Relation between Nipigon Bay Benthic Macroinvertebrates and Selected Aspects of Their Habitat[1]

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In areas of Nipigon Bay unaffected by pulp and paper mill effluent, the benthic macroinvertebrate community was characterized by low standing stocks and high diversity. The coefficient of community and percentage similarity of community defined two major environments in Nipigon Bay, generally related to distance from the mill outfall. Near the pulp and paper mill outfall, further zonation of the benthic macroinvertebrate community was apparent. Inhibition and ultimate extinction of oligochaete populations appeared related to increasing levels of organic carbon and total sulphur, both associated with proximity to the outfall. Since a 10-yr period following abatement measures has not resulted in major responses by the macroinvertebrate community, recovery is expected to be slow.

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Dans les régions de la baie Nipigon qui ne sont pas affectées par l'effluent de moulins de pâte et de papier, la communauté de macroinvertébrés benthiques est caractérisée par une faible biomasse et une forte diversité. Le coefficient de communauté et la similitude de communauté en pourcentage servent à définir deux environnements majeurs dans la baie Nipigon, liés en général à la distance de l'émissaire du moulin. Près de l'émissaire du moulin de pâte et de papier, d'autres zones sont évidentes dans la communauté de macroinvertébrés benthiques. L'inhibition et finalement l'extinction des populations d'oligochètes semblent liées aux niveaux croissants de carbone organique et de soufre total, tous deux associés à la proximité de l'émissaire. Etant donné qu'une période de 10 ans s'est écoulée depuis l'application de mesures de suppression sans provoquer de réponses majeures de la part de la communauté de macroinvertébrés, on s'attend que le rétablissement sera lent.

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THE general level of production, or trophic status, may be expected to influence the distribution and abundance of many benthic macroinvertebrates (Johnson and Brinkhurst 1971). Furthermore, the very processes of production may couple with perturbative factors to directly alter the benthic environment. Consequently, I sought to determine the number and character of the benthic macroinvertebrate communities in Nipigon Bay and, where possible, relate these parameters to habitat conditions associated with the pulp and paper mill operating there.

Aspects of the Lake Superior benthic macroinvertebrate community have been presented by Henson (1966), Hiltunen (1969), and more recently Cook and Johnson (1974). Studies in Nipigon Bay itself have, however, been limited (Thomas 1966; Freitag et al. 1973). The attempts made to relate structure of benthic macroinvertebrate communities to the influence of the pulp and paper mill (German 1968; Beak 1970; Brouzes 1971) have differed widely in their interpretations as to the severity and extent of the mill effects. This study sought to further interpretive capabilities for the association of benthos to specific substrate characteristics described by Sandilands (1977).

[1]This paper is part of a series concerning the impact of pulp and paper mill wastewater discharges into Lake Superior. This study was carried out in 1974 and 1975 under the auspices of the International Joint Commission, Upper Great Lakes Reference Group.

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Methods

COLLECTION AND IDENTIFICATION OF MACROINVERTEBRATES

Sampling was carried out on a longitudinal and latitudinal grid at 30-s intervals. Eleven stations (Fig. 1), not confined to the grid system, were sam-

