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Hydrographic and Sedimentary Conditions in the L'Etang Inlet during 1985

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ABSTRACT

Wildish, D. J., J. D. Martin, A. J. Wilson, and A. M. DeCoste. 1986. Hydrographic and sedimentary conditions in the L'Etang Inlet during 1985. Can. Tech. Rep. Fish. Aquat. Sci. 1473: iii + 14 p.

Hydrographic and sedimentary measurements were used to assess the spatial extent and development of anoxic/hypoxic conditions in the L'Etang resulting from pulp mill effluent discharge. A second aim was to assess the development of anoxic/hypoxic conditions in sediments and water near the recently developed salmonid cage culture sites at the seaward end of L'Etang Inlet.

There has been a slight decrease in production of corrugated paper by the pulp mill over the initial design capacity. However, dissolved oxygen conditions in the receiving water remained the same as in a 1975 survey. There was no evidence that the anoxic/hypoxic zone caused by the discharge of pulp mill effluent had moved seaward in the L'Etang Inlet.

At one salmonid culture site, which has been operating since 1980, the sediment in a localized area directly beneath the cages was anoxic as indicated by negative redox values and overgrowth by a white, microbial slime. Localized hypoxia/anoxia of this kind may result from sedimenting salmonid faeces or waste food and occurs only where the sedimentary regime is a net depositional one. Core data suggested that the depositional rate at the salmonid cage site was ~2 cm/year.

RÉSUMÉ

Wildish, D. J., J. D. Martin, A. J. Wilson, and A. M. DeCoste. 1986. Hydrographic and sedimentary conditions in the L'Etang Inlet during 1985. Can. Tech. Rep. Fish. Aquat. Sci. 1473: iii + 14 p.

On a analysé l'eau et les sédiments de l'inlet L'Etang pour évaluer l'évolution de l'anoxie et de l'hypoxie provoquées par le déversement des effluents d'une usine de pâtes et papiers et déterminer l'étendue de la zone touchée. On a aussi étudié l'évolution de l'anoxie et de l'hypoxie dans les sédiments et les eaux à proximité d'une station de salmoniculture en cages récemment installée à l'embouchure de l'inlet.

La production de carton ondulé a baissé légèrement en-deçà de la capacité de l'usine de pâtes et papiers. Cependant, la concentration d'oxygène dissous dans les eaux réceptrices est demeurée la même que celle mesurée lors d'un relevé, en 1975. Rien n'indiquait que la zone d'anoxie et d'hypoxie apparue à cause du déversement des effluents de l'usine s'est étendue vers l'entrée de l'inlet.

Dans une des installations de samoniculture, ouverte en 1980, on a constaté que dans un secteur localisé, situé juste sous les cages, les valeurs du potentiel redox étaient négatives et les sédiments étaient couverts d'une couche microbienne blanche, signes d'anoxie. L'apparition de zones d'hypoxie ou d'anoxie ainsi localisées peut être due au dépôt des excréments des poissons ou des restes d'aliments et ne se voit que dans les lieux où le régime de sédimentation net est favorable au dépôt des particules. L'analyse de carottes indique que le taux de sédimentation à l'emplacement des cages de salmoniculture est d'environ 2 cm/an.

INTRODUCTION

Prior to 1971 the L'Etang Inlet was basically a pristine body of inland marine water. Geographically, the Inlet is considered to have arisen during the last Ice Age when a moraine at the south end of Lake Utopia blocked the flow from the lake and forced the freshwater out via the present Magaguadavic River and the gorge at St. George. Because of the limited freshwater runoff into the L'Etang, it remains saline for much of its 14 km length. In 1967 a causeway was built to carry a highway (Route 1) across the L'Etang approximately 2 km from its most landward point. The causeway reduced tidal exchange so that the maximum tidal amplitude in the upper L'Etang was approximately 15 cm, although in the Lower L'Etang the mean tidal amplitude is 5.5 m with large spring tides ranging up to 7.8 m.

In April 1971 pulp mill effluent (PME) from a small 250 t/day neutral sulfite pulp mill, which produces corrugated lining paper, first began entering L'Etang. Hydrographic and benthic conditions within Lower L'Etang before the PME had markedly affected it were studied by Wildish et al. (1971). Subsequent studies (Wildish et al. 1974; Poole et al. 1976) showed that the hydrographic and benthic changes associated with PME had stabilized by 1972-1975. This included an area on the seaward side of the causeway which was anoxic at LW but which became hypoxic as seawater returned on the flooding tide. The clean-up alternatives for L'Etang were discussed following construction of a mathematical model of the Upper L'Etang (Wildish et al. 1979). In 1985 the pulp mill was producing slightly less than its design capacity of 250 t/day (a maximum of 200 t/day).

