

## DISTRIBUTION OF PHOTOSYNTHETIC PIGMENTS IN NEARSHORE SEDIMENTS OF LAKE MICHIGAN

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**ABSTRACT.** To characterize nearshore detrital deposits and to identify potential input sources, photosynthetic pigments were examined in sediment cores taken from three stations in nearshore Lake Michigan between May and October 1979. Two stations were located at 11 m and one was at 23-m depth. At the 11-m stations, total pigment concentrations in the upper 0-1 cm layer were greatest in May and then declined, while seasonal changes at the 23-m station were not apparent. A high proportion of the spring influx of pigment at the 11-m depth was undegraded, indicating freshly settled material from the water column as a likely source. Sediment chlorophyll concentrations in the spring were as high as 212  $\mu\text{g/g}$ , but typical summer values were 1-7  $\mu\text{g/g}$ . Although these pelagic inputs are temporary, strong links exist between this material and benthic invertebrate distributions. **ADDITIONAL INDEX WORDS:** Chlorophyll, detritus, benthos, pigments, invertebrates.

### INTRODUCTION

In sampling the benthos in a nearshore area of Lake Michigan over a 4-year period, we found that some temporal and spatial variability in benthic invertebrate distributions was related to differences in the amount of surface detritus (Nalepa and Robertson 1981, Nalepa and Quigley 1983). This detrital material had a high organic carbon content (Chambers and Eadie 1980) and likely served as a source of food for the benthos. Detrital amounts were greatest in the spring and it was suggested that this material probably consisted of allochthonous materials deposited during spring runoff and/or of plankton settled from the spring diatom bloom (Nalepa and Quigley 1983); also, this detritus may have consisted of fine material transported from offshore areas during winter resuspension activities (Eadie *et al.* 1984).

To further quantify and characterize this detrital layer, we measured sedimentary pigments at three nearshore sites on a seasonal basis. Photosynthetic pigments are the easiest organic material to extract and they provide an indication of the nature and relative sources of organic inputs to the sediments. Sedimentary pigments may occur as either chlorophyll or chlorophyll degradation products such as

phaeophytin, phaeophorbides, or chlorophyllides (phaeopigments). Chlorophyll is associated with intact cells, and sediment sources include living benthic algae and algae recently settled from the water column. Both benthic and planktonic species have been found in the nearshore sediments of Lake Michigan (Stevenson and Stoermer 1981). In general, however, a considerable portion of the total pigment present in sediments consists of chlorophyll degradation products (Moss 1968, Leach 1970, Jansson and Wulff 1977). Chlorophyll degrades during prolonged exposures to darkness, during bacterial, viral, or autolytic cell lysis, and during ingestion by invertebrates (Daley 1973, Daley and Brown 1973).

By measuring seasonal changes in amounts of total pigment and relative proportions of degraded and undegraded chlorophyll in the nearshore zone, the significance of spring inputs of organic material can be put into perspective relative to amounts present at other times of the year.

### METHODS

The three sampling stations were located in southeastern Lake Michigan near the mouth of the Grand River (Fig. 1). Two stations were located at

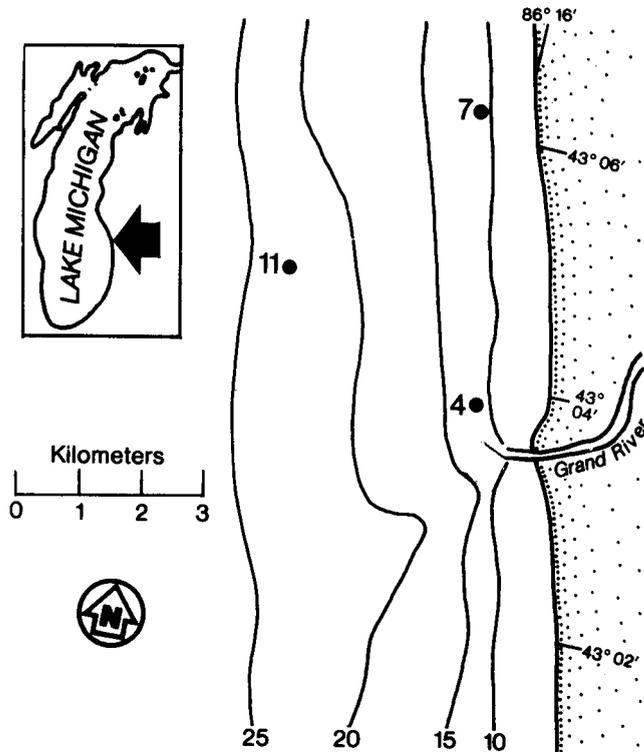


FIG. 1. Sampling stations in nearshore Lake Michigan. Depth contours in meters.

