Inshore–Offshore Sedimentation Differences Resulting from Resuspension in the Eastern Basin of Lake Erie[1]

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From June through October 1978 sediment traps were moored at three stations in an inshore–offshore transect in the Eastern Basin of Lake Erie. Settling fluxes measured with the traps exposed close to lake bottom were rather similar at all three stations during summer stratification, averaging 6.1 $g \cdot m^{-2} \cdot d^{-1}$ for dry weight, 293 $mg \cdot m^{-2} \cdot d^{-1}$ for particulate organic carbon (POC), 38 $mg \cdot m^{-2} \cdot d^{-1}$ for particulate nitrogen (PN), and 5.44 $mg \cdot m^{-2} \cdot d^{-1}$ for particulate phosphorus (PP). A comparison of the hypolimnetic traps with the epilimnetic traps at the offshore station indicated that considerable resuspension takes place even in summer. During fall, however, the nearshore sedimentation rates were markedly increased because of storm-induced bottom resuspension. By comparing the trap catches with sediment cores taken at all three stations, a resuspension model for dry weight, POC, and PN was developed. The calculations showed that newly formed organic material is resuspended and redeposited more frequently at nearshore locations than offshore. This repeated nearshore resuspension enhances decomposition of detritus, as shown by low relative phytoplankton activity in the hypolimnetic traps, and results in horizontal transport of fine-grained organic matter in the offshore direction. The significant POC and PN concentration differences found in the inshore–offshore transect of the bottom sediments can be explained by these two processes.

Key words: sedimentation, sediment traps, sediment cores, resuspension, inshore–offshore differences

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De juin à octobre 1978, des trappes à sédiment ont été ancrées à trois stations sur une section allant du rivage vers le large dans le bassin est du lac Érié. Les flux de sédimentation, mesurés avec les trappes exposées près du fond du lac, sont plutôt identiques aux trois stations au moment de la stratification estivale, en moyenne 6,1 $g \cdot m^{-2} \cdot d^{-1}$ pour le poids sec, 293 $mg \cdot m^{-2} \cdot d^{-1}$ pour le carbone organique particulaire (POC), 38 $mg \cdot m^{-2} \cdot d^{-1}$ pour l'azote particulaire (PN) et 5,44 $mg \cdot m^{-2} \cdot d^{-1}$ pour le phosphore particulaire (PP). À la station du large, une comparaison des trappes hypolimnétiques et épilimnétiques démontre que, même en été, il y a resuspension considérable. En automne, cependant, les taux de sédimentation près du rivage augmentent de façon marquée par suite d'une resuspension au fond provoquée par les tempêtes. Nous avons construit un modèle de resuspension pour le poids sec, le POC et le PN en comparant les prises des trappes avec des carottes de sédiment prélevées aux trois stations. Les calculs indiquent que le matériel organique nouvellement formé est resuspendu et redéposé plus fréquemment près du rivage qu'au large. Cette resuspension répétée près du rivage favorise la décomposition des détritus, comme le démontre une activité relativement faible du phytoplancton dans les trappes hypolimnétiques, et résulte en un transport horizontal de fines matières organiques en direction du large. Les différences significatives de POC et de PN dans les sédiments benthiques le long de la section du rivage vers le large peuvent s'expliquer par ces deux processus.

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USUALLY lake models and lake budget calculations are derived from physical, chemical, and biological data collected from a single sampling site (e.g. deepest) or from a few sites strategically located.

Though it is well recognized that overall differences within a lake are present, they are either considered to be negligible, or in most cases too time-consuming and costly to investigate. However, lake-wide surveys have been realized in many Great Lake's studies as a result of the extensive variability associated with these large bodies of water (e.g. Callender 1969; Burns 1976a; Munawar 1978; Kwiatkowski 1978, 1980). In addition, some small lakes have been investigated regarding the problems of horizontal differentiation (Davis 1968, 1973; Davis and Brubaker 1973; Serruya 1977; von Orelli 1980; Evans and Rigler 1980).

Horizontal variabilities in lakes are usually found in different lake basins; however, they may also be present in inshore–offshore transects. These differences between pelagic and littoral locations are dependent on lake size and morphometry. In Lake Erie, inshore–offshore differences have been reported for nutrients (Burns 1976b), phytoplankton standing crop and species composition (Munawar and Munawar 1976), and zooplankton distribution (Watson 1976). Moreover, the texture of surficial sediments shows distinct inshore–offshore differences mainly in the East and Central Basins (Thomas et al. 1976).

The objective of this study was to examine inshore–offshore differences in sedimentation processes in the Eastern Basin of Lake Erie. A hypothesis was formulated that assumed different lake depths, i.e. different sinking distances would influence the mineralization of plankton biomass and detritus. In addition, lake depth would affect settling fluxes caused by sediment resuspension resulting from water turbulence. Thus, the formation of bottom sediments is a dynamic process essentially governed by lake depth and wind-induced currents (Håkanson 1981). It is of crucial importance for whole lake metabolism in which way the sediments are affected by sedimentation, resuspension, transport and redeposition, release, and final burial of particulate carbon, nitrogen, and phosphorus. One possible method to quantify these processes is the combined analysis of settling particulate matter (sediment traps) and bottom deposits (cores) (Bloesch 1977).

Methods

From June 28 through October 10, 1978, cylindrical sediment traps (height 91.4 cm, diameter 6.6 cm, see fig. 8 in Bloesch and Burns 1980) were exposed at three stations (Fig. 1) and retrieved at biweekly intervals. Experiments conducted on trap efficiency proved the validity of these traps and the exposure time (see tables 2, 5–7 in Bloesch and Burns 1980). No resuspension of settled material within the traps was observed upon retrieval, thus the supernatant water was drained off and the sediment samples were taken from the last litre of each of the five replicate traps.

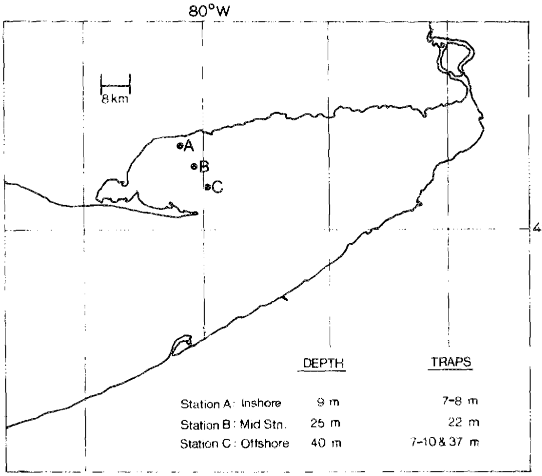


FIG. 1. Eastern Basin of Lake Erie. Sampling and trap mooring sites (A, B, C).

