Temporal Changes of Sublittoral Macrofauna in L'Etang Inlet Caused by Sulfite Pulp Mill Pollution

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TEMPORAL CHANGES OF SUBLITTORAL MACROFAUNA IN L'ETANG INLET CAUSED BY SULFITE PULP MILL POLLUTION

by

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This is the one hundred and fifth Technical Report from the
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ABSTRACT

Wildish, D. J., N. J. Poole, and D. D. Kristmanson. 1977. Temporal changes of sublittoral macrofauna in L'Etang Inlet caused by sulfite pulp mill pollution. Fish. Mar. Serv. Tech. Rep. 718: 13 p.

Local extinction of the eukaryotic macrofauna in L'Etang Inlet, New Brunswick, as a result of anoxia or hypoxia caused by the presence of pulp mill effluent is described. Temporal changes of species composition, including repopulation by opportunistic anoxia-tolerant species, are described. The ecological relevance of the changes is assessed by computing the standing crop and production potentially available to fish and invertebrate carnivores lost in the affected zone.

The precise stage during the development of anoxia causing local extinctions was not determined in this study. Circumstantial evidence implicates low dissolved oxygen, presence of hydrogen sulfide, and changes in microbial food affecting larvae or adults.

Keywords: sublittoral benthos, biomass, production, anoxic basins, marine pollution.

RESUME

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L'extinction locale de la macrofaune des eucaryotes dans l'inlet l'Etang, au Nouveau-Brunswick, par suite d'anoxie ou d'hypoxie causée par les effluents d'une fabrique de pâte est décrite, ainsi que les changements chronologiques de la composition des espèces, y compris la repopulation par des espèces opportunistes tolérantes. L'importance écologique des changements est évaluée par le calcul de la biomasse et de la production potentiellement disponible aux poissons et invertébrés carnivores disparus dans la zone touchée.

Le stade précis au cours du développement de l'anoxie, qui cause les extinctions locales n'a pas été déterminé. Des preuves indirectes accusent une faible teneur en oxygène dissous, la présence de sulfure d'hydrogène et des changements dans la nourriture microbienne ingérée par les larves ou les adultes.

INTRODUCTION

A mixed hardwood pulp mill situated between Lake Utopia and the L'Etang Inlet became operational early in 1971. The pulp mill produces approximately 250 tons/day of corrugated paper. The pulp is produced by a semi-chemical process, chipped particles of wood being treated with a sulfite solution (originally ammonia, but now sodium sulphite) at a high temperature. The treatment facilities, described in Wildish et al. (1972), have not been effective in removing either the high BOD_5 or suspended solid component of the effluent (Wildish et al. 1974). The poorly treated effluent is discharged into an open ditch which, in turn, empties into the most landward part of the marine dominated L'Etang Inlet.

The physiography and hydrography of the receiving water are described by Wildish et al. (1972) and Kristmanson et al. (1976). The anoxic condition of the upper part of the L'Etang and detailed microbiology of the whole system were examined by Poole et al. (1976, 1977).

The purpose of this report is to present work documenting the changes in sublittoral macrobenthos caused by this pulp mill effluent (PME) up to 1976.

METHODS

Sampling stations were as used previously (Wildish et al. 1972), with the following five stations selected for detailed investigation:

Number	Position	
15	45°08.3'N	66°46.3'W
10	45°08.2'N	66°46.3'W
7	45°06.7'N	66°46.5'W
11	45°06.0'N	66°47.7'W
4	45°04.8'N	66°48.0'W

MACROFAUNAL SAMPLING

All samples were taken with a 0.1 m^2 Smith-McIntyre grab with a 16-cm effective digging depth. Samples taken in 1970, 1971, and 1972 were sieved through a 3 mm^2 mesh screen and triplicate samples consolidated for analysis (Wildish et al. 1972, 1974). Samples taken in July 1975 were sieved through a 1 mm^2 mesh screen and the three replicates sorted individually. The 1975 samples were identified by the Identification Centre, Biological Station, St. Andrews, N.B., and types from this collection and the earlier collections are deposited there. In addition, untrained personnel also sorted groups of taxa without naming them (rapid sort method) followed by reconsolidation before submission to the Identification Centre where they were identified by trained personnel.

Numerically dominant species are defined as those occurring in two or more consolidated samples for 4 up to 12 monthly samplings in 1971. Ranking of numerically dominant species according to wet weight (inclusive of shell weight) gave a biomass dominance estimate for each station. Species which occurred once but at wet weights greater than 1 g were also included in this list.