11 m (stations 4 and 7) and one station was located at 23 m (station 11). Sediment samples were generally taken on a monthly basis from May to late October 1979.

All samples were collected by divers using SCUBA. Three replicate sediment cores were taken at each station on each sampling date. A clear acrylic tube (23 cm long, 5 cm diameter) was forced 7–12 cm into the sediment, stoppered at both ends, and placed upright in a plastic carrying basket. After the cores were brought to the surface, the amount of surface detritus was recorded to the nearest millimeter and the overlying water was decanted. The sediments were frozen in dry ice and kept frozen in the dark until pigment analysis.

Within 3 weeks after collection, the cores were sectioned into 1-cm intervals to a depth of 6 cm. The core sample was extruded and the still-frozen sediment was sliced with a nichrome wire heated with an electrical current. One portion of each section was analyzed for pigments and another portion was analyzed for water content. Sediment for pigment analysis (0.5–5.0 g) was placed into pre-

weighed 5-dram vials. The pigment was extracted with 12 mL of boiling methanol, and fluorescence was measured with a Turner 110 fluorometer having standard filters for excitation and emission. The fluorescence of the sample was read before and after acidification with HCL (final molarity of .003) (Holm-Hansen 1978). Although the fluorometric method does not differentiate between the various phaeopigments, the ratio of unacidified to acidified extract (U/A ratio) provides an indication of the relative proportion of chlorophyll and phaeopigments in the sample. When using acetone as the extracting solvent and oxalic acid to acidify, the ratio ranges from 1.7 for pure chlorophyll *a* to 1.0 for totally degraded pigment (Yentsch and Menzel 1963; Lorenzen 1965, 1967). However, when using methanol and HCL to first extract and then acidify, the U/A ratio is about 2.4 for pure chlorophyll *a* (Holm-Hansen *et al.* 1965). In our sample extracts, individual U/A ratios ranged from 1.79 to 1.14.

Standard dilutions were made from a stock solution of 1 mg chlorophyll *a* (Sigma Chemical Co.) in 1 liter of methanol. Four serial dilutions were made to obtain readings between 10 and 50 using the 3x door. Each dilution was acidified as in the sample extracts. These standard procedures were repeated each day sediment pigments were determined.

Chlorophyll and phaeopigments were calculated as outlined by Strickland and Parsons (1968). The acid factor and the fluorometric conversion factor used in the calculations were the mean values obtained from the four serial dilutions.

The weight of sediments used in the extractions were determined after drying at 60°C for 48 hours.

## RESULTS AND DISCUSSION

Seasonal changes in the amount of detritus overlying the sandy substrate are given in Table 1. At the 11-m stations, amounts of detritus were greatest in May and then declined. At the 23-m station, small amounts of detritus were observed only in June. The decrease after spring at the 11-m stations was likely a result of this material being resuspended and swept into deeper areas by wave action and longshore currents. Little or no permanent deposition occurs in Lake Michigan at depths less than 50 m (Edgington and Robbins 1975).

Seasonal differences in amounts of both total pigment and chlorophyll in the upper 1 cm of sediment were quite pronounced, with peak concentra-

TABLE 1. Mean ( $\pm$  SE) thickness (millimeters) of the detrital layer at each of the three stations on each sampling date. When detritus was present in trace amounts and did not cover the entire surface of the sediment core sample, a value of 0.5 mm was assigned for computational purposes.