Dry weight was measured gravimetrically by centrifuging homogeneously mixed subsamples (400–800 mL) and drying at 50°C for a minimum of 48 h. Chemical analysis of particulate matter was carried out on material that had been dried on filters. Subsamples (10–100 mL) were filtered through Whatman GF/C glass fiber filters, preheated at 500°C, for particulate organic carbon (POC), particulate nitrogen (PN), and chlorophyll (chl *a*) analysis, and through Millipore HA 0.45-μm filters for particulate phosphorus (PP) analysis, respectively. POC and PN were analyzed with a Hewlett Packard 185 CHN analyzer after filter treatment with acidified water (0.3 mL H_2SO_4/100 mL H_2O) to remove inorganic C, and PP was analyzed colorimetrically with a Technicon AA II autoanalyzer (ammonium molybdate, $SnCl_2$, 660 nm) after digesting the filters in 50 mL acidified water (1 mL 30% H_2SO_4/100 mL H_2O). Chl *a* was measured and corrected for pheo-pigments according to Strickland and Parsons (1972). Biological subsamples were counted for phytoplankton with an inverted microscope (Utermöhl 1958), and ^{14}C-experiments (liquid scintillation technique, Vollenweider 1974) were used to measure primary productivity and relative activity of phytoplankton in the traps. One hundred and fifteen-millilitre bottles were usually exposed for 5 h during trap exchange between 09:00 and 16:00 in the depth of 1 and 5 m for water samples, and in the depth of trap position for the trap samples. After retrieval, 25 mL were filtered through Sartorius cellulose nitrate filters (0.45 μm, No. 11306), acidified with 0.5 mL 0.5 N HCl, and dissolved with 10 mL PCS scintillator.

At the beginning of October, sediment cores were taken at all three stations with a gravity corer. The cores were sectioned into $\frac{1}{2}$-cm slices from 0 to 3 cm and into 1-cm slices from 3 to 5 cm (stations B and C), and into 1-cm slices from 0 to 5 cm (station A), respectively. After drying at 50°C, these subsamples were pulverized and analyzed for POC, PN, and PP with the same methods as the trap material.

In an accompanying program, the lake was investigated also in the inshore–offshore transect, and water temperature was measured in situ by EBT (electronic bathythermograph) profiles. Chemical water analysis included P, N, and C components: soluble reactive phosphorus (SRP) was measured colorimetrically at 660 nm in an autoanalyzer using ammonium molybdate and $SnCl_2$ as reagents. Total phosphorus was analyzed as for SRP after digestion with H_2SO_4 (1 mL 30% H_2SO_4/100 mL H_2O) and $K_2S_2O_8$ in an autoclave for 30 min at about 112°C. PP was calculated by subtracting total

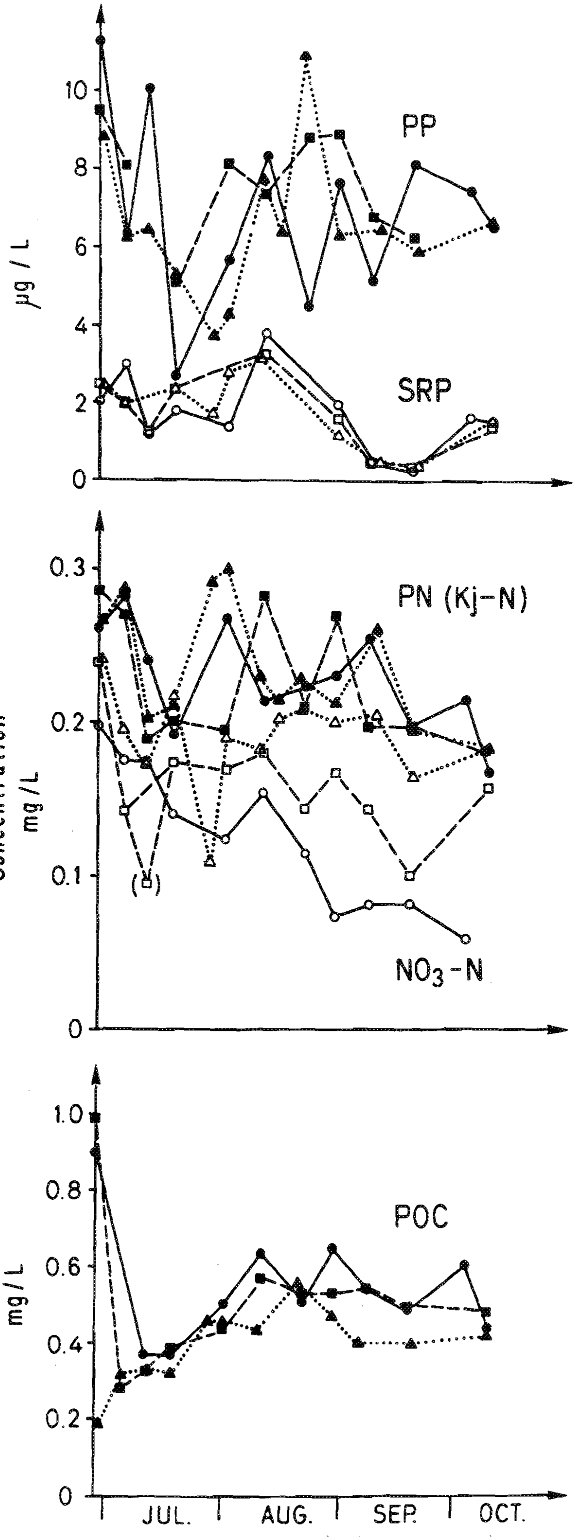


FIG. 2. P, N, and C inshore–offshore differences in the Eastern Basin of Lake Erie, June–October 1978. Mean concentrations in total water mass: ●, ○ inshore station A; ■, □ mid-station B; ▲, △ offshore station C.

P in the filtrate from total P in the unfiltered samples, while nitrate plus nitrite were measured colorimetrically at 550 nm in an autoanalyzer with cadmium reduction and sulfanylamide/naphtylendiamine as reagents. PN (total Kjeldahl nitrogen) was measured with the method of El-Kei (1976), and POC was analyzed with a Hewlett Packard 185 CHN analyzer in the same way as sediment samples.

Results

The results are presented in the sequence of (1) lake water, where particulate matter is produced and suspended; (2) sediment traps to follow the sinking process of particles; and (3) bottom sediments, where the settling particles are deposited.

1) The P, N, and C components in the water vary seasonally for each of the three sampling locations on the inshore–offshore transect (Fig. 2). A nutrient depletion caused by phytoplanktonic activity is evident for both SRP and NO_3, while the fluctuations of the particulates were rather irregular. The inshore–offshore difference in SRP was very slight whereas NO_3 showed a large change in concentration increasing from station A nearshore to station C offshore. Of the particulate variables, PP showed the greatest inshore–offshore difference while PN indicated only slight differences, and POC showed the least change horizontally.

