-September biomass slumped to 387 mg/m^3 and species composition shifted to 41% Chrysophyceae, 31% Chlorophyceae and 10% Diatomeae. In early October biomass increased to 989 mg/m^3. Throughout October, Chrysophyceae dominated with major species being *Chrysochromulina* sp., *Mallomonas* sp., and *Salpingoeca frequentissima*. Biomass averaged 860 mg/m^3 during this period.

Metalimnion (Fig. 2): During late May 1979, the biomass in the metalimnion of Lake 223 was 4300 mg/m^3. The standing crop was represented by 66% Chlorophyceae (*Chlorella* cf *mucosa* was the dominant species) and 26% Chrysophyceae. Biomass decreased during June with dominance shifting from Chlorophyceae to Chrysophyceae in late June; however, *Chlorella* cf *mucosa*, a chlorophyte, remained the dominant species. *Dinobryon bavaricum*, *Uroglena americana*, and *Chrysochromulina* sp. were the common chrysophytes. Biomass fluctuated from 1350 mg/m^3 to 1054 mg/m^3 during July with Chrysophyceae dominating as a group, but *Chlorella* cf *mucosa* remained the dominant species. In early August, biomass increased to 2839 mg/m^3 as *Chlorella* cf *mucosa* became extremely abundant representing 40% of the total standing crop. Chrysophyceae became dominant in late August, at which time the plankton assemblage was represented by 50% Chrysophyceae (*Dinobryon sertularia*, *Uroglena americana*, *Chrysochromulina* sp., and *Chrysosphaerella multispina*), 22% Diatomeae (*Synedra acus* and *Rhizosolenia eriensis*), and 19% Chlorophyceae (*Chlorella* cf *mucosa*). By early September, biomass increased to 4476 mg/m^3. This increase correlated with an increase in *Chlamydomonas* sp. which became dominant at this time. Biomass continued to increase, reaching 5989 mg/m^3 in mid-September. Sampling was discontinued at this time as the epilimnion extended below the maximum depth of the euphotic zone.

Hypolimnion (Fig. 3): In late May 1979, the standing crop of phytoplankton was represented by 36% Chlorophyceae (*Chlorella* cf *mucosa* and *Scourfieldia cordiformis*), 30% Cryptophyceae (*Cryptomonas* spp.), 21% Chrysophyceae (*Chrysococcus* sp., *Kephyrion boreale* and *Chrysochromulina* sp.), and 10% Peridineae. A biomass of 2350 mg/m^3 was recorded at this time. Throughout June and early July Chlorophyceae increased and on July 11, represented 81% of the biomass which had increased to 10,222 mg/m^3. *Chlorella* cf *mucosa* represented 70% of the biomass at this time with a live cell estimate of 72 x 10^6 cells/L or 7250 mg/m^3. In the latter part of July biomass decreased to 5084 mg/m^3 with Chlorophyceae representing 77% of the standing crop and Chrysophyceae an additional 17%. *Chlorella* cf *mucosa* remained the dominant species. Sampling was discontinued because the depth of the metalimnion exceeded the 1% light level at this time.

DISCUSSION

Altering the epilimnetic pH from 7.0 to 5.6 over 4 years has had an effect on the phytoplankton community in Lake 223.

Epilimnion: Biomass has increased 1.5 to 2x since acidification began in 1976 (Fig. 1, Table 1). In Fig. 1 biomass appears to be increasing from 1976 to 1978, and declining slightly in 1979, the acidification years. This becomes more evident when compared to the biomass for Lake 224, a control lake, upstream from Lake 223 (Fig. 4). From 1974 to 1977 biomass in Lake 224 has remained stable with very little fluctuation; however, biomass in Lake 223 has increased. This can be substantiated by comparing mean biomass (for the ice-free season corrected for morphometry) for Lakes 223 and 224 (Table 1). Biomass in Lake 224 ranges from 972 to 1107 kg from 1974 to 1977 and from 782 to 1486 kg from 1974 to 1977 in Lake 223. This is a 12% increase in 224 and 40% in 223.

Species composition also appears to be affected (Fig. 1) in Lake 223, with a trend towards a larger proportion of Chlorophyceae, especially in 1979 when in fact they dominated in early spring (mainly *Chlorella* cf *mucosa*). This was the first time a species other than Chrysophyceae dominated Lake 223. In Lake 224 (Fig. 4) there appears to be a similar but less pronounced increase in the chlorophycean population from 1974 to 1977 making the shift in Lake 223's epilimnion appear to be significant.

A comparison of the index of diversity for Lake 223 (Fig. 5) and Lake 224 (Fig. 4) indicates there has been no significant change in the species diversity, although Lake 223 does appear to be more diverse than Lake 224.

Metalimnion: It is difficult to determine the true effects acidification has had on the metalimnion in Lake 223 because of the lack of pre-acidification data. There are, however, several interesting changes which have occurred since 1976.

The metalimnetic biomass has increased over the four years of acidification (Fig. 2, Table 1). This becomes more evident when comparing Lake 223 biomass estimates to those of Lake 224 (Fig. 7, Table 1). Lake 224 had a very stable biomass throughout 1976 and 1977 in comparison to Lake 223 which appears to be increasing. Table 1 indicates biomass in the metalimnion of Lake 223 has tripled.

Further, there was a significant change in species composition with a shift towards Chlorophyceae from the predominant Chrysophyceae (Fig. 2). This shift appears to be of significance when the composition of Lake 223 is compared to that of Lake 224 (Fig. 7). Lake 223 in 1979 was dominated by *Chlorella* cf *mucosa* for the entire season, thus, this change appears to be real.

When comparing the index of diversity for the metalimnion of Lake 223 and 224, there appers to be no significant change with the possible exception of 1979, when diversity in Lake 223 was highest (Fig. 7).

Hypolimnion: The hypolimnion biomass was the population most affected by acidification (Fig. 3), especially when compared to the biomass of Lake 224 (Fig. 9). Lake 224 had stable biomass from 1975 to 1977, while biomass increased in Lake 223. However, we believe that this increase is an artifact of sampling because for a large part of the year, the hypolimnion is below the 1% light level and when calculating mean biomass a zero value is entered when this situation occurs, thus lowering the actual value. The hypolimnion values in Table 1 point out that biomass has not increased, that it has remained similar from 1975 to 1979 as did Lake 224's biomass.