Date	Station		
	4	7	11
15 May	40.0 $\pm$ 0	4.0 $\pm$ 0.7	—
21 Jun	0.3 $\pm$ 0.2	0.7 $\pm$ 0.2	0.5 $\pm$ 0
23 Jul	0	0	0
15 Aug	0	0	—
03 Sep	—	0	—
01 Oct	1.0 $\pm$ 1.0	1.7 $\pm$ 1.7	0
25 Oct	0	0	0

tions being found in spring (Fig. 2, Table 2). For chlorophyll, concentrations at the 11-m stations varied from 212  $\mu\text{g/g}$  (15 May) to 0.7  $\mu\text{g/g}$  (25 October) at station 4 and from 67  $\mu\text{g/g}$  (15 May) to 1.4  $\mu\text{g/g}$  (15 August, 1 October) at station 7. Seasonal changes at the 23-m station were not apparent; however, samples at this station were not taken in May when pigment concentrations would likely have been highest.

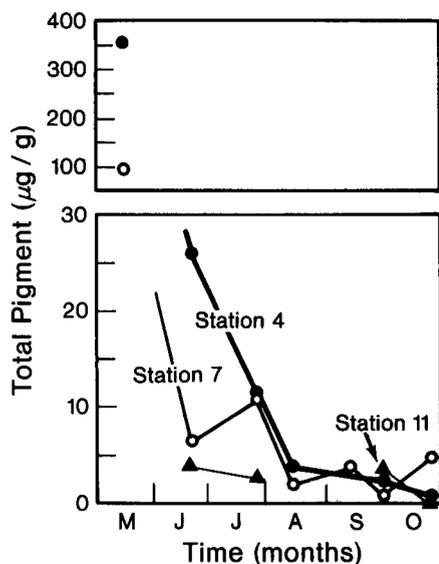


FIG. 2. Seasonal changes in total pigment in the upper 0-1 cm layer at each of the three stations.

Considering that a large portion of the detrital influx consisted of undegraded pigment as indicated by the high U/A ratios (Table 2), a likely source of these inputs would be the spring diatom bloom. Although we did not measure corresponding pigment concentrations in the water column, others have found that both diatom abundances and chlorophyll concentrations in the study area are greatest in April, as associated with thermal bar conditions (Stoermer 1968, Kopczynska 1973, Schelske *et al.* 1980). In spring, low water temperatures and minimum numbers of planktonic grazers allow sinking cells to reach the bottom relatively intact. Rapid mass sedimentation of cells following a spring bloom has been reported in both lakes and nearshore marine waters (Jewson *et al.* 1981, Reynolds *et al.* 1982, Smetacek 1980). Conceivably, some of the sediment chlorophyll may be attributed to an active benthic algal component; however, the large amount of surface detritus would indicate mostly a pelagic source.

Total pigment concentrations at the 11-m stations declined by 94% between May and June and then more gradually until the end of the sampling period (Fig. 2). This decline was closely related to the decrease in visible amounts of surface detritus and, as noted previously, can be attributed to physical resuspension and transport to offshore areas. Although a slight increase was observed in August, the U/A ratio generally declined from May to October, indicating degradation of the spring chlorophyll influx either by cell lysis or ingestion by benthic organisms.

Monthly comparisons between the two 11-m stations indicated significantly (*t*-test;  $P < 0.1$ ) greater amounts of total pigment at station 4 than at station 7 in May and June. Station 4 was located nearest the river mouth where not only is the intensity of the spring bloom greater than in nearby areas (Kopczynska 1973, Moll and Brahe 1986), but where a greater portion of the suspended detrital material from the river is deposited. The U/A ratio at station 4 was lower than at station 7 on all but the two October sampling dates (Table 2), indicating some contribution of degraded material from the river at the former station.

Both total pigment concentrations and U/A ratios were significantly lower ( $P < 0.1$ ) at the 23-m station than at the two 11-m stations in June and July. Throughout the summer, divers noted strong bottom currents at the deeper station which likely prevented any accumulation of sedimented material. Differences between the two sampling depths

TABLE 2. Mean ( $\pm$ SE) chlorophyll concentration ( $\mu\text{g/g}$ ) in the upper 1 cm layer of sediment at the various stations. The U/A ratio is given in parentheses. Stations 4 and 7 were at 11-m depth and station 11 was at 23-m depth.