Temperature profiles (isotherms in Fig. 3) indicate sharp differences in the horizontal transect. Offshore station C was stratified during the entire study period, whereas the nearshore station A was not found to be normally stratified during summer. At this station A the water column was sometimes isothermal from surface to bottom, but the isothermal conditions were periodically interrupted by inflowing cold-water masses from the deeper portions of the lake (arrows in Fig. 3). Though mid-station B also showed indications of these cold-water movements, this station was similar to the offshore station C in the stability of the thermal structure. The nearshore station was the first site with an entire circulation, when the water temperature started to decrease gradually in the early fall. By late September, fall turnover was all but complete at the mid-station B, while the offshore station was still stratified at the end of the study period on October 10.

The biological variables primary production, phytoplankton biomass, and chlorophyll *a* (Fig. 4 and 5) did not show great inshore–offshore differences. The phytoplankton developed peak biomass at offshore station C in September, but chl *a* concentrations were greatest at nearshore station A during the same period. Detailed phytoplankton results were obtained during this study by M. Munawar and D. B. Shindler (unpublished data).

2) During the summer months (June 28 through September 8) when the water was stratified, settling fluxes measured near bottom were similar at all three stations, averaging 6.1 $g \cdot m^{-2} \cdot d^{-1}$ for dry weight, 293 $mg \cdot m^{-2} \cdot d^{-1}$ for POC, 38 $mg \cdot m^{-2} \cdot d^{-1}$ for PN, and 5.44 $mg \cdot m^{-2} \cdot d^{-1}$ for PP (Table 1). When fall turnover was initiated in early September by decreasing temperatures and increasing storm activity, trap catches increased 6–13 times at the nearshore station (depth 9 m). This apparent change in sedimentation must have been the result of resuspension of bottom sediments. Because no stratification of the water column existed in this location, storm-induced turbulence reached the sediment–

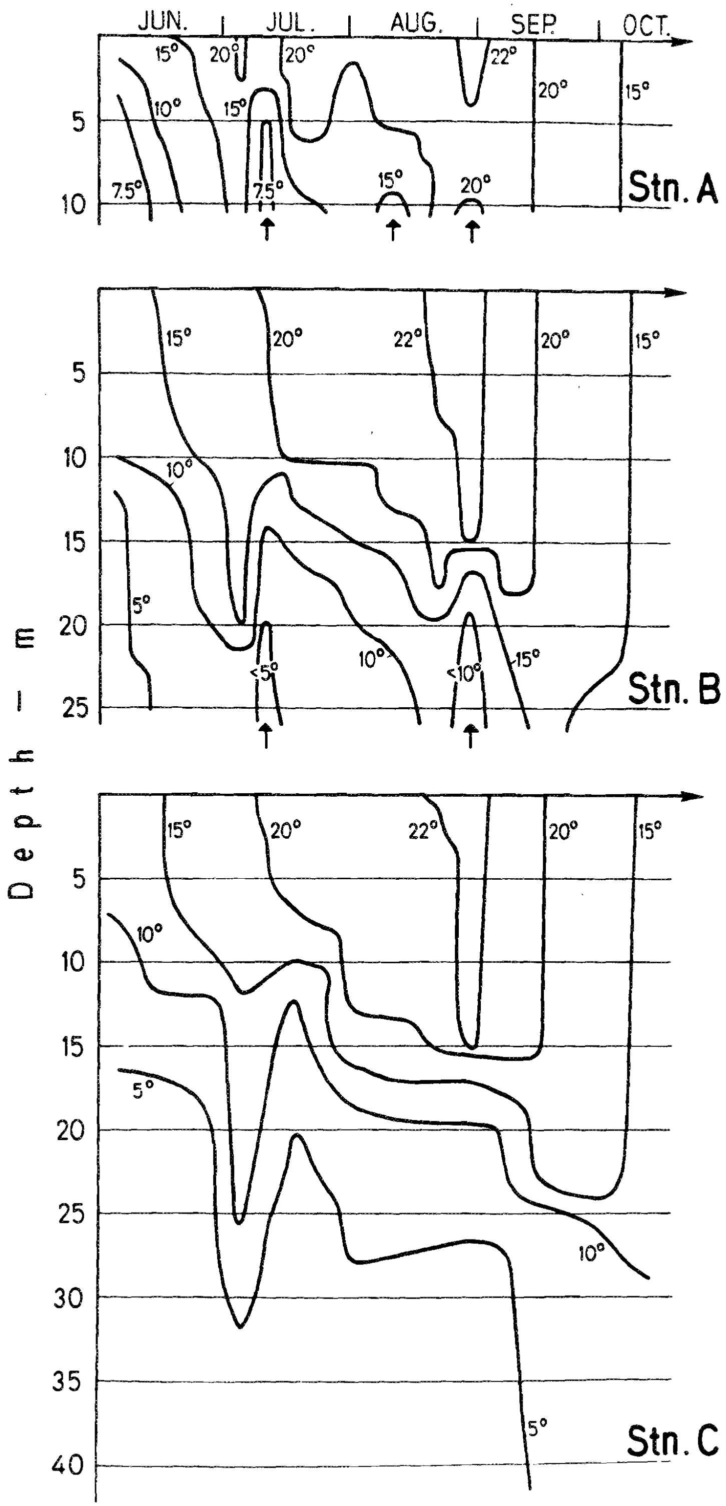
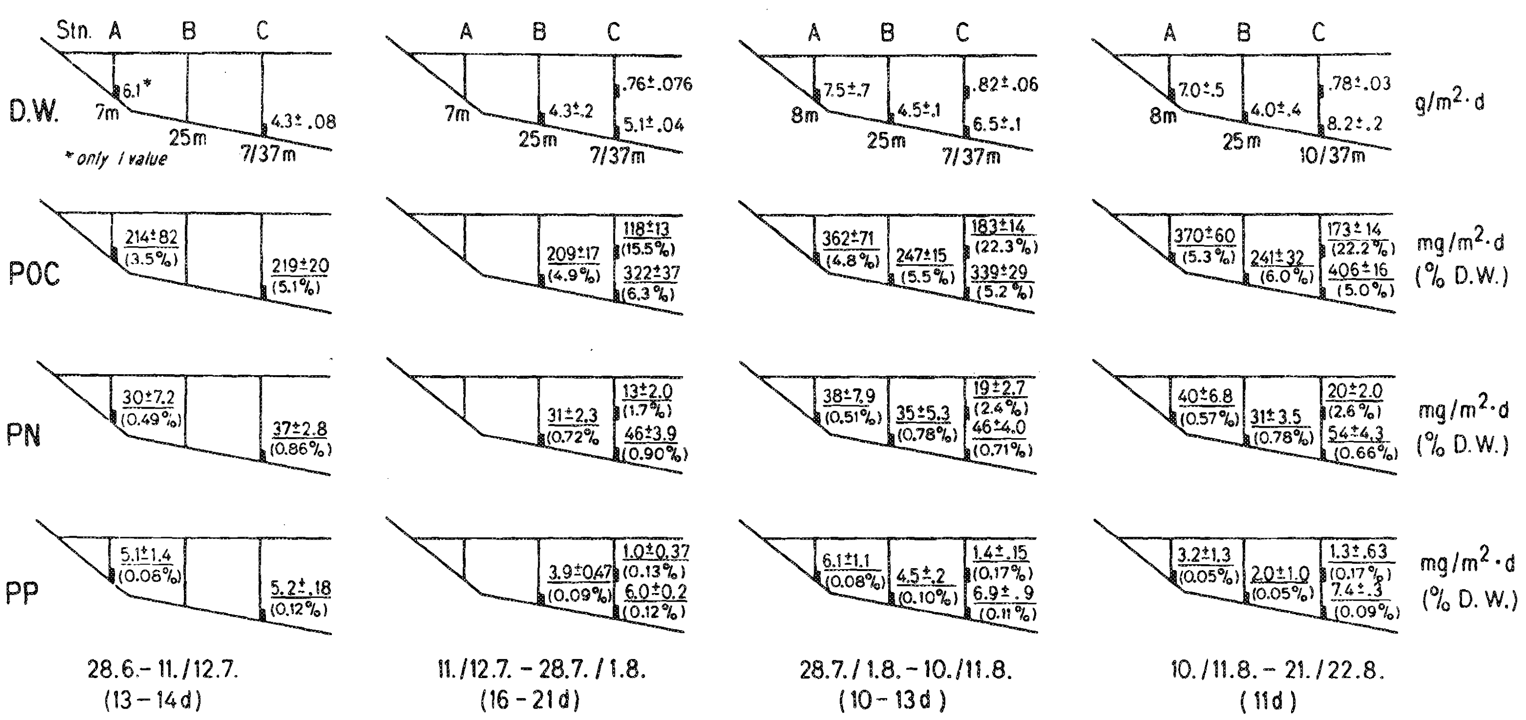