A significant change in species composition (Fig. 3) did occur with a shift to Chlorophyceae dominance. In 1979 *Chlorella* cf *mucosa* constituted up to 85% of the total standing crop and was the dominant species. The significance of this shift is enhanced when species composition of Lake 223 is compared to that of Lake 224 (Figs. 3 and 9). During the same time period Lake 224 has had no significant shifts in composition where 223 has had a drastic shift to Chlorophyceae.

A comparison of the index of diversity for the respective hypolimnions of Lake 223 and 224 indicates there is no change in diversity until 1979 when in fact it increases (Fig. 10).

Whole Lake (about 1% light level): There are two significant changes in Lake 223 since acidification began in 1976. The most obvious is the increased biomass (Table 1). Biomass has increased 50% from 1975 to 1977 compared to a 25% increase in Lake 224 for the same period. The increase in Lake 223 is due mainly to the epilimnion while the increase in 224 occurred throughout the whole lake.

The second change is the shift in species composition towards a Chlorophyceae dominance. This shift was more noticable in the deeper strata.

These changes have occurred during years of acidification and when compared to a control system suggest that they are due to the additions of acid.

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Table 1. Mean biomass above the 1% light level corrected for morphometry, for the ice-free seasons (1974-1979), for Lake 223 and Lake 224.

	Epilimnion (kg)		Metalimnion (kg)		Hypolimnion (kg)		Total biomass (kg) above the 1% light level	
Year	223	224	223	224	223	224	223	224
1974	782	1,062	n/s	n/s	n/s	n/s		
1975	883	1,107	*	*	582	652	1,465	1,759
1976	1,113	1,095	305	310	352	677	1,775	2,082
1977	1,486	973	906	471	557	771	2,948	2,215
1978	1,377	n/s	673	n/s	483	n/s	2,532	n/s
1979	1,183	n/s	816	n/s	387	n/s	2,386	n/s

* Metalimnion was combined with hypolimnion.

n/s No sample.

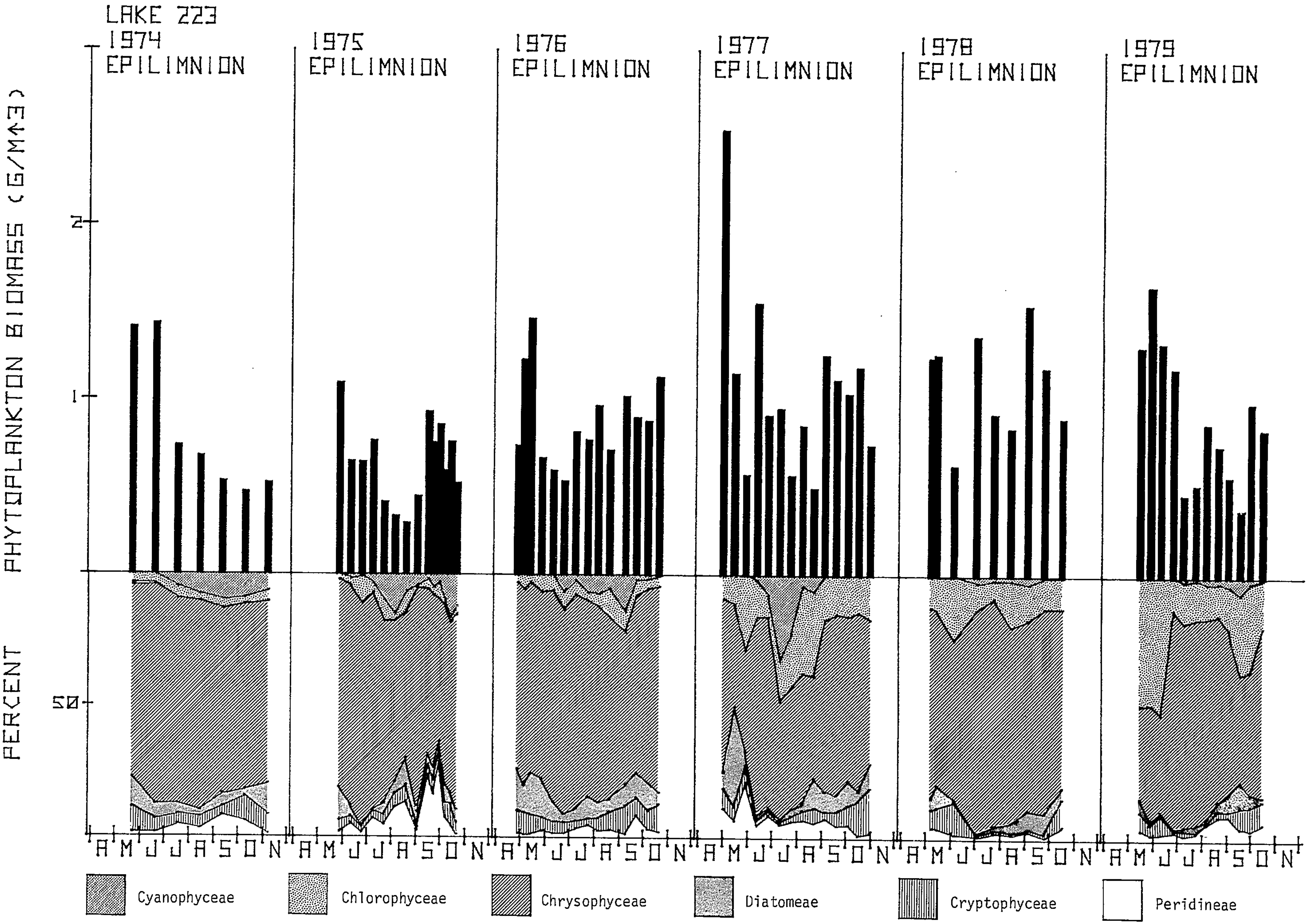

Figure 1. Average phytoplankton volume in the epilimnion of Lake 223 in 1974-1979, and accumulative percent composition.