Sea-cage culture of Atlantic salmon began in the southwest Bay of Fundy in 1978 (Sutterlin et al. 1981) following the success of a pilot-scale study. By 1985 five salmonid sea-cage culture facilities were operating with an estimated annual production of 213 t worth $2.3 million, of which 54.5 t worth $0.6 million was from the L'Etang (E. B. Henderson, pers. comm.). During 1985 additional sites became operational and applications were received for further sites. The preferred sites were in the seaward part of L'Etang Inlet which has year-round temperatures above the lethal limit of -0.7°C (Saunders et al. 1975) and is in a wave-protected harbor. Salmonid culture operations involves high fish densities and feeding large quantities of pelleted food. The build-up of fish faeces and waste food beneath the cages can result in the development of anoxia in sediments and water (see Kadowaki et al. 1980).

The twin aims of this study were therefore to:

- determine the extent of anoxia/hypoxia in the upper part of Lower L'Etang caused by pulp-mill pollution, and

- determine whether anoxia/hypoxia beneath existing or planned culture facilites was already present and to obtain baseline data for planned facilities starting up in 1986,

using the same hydrographic and sediment measurements.

METHODS

Hydrographic and sediment core sampling was carried out during late summer 1985 from the NAIS using the hydrographic boom and winch. Photographic sediment profiling was accomplished from the J.L. HART on 20 September or from the fishing vessel S.L.S. on 25 September.

HYDROGRAPHY

Bottom seawater samples were taken with a closing water bottle (2.5 L capacity) from within 1 m of the sediment. A clean bucket was used to collect surface samples. Temperature was determined by inserting a mercury thermometer read to the nearest 0.1°C. Subsamples of seawater were taken as follows:

- 300 mL for determination of dissovled oxygen (D.O.) by the azide modification of the Winkler method (Strickland and Parsons 1968). Expressed as mgO_2/L or as percentage of saturation.

- 100 mL for determination of salinity by conductimetric determination on a Guildline Autosal apparatus. Expressed as S o/oo.

- 2-5 mL for determination of the UV absorbance at 250 nm (A250) with deionized water in the reference cell. Expressed as A250 x 10^3.

- 15 mL for determination of adenosine triphosphate (ATP) in the living microorganisms within the sample. The sample was filtered on a 0.45-μ Swinnex filter and the ATP extracted in boiling Tris buffer (5 mL). Analytical conditions were 100 μL sample or standard ATP and 100 μL of Dupont luciferin-luciferase (6 mL deionized water per vial). Analysis involved integration of the first 10 s of light flash. Results included correction for the actual volume of filtrate remaining after boiling and is expressed as ng ATP/L of seawater. An increase of 45% has been made to the data to account for salinity carry-over as in Wildish et al. (1977).

SEDIMENT SAMPLING

A 20 kg Kajak corer was deployed from the NAIS. The plexiglass sampling cylinder within the corer was 50 cm long with an internal diameter of 4.7 cm. The surface area sampled was therefore 17.36 cm^3. The corer was operated with orange peel retaining fingers in place to retain soft sediment and the plunger inactive after allowing the apparatus to free-fall into the mud. The sampling cylinders had been drilled with 7 mm diameter holes at 5 cm intervals in a helical pattern. Each hole was covered with a piece of electrical tape. Sampling was with a straight-bore, cut-off 1 cc syringe at a known depth below the sediment-water interface. The 1 cc sample was extruded into a petri dish and the sediment redox potential at this depth measured with a combined redox electrode (Orion 96-78) and Orion Ionanalyzer (Model 399A). The readings were taken after at least 1 min contact with the sediment, followed by careful cleaning with distilled water of the probe tip. The results are reported relative to the normal hydrogen electrode (Whitfield 1971) by adding 244 mV at 20°C to the mV reading on the Ionanalyzer.

The sediment profile camera (REMOTS) was deployed from the cherry picker winch aboard the J.L. HART or the boom winch aboard the S.L.S. The equipment was operated by G. Revelas of Science Applications International Corporation (SAIC) and involved repeated insertions of the sediment profiler if the resistance to penetration of the prism was markedly greater than the previous station. This allowed optimization of the depth sampled by the profiler. The redox profile discontinuity (RPD) depth in cm was determined and other operating and analytical details are given in Rhoads and Germano (1982). Two additional measures provided in the data supplied by SAIC are:

(1) Surface roughness, simply measured as the maximum distance, in cm, between the highest and lowest point of the sediment surface profile.