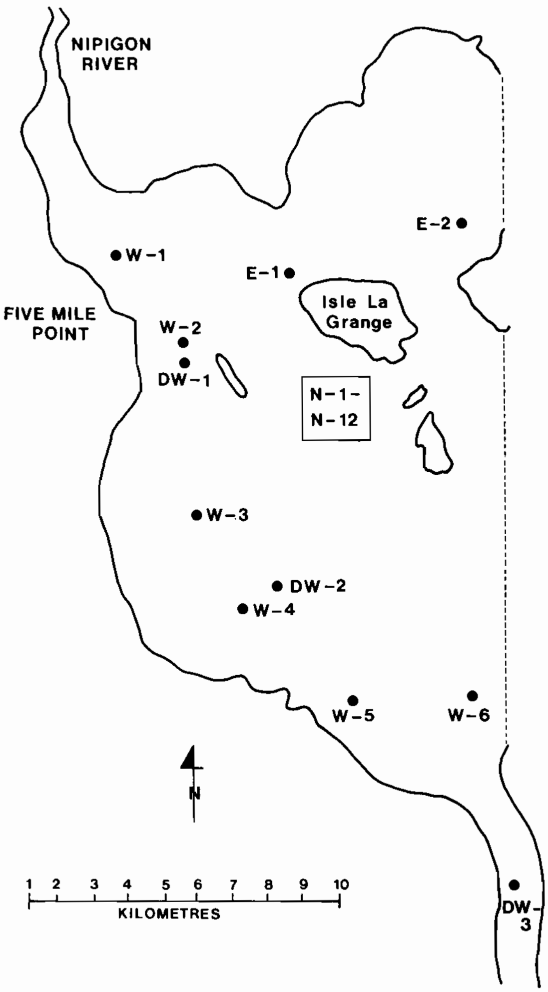

FIG. 1. Nipigon Bay macroinvertebrate study area.

pled 15 times with the exception of one which was sampled only 10 times. Replicate samples at 20 m were taken at eight stations in the eastern and southern channels and remaining stations were sampled at 50 m. A further 11 stations were established at varying depths between the effluent outfall and Five Mile Point. Stations were located by dead reckoning from marker buoys and prominent landmarks and by comparison of depths recorded by an echo sounder (Furuno F-200) to those on Canadian Hydrographic Chart 2312.

Each Ponar grab sample was 500 cm^2. Macroinvertebrates and coarse debris were separated from the finer substrate by an 8 mesh cm^{-1} boxed screen. Gross substrate characteristics were noted on collection. Later, coarse screened samples were concentrated further and preserved in ethanol.

General invertebrate taxonomy was according to Pennak (1953) while additional consultations from appropriate keys were employed when required.

Community Comparisons

Two measures were used to identify associations of macroinvertebrates, the "coefficient of community" (CC), and "percentage similarity of community" (PSc) (Whittaker and Fairbanks 1958; Johnson and Brinkhurst 1971). The coefficient of community measures the percentage of taxa shared by two samples as:

$$CC = \frac{c}{a + b - c} \cdot 100$$

where a is the number of taxa in the first sample, b is the number of taxa in the second, and c is the number of taxa common to both. The coefficient of community emphasizes likeness of samples on the basis of similar distributions of constituent taxa without regard to aspects involving relative abundance. Relative abundance is, however, included in the percentage similarity of community

$$PSc = 100 - 0.5\, \Sigma\, |a' - b'| = \Sigma \min\,(a', b')$$

in which a' and b' are, for each taxon, the respective percentages of total animals in samples A and B. Both indices have values between 0 and 100, representing the lowest and highest affinity, respectively, between two samples.

Each measurement has its advantages and limitations (Whittaker and Fairbanks 1958). The coefficient of community overvalues rarer species which the percentage similarity of community largely neglects. Used together, the two indices are useful not only in describing the nature of affinities between samples but also in distinguishing between environmental factors influencing macroinvertebrate distributions.

Both indices were computed for all comparisons among the 11 stations at which replicate samples were collected. The 15 samples from one station, W-3, were subdivided into 5 sets of 3 and the CC and PSc were computed, providing criteria for establishing levels of affinity. Station W-3 with the greatest diversity of taxa was selected since it would be expected to produce minimum values for CC and PSc in establishing limits for high affinity between samples. Values for CC ranged from 42 to 89 with a mean of 68 while PSc values ranged from 69 to 85 with a mean of 77. The minimum values, CC = 42 and PSc = 64, were considered the lowest limits which indicated high affinity. Values of one half of these, that is a CC of 21 and a PSc of 32, were arbitrarily taken as separating sets with low and intermediate affinity.