The number of accumulated individuals (log N) plotted against the number of original species (arithmetic S) in successive replicates at the same station has been used to calculate species diversity. Fisher et al. (1943) give the slope of this relationship, α, and a means of determining its standard error (SE).

PHYSICAL AND CHEMICAL METHODS

Depth - Refers to the depth in meters at the time of low water sampling.

Volatile solids - The percentage loss in weight of a dried sample on combustion at 500°C for 1 hr.

Redox potential - The Eh value relative to the normal hydrogen electrode is given. Measurements were made with an Orion combined redox electrode and model 401 Orion meter.

Salinity - Was determined by titration of the halides with silver nitrate and conversion of chlorinity to salinity (S ‰) with the empirically derived Knudsen's formula.

Temperature - Accurate to 0.1°C and measured with a mercury bulb thermometer.

Dissolved oxygen - Measured by the azide modification of the Winkler method.

RESULTS

Raw data for 1970-71 and 1972 are given elsewhere (Appendices 4 and 5 in Wildish et al. (1974)). The 1975 data are presented in Appendix 1 of this report.

One aim of the 1975 sampling was to test the possibility of rapid identification of benthic macrofauna by untrained personnel as was suggested for freshwater macrofauna (Cairns and Dickson 1971). The results (Table 1 and Fig. 1) suggest that "rapid sorting" is not a feasible alternative and that a relatively expensive commitment of time (unpublished data) by trained personnel is required for this work. Based on α values and confidence intervals of 95%, significant differences were found between data obtained by trained and untrained personnel at stations 10, 11, 4, and 12. No systematic difference for α was found at these stations precluding the possibility of a correction to "rapid sort" data.

Table 1. Comparison of identified taxa (S) and numbers of individuals (arithmetic N) for 1975 found by trained and untrained personnel.

	Untrained			Trained		
Station	S	N	α ± SE	S	N	α ± SE
	1	282		1	236	
15	1	294		1	243	
	1	360	0.1±0.08-.12	1	268	0.1±0.08-.12
	4	95		8	91	
10	4	145		9	156	
	4	207	1.0±0.8-1.2	12	204	2.4±2.02-2.78
	9	22		6	20	
7	11	76		10	45	
	11	101	2.7±2.2-3.2	11	65	3.0±2.4-3.6
	13	271		16	104	
11	17	431		23	167	
	(sample	lost)	2.8±2.4-3.2	(sample	lost)	7.1±6.1-8.1
	18	153		25	468	
4	18	343		38	947	
	18	530	3.7±3.3-4.1	48	1349	10.1±9.4-10.8
	19	240		27	315	
12	26	446		42	844	
	30	629	6.5±5.9-7.1	50	1306	10.5±9.8-11.2

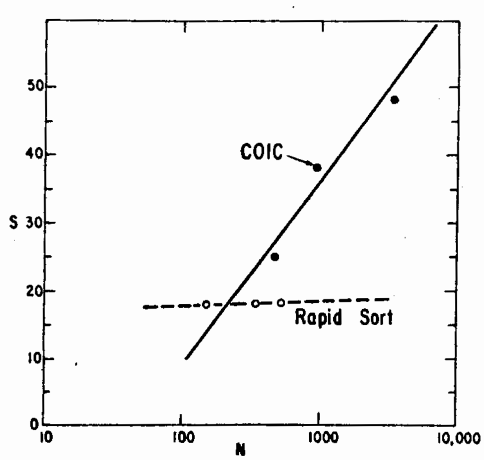

Fig. 1. Plot of S versus log N at station 4 using two identification methods.

TROPHIC GROUP ANALYSIS

Biomass dominants were tentatively classified into the trophic groups recognized by Pearson (1971) as shown in Table 2. It should be realized that assignment to each group is based largely on circumstantial evidence (mouth part structure, cursory observations in literature, or observations in experimental mud/water tanks in the laboratory).

The analysis clearly shows two major community types:

1. *Suspension feeding community*

The limits of this community are from the uppermost part of lower L'Etang to a point between stations 11 and 4, a distance of about 4 km. The community is characterized by 12 suspension feeders compared to 2 deposit swallowers which form only a minor part of the biomass. Characteristic species of this association are *Modiolus modiolus* and *Chiridota laevis*.