(2) The organism-sediment index (OSI) shown in Table 1. It is a composite of measures designed to indicate the degree of anoxic development.

Table 1. The REMOTS ® Organism-Sediment Index (OSI). For each station, the appropriate index value of the observation is summed with a possible range of -10 (most anoxic) to +11 (most aerobic).

	Observation	Index value
Mean RPD Depth (cm)	>0-0.75	1
	0.76-1.50	2
	1.51-2.25	3
	2.26-3.00	4
	3.01-3.75	5
	>3.75	6
Chemical Parameters	Methane present	-2
	No/low D.O.	-4
Successional Stage (primary succession)	Azoic	-4
	Stage 1	1
	Stage 1-2	2
	Stage 2	3
	Stage 2-3	4
	Stage 3	5
Successional Stage (secondary succession)	Stage 1 on a Stage 3	5
	Stage 2 on a Stage 3	5

REMOTS ® Organism-Sediment Index = total of all subset indices.

RESULTS

The hydrographic and sediment core stations worked during August 1985 are shown in Fig. 1. Stations were selected for two reasons as follows:

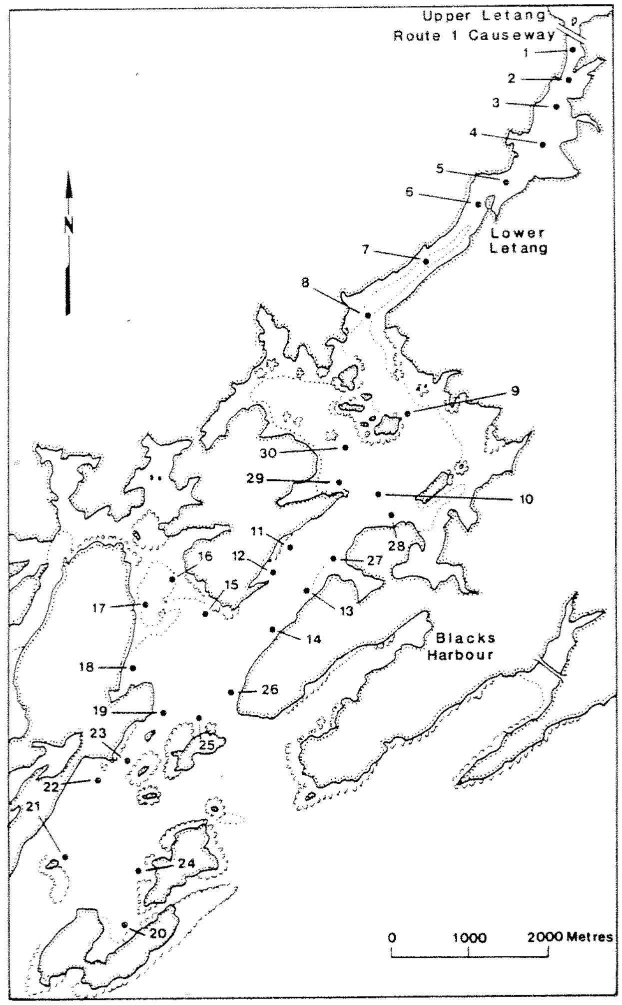

Fig. 1. Hydrographic and sediment core sampling locations worked in the L'Etang during August, 1985.

- a transect to cover the suspected area of the anoxic and hypoxic zones of the most landward part of the Lower L'Etang caused by the input of pulp mill effluents in the Upper L'Etang (Stations 1-10).

- to be near existing and proposed (11-29, Fig. 1) salmonid culture sites correct in 1985.

A description of each station, in which old station numbers refer to Wildish et al. (1971), is shown in Table 2.

Because of changes in the status of salmonid culture sites due to approvals, rejections or relocations, we include a list of approved and established sites (Table 3).

Table 2. List of stations in L'Etang Inlet sampled conventionally for sediment and seawater characteristics.