Surficial Sediment Characteristics

Sandilands (1977) revealed, through cluster analysis of a coefficient of correlation matrix, the existence of five zones or environments as follows:

1) Nipigon River mouth area, characterized by the highest values for calcium and inorganic carbon,

2) Eastern channel area, characterized by high values for a cluster of variables associated with clay minerals,

3) Mill outfall area distinguished by the highest

TABLE 1. Mean macroinvertebrate densities (500 cm^{-2}) from 11 areas of Nipigon Bay.

Station depth (*m*)	W-1 20	W-2 20	W-3 20	W-4 20	W-5 20	W-6 20	E-2 20	E-2 20	DW-1 50	DW-2 50	DW-3 50
Ephemera stimulans	—	—	0.20	—	0.07	—	0.07	0.07	—	0.07	—
Hexagenia limbata	0.07	—	0.20	0.27	0.13	0.07	0.13	—	—	—	—
Limnephilidae	—	—	—	—	—	—	—	—	—	0.07	—
Chironomidae	6.13	4.93	1.80	1.47	2.33	4.30	2.27	1.60	3.47	3.67	7.90
Palpomyia spp.	—	—	0.07	—	—	—	—	—	—	—	—
Asellus spp.	—	—	0.20	—	—	—	—	—	—	0.13	—
Pontoporeia affinis	0.40	—	6.93	10.0	29.00	33.87	20.33	50.13	—	0.07	8.40
Mysis relicta	—	—	—	—	—	—	—	—	0.07	0.47	—
Pisidium spp.	2.13	0.20	1.13	1.87	1.00	0.73	3.33	1.80	—	1.80	1.10
Sphaerium spp.	0.33	—	1.53	0.07	—	—	—	—	—	—	—
Unionidae	0.07	—	—	—	—	—	—	—	—	—	—
Valvata sincera	0.13	—	0.87	0.53	0.67	—	1.33	—	—	0.40	—
V. tricarinata	—	—	—	0.13	0.07	—	—	—	—	—	—
Oligochaeta	6.53	66.27	5.07	7.47	0.13	0.87	20.00	7.73	404.67	71.27	10.90
Acari	0.13	—	0.20	—	—	0.47	0.07	—	—	—	—

values for organic carbon, total sulphur, mercury and reduced pH, where organic carbon and total sulphur were strongly correlated ($r = .921$),

4) Northeast fringe area comprising a transitional zone between 1, 2, and 3 above,

5) South channel zone yielding high values for magnesium and phosphrus.

The three major sedimentary zones (east channel, south channel, and mill area) were utilized in comparisons with apparent zones delimited on the basis of macroinvertebrate distributions. All following reference to chemical characteristics of Nipigon Bay sediments is from Sandilands (1977).

Results

Macroinvertebrate Distribution

The relative densities and diversity of macroinvertebrates (Table 1) indicated that although most taxa were commonly widespread, organismic abundance was greatly influenced in certain areas associated with the mill outfall.

Analysis of the 11 sets of data from the replicate sampling (Fig. 2) yielded the following observations. High affinity for the CC was noted in 26 of the 55 comparisons. Little if any affinity was found in only 5 of the comparisons and all of these involved station DW-1 where only three taxa were collected. Twenty-two of the 29 comparisons indicating low or intermediate affinity

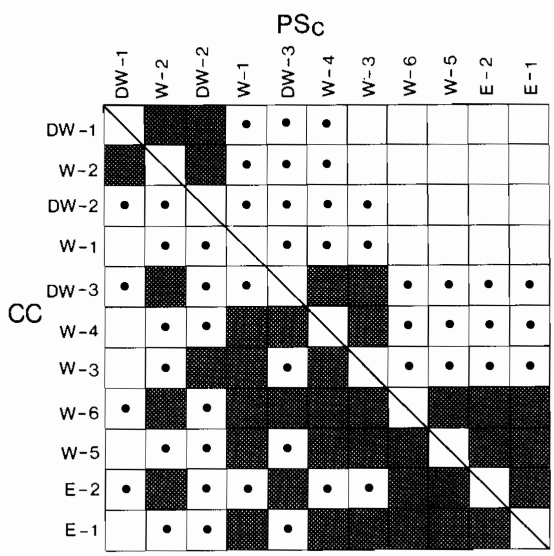

FIG. 2. Values of the coefficient of community (CC, lower triangle) and percentage similarity of community (PSc, upper triangle) for 11 stations, replicate sampled in Nipigon Bay. Solid squares indicate high affinity between macroinvertebrates of two stations; dots, intermediate affinity; open squares; little if any affinity.