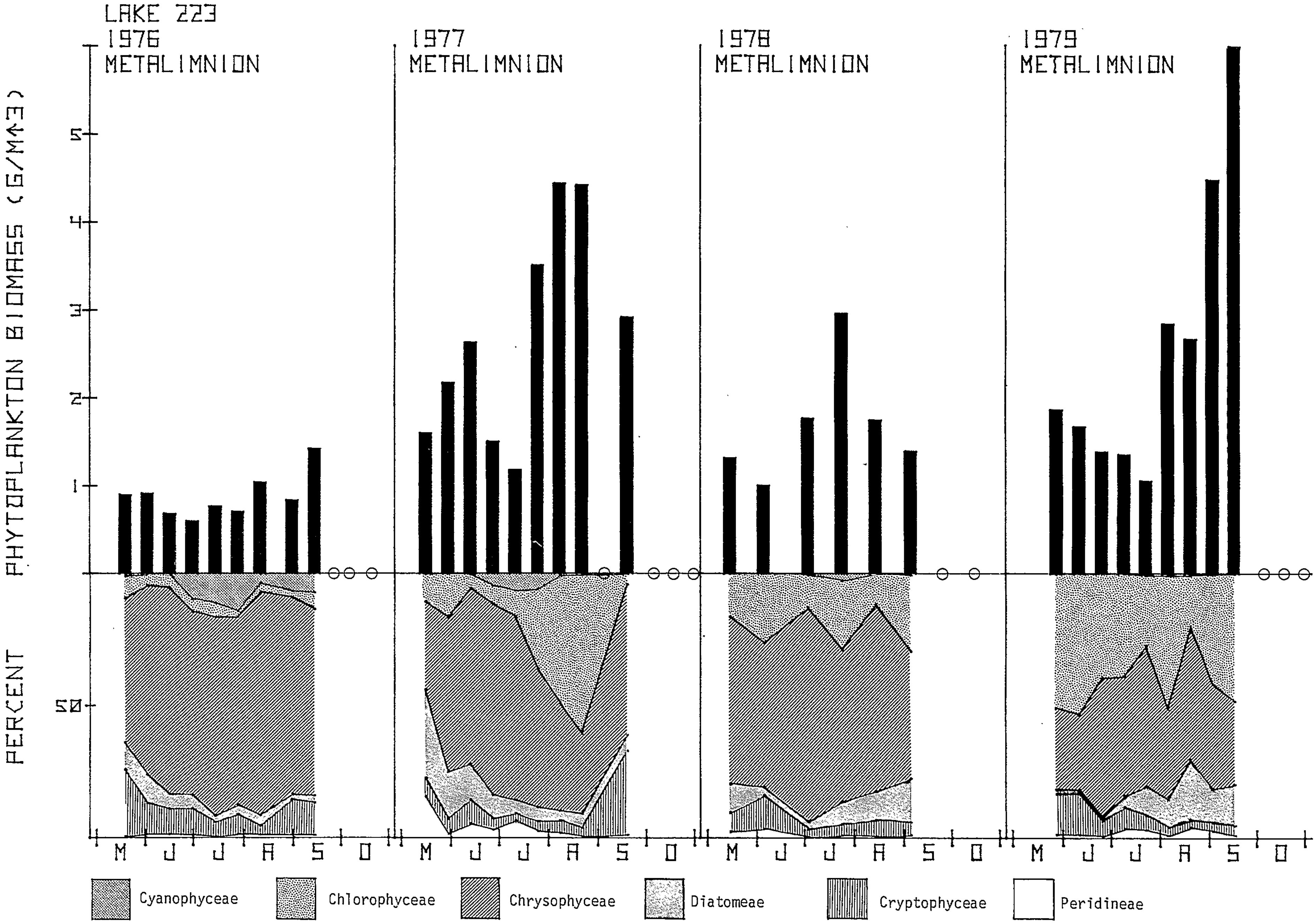

Fig. 2. Average phytoplankton volume in the metalimnion of Lake 223 in 1976-1979, and accumulative percent composition.
○- means that this strata was below the 1% light level when the lake was sampled, therefore, no sample was taken.