Station	Name	Comments
1	Near Route 1 causeway	Old Station 15
2	Pull- and Be-Damned narrows	
3	Near old Station 10	
4	Opposite Trainor's Cove	
5	North of Guthrie Point, near powerline	Near old Station 7
6	South of Guthrie Point	Near old Station 8
7	Old Station 11	
8	Indian Point	
9	NE of Park Island	
10	NE of Goss Point, near Haddock Ledge	
11	Granger Cove, Jail Island Salmon #2	L'Etang
12	Granger Point, Larry Ingalls	Harbour
13	L'Etang Harbour, D. Anthony (former site)	
14	L'Etang Harbour, Wayne Hooper (former site)	
15	West of Kings Point, Ian Hamilton	Lime Kiln Bay
16	Chris Saulnier	
17	Colin Borthwick	
18	Jail Island Salmon #1	Birch Cove
19	Wayne Hawkins	
20	Fishermans Cove, Garnet Matheson	
21	Man of War Is.	Bliss Harbour
22	Frye Island	
23	Fox Island	
24	Money Cove	
25	McCann Island	
26	L'Etang Head	
27	Greenlaw Cove, D. Anthony	L'Etang Harbour
28	Sturgeon Cove	
29	Hickey's Cove	Scotch Bay
30	South of Park Island	

Table 3. List of established and approved salmonid aquaculture sites provided by the Department of Forestry, Mines and Energy at St. George in April 1986. Locations shown in Appendix 8.

	Name	Area
1	Jail Island Salmon #2	L'Etang Harbour
2	Larry Ingalls	
3	Dana Anthony	
4	Ian Hamilton	Lime Kiln Bay
5	Chris Saulnier	
6	Colin Borthwick	
7	Jail Island Salmon #1	Birch Cove
8	Wayne Hooper	
9	Wayne Hawkins	
10	Richard Palland	Back Bay
11	Phillip Hooper	
12	Jeffrey Stewart	Bliss Harbour
13	Garnet Matheson	
14	Brendan Armstrong	Deadman's Harbour
15	Reid Hatt	Little L'Etang
16	Maurice McGee	
17	Weldon Mitchell	
18	Phillip Hooper	
19	Sea Farms	Bliss Harbour
20	Sea Farms	

HYDROGRAPHY

A highwater (HW) transect at Stations 1-10 (Fig. 1) was completed on 14 August (Appendix 1) when the HW at Saint John was predicted to be at 1107 AST (Anon. 1985). A low water (LW) transect at Stations 1-10 (Fig. 1) for 22 August is shown in Appendix 2 when predicted LW was 1116 (Anon. 1985).

Of interest is the steady decline in dissolved oxygen concentration along the transect for both HW and LW surveys in the landwards direction (Fig. 2). At Station 1 the bottom seawater at HW is devoid of oxygen (anoxic). Many of the other stations are hypoxic consistent with earlier findings of Poole et al. (1976).

An unreported study (Appendix 3) completed in 1977 shows that the hydrographic conditions relative to the tidal cycle near the Route 1 causeway are as shown in Fig. 3. At HW, seawater is flooding through the causeway culverts in the landwards direction. As the ebb progresses, the direction of flow reverses and anoxic, more dilute seawater from Upper L'Etang forms a surface layer. Near LW, the anoxic, dilute layer dominates but as seawater begins flooding back, it lifts the dilute, anoxic layer. The more saline oxygenated, deeper water here is subject to chemical oxygen demand and undergoes partial depletion of its oxygen content.

At Station 7 (Fig. 1), a 12 h tidal cycle observation of hydrographic parameters was made in 1985. The complete results are tabulated in Appendix 4. An obvious feature of this data is the relationship between absorbance and ATP (Fig. 4). When the absorbance is high, the ATP values also reach their maximum followed by a decline when absorbance falls. Correlated with the high absorbance is a drop in dissolved oxygen saturation values, suggesting aerobic microbial activity and or chemical oxidation because the saturation values