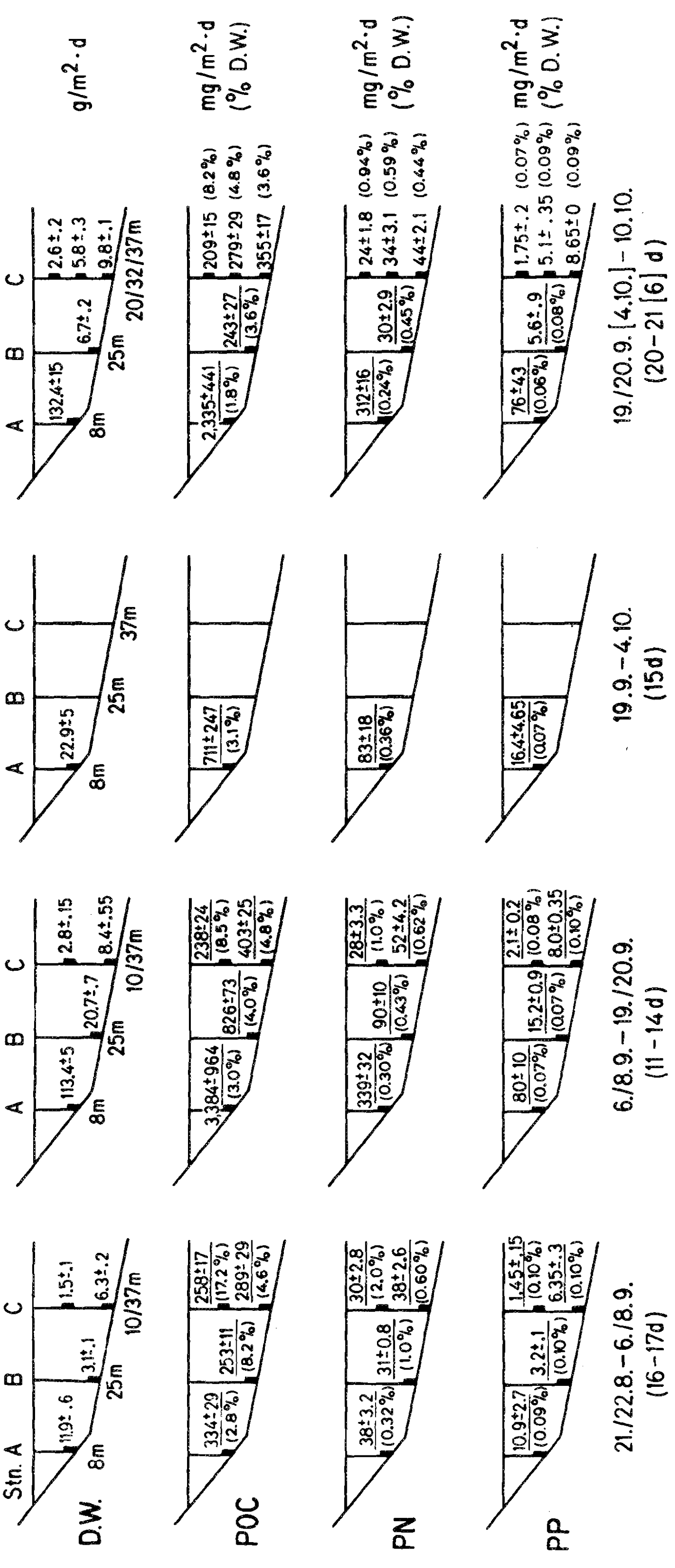
FIG. 3. Temperature inshore–offshore differences in the Eastern Basin of Lake Erie, June–October 1978. Isotherms (°C).

TABLE 1. Inshore–offshore differences in dry weight (D.W.), POC, PN, and PP sedimentation in the Eastern Basin of Lake Erie, June 28–Oct. 10, 1978. Mean values of five replicates, g and mg·m^{-2}·d^{-1}, values in parentheses as percent dry weight.