Table 2. Tentative classification of biomass dominants according to trophic groups recognized by Pearson (1971) for 1970-71 data.

Station (Replicates/ station)	Suspension feeders	Surface deposit feeders	Deposit swallowers	Algal scrapers	Predators
Upper L'Etang	———	———	Anoxic	———	———
Lower L'Etang 15 (21)	*Modiolus modiolus* *Amphitrite johnstoni*			*Nereis virens* *Littorina littorea* *Strongylocentrotus droebachiensis*	*Buccinum undatum* *Nephtys ciliata* *Nephtys* sp.
10 (24)	*Modiolus modiolus* *Unciola irrorata* *Musculus niger*	*Unciola irrorata*	*Pectinaria granulata*	*Littorina littorea* *Nereis virens* *Lunatia pallida* *Strongylocentrotus droebachiensis* *Ischnochiton albus*	*Buccinum undatum* *Nepthys ciliata* *Nepthys* sp. *Eteone heteropoda*
7 (12)	*Mya arenaria* *Chiridota laevis* *Macoma balthica* *Modiolus modiolus* *Astarte undata* *Musculus niger*	*Macoma balthica* *Nepthys incisa*		*Littorina littorea* *Nereis virens* *Edotea montosa* *Strongylocentrotus droebachiensis*	*Buccinum undatum* *Nephtys ciliata* *Nephtys incisa* *Nephtys* sp.
11 (36)	*Cyclocardia borealis* *Chiridota laevis* *Cucumaria frondosa* *Leptocheirus pinguis* *Mya arenaria* *Lyonsia hyalina*	*Leptocheirus pinguis* *Sternaspis scutata* *Nephtys incisa*	*Clymenella torquata* *Pectinaria granulata*	*Nereis virens* *Lunatia pallida* *Lunatia triseriata* *Edotea montosa*	*Nephtys ciliata* *Nephtys incisa* *Nephtys* sp. *Spio filicornis*
4 (36)	*Cyclocardia borealis* *Astarte undata* *Crenella glandula* *Artica islandica* *Periploma* sp. *Cerastoderma pinnulatum*	*Leptocheirus pinguis* *Phascolion strombi* *Sternaspis scutata* *Nephtys incisa*	*Lumbrinereis fragilis* *Yoldia sapotilla* *Nuculana tenuisulcata* *Yoldia myalis* *Praxillella praetermissa* *Praxillella gracilis*	*Littorina littorea* *Nereis virens* *Strongylocentrotus droebachiensis* *Lunatia triseriata*	*Nephtys incisa* *Nephtys ciliata* *Nephtys* sp. *Eteone* sp.
12 (36)	*Cyclocardia borealis* *Astarte undata* *Crenella glandula* *Spirorbis* sp. *Dendroda carnea* *Musculus discors* *Musculus niger* *Cerastoderma pinnulatum* *Artica islandica*	*Leptocheirus pinguis* *Phascolion strombi* *Nephtys incisa*	*Lumbrinereis fragilis* *Ninoe nigripes* *Amphipholis squamata*	*Acmaea testudinalis* *Ischnochiton albus* *Nereis virens* *Strongylocentrotus droebachiensis* *Lunatia triseriata* *Margarites costalis*	*Goniada maculata* *Nephtys ciliata* *Nephtys incisa* *Nephtys discors*

2. *Deposit feeding community*

This community extends from a point between stations 11 and 4 seaward to near the mouth of the lower L'Etang. It is a predominantly protobranch-maldanid community with a significant biomass of lumbrinereids (according to Gosner (1971) these are "generally carnivorous") and the deposit-feeding brittle star *Amphipholis squamata*. There are at least 9 deposit swallowing species and 9 suspension feeders in the community. Of the latter all are small, shallow-burrowing, lamellibranch molluscs.

CHANGES OF SPECIES COMPOSITION

Changes in species composition during the period 1971-75 were marked at the three most inland stations (Table 3). Little change had occurred by July 1972, but by this month in 1975 a surface deposit feeding and deposit swallowing community had developed at stations 15, 10, and 7, completely or partially replacing the previously reported suspension feeding association (Table 4). No marked community changes were found at station 11 and below by 1975. All the replacement surface deposit feeding and deposit swallowing species live in shallow burrows (see Pearson and Rosenberg 1976) and are tolerant of anoxic or hypoxic conditions.