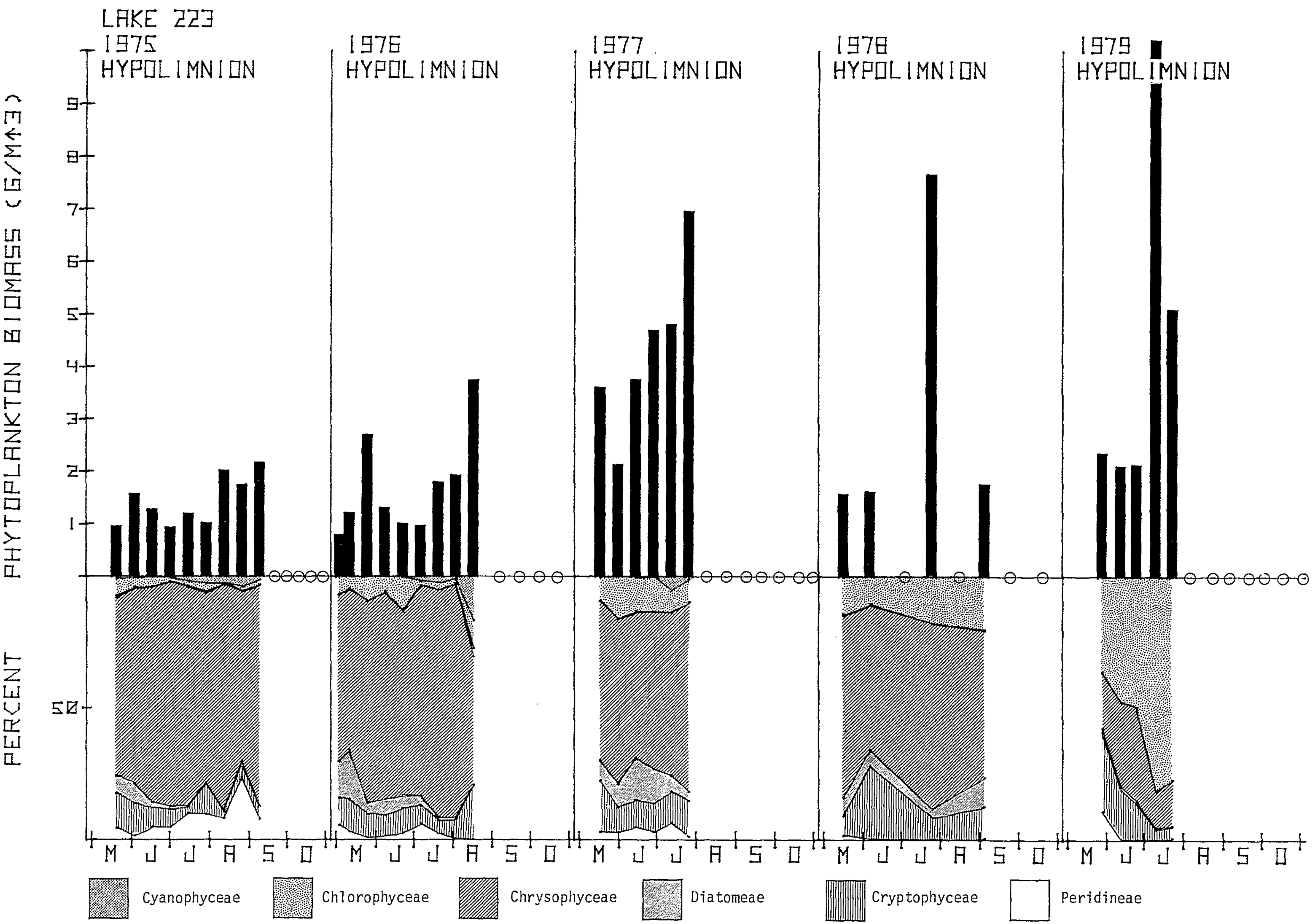

Fig. 3. Average phytoplankton volume in the hypolimnion of Lake 223 in 1975-1979, and accumulative percent composition.
○ - means that this strata was below the 1% light level when the lake was sampled, therefore, no sample was taken.

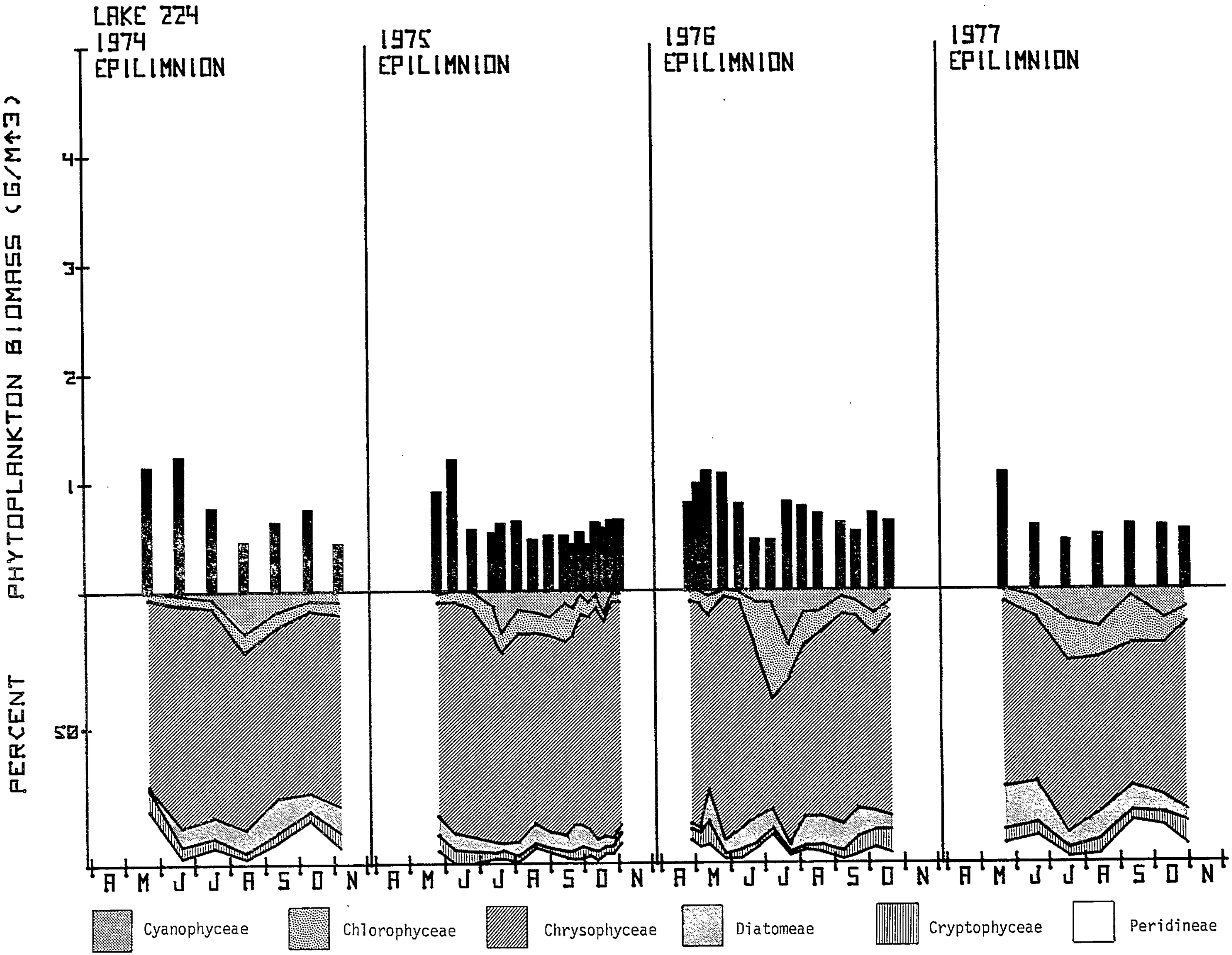

Fig. 4. Average phytoplankton volume in the epilimnion of Lake 224 in 1974-1977, and accumulative percent composition.