	Stn.	28.6.– 11./12.7. (13–14d)	11./12.7. – 28.7./1.8. (16–21d)	28.7./1.8. – 10./11.8. (10–13d)	10./11.8. – 21./22.8. (11d)	
D.W.	A	6.1*		7.5±.7	7.0±.5	g/m^2·d
	B		4.3±.2	4.5±.1	4.0±.4	
	C	4.3±.08	.76±.076 5.1±.04	.82±.06 6.5±.1	.78±.03 8.2±.2	
POC	A	214±82 (3.5%)		362±71 (4.8%)	370±60 (5.3%)	mg/m^2·d (% D.W.)
	B		209±17 (4.9%)	247±15 (5.5%)	241±32 (6.0%)	
	C	219±20 (5.1%)	118±13 (15.5%) 322±37 (6.3%)	183±14 (22.3%) 339±29 (5.2%)	173±14 (22.2%) 406±16 (5.0%)	
PN	A	30±7.2 (0.49%)		38±7.9 (0.51%)	40±6.8 (0.57%)	mg/m^2·d (% D.W.)
	B		31±2.3 (0.72%	35±5.3 (0.78%)	31±3.5 (0.78%)	
	C	37±2.8 (0.86%)	13±2.0 (1.7%) 46±3.9 (0.90%)	19±2.7 (2.4%) 46±4.0 (0.71%)	20±2.0 (2.6%) 54±4.3 (0.66%)	
PP	A	5.1±1.4 (0.06%)		6.1±1.1 (0.08%)	3.2±1.3 (0.05%)	mg/m^2·d (% D.W.)
	B		3.9±047 (0.09%)	4.5±.2 (0.10%)	2.0±1.0 (0.05%)	
	C	5.2±.18 (0.12%)	1.0±0.37 (0.13%) 6.0±0.2 (0.12%)	1.4±.15 (0.17%) 6.9±.9 (0.11%)	1.3±.63 (0.17%) 7.4±.3 (0.09%)	

* only 1 value


Stn. A
B
C
D.W.
POC
PN
PP
8m
25m
10/37m
11.9±.6
3.1±.1
1.5±.1
6.3±.2
334±29 (2.8%)
253±11 (8.2%)
258±17 (17.2%)
289±29 (4.6%)
38±3.2 (0.32%)
31±0.8 (1.0%)
30±2.8 (2.0%)
38±2.6 (0.60%)
10.9±2.7 (0.09%)
3.2±.1 (0.10%)
1.45±.15 (0.10%)
6.35±.3 (0.10%)
21/22.8.–6/8.9.
(16–17d)
113.4±5
20.7±.7
2.8±.15
8.4±.55
3,384±964 (3.0%)
826±73 (4.0%)
238±24 (8.5%)
403±25 (4.8%)
339±32 (0.30%)
90±10 (0.43%)
28±3.3 (1.0%)
52±4.2 (0.62%)
80±10 (0.07%)
15.2±0.9 (0.07%)
2.1±0.2 (0.08%)
8.0±0.35 (0.10%)
6/8.9.–19./20.9.
(11–14d)
22.9±5
37m
711±247 (3.1%)
83±18 (0.36%)
16.4±4.65 (0.07%)
19.9.–4.10.
(15d)
132.4±15
6.7±.2
2.6±.2
5.8±.3
9.8±.1
20/32/37m
g/m²·d
2,335±441 (1.8%)
243±27 (3.6%)
209±15 (8.2%)
279±29 (4.8%)
355±17 (3.6%)
mg/m²·d
(% D.W.)
312±16 (0.24%)
30±2.9 (0.45%)
24±1.8 (0.94%)
34±3.1 (0.59%)
44±2.1 (0.44%)
mg/m²·d
(% D.W.)
76±43 (0.06%)
5.6±.9 (0.08%)
1.75±.2 (0.07%)
5.1±.35 (0.09%)
8.65±0 (0.09%)
mg/m²·d
(% D.W.)
19./20.9.[4.10.]–10.10.
(20–21[6] d)

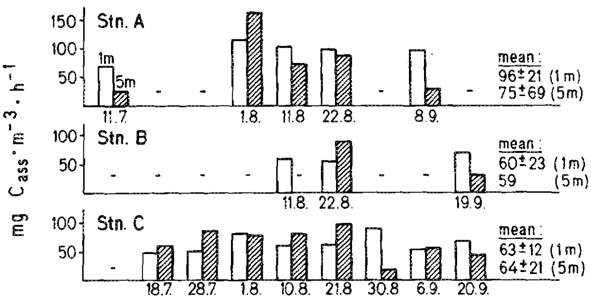


FIG. 4. Inshore–offshore differences in primary production in the Eastern Basin of Lake Erie, July–September 1978.

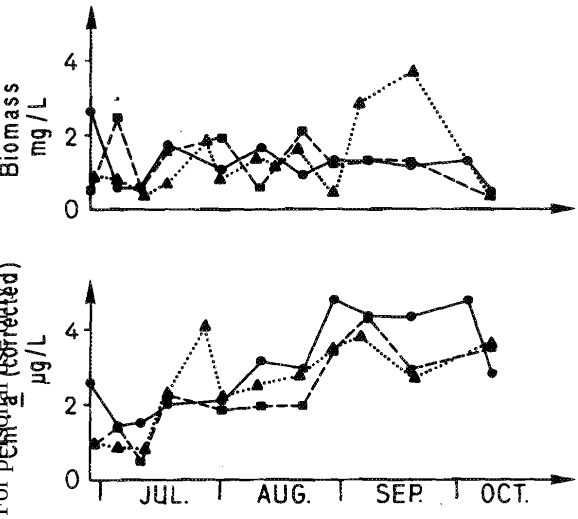


FIG. 5. Phytoplankton biomass and chlorophyll *a* (corrected) inshore–offshore differences in the Eastern Basin of Lake Erie, June–October 1978. Mean concentrations in the epilimnion: ●, inshore station A; ■, mid-station B; ▲, offshore station C.

water interface and subsequently mixed the sediments into the overlying water which then settled into the traps. During the same period, weaker mixing of the bottom sediments at the mid-station (depth 25 m) was evident by a flux increase of 1.5–2.5. The thin hypolimnion remaining at this station provided enough insulation from the storm-induced turbulence to shield sufficiently the sediment–water interface to prevent the mixing that occurs in the unstratified areas. At the offshore location (depth 40 m) where the hypolimnion was still over 10 m thick, sedimentation rates were only slightly greater than those measured during the summer months. The effect of resuspension was diminished during the second half of September at station A nearshore as a result of calm weather conditions, but again increased at the beginning of October when storms intensified.

At the offshore station settling fluxes were also measured in the epilimnion just above the thermocline (trap depth 7/10/20 m; the traps were lowered three times during the study period according to the downward movement of the metalimnion). The average sedimentation rates in summer were 1 $g \cdot m^{-2} \cdot d^{-1}$ for dry weight, 183 $mg \cdot m^{-2} \cdot d^{-1}$ for POC, 20.5 $mg \cdot m^{-2} \cdot d^{-1}$ for PN, and 1.3 $mg \cdot m^{-2} \cdot d^{-1}$ for PP. These rates were markedly smaller than those measured in the hypolimnetic traps during the same period. Epilimnetic settling fluxes for POC and PN were 1.2–3 times less, and the dry weight and PP were 4–20 times less than the fluxes measured in the hypolimnion. Resuspension of bottom sediments into the hypolimnion was considered responsible for these differences in sedimentation rates. However, the composition of the sedimentary material differed in the two both the hypo- and epi-limnion. For example, POC and PN (as percent dry weight) were less in the hypolimnion than in the epilimnion. The PP %, however, was almost the same. These differences mean that the resuspended sediment at station C consists of material with relatively low organic content.