The data suggest a gradient of anoxia tolerant species in 1975 with station 15 being the most affected in lower L'Etang. Thus, the only species at 15 is *Capitella capitata* (density = 861/m^2). At station 10, *C. capitata* (214/m^2), the oligochaete, *Peloscolex benedeni* (204/m^2), *Polydora ligni* (105/m^2), *Eteone longa* (86/m^2), and *Nereis diversicolor* (9/m^2) are anoxia tolerant colonizers. At station 7 the major anoxia tolerant colonizers are *Nereis diversicolor* (96/m^2), *Ampelisca abdita* (92/m^2), *Unciola irrorata* (36/m^2), and *Eteone longa* (20/m^2). The appearance of amphipods at station 7 and the disappearance of *U. irrorata* at 10 suggests a limiting factor appearing somewhere between these two stations.

There is some suggestion of an increase in amphipod numbers at all stations below 7 between 1972 and 1975, although the comparison is not conclusive because of the different mesh sizes used in 1972 (3 mm^2) and 1975 (1 mm^2). High densities of *Leptocheirus pinguis* and *Unciola irrorata* were recorded in 1975 at stations 4 and 12. At station 11, *L. pinguis* had previously been found only at low density, but in 1975 was present at a higher density (305/m^2); similarly with *Unciola irrorata* (175/m^2) which had previously been found at low densities.

Amphipods have previously been recorded as benefiting by enrichment (e.g. Barnard 1958; Waldichuk and Bousfield 1962). We have also discovered *Gammarus oceanicus*, associated with wood chips, just downstream from a combined pulp and paper mill in Saint John Harbour.

Table 3. Summary of species number (S), number of individuals (N), and α value of Fisher et al. (1943) for lower L'Etang.

Year	Mesh sieve mm^2	Station	Number of replicates	S	N	α
		15	21	20	207	5.5
		10	24	43	271	14.0
1970-71	3.0	7	12	19	189	5.2
		11	36	35	699	7.5
		4	36	53	840	12.5
		15	15	10	94	2.5
		10	12	19	86	7.0
1972	3.0	7	-	-	-	-
		11	15	31	309	8.0
		4	15	38	222	13.0
		15	3	1	268	0.1
		10	3	10	192	2.1
1975	1.0	7	3	10	85	2.8
		11	2	23	166	7.0
		4	3	48	1349	9.5

Table 4. Presence (p), absence (a) data for lower L'Etang in July 1971, 1972, and 1975. Sampling effort three 0.1-m^2 Smith-McIntyre grabs/station. Mesh size 1 mm^2 in 1975, 3 mm^2 in other years.

Station	Dominant species	1971	1972	1975
	Modiolus modiolus	p	p	a
	Amphitrite johnstoni	p	p	a
	Nereis virens	p	p	a
	Littorina littorea	p	a	a
15	*Strongylocentrotus droebachiensis*	p	a	a
	Buccinum undatum	p	p	a
	Gattyana cirrosa	p	a	a
	Nephtys ciliata	p	p	a
	Capitella capitata	a	a	p
	Modiolus modiolus	p	p	p
	Chiridota laevis	p	a	a
	Unciola irrorata	p	a	a
	Musculus niger	p	a	a
	Pectinaria granulata	p	p	a
	Littorina littorea	p	p	a
	Nereis virens	p	p	p
	Lunatia pallida	p	p	a
	Strongylocentrotus droebachiensis	p	a	a
10	*Ischnochiton*	p	a	a
	Buccinum undatum	p	p	a
	Lepidonotus squamatus	p	a	a
	Harmothoe imbricata	p	a	a
	Nephtys ciliata	p	p	a
	Eteone heteropoda	p	a	a
	Nephtys caeca	a	p	a
	Eteone longa	a	a	p
	Capitella capitata	a	a	p
	Polydora ligni	a	a	p
	Peloscolex benedeni	a	a	p
	Neries diversicolor	a	a	p
	Mya arenaria	p	-	a
	Chiridota laevis	p	-	a
	Macoma balthica	p	-	a
	Modiolus modiolus	p	-	a
	Astarte undata	p	-	a
	Musculus niger	p	-	a
	Nepthys incisa & ciliata	p	-	p
	Littorina littorea	p	-	a
7	*Nereis virens*	p	-	a
	Edotea montosa	p	-	p
	Strongylocentrotus droebachiensis	p	-	a
	Buccinum undatum	p	-	a
	Eteone longa	a	-	p
	Nereis diversicolor	a	-	p
	Polydora sp.	a	-	p
	Ampelisca abdita	a	-	p
	Coroplium volutator	a	-	p
	Unciola irrorata	a	-	p

CORRELATION BETWEEN PHYSICAL AND BIOLOGICAL DATA

Measurements of dissolved oxygen in bottom water (Table 5) show that at both high water (HW) and low water (LW) dissolved oxygen (DO) is reduced to less than 3.0 mg/ℓ at stations 15, 10, and 7. This area corresponds to the presence in 1975 of the anoxia tolerant association of macroinvertebrates.