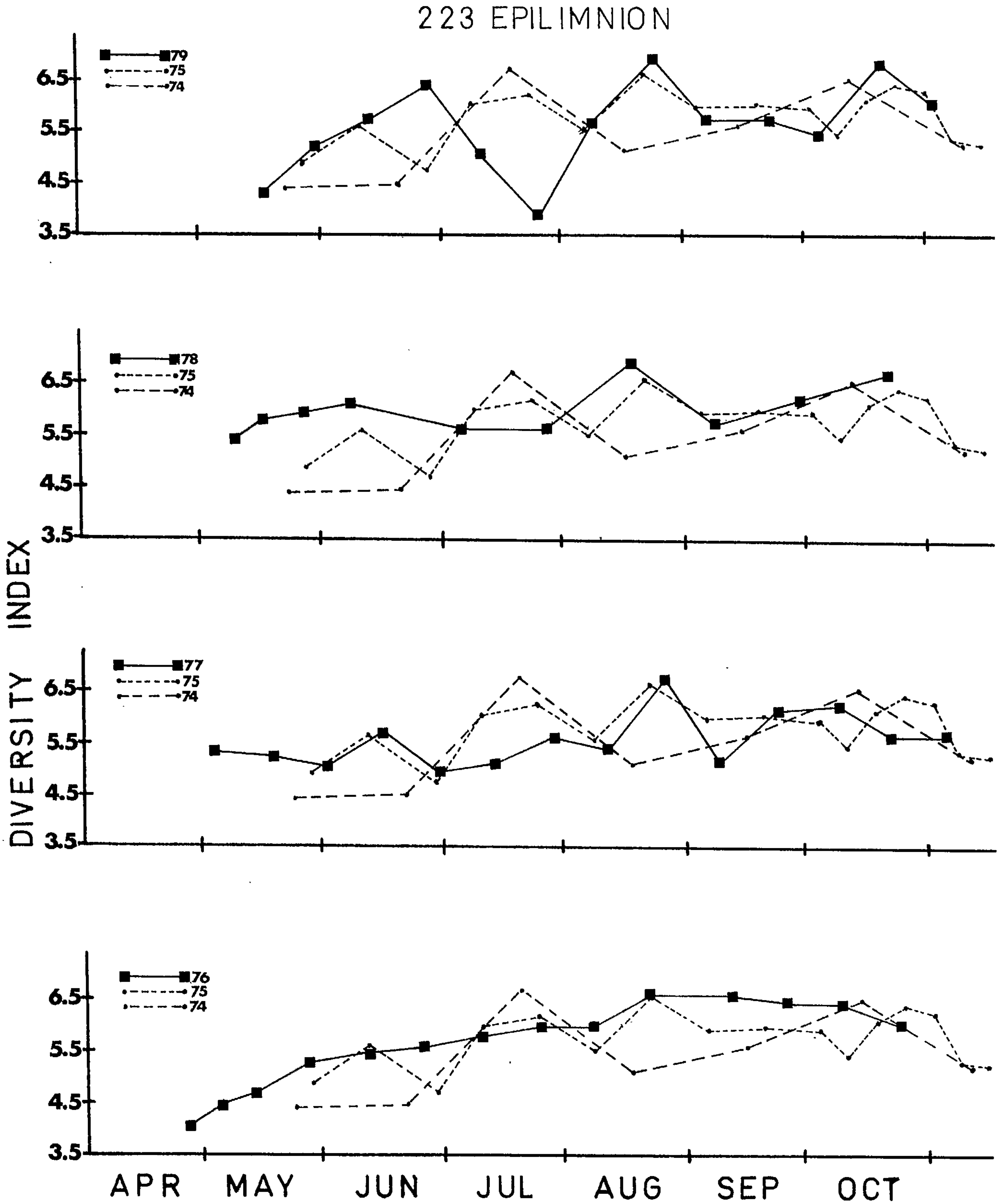

Fig. 5. A comparison of the index of diversity for the epilimnion (ice-free seasons) in Lake 223. Acidification years 1976-1979 are plotted with preacidification years 1974 and 1975.