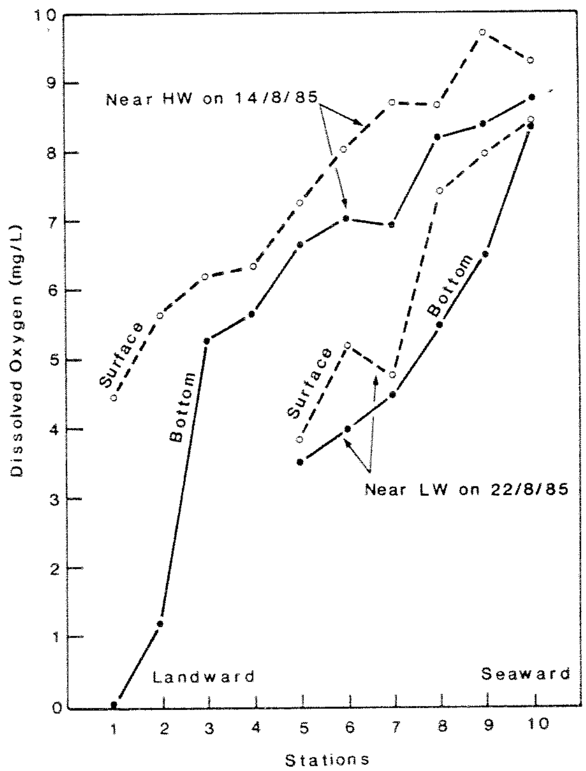

Fig. 2. Dissolved oxygen concentrations in L'Etang seawater on two sampling dates. Stations refer to those shown in Fig. 1.

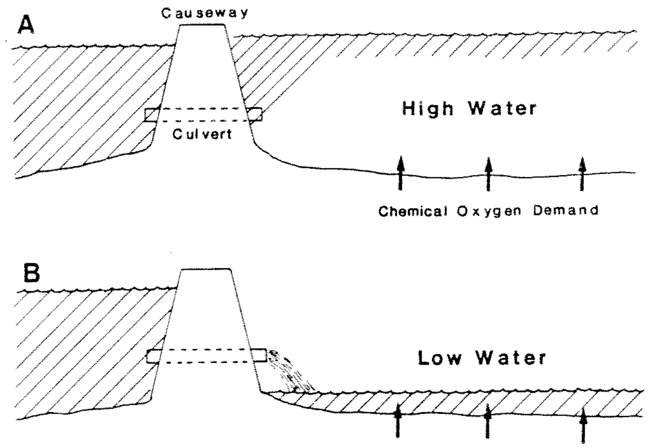

Fig. 3. Hydrographic conditions on either side of Route 1 causeway in upper and lower L'Etang. A. at high water, and B, at low water. Diagram based on data obtained in July-August 1977 (Appendix 3). Hatched is dilute, anoxic seawater.

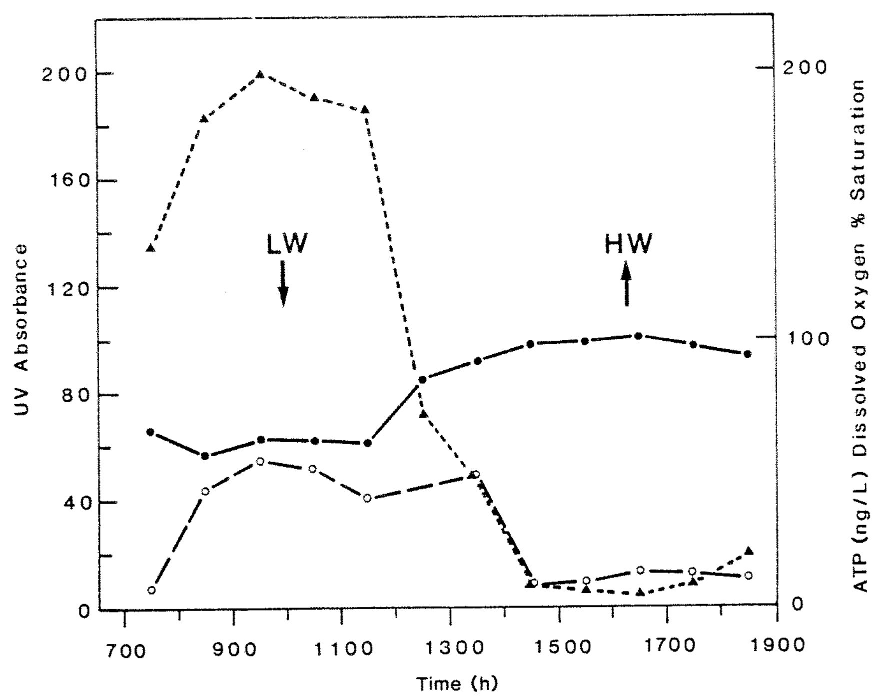

Fig. 4. Temporal change of ATP (▲), UV absorbance (○) and dissolved oxygen concentration (●) at station 7 (Fig. 1) on 21 August 1985.

increase after absorbance values decline and clean seawater returns at the bottom of the flooding tide. The situation is similar to that at Station 1, near the causeway, although the bottom seawater at LW is never completely devoid of oxygen.