The data of Table 5 also suggest a tidal cyclical change of oxygen demand. This may be partly explained by chemical oxidation of sulfides produced by sulfate-reducing bacteria. The limiting factor controlling this cycle may be due to changes in pressure associated with LW to HW cycles and its effect on release of H_2S from sediments.

The LW dissolved oxygen concentrations range up to 0.3 mg/ℓ in the station 15 to 7 zone. Difficulties in reading Winkler titration end-points were found at these concentrations because of the dark stain of pulp mill effluent in the water. Use of DO probes was precluded because of rapid poisoning of the probes in the reducing conditions of the water. The dissolved oxygen concentrations at HW showed a gradient of 0.4 mg/ℓ at station 15 to 6.6 mg/ℓ at station 11, which corresponds with the gradient of anoxic and hypoxic tolerant species mentioned previously.

Possible limiting physical conditions in the inland part of lower L'Etang for sublittoral benthic macrofauna are shown in Table 6 and Fig. 2. Among the anoxia-tolerant species, *C. capitata* was apparently more tolerant than other species included (0.4 mg/ℓ DO at HW). These species may require more DO at HW (≈1.5 mg/ℓ). Less resistant species which dissappeared by 1975 in the anoxic zone were shown previously (Table 4). The more resistant species of the original macrofauna include:

Modiolus modiolus	(1.5-0.3 mg/ℓ DO)
Nereis virens	" " "
Nepthys sp.	(4.0-0.2 mg/ℓ DO)
Edotea montosa	" " "

In addition, a number of amphipods *(Ampelisca abdita, Corophium,* and *Unciola)* have extended their distribution to station 7.

ESTIMATION OF LOSS OF STANDING CROP AND PRODUCTION DUE TO PME

A crude estimate of standing crop and production losses can be made provided the following assumptions are made:

1. That all production in the anoxic and hypoxic zone (to a limit between stations 7 and 11) is totally lost because of its unsuitability or avoidance of it by feeding fish or invertebrates.

Table 5. Physical characteristics of bottom water and sediment in lower L'Etang. HW sampled August 18, 1975; LW sampled July 19-21, 1976.

Parameter	Upper L'Etang	#15 HW	#15 LW	#10 HW	#10 LW	#7 HW	#7 LW	#11 HW	#11 LW
Water S‰	28.5	30.5	29.0	30.9	29.6	32.6	29.5	32.3	31.0
Temp. °C	22.0	14.6	20.0	14.8	21.7	13.8	21.0	12.8	15.3
D.O. ppm	0.0	0.4	?	1.5	0.3	4.0	0.2	6.6	3.0
Eh	-90	+120	+25	+320	+25	+460	+20	+300	+340
Sediment depth, m		1.0		1.5		1.0		5.0	
V.S. %	15.1	6.7	10.1	-	6.2	4.8	4.8	3.9	6.2
Eh	-160	-160	-73	-	+136	+40	+227	+40	+179

Table 6. Macrofaunal dominants and apparent limiting physical conditions.

Description	Bottom water D.O.	Bottom water Eh	Sediment Eh	Macrofauna dominants
Anoxic	0.0	<0	≤-160	Absent
Hypoxic	>0.1-4.0	>0	-160→+250	*C. capitata* *Peloscolex benedeni* *Polydora ligni* *Nereis diversicolor* *Eteone longa*
Oxic	>2.0	>0	0→	