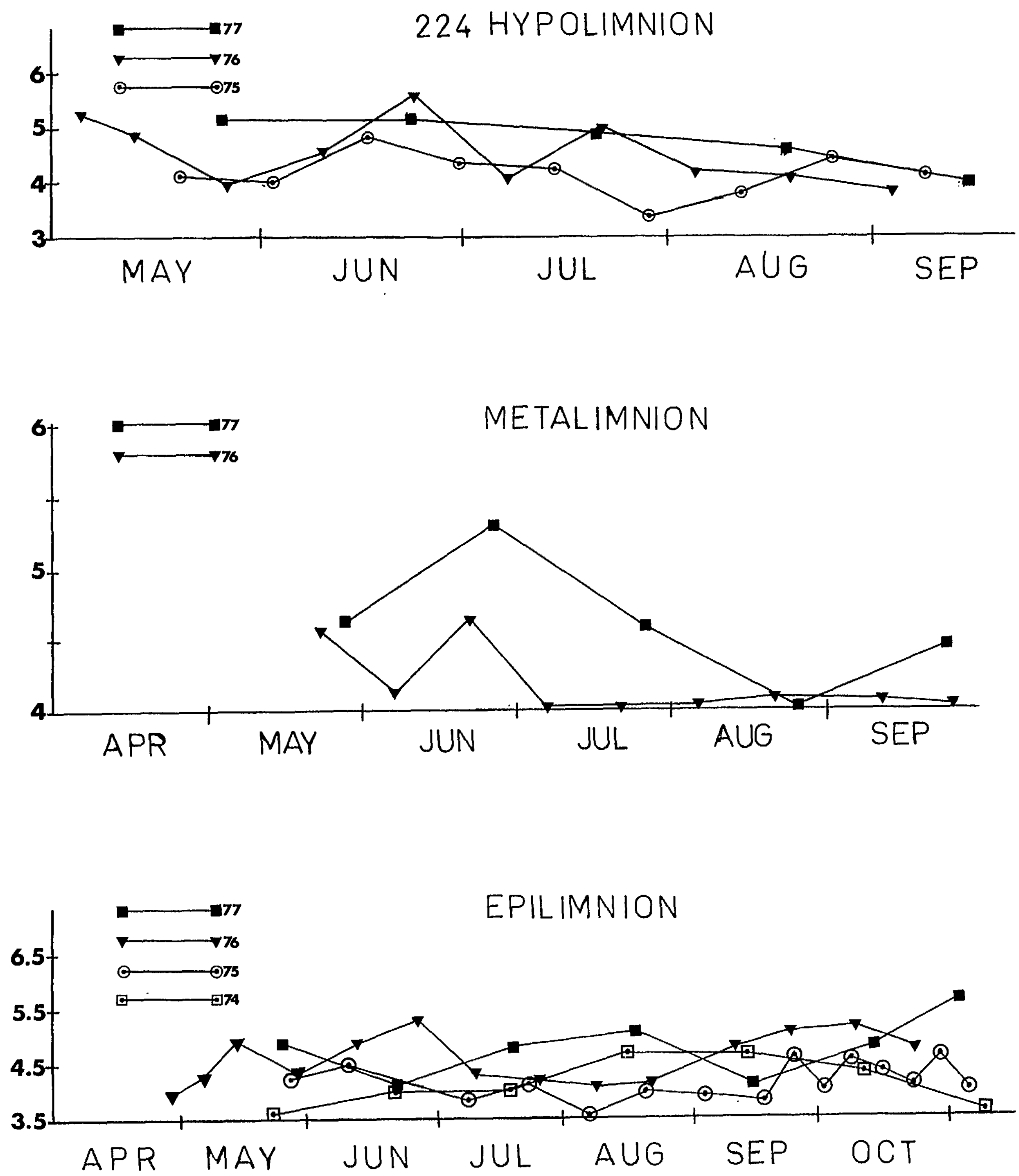

Fig. 6. The index of diversity for the epilimnion, metalimnion and hypolimnion (ice-free season) in Lake 224 1974-1977.

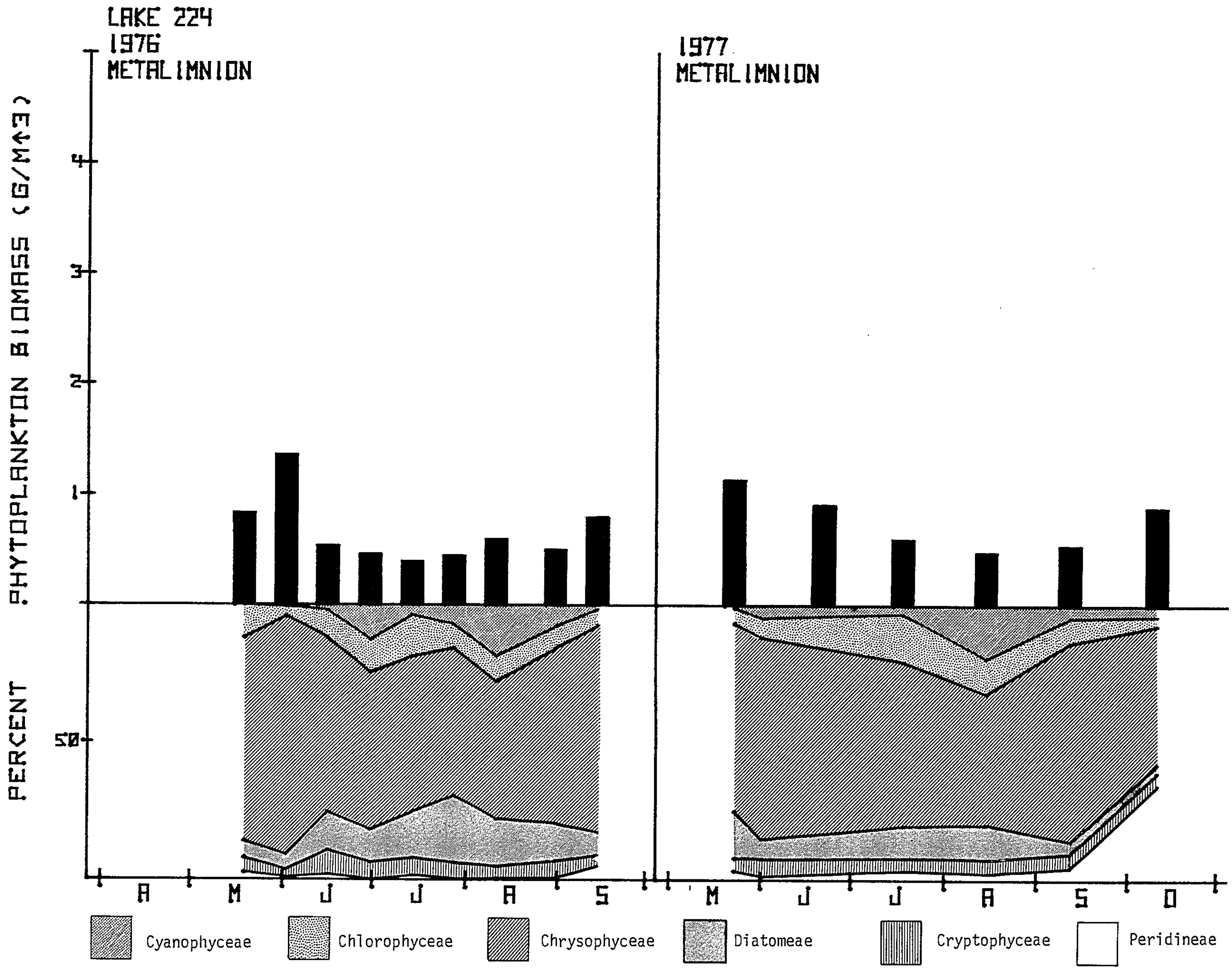

Fig. 7. Average phytoplankton volume in the metalimnion of Lake 224 in 1976 and 1977, and accumulative percent composition.