Surface and bottom hydrographic data for the salmonid culture sites is shown in Appendix 5.

SEDIMENT CORING

Sediment cores were taken from Stations 11-30 (Fig. 1) and the results presented in Appendix 6. All of the values recorded are positive with the single exception of #18. This suggests that normal aerobic respiration is the dominant metabolic process occurring throughout L'Etang sediment. Lynch and Poole (1979) state that redox potential measurements are good indicators of the predominant form of microbial metabolism and electron acceptor used in this process. Hence:

Respiration type	Redox potential	Electron acceptor	Products
Aerobic:	>0	O_2	H_2O
Anaerobic:			
-denitrification	0 to -149	NO_3^-	NO_2^-, NH_4^+, NH_3, N_2
-sulfate reduction	-150 to -200	SO_4^{2-}	HS^-, H_2S
-methanogenesis	-250 to -300	CO_2	CH_4

Station #18 was sampled close to the salmonid cages and because the top 7.5 cm of the sediment profile was -146 to -156 mV relative to the normal hydrogen electrode, sulphate reducing bacteria were active. At a depth of 12.5 cm and greater in the profile, aerobic conditions were still present, indicating the recent origin of the surface anaerobic layer. If it is assumed that the anaerobic layer is ∿9 cm thick and because this culture site has been operating for 5 yr (since 1980), it is possible to calculate the rate of sedimentation, due to build-up of salmonid faecal matter, waste food plus natural sedimentation, as 2 cm per year. Scuba diving at this site showed the bottom to be covered with a white-reflecting microbial mat consistent with the presence of sulphate reducing bacteria.

SEDIMENT PROFILING

A total of 50 stations were sampled with the REMOTS camera system of which 44 stations (Fig. 5) were analyzed (Appendix 7).

In the L'Etang landwards of Indian Point (Fig. 5), there is a sharp gradient in redox discontinuity depths, with the most landward Station, #17, being anoxic to the sediment surface (Table 4). This is consistent with finding a complete lack of dissolved oxygen in bottom water at this station. Station #18 is similar and both have a negative organism-sediment index value showing that this area is environmentally disturbed by the development of anoxic conditions.

DISCUSSION

The 1985 survey data presented here shows no evidence that the anoxic/hypoxic zone below the causeway has moved significantly seaward, because bottom water near HW is anoxic/hypoxic at the two most landward stations (#1 & 2, Fig. 1) and the

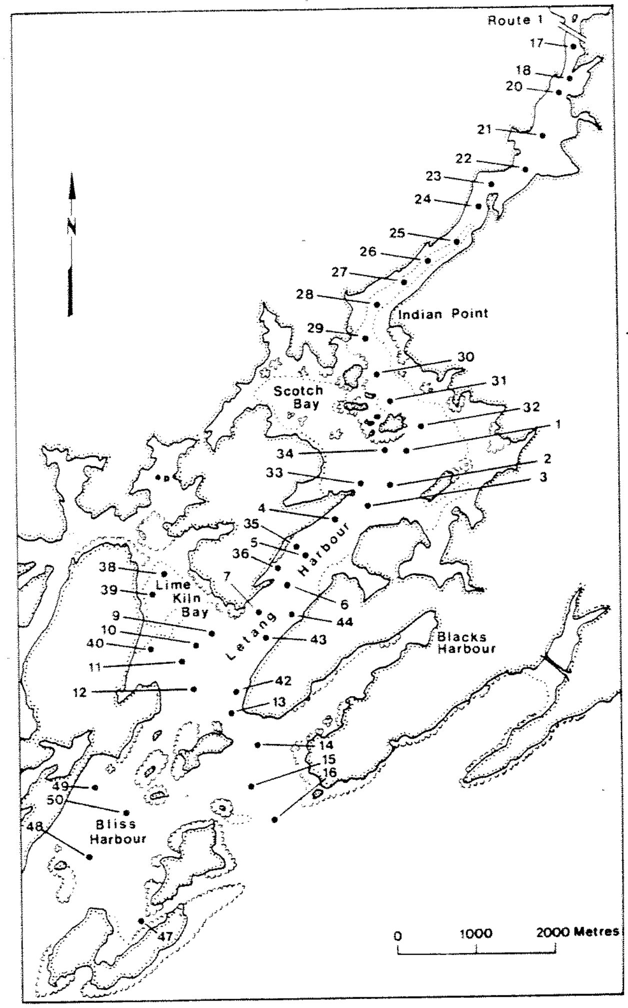

Fig. 5. Sediment profiling stations worked on 20 and 25 September 1985.