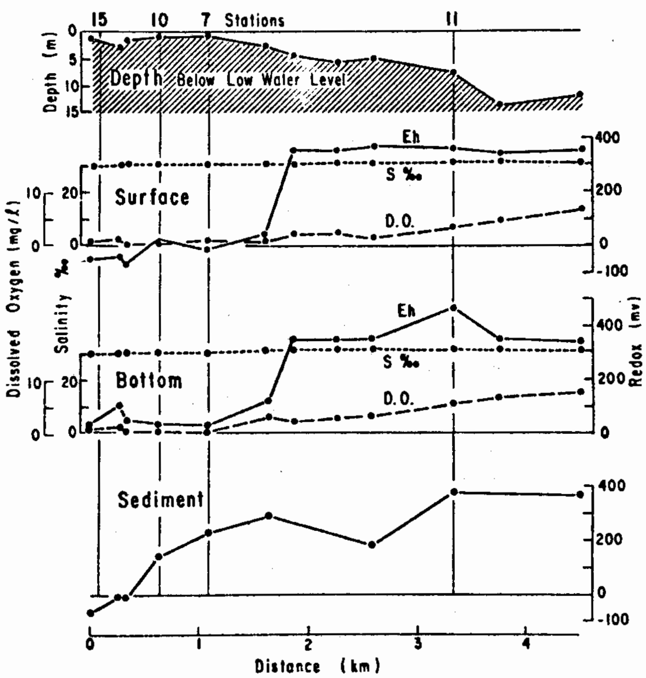

Fig. 2. Bottom profile and some physical and chemical parameters of lower L'Etang in July 1975.

2. That standing crop and production would have been the same in 1975 as in 1971 when the estimates were made.

3. The conversion of wet to dry weight is made by multiplying by 0.3.

4. The P/B ratios are
   0.5 $year^{-1}$ for the suspension feeding association
   2.0 $year^{-1}$ for the deposit feeding association.

The following calculations were made:

The littoral and sublittoral surface area of upper L'Etang = 1.33 km^2.

The littoral and sublittoral surface area of lower L'Etang to a line equidistant between stations 7 and 11 = 1.42 km^2.

Biomass, as wet weight of living tissue, per m^2 is shown in Table 7. Mean annual biomass and maximum/minimum for any month are also shown.

For stations 15, 10, and 7 the following further calculations were made:

B x bottom surface area (m^2) = total wet biomass standing crop with B for upper L'Etang assumed to be as at station 15; the lower L'Etang area divided equally between stations 15, 10, and 7.

A total of: 1.33×10^6 m x 316 ÷ 1000 = 4.20×10^5

Plus 1/2 (1.42×10^6 m)x 316 ÷ 1000 = 1.49×10^5

(1.42×10^6 m)x 191 ÷ 1000 = 0.90×10^5

(1.42×10^6 m)x 296 ÷ 1000 = 1.39×10^5

or 7.99×10^5 kg of wet weight standing crop biomass was the estimated loss due to PME pollution.

The annual production (P) as increase in dry weight, assuming 30% of wet is equivalent to dry weight, is:

$$B \times 0.5 = P(g^{-1}\ m^2\ yr^{-1})$$

or $$B \times 2.0 = P(\ \ "\ \ )$$

Computed values are shown in Table 7. For stations 15, 10, and 7:

1.33×10^6 m x 48 ÷ 1000 = 63.8×10^3

Table 7. Wet weight biomass (B) and production (P) estimates based on dry weights and assumed P/B ratios in 1970-71.

	B, $g^{-1}m^2$			Dry weight $g^{-1}m^2$			P, $g^{-1}m^2yr^{-1}$		
Station	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean
15	1532	19	316	460	6	95	230	3	48
10	485	38	191	146	11	57	73	6	29
7	586	79	296	176	24	89	88	12	45
11	391	1	141	117	0	42	59	0	21
4	267	16	112	80	5	34	160	10	68

N.B. Bivalve molluscs *(Modiolus, Mya)* dominant at 15, 10, and 7, not corrected for shell weight.

0.47×10^6 m $\times 48 \div 1000 = 22.6 \times 10^3$
" $\times 29 \div 1000 = 13.6 \times 10^3$
" $\times 45 \div 1000 = 21.2 \times 10^3$

A total of 121.2×10^3 g^{-1} m^2 yr^{-1} production was estimated to be lost in this area due to PME pollution. Some, or all, of the loss in production may have been compensated for by an increase in production seaward of the anoxic zone, notably by an increase in amphipod production.