TABLE 2. Macroinvertebrate densities (m^{-2}) and frequency (%) of occurrence from two areas associated with the mill outfall.

	Mill area A[a]		Mill area B-1[b]	
Macroinvertebrates	Density 500 cm^{-2}	Frequency (%)	Density 500 cm^2	Frequency (%)
Palpomyia spp.	—	—	0.40	6.7
Tendipedidae	0.28	14.2	6.70	87.0
Pisidium spp.	—	—	0.10	6.7
Amnicola spp.	0.14	14.3	0.20	6.7
Valvata sincera	—	—	0.10	6.7
Hyallela azteca	—	—	0.90	13.3
Oligochaeta	0.14	14.3	106.0	73.3

[a]pH, 5.5; % Organic C, 21.7; % Total S, 0.26.
[b]pH, 6.3; % Organic C, 4.6; % Total S, 0.06.

were associated with stations DW-1, W-2, and DW-2. With the exception of these three stations, relatively high affinity was widespread.

High affinity for PSc was found in only 12 of the comparisons while 25 comparisons indicated intermediate affinity. Three distinct associations were noted in the PSc analyses. Firstly, stations DW-1, W-2, and DW-2 vere very similar in composition, as the PSc in this group had values of 94, 95, and 96. A second group with high affinity involved stations DW-3, W-3, and W-4. The third and largest group of stations showing high similarity was composed of W-5, W-6, E-1, and E-2. The second distinct group was associated with the first and third in a manner indicating intermediate affinity while little if any affinity between the first and third groups was noted.

A comparison of the three macroinvertebrate associations, or groups, with the three major sediment zones indicated that since both the CC and PSc comparisons between eastern and southern channel stations showed a high degree of affinity, only two major environments are evidenced: that area associated with the mill outfall and that area not associated with the mill outfall.

Distribution of Sediments and Macroinvertebrates in the Mill Area

Although the mill area was described as a single major zone on the basis of sediment characteristics (Sandilands 1977), two distinctly different areas are present (R. G. Sandilands personal communication). The near-outfall area "A" was characterized by extremely high organic carbon, total sulphur, and mercury levels and consequently two stations in this area were omitted by Sandilands (1977) from the cluster analysis for statistical reasons. Analysis of the distribution of benthic fauna in the mill area

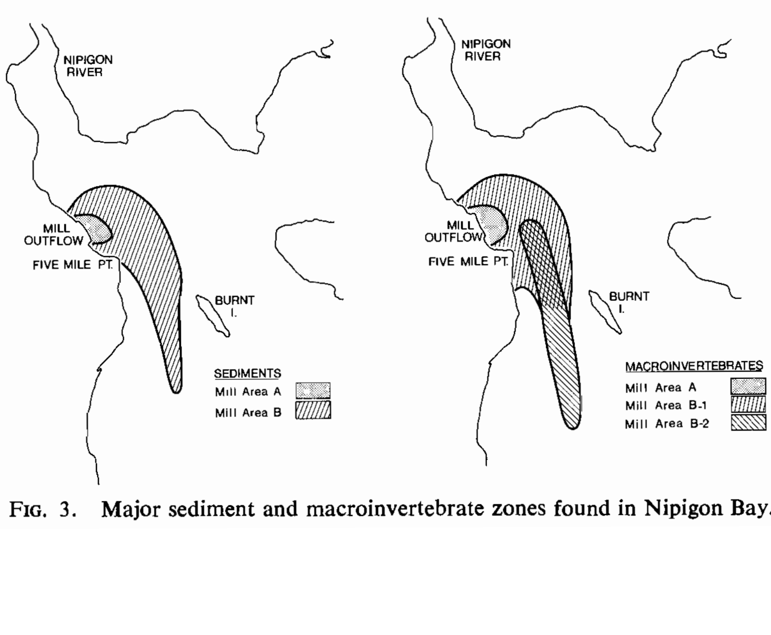

FIG. 3. Major sediment and macroinvertebrate zones found in Nipigon Bay.