Table 4. Redox discontinuity depth (RPD) and the organism-sediment index calculated from sediment profiling in L'Etang Inlet.

Position	Station	RPD (cm)	Organism-sediment index
Landwards	17	0	-3
	18	0.1	-2
	20	2.81	9
	21	3.11	10
	22	N/A	?
	23	2.72	9
	24	2.21	?
	25	2.22	8
	26	N/A	?
	27	5.67	11
	28	7.02	11
Seawards	29	9.65	11

sediments here have RPD's at or near the sediment-water interface as indicated by sediment profile photograph (#17 & 18, Table 4). These results are similar to dissolved oxygen conditions in seawater and RPD values observed in 1975 by Poole et al. (1976). The pattern of oxygen distribution at HW and LW (Fig. 3) is essentially the same at Stations 1 and 7 (Fig. 1) with the dissolved oxygen being completely stripped at Station 1, but only partially so at Station 7 at LW. This is consistent with the known hydrography of the Lower L'Etang with its approximately three excursion lengths and long residence time of 85-815 d (Wildish et al. 1971).

At only one salmonid culture site, the largest and longest established, was there evidence of a rapid build-up of sediment which was anoxic. The cages were situated over a net depositional sediment and indicates the importance of selecting a site where rapid build-up of faecal matter cannot take place (i.e. a net erosional sediment). It is of interest that the bottom water immediately above the anoxic microbial mat was fully oxygen saturated and demonstrates that the D.O. profiles must have sharp gradients near the sediment water interface.

The general concordance between results obtained by conventional methods (e.g. D.O. and redox measurements) and sediment profile photographs is gratifying. Thus, HW profiles of D.O. decreased landwards above Station 7 (Fig. 1) whilst the sediment-organism-index was reduced slightly above Station 25 (Fig. 5) in the landwards direction, i.e. in the same approximate area. The presence of an epifaunal suspension-feeding community throughout much of L'Etang - including mussel beds between locations 22-27 (Fig. 5) and the presence of dense polychaete and/or amphipod tube mat communities (Fig. 6) in the seaward mouth of the L'Etang is indicated by the sediment profile photography. We interpret this to be an equilibrium community for a soft-sediment area where there is ample tidal energy to support filter-feeding. Although similar to the Stage 1 succession of Rhoads and Germano (1982), it differs in that the RPD does not reach the sediment-water interface.

The L'Etang has previously been assessed from the point of view of multiple-use resource conflict (Wildish 1983). The recent rapid development of salmonid culture facilities in the seaward mouth of L'Etang makes even more important the resolution of the problem of pollution in the upper part of L'Etang.

Of interest to salmonid culturists is the extent to which a given, finite body of water such as the L'Etang will support a given maximum number and density of cultured salmonid fish. Metabolic oxygen demands of both the fish and the wastes (excreta, food, etc.) are high and the question is at what density does the overall dissolved oxygen balance of L'Etang become a negative one and the DO lowered? Because of the technical difficulty of modelling due to the indented coastline and the complex flows of lower L'Etang, we have abandoned this as an approach to resolving this problem.

We believe that an earlier indication of potential problems, due to salmonid overstocking in the lower L'Etang, would be obtained by monitoring the development of eutrophication. Eutrophication results from the microbial degradation of organic matter such as fish excreta and waste food which releases enhanced quantities of plant nutrients such as nitrogen and phosphorous containing compounds into L'Etang seawater. Greater quantities of these plant food substances stimulate phytoplankton growth and result in blooms (Barlow et al. 1963). A common feature of this effect would be a reduction in diversity and increase in density of phytoplankters. Dinoflagellates, some of which cause red tide blooms, would be expected to bloom because of the enhanced quantities of plant food substances present. Such blooms have been known to cause fish kills, for example, herring which have fed on zooplankters containing the toxic dinoflagellate, Gonyaulax excavata (White 1981). The effect of die-back of phytoplankton blooms may result in localized areas of reduced DO due to aerobic microbial activity. Thus, Gascoine and Wildish (1971) reported a reduction in the DO sag curve following the degradation of a diatom bloom in the Medway river and estuary, U.K. We consider that monitoring phytoplankton species diversity and density might give an early warning of the development of eutrophic conditions in L'Etang. Spencer (1985) has shown that monitoring plant nutrients and chlorophyll at a single marine station, contrary to the situation in fresh water, does not provide a good indication of the development of