Date	Station		
	4	7	11
15 May	211.9 $\pm$ 61.2 (1.55)	67.0 $\pm$ 29.7 (1.66)	—
21 Jun	10.8 $\pm$ 8.7 (1.50)	4.0 $\pm$ 1.2 (1.59)	1.8 $\pm$ 0.2 (1.42)
23 Jul	6.6 $\pm$ 1.1 (1.47)	7.1 $\pm$ 3.6 (1.52)	1.7 $\pm$ 0.6 (1.40)
15 Aug	2.2 $\pm$ 0.9 (1.51)	1.4 $\pm$ 0.1 (1.68)	—
03 Sep	—	2.3 $\pm$ 0.9 (1.49)	—
01 Oct	1.9 $\pm$ 0.2 (1.48)	1.4 $\pm$ 0.5 (1.46)	2.5 $\pm$ 0.2 (1.45)
25 Oct	0.7 $\pm$ 0.1 (1.34)	4.7 $\pm$ 2.8 (1.37)	0.5 $\pm$ 0.1 (1.30)

might also be attributed to lower productivity in both the sediments (Stevenson and Stoermer 1981) and in the water column (Schelske *et al.* 1980, Moll and Brahe 1986) at the deeper depth.

Concentrations of total pigment below the 2-cm vertical depth were generally less than 1  $\mu\text{g/g}$  at all three stations regardless of date; this might be expected considering the nondepositional nature of the nearshore zone. The exception was the relatively high concentrations of pigment to 6-cm depth at station 4 in May; mean amounts at the 0–1 cm through the 5–6 cm interval were 352, 149, 212, 19, and 4  $\mu\text{g/g}$  respectively. These pigment concentrations correspond to the large amounts of detritus (up to 4 cm thick) at this station in May.

Although estimates of sediment chlorophyll using the fluorometric technique may be in error by as much as 39% (Trees *et al.* 1985), relative comparisons to other nearshore areas of similar depth and substrate type would put our results in perspective. Assuming that chlorophyll concentrations in the summer more accurately reflect resident benthic algal standing stocks than concentrations in the spring (i.e., no detrital layer present), typical summer chlorophyll values in Lake Michigan varied from 1–7  $\mu\text{g/g}$ . This compares to summer values of 2–4  $\mu\text{g/g}$  in Kiel Bay (Boje-Volkman 1977) and to 4–20  $\mu\text{g/g}$  in Loch Ewe (Steele and Baird 1968). On an areal basis, summer chlorophyll in the upper 1 cm of Lake Michigan sediments was 11–77  $\text{mg/m}^2$  (1  $\text{cm}^3 = 1.1$  g dry weight); this compares to 20–30  $\text{mg/m}^2$  for a similar time period in nearshore Buzzards Bay, Massachusetts (Roman and Tenore 1978). Thus, absolute amounts of summer chlorophyll in nearshore sedi-

ments of Lake Michigan were comparable to amounts found in these other areas. However, when comparing the relative influx of chlorophyll in the spring, much greater amounts were apparent in Lake Michigan. For instance, at 11 m in Lake Michigan, sediment chlorophyll concentrations in the spring were up to 17 times greater than concentrations found later in the year. In Kiel Bay, seasonal changes in chlorophyll concentrations were not apparent, while in Loch Ewe and Buzzards Bay, concentrations in the spring were only three and four times greater than found at other times.

Certainly the most striking aspect of these results is the magnitude of the spring influx of undegraded organic material. The length of time this material remains in the nearshore zone and its distribution on the bottom is highly variable, changing from year to year depending on the physical forces of waves and currents. It can occur as a thin layer over the sandy substrate for just a short period, or it can occur in thick, distinct patches throughout the summer (Chambers and Eadie 1980, Nalepa and Quigley 1983). Yet, although these pelagic inputs are temporary, strong links exist between this material and benthic invertebrate populations in the nearshore zone. For instance, seasonal and annual fluctuations as well as vertical and horizontal distributions of the nearshore epibenthos, meiobenthos, and macrobenthos have been shown to be influenced by these deposits to some extent (Nalepa and Robertson 1981; Nalepa and Quigley 1983, 1985). In turn, invertebrate populations mineralize this material, allowing nutrients to be recycled within the system (Gardner *et al.* 1981; Quigley and Robbins 1984, 1986).

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