indicated three distinctly different zones (Fig. 3). The first was coincident with the near outfall area "A" while the second, "B-1," and third, "B-2," were found in the intermediate outfall area, consequently subdividing the sediment zone "B."

Seven stations sampled in mill area "A" revealed the virtual absence of macroinvertebrates (Table 2), while 15 stations sampled in mill area "B-1" indicated an overall depression of taxon diversity with high oligochaete numbers in the deeper waters. The third macroinvertebrate zone, mill area "B-2," included stations W-2, DW-1, and DW-2 where the mean oligochaete density for 45 samples was 3600 m^{-2}.

Inhibition and ultimate extinction of oligochaete populations appears related to increasing levels of organic carbon and total sulphur (Fig. 4). Organic carbon levels of greater than 3.4% and total sulphur levels of greater than .049% were accompanied by a reduction of oligochaete numbers.

Spatial Distribution of Macroinvertebrates in the South Channel

The distribution of "tolerant" oligochaete and "intolerant" *Pontoporeia affinis* (Fig. 5 and 6) shows progressively greater stress towards the mill. Furthermore, sampling at the 20 and 50 m depths indicate that deeper water areas were subject to greater stress than shallow areas. Stations W-2 and DW-1 had both a low organismic diversity and high oligochaete numbers. The oligochaetes comprised a tubificid association in which *Tubifex tubifex* and *Limnodrilus hoffmeisteri* were well represented. The absence of *P. affinis* in the deeper waters further emphasized a vertical stress gradient in the southern channel.

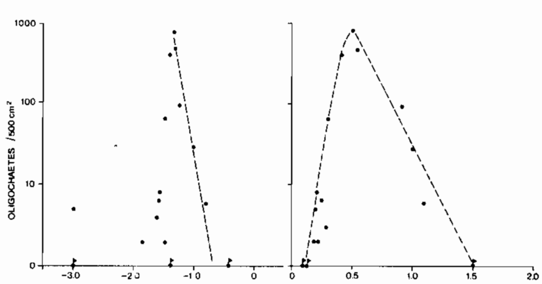

FIG. 4. The relationships between oligochaete numbers and organic carbon, and oligochaete numbers and total sulphur, derived from 16 stations at which benthic fauna sampling and sediment sampling were coincident. Flags denote 0 values.

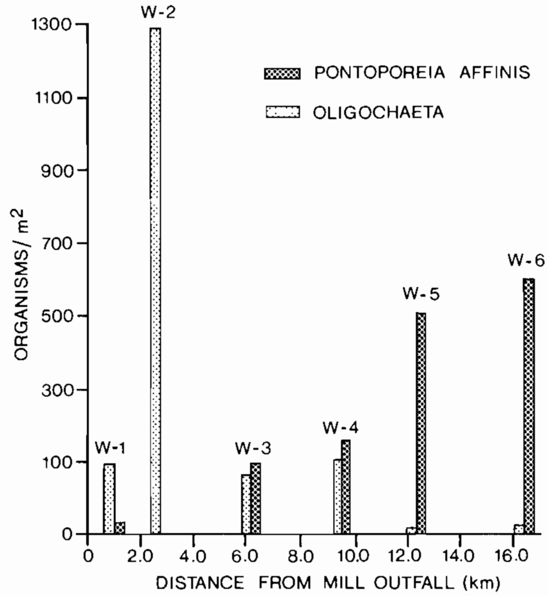

FIG. 5. Numbers of oligochaeta and *Pontoporeia affinis* in relation to distance from the mill outfall at 20.0 m.