DISCUSSION

The physical and biological changes associated with the development of anoxia are caused by the addition of excessive amounts of non-specific particulate or dissolved carbon sources. The extinction of local populations of macrobenthic fauna for this reason must be a commonplace event within the natural environment, and it is not surprising that a definite succession of anoxia-tolerant species has evolved to exploit such occurrences. "Opportunistic species" as defined by Grassle and Grassle (1976) are characterized by a short lifespan, high mortality, and long spawning period, and probably development of special mechanisms to tolerate low DO and high sulfide levels. Theede et al. (1969) consider this originates partly at the cellular level. Thus, metal containing enzymes are resistant to poisoning by sulfides in anoxia-tolerant species and energy cycles not requiring molecular oxygen can be used in conditions of hypoxia. Because of the often inverse relationship between sulfide and oxygen in sea water near the sediment/water interface, it is not surprising that field work has failed to identify the exact cause of local extinctions associated with hypoxia or anoxia. Theede et al. (1969) have demonstrated that sulfide only slightly increases lethality to hypoxia in some macrobenthic animals. Other possibilities are that the changes in microbenthos associated with anoxia influence macrobenthos by altering the food supply or that the egg or larval stages of macrobenthos may be extremely sensitive to anoxic conditions and settlement is hindered.

Determining the exact cause of local extinctions of macrofauna associated with the development of anoxia is considered to be an important research objective because it may enable choice of the best parameters with which to characterize damage in marine receiving waters. It has previously been shown that extensive macrobenthic sampling is not an efficient way of characterizing the effects of anoxia because of the community response lag time involved (this study) and the large amount of time required to process samples (unpublished data). One approach has been to measure physical factors such as DO, redox conditions, and H_2S as correlates of macrobenthic distribution. As shown here, the limits overlap and, moreover, are seasonal (Poole et al. 1977), or tidal in nature. Another approach which should be tried in conjunction with physical methods is to characterize the activities and types of microbenthic populations (e.g. proportion of aerobes:anaerobes, proportion of sulfate reducers, methane producers, etc.) in relation to macrobenthic distribution.

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Appendix 1. Species x individuals matrix for 3 replicated samples taken on August 20, 1975.

Number	Species	Samples 1	2	3
STATION 15				
363	*Capitella capitata*	236	7	25
STATION 10				
107	*Modiolus modiolus*	1		
262	*Eteone longa*	11	7	8
222	*Nereis diversicolor*			2
201	*Nereis virens*	1		
363	*Capitella capitata*	39	13	13
279	*Streblospio benedicti*	2		
364	*Polydora ligni*	16	16	4
	Polydora sp.			
390	*Peloscolex benedeni*	14	28	20
	Unknown oligochaetes	7		
401	*Edotea montosa*			1
STATION 7				
262	*Eteone longa*	2	3	1
	Nepthys sp.	1		
	Nepthys sp.		1	
222	*Nereis diversicolor*	5	14	10
	Polydora sp.	1		
401	*Edotea montosa*		4	
524	*Ampelisca abdita*	9	13	6
521	*Corophium volutator*			2
503	*Unciola irrorata*	2	8	1
504	*Gammarus oceanicus*		1	
508	*Leptocheirus pinguis*		1	
STATION 11				
017	*Lunatia triseriata*		2	
043	*Mitrella dissimilis*		1	
027	*Cylichna alba*	1		
111	*Astarte undata*	2		
114	*Venericardia borealis*		2	
115	*Thyasira gouldii*	3	10	
260	*Phyllodoce maculata*	2		
262	*Eteone longa*	1		
365	*Harmothoe oerstedi*	1		
269	*Goniada maculata*		1	
203	*Nepthys incisa*	2	4	
271	*Syllis cornuta*	2		
282	*Lumbrineris fragilis*	11	1	
298	*Tharyx acutus*	2	1	
346	*Terebellides stroemi*	1	1	

Appendix 1. (cont'd)