The phytoplankton settling fluxes during summer (Table 2) averaged 586 mg biomass$\cdot m^{-2} \cdot d^{-1}$ in the epilimnetic traps at offshore station C and 243 mg biomass$\cdot m^{-2} \cdot d^{-1}$ in the hypolimnetic traps of all three stations. There was no distinct inshore–offshore variation. However, during the fall, resuspension was evident at nearshore station A where the fluxes were increased 3–5 times.

By means of autoradiography it is possible to estimate the portion of live and dead cells of the entrapped algal species. In our samples (M. Munawar and D. B. Shindler unpublished data) the flagellates were the most active phytoplankters; however, they were not abundant in the traps, as they are rapidly decomposed during settling as a result of their delicate cell walls. The dominant greens and diatoms were usually senescent or dead, especially in the deeper traps. The total phytoplankton community in the hypolimnetic traps of stations B and C was mostly inactive (Table 3), whereas the phytoplankton activity increased 5–10 times in the bottom trap of nearshore station A. The highest activity, however, was found in the epilimnetic trap at offshore station C. These findings suggest that most of the activity of algae is lost after a settling distance of about 25 m.

The settling fluxes of chlorophyll *a* in summer averaged 1240, 650, and 1160 $\mu g \cdot m^{-2} \cdot d^{-1}$ in the hypolimnetic traps at stations A, B, and C, respectively, and were relatively low in the epilimnetic traps at offshore station C when compared with the phytoplankton biomass (mean value for summer stratification 900 $\mu g \cdot m^{-2} \cdot d^{-1}$, Table 4).

3) The composition of sediment which could be resuspended was obtained from cores taken at each of the three stations at the beginning of October and analyzed for POC, PN, and PP content (Table 5). These components were distributed quite homogeneously in the upper 3–5 cm of the sediments. Significant inshore–offshore differences show an increasing concentration gradient from station A to station C. These differences can be explained by the similar distribution of the clay-size fraction in the sediment according to Thomas et al. (1976), who interpreted the inshore-to-offshore decrease in grain size to reflect decreasing energy with increasing water depth. This general statement is illustrated by the temperature profiles at the beginning of October 1978, when inshore and mid-lake stations were circulating to the lake bottom, and the offshore station was still stratified (Fig. 3).

TABLE 2. Inshore–offshore differences in phytoplankton biomass sedimentation in the Eastern Basin of Lake Erie, July 11–Oct. 10, 1978 ($mg \cdot m^{-2} \cdot d^{-1}$).

Date (1978)	Exposure time, d	Station A 7/8 m[a]	Station B 25 m	Station C 7/10/20 m[a]	Station C 37 m
July 11–12	13/14	91	—	—	272
July 18	6	—	—	—	194
July 28	16	—	—	652	224
Aug. 1	21/4	—	177	—	214
Aug. 10–11	10/13	253	195	765	590
Aug. 15	5	—	—	—	425
Aug. 21–22	11	287	144	252	159
Aug. 30	9	—	—	—	174
Sept. 6–8	17/16	347	191	676	196
Sept. 19–20	11/14	1288	340	164 ?	401
Oct. 4	15	166	—	—	—
Oct. 10	6/21/20	1348	142	202	233

[a] The traps were lowered three times during the study period according to the downward movement of the metalimnion.

TABLE 3. Relative activity of phytoplankton in the traps exposed in the inshore–offshore transect in the Eastern Basin of Lake Erie, August–September 1978. Primary production: $\mu g\ C_{ass} \cdot trap\ area^{-1} \cdot h^{-1}$ (mean of duplicates); trap area = 34.25 cm^2.

Date (1978)	Station A 8 m	Station B 25 m	Station C 7/10 m[a]	Station C 37 m
Aug. 10–11	284	20	2820	34
Aug. 21–22	413	46	707	47
Aug. 30	—	—	—	35
Sept. 6–8	168	—	393	17
Sept. 19–20	—	52	390	163
Mean	288	39	1078	59

[a] The traps were lowered three times during the study period according to the downward movement of the metalimnion.

Resuspension Model

Comparison of the core and trap results (Table 5 vs. Table 1) shows that PP concentrations of the bottom sediments are slightly higher than PP concentrations in trapped material at all three stations. In contrast, POC and PN contents were higher in the traps by a factor of 5–6 at the inshore station, by a factor of 4 at station B, and 0.5 times greater at the offshore station. These differences are the basis for the resuspension model presented.

The amount as well as the origin of the entrapped resuspended material can be estimated by the following calculations and statements illustrated in Fig. 6. Total resuspension fluxes R_D, R_C, R_N, R_P at offshore station C during summer stratification are calculated by equation (1):

$$(1)\quad R_D = T_D - E_D;\quad R_C = T_C - E_C;\quad \text{etc.},$$

assuming epilimnion traps represent the net downward flux near lake bottom, while the bottom traps represent the net downward flux plus resuspension. The results in Table 6 show a surprisingly high resuspension, contributing about 50% of the POC and PN and about 80% of the PP and dry weight material to the trap catches. Even if we would assume possible mineralization at a rate of 40% in the epilimnetic traps (Rathke et al. 1981), decreasing the calculated values, resus-

TABLE 4. Inshore–offshore differences in chlorophyll *a* (corrected) sedimentation in the Eastern Basin of Lake Erie, July 11–Oct. 10, 1978. ($\mu g \cdot m^{-2} \cdot d^{-1}$, mean values of five replicates.)

Date (1978)	Exposure time, d	Station A 7/8 m[a]	Station B 25 m	Station C 7/10/20 m[a]	Station C 37 m
July 11–12	13/14	321	—	—	907
July 18	6	—	—	—	1805
July 28	16	—	—	574	1682
Aug. 1	21/4	—	623	—	946
Aug. 10–11	10/13	871	536	635	1168
Aug. 21–22	11	1106	405	799	806
Aug. 30	9	—	—	—	833
Sept. 6–8	17/16	2658	1048	1584	1120
Sept. 19–20	11/14	6560	2326	1024	1896
Oct. 4	15	2446	—	—	—
Oct. 10	6/21/20	5105	644	1277	1729

[a] The traps were lowered three times during the study period according to the downward movement of the metalimnion.

TABLE 5. Inshore–offshore differences in bottom sediments of Eastern Lake Erie. Cores taken on Oct. 4, 1978, at the inshore and mid-stations, on Oct. 10, 1978, at the offshore station. Mean values from the upper 3 cm of the cores in % of dry weight.