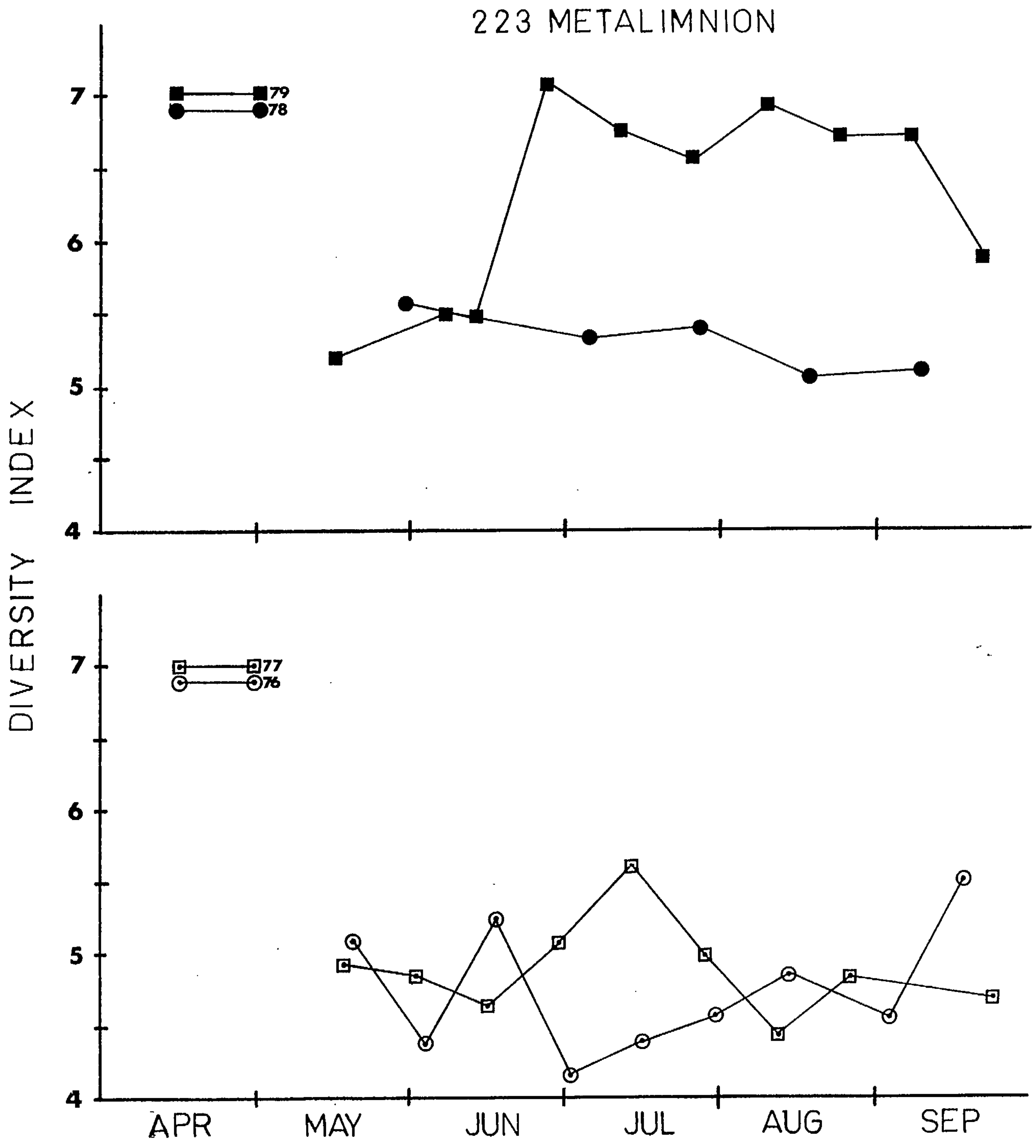

Fig. 8. Index of diversity for 1976-1979, experimental acidification years, in the metalimnion of Lake 223 (ice-free seasons).