Number	Species	Samples 1	2	3
STATION 11 (cont'd)				
587	*Eudorella truncatula*	1		
584	*Diastylis sculpta*	1		
525	*Corophium bonelli*		6	
503	*Unciola irrorata*	18	17	
517	*Harpinia propinqua*	5	2	
508	*Leptocheirus pinguis*	51	10	
526	*Stenopleustes inermis*		1	
603	*Chiridota laevis*		4	
STATION 4				
012	*Margarites costalis*			1
045	*Margarites (olivaceus?)*	1		
042	*Alvania carinata*	1		
017	*Lunatia triseriata*	1		
043	*Mitrella dissimilis*	1		
023	*Neptunea decemcostata*		1	
027	*Cylichna alba*			1
131	*Yoldia myalis*			1
103	*Yoldia sapotilla*	1		
102	*Nuculana tenuisulcata*			
106	*Musculus niger*	1		
108	*Crenella glandula*	2	4	1
111	*Astarte undata*	6	4	7
114	*Venericardia borealis*	3	6	4
113	*Arctica islandica*			
115	*Thyasira gouldii*	1	1	
116	*Cerastoderma pinnulatum*	2	1	1
119	*Hiatella arctica*			
132	*Lyonsia arenosa*			
127	*Periplima papyratium*			1
286	*Phyllodoce mucosa*		7	
	Phyllodoce sp.	5		
207	*Harmothoe imbricata*	1	1	
	Nepthys sp.			2
	Nepthys sp.	1		
291	*Exogone verugera*		1	
271	*Syllis cornuta*		3	
274	*Praxillella praetermissa*		1	
357	*Sternaspis scutata*		1	
282	*Lumbrineris fragilis*	4	4	3
298	*Tharyx acutus*		1	
340	*Pectinaria granulata*		1	
346	*Terebellides stroemi*		2	4
353	*Brada villosa*	1	1	1
361	*Potamilla neglecta*		1	
362	*Spirorbis spirillum*			4
585	*Campylaspis rubicunda*	3		
584	*Diastylis sculpta*	5	4	2
581	*Diastylis quadrispinosa*	21	10	7
	Cyathura sp.		1	
527	*Corophium crassicorne*	4	5	
523	*Erichthonius rubricornis*		1	
503	*Unciola irrorata*	75	61	36

Appendix 1. (cont'd)

Number	Species	Samples 1	2	3
STATION 4 (cont'd)				
507	*Anonyx lilljeborgi*	2	7	2
511	*Orchomenella minuta*	22	43	11
508	*Leptocheirus pinguis*	300+	300+	300+
517	*Harpinia propinqua*	4	3	
440	*Aeginina longicornis*		3	6
680	*Amphipholis squamata*			1
801	*Phascolion strombi*			4
834	*Bostrichobranchus pilularis*			1
	Cricotopus sp. (Chironomidae)			1
STATION 12				
044	*Puncturella noachina*	1		
012	*Margarites costalis*			1
042	*Alvania carinata*	1		
019	*Velutina undata*		1	
043	*Mitrella dissimilis*	3		
046	*Colus pygmaea*			
028	*Dentalium entale*	2	2	
102	*Nuculana tenuisulcata*			2
134	*Nuculana minuta*	1		
108	*Crenella glandula*			
135	*Anomia aculeata*			
111	*Astarte undata*	4	3	1
112	*Astarte subaequilatera*	1		
114	*Venericardia borealis*	3	10	3
113	*Arctica islandica*		1	1
116	*Cerasoderma pinnulatum*	5	13	9
128	*Clinocardium ciliatum*			
119	*Hiatella arctica*		1	
120	*Lyonsia hyalina*		1	
136	*Nucula tenius*			1
	Phyllodoce sp.		2	
	Phyllodoce sp.			17
	Phyllodoce sp.	1		
207	*Harmothoe imbricata*	3		2
269	*Goniada maculata*	1		
204	*Nepthys ciliata*		4	
282	*Lumbrineris fragilis*	5	5	1
	Fam. Teribellidae			5
346	*Terebellides stroemi*			1
353	*Brada villosa*			1
366	*Diplocirrus hirsutus*			1
362	*Spirorbis spirillum*	6	12	1
570	*Achelia spinosa*		1	
571	*Phoxichilidium femoratum*		1	3
587	*Eudorella truncatula*		1	
585	*Campylaspis rubicunda*		1	
584	*Diastylis sculpta*	6	10	12
581	*Diastylis quadrispinosa*	13	16	25

Appendix 1. (cont'd)

Number	Species	Samples 1	2	3
STATION 12 (cont'd)				
401	*Edotea montosa*	2	2	3
527	*Corophium crassicorne*		16	
503	*Unciola irrorata*	19	45	39
506	*Maera danae*		1	
507	*Anonyx lilljeborgi*	1	1	
511	*Orchomenella minuta*	12	33	6
513	*Monoculodes edwardsi*	1		
508	*Leptocheirus pinguis*	200	300+	300+
517	*Harpinia propinqua*	1	1	4
516	*Syrrhoe crenulata*		1	
440	*Aeginina longicornis*	19	33	9
455	*Pagurus pubescens*	1		
680	*Amphipholis squamata*		1	2
801	*Phascolion strombi*	1	4	6
834	*Bostrichobranchus pilularis*		1	2