Discussion

The relationship between total sulphur and oligochaete numbers is likely a fortuitous one unless substrate concentrations of sulphur are directly related to production of H_2S or other compounds known to be toxic (Van Horn et al. 1949; Smith and Oseid 1972) in the interstitial sediments and sediment–water interface. The significance of this relationship is that since increasing levels of organic carbon are not expected to cause conditions which will inhibit pollution tolerant oligochaetes, some factor or group of factors related to the deposition of organic materials originating from the mill must be present in toxic proportions.

An investigation of some toxic organic compounds in the Nipigon Bay sediments (Fox 1976) has indicated that dehydroabietic acid is distributed in a similar, though somewhat more extensive manner than organic carbon. Unfortunately, investigations of any toxic materials associated with organics in the sediments will not readily provide an explanation for reduced or eliminated tolerant macroinvertebrates without precise information about the relationship between such substrate contaminants and levels in the microhabitats associated with the sediment–water interface. In the absence of this information, organic carbon appears to provide an appropriate index of "stress" in the benthic environment.

The increase in numbers of *P. affinis* with in-

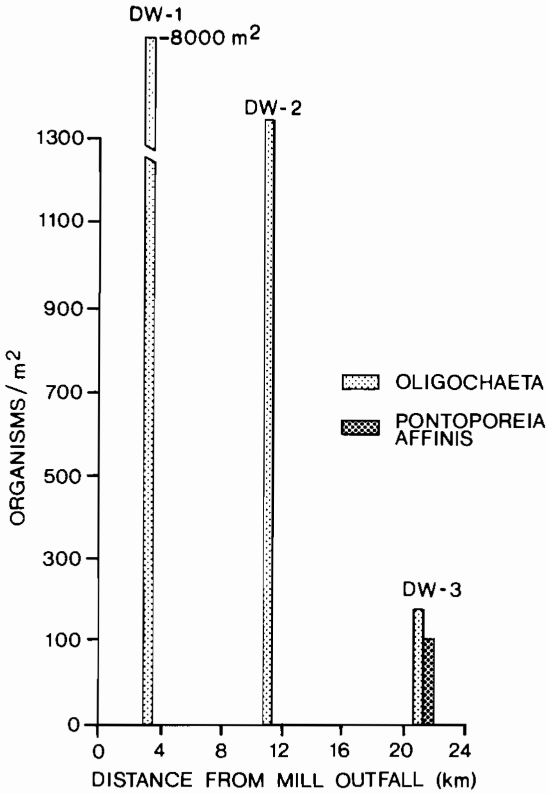

FIG. 6. Numbers of oligochaeta and *Pontoporeia affinis* in relation to distance from the mill outfall at 50.0 m.

creasing distance from the mill is probably at least partly due to the transitional nature of the area from a lotic to lentic environment. Although *P. affinis* has been found to be the dominant species in Lake Superior and associated bays (Adams and Kregear 1969; Hiltunen 1969; Freitag et al. 1973), its distribution in the Nipigon River and Helen Lake north of Nipigon Bay was limited (Ontario Ministry of the Environment, unpublished data). This transitional trend, however, does not acocunt for the total absence of *P. affinis* in the deeper waters of the southern channel from the mill to a point at least 10.5 km downstream.

Industrial pollution abatement measures usually take the form of on-site modifications to processes and treatment systems. Consequently, improvements in the benthic environment may not necessarily be expected in the short term since they depend on the natural ability of the receiving waters to flush and degrade accumulated contaminants.

Among the abatement measures effected at the Red Rock mill since 1969 was the provision for primary clarification of the effluent in 1972. Comparisons with macroinvertebrate data from earlier studies (German 1968; Beak 1970; Brouzes 1971) in fact indicate that there have been few if any significant alterations in the benthic community in the associated period. Clearly, since the earlier descriptions of pulp fiber deposits indicate that there has been little change up to the present, major alterations in macroinvertebrate communities are not expected for some time.

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