	Station A inshore	Station B midshore	Station C offshore
POC	0.31	0.62	2.13
PN	0.04	0.10	0.32
PP	0.076	0.085	0.120

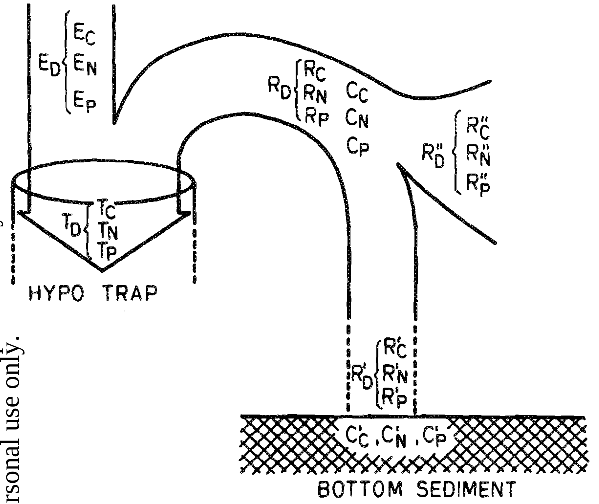


FIG. 6. Catch of a sediment trap exposed near lake bottom, general model used for calculations of resuspension.

E_D, E_C, E_N, E_P represents measured total dry weight, POC, PN, and PP flux in epi-traps;

T_D, T_C, T_N, T_P represents measured total dry weight, POC, PN, and PP flux in hypo-traps;

R_D, R_C, R_N, R_P represents measured total dry weight, POC, PN, and PP flux in hypo-traps due to resuspension;

$C_C = \frac{R_C}{R_D}$, $C_N = \frac{R_N}{R_D}$, $C_P = \frac{R_P}{R_D}$ represents concentration of POC, PN, and PP in dry weight material resuspended into the hypo-traps;

R'_D, R'_C, R'_N, R'_P represents total dry weight, POC, PN, and PP resuspension flux consisting of bottom sediments originating from the vicinity of the traps;

$C'_C = \frac{R'_C}{R'_D}$, $C'_N = \frac{R'_N}{R'_D}$, $C'_P = \frac{R'_P}{R'_D}$ represents measured concentration of POC, PN, and PP in dry weight material from bottom sediments in the vicinity of the traps;

R''_D, R''_C, R''_N, R''_P represents total dry weight, POC, PN, and PP resuspension flux consisting of material with other composition than the bottom sediments in the vicinity of the traps.

pension would still amount to 83% for dry weight, 10% for POC, 26% for PN, and 68% for PP, respectively. On the other hand, mineralization processes are also effective in the hypolimnetic traps (causing a loss of material in the order of 10% (Bloesch and Burns 1980)) and during sedimentation in the hypolimnion, thus increasing the minimum amount of resuspension presented in Table 6 to an unknown degree.

Fall resuspension for all three stations is calculated in the same manner, using the mean of the four summer values from the epilimnetic traps at station C as the general net downward flux over the inshore–offshore transect, and the trap catches of September 19 as representative of both downward flux and resuspension (Table 7). At offshore station C the calculation shows only a slight increase over the summer resuspension estimates, as would be expected because this station was still stratified. In contrast the two nearshore stations showed a considerably increased resuspension rate, particularly at station A.

TABLE 6. Resuspension (in % of bottom trap catch) during summer stratification. Offshore station C, Eastern Basin of Lake Erie 1978.

Date (1978)	Dry wt, %	POC, %	PN, %	PP, %
July 12–28	85	63	71	83
July 28–Aug. 10	87	46	59	80
Aug. 10–21	90	57	63	82
Aug. 21–Sept. 6	76	11	21	77
Mean	85	46	55	81
Mean, corrected	83	10	26	68

TABLE 7. Inshore–offshore differences in resuspension (in % of bottom trap catch) during fall. Eastern Basin of Lake Erie, Sept. 19, 1978.

	Dry wt, %	POC, %	PN, %	PP, %
Station A	99	95	94	98
Station B	95	78	77	92
Station C	88	55	61	84

TABLE 8. Total fall resuspension flux measured by the hypolimnetic traps, and composition of resuspended dry weight material.

Station	Component	Flux $mg \cdot m^{-2} \cdot d^{-1}$	Concn. % of dry wt
A	Dry wt	112 430	—
	POC	3 201	2.85
	PN	318.5	0.28
	PP	78.7	0.070
B	Dry wt	19 730	—
	POC	643	3.26
	PN	69.5	0.35
	PP	13.9	0.071
C	Dry wt	7 430	—
	POC	220	2.96
	PN	31.5	0.42
	PP	6.7	0.090

Resuspension in the fall cannot consist totally of material from bottom sediments originating in the vicinity of the station, because the POC, PN, and PP concentration of the trapped resuspended material (Table 8) is not the same as the measured concentration found in the cores (Table 5). The trap POC and PN contents are greater than found for the cores; this difference decreases from inshore to offshore. The trapped PP

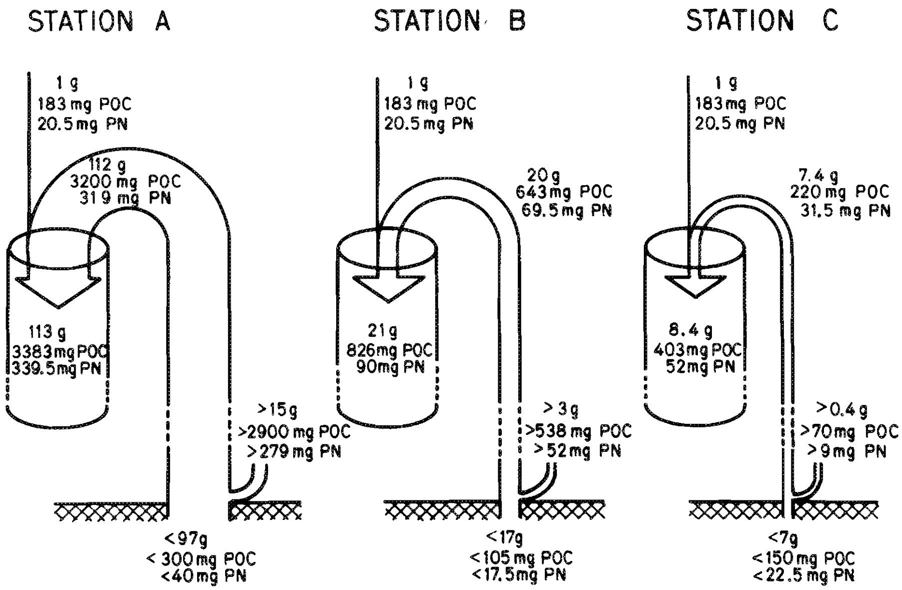


FIG. 7. Models of calculated dry weight, POC, and PN resuspension at the inshore and offshore stations in the Eastern Basin of Lake Erie, Sept. 19, 1978. Values in g or $mg \cdot m^{-2} \cdot d^{-1}$.