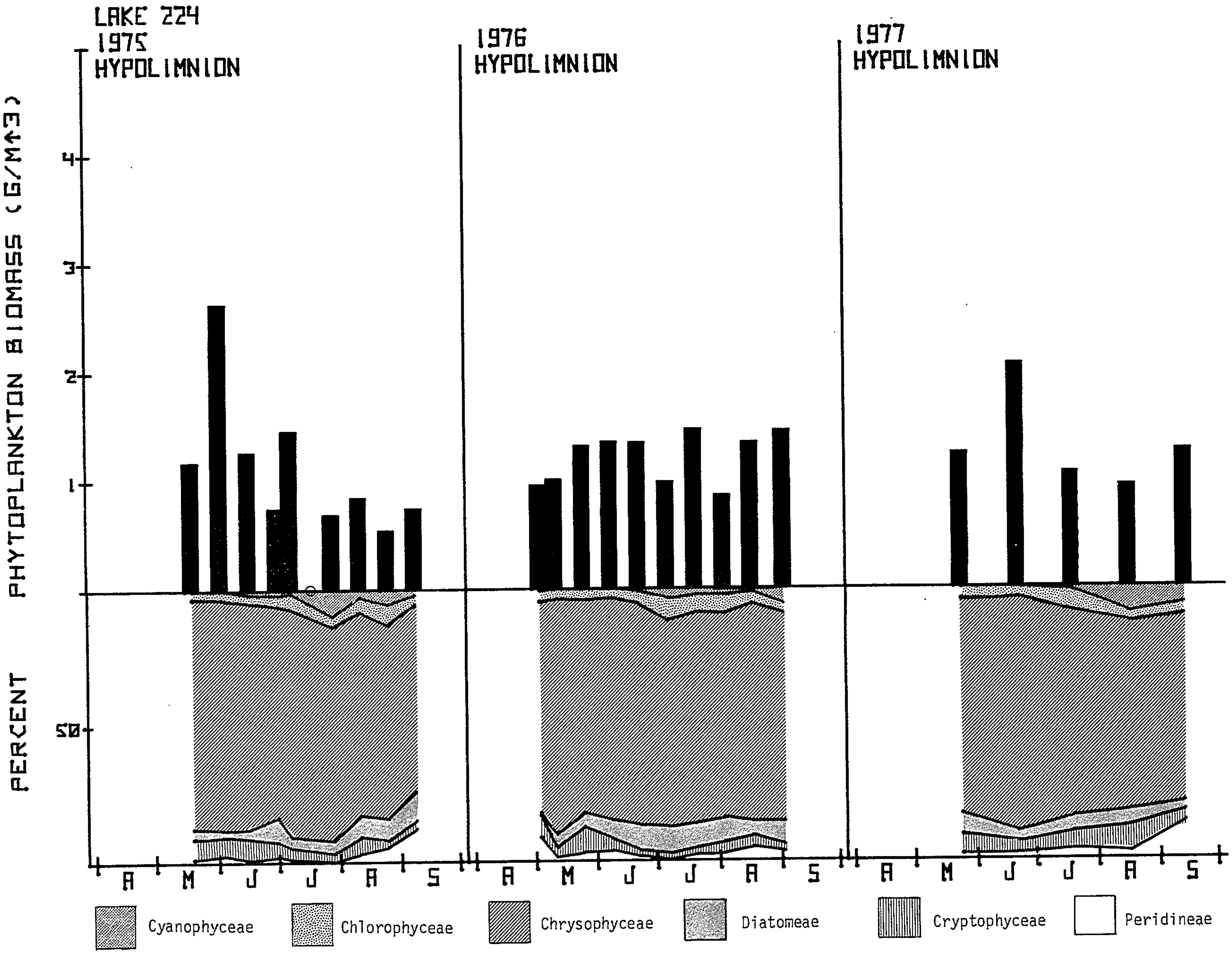

Fig. 9. Average phytoplankton volume in the hypolimnion of Lake 224 in 1975-1977, and accumulative percent composition.

○ - means that this strata was below the 1% light level when the lake was sampled, therefore, no sample was taken.

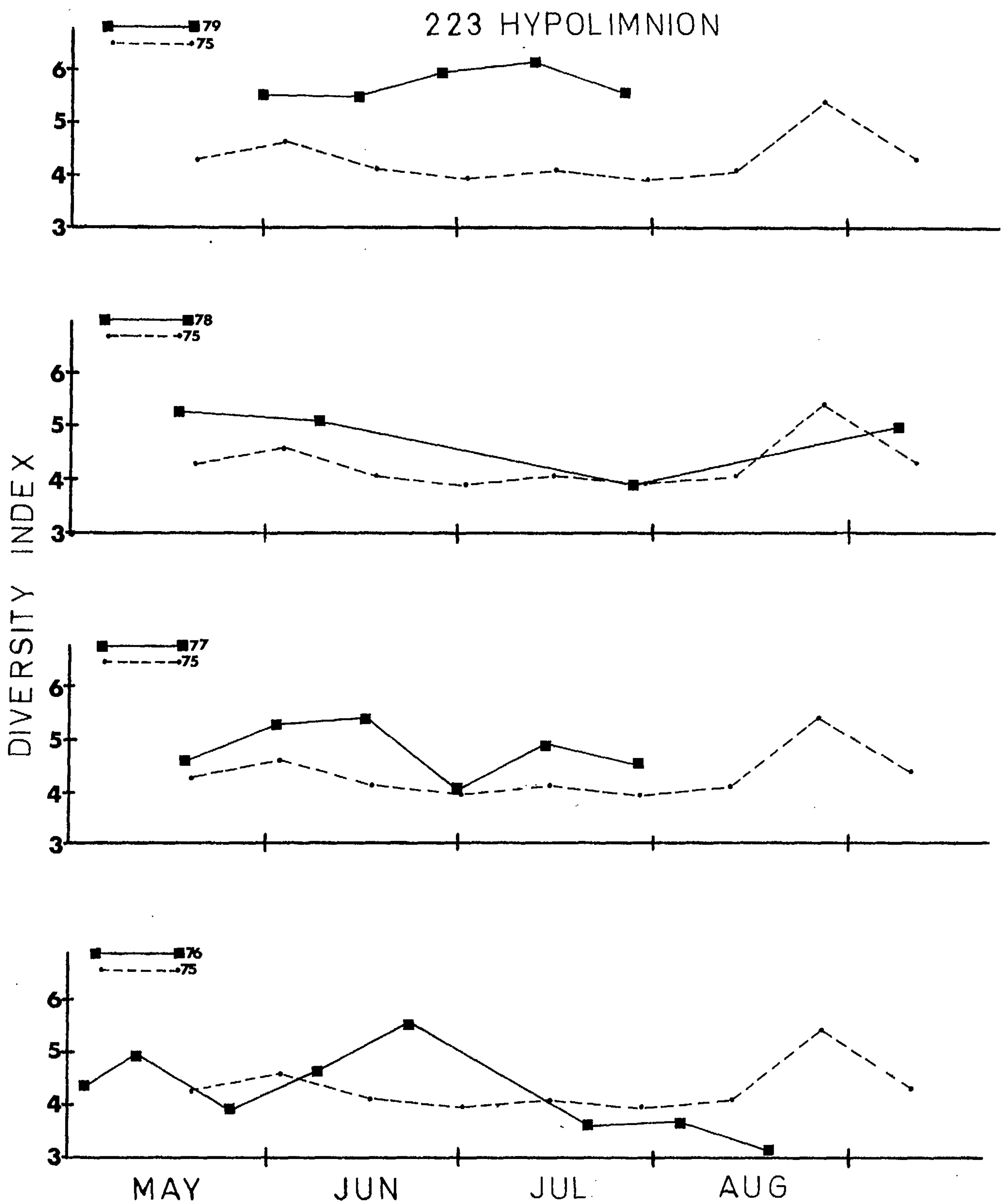

Fig. 10. A comparison of the index of diversity for the hypolimnion (ice-free seasons) in Lake 223. Acidification years 1976-1979 are plotted with preacidification year 1975.

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