content is not significantly different from that found for the cores at all three stations. Consequently

$$R'_D < R_D,$$

$$R'_C = C'_C \cdot R'_D < C_C \cdot R_D = R_C,$$

$$R'_N = C'_N \cdot R'_D < C_N \cdot R_D = R_N,$$

$$\text{and } R'_P = C'_P \cdot R'_D \simeq C_P \cdot R_D = R_P.$$

The maximum dry weight flux from the bottom sediments in the vicinity of the traps, R'_D, can be calculated according to equation (2) by using the POC and PN concentrations of trap and core material (this calculation is not valid for PP because of the insignificant differences between R_P/R_D and R'_P/R'_D):

$$(2) \quad \frac{R_C}{R_D} = x \cdot \frac{R'_C}{R'_D} + (1-x) \cdot \frac{R''_C}{R''_D}$$

$$\text{and } \frac{R_N}{R_D} = x \cdot \frac{R'_N}{R'_D} + (1-x) \cdot \frac{R''_N}{R''_D}$$

where x = portion of dry weight resuspension flux from bottom sediments originating in the vicinity of the station, $1 - x$ = portion of dry weight resuspension flux consisting of material with other composition than the bottom sediments in the vicinity of the traps,

$$\text{and } \frac{R''_C}{R''_D} \leq \frac{E_C}{E_D}; \quad \frac{R''_N}{R''_D} \leq \frac{E_N}{E_D}$$

assuming that the material originating from other than bottom sediments has maximum possible POC and PN concentrations similar to that in the material caught in the epilimnetic traps. It is evident that the remaining minimum flux of resuspended material originating from other than the vicinity of the station, $R''_D = R_D - R'_D$, must contain more POC and PN than has been found in the sediments at all three stations, but certainly not more than has been found in the epilimnetic traps. Because a horizontal transport of resuspended POC- and PN-rich bottom sediments originating from offshore regions towards the shore seems unlikely, I assume that fresh material sinking down from the epilimnion is resuspended and redeposited repeatedly over an infinite time period. The existence of such a vertical cycle is supported because no distinct accumulation of POC and PN could be detected in the upper 5–10 mm of the cores.

The results of these model calculations, summarized in Fig. 7, show that at the offshore station C a large portion of dry weight resuspension is originating from bottom sediments in the vicinity of the station (R'_D), whereas only a small fraction represents fresh material originating from the epilimnion (R''_D). The ratios between the corresponding POC and PN fluxes (R'_C vs. R''_C and R'_N vs. R''_N) are distinctly smaller, because POC and PN concentrations are much higher in the freshly sedimenting material.

At the nearshore stations A and B these ratios are decreased significantly. Because R''_D is 38 times greater at station A than at station C, whereas this factor is only 14 when comparing R'_D, it is obvious that this vertical cycle is much more intensive at nearshore locations than in offshore regions. Consequently, the frequently resuspended organic material sinking down from the epilimnion is decomposed to a greater extent before its final burial at nearshore locations, because conditions for mineralization are more favorable in the water mass than in the sediments.

Phytoplankton is undoubtedly already decomposed to a great extent in the epilimnion, considering the favorable temperatures (>20°C) for mineralization and the relatively low sinking velocities of algae (<50 cm·d^{-1}, Rathke et al. 1981), enabling a mean epilimnetic (above 10 m) residence time of at least 20 d. The ratio of POC to algal C (taken as 10% of phytoplankton fresh weight (Nauwerck 1963)) indicates that 77% of POC is detrital C in the epilimnetic traps at offshore station C. However, the detrital fraction of POC amounted to 91–95% in the near-bottom traps of all three stations, and most of the trapped phytoplankton cells were senescent or dead (Table 3, and M. Munawar and D. B. Shindler unpublished data). In fall, the resuspended material at station A mainly consisted of detritus because the measured nearshore phytoplankton fluxes increased only 3 times, whereas POC increased 8 times.

Discussion

The phenomenon of bottom resuspension is well known to interfere with measurements of sedimentation rates and has been the subject of many attempts to apply a correction (Davis 1968, 1973; Edwards 1973; Charlton 1975; Gasith 1975; Lastein 1976; Johnson 1977; Serruya 1977). The application of an appropriate correction factor enables the interpretation of settling fluxes measured with traps which have been moored too close to the bottom of deeper lakes, when resuspension is recognized to have caused interferences. However, strong resuspension prevents the use of traps in very shallow and highly turbulent water bodies.

Lake Erie is shallow, having a mean depth of less than 25 m. The Eastern Basin is the deepest segment (max. depth 64 m) with an east–west wind fetch of about 400 km. Consequently the lake is very susceptible to wind-induced turbulence and bottom resuspension. The traps, despite being moored 3 m above the bottom, were still close enough to the bottom that the measurement of net downward settling fluxes were subject to interference by resuspension. A vertical set of traps in the hypolimnion would provide information about the thickness of the water layer that is affected by resuspension.

Neither particulate suspended material (Fig. 2) nor phytoplankton biomass and primary production (Fig. 4 and 5) showed distinct inshore–offshore differences during the study period from June through October 1978. The settling fluxes to the lake bottom measured with traps through the summer months are uniform at all three stations with only small variations. However, the nearshore station changed dramatically in the early fall. The greatly increased sedimentation rates near the lake bottom in the shore zone must result from current- or turbulence-induced resuspension of the sediments. Even in the lower energy zone of station C the differences between fluxes in the epilimnion and hypolimnion indicate a high amount of resuspension taking place during summer (Table 6). Because of the near level bottom of Lake Erie, sediment accumulation in the deeper water zones in and around station C caused by slumping of sediments does not seem to be the explanation for increase in hypolimnion rates, thus resuspension is considered to be the major factor. In Lake Erie sediment focusing is initiated by water currents that redistribute settled material.

The bottom sediments showed significant inshore–offshore differences in POC and PN concentrations (Table 5). These differences cannot be explained by different vertical sedimentation inputs of organic material. The intensive nearshore resuspension, induced mainly in fall by storms, intensifies decomposition of settling organic material and causes a sorting of grain size, with greater particles buried nearshore and finer particles kept suspended in the water and transported in the offshore direction where they can settle to the lake bottom because of a decrease in turbulence (Thomas et al. 1976). Both processes of enhanced mineralization and particle sorting, which are the result of wind-induced turbulence, lead to the low content of organic material in nearshore lake sediments and are responsible for the POC and PN concentration differences found between the cores (Table 5). This emphasizes the crucial importance of nearshore resuspension for overall metabolism of Lake Erie.

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