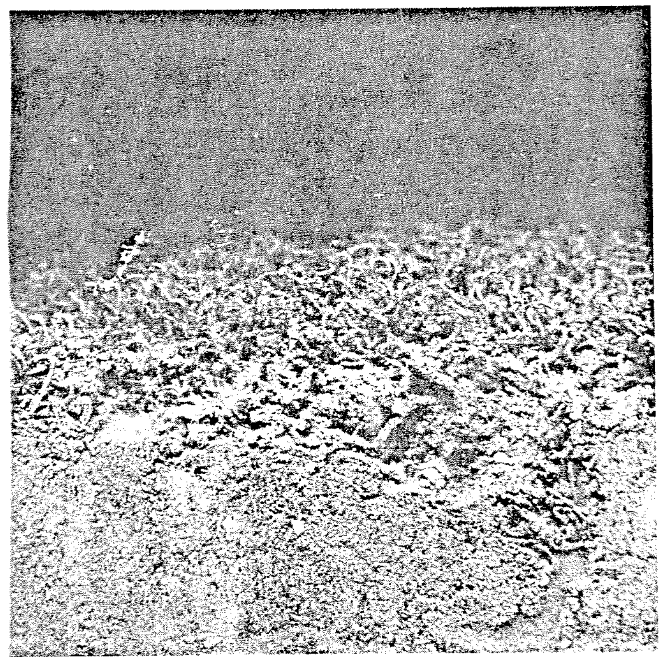

Fig. 6. Sediment profile photograph showing a dense polychaete tube mat. Station 15 in Fig. 6.

eutrophic conditions in the sea because of the spatial and temporal heterogeneity involved. Consequently, our proposal is to monitor phytoplankton community structure for this purpose, rather than the measures used by Spencer (1985). We believe this would be preferable due to the more conservative nature of the community measure.

CONCLUSIONS

1. The area of the upper part of Lower L'Etang affected by pulp mill pollution has not moved seawards since 1975.

2. Water quality in Lower L'Etang is adequate at least to Indian Point.

3. Only one culture site showed evidence of a build-up of faecal matter underneath the cages, and was in a net sediment depositional area.

4. Recommendations for monitoring water and sediment quality in L'Etang in the future are:

   - above Indian Point: a dissolved oxygen and/or sediment redox profile study in August/September when water temperatures are highest and DO conditions likely to be at their lowest.

   - below Indian Point: twice monthly sampling from May to September at one or two fixed stations. Water samples to be analyzed for algal species and their densities as a means of early warning of the development of eutrophication.

   - a geographic survey of sediments in the Lower L'Etang to map areas of net depositional and erosional sediments of use in predicting where faecal matter buildup may occur under salmonid cages.

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Appendix 1. Hydrographic parameters in the Lower L'Etang for 14 August 1985. See station positions in Fig. 1. HW predicted as 11:07.

Station #	Time	Depth (m)	Temp. (°C)	Salinity (o/oo)	D.O. mg/L	D.O. % saturation
Surface						
1	10:30	0	16.9	26.7	0	0
2	10:45	0	16.3	29.2	1.21	14.3
3	10:55	0	15.3	30.9	5.28	61.2
4	11:05	0	15.5	31.1	5.65	67.1
5	11:15	0	15.0	31.3	6.63	77.3
6	11:25	0	14.7	31.4	7.01	81.8
7	11:35	0	15.2	31.3	6.91	80.7
8	11:50	0	14.7	31.6	8.22	97.1
9	12:00	0	14.5	31.6	8.35	98.7
10	12:10	0	13.7	31.7	8.73	101.3
Bottom						
1	10:30	5.18	16.0	30.9	4.44	52.6
2	10:45	5.18	15.2	31.1	5.65	65.8
3	10:55	5.18	15.0	31.2	6.21	72.5
4	11:05	6.40	15.0	31.3	6.35	74.2
5	11:15	7.62	14.5	31.5	7.24	84.3
6	11:25	9.14	14.5	31.6	8.03	94.8
7	11:35	10.06	14.3	31.6	8.68	100.7
8	11:50	10.06	13.9	31.7	8.64	100.2
9	12:00	14.94	13.6	31.7	9.66	111.9
10	12:10	25.60	13.5	31.7	9.25	107.1

Appendix 2. Hydrographic parameters in the Lower L'Etang for 22 August 1985. See station positions in Fig. 1. LW predicted as 11:16.

Station #	Time	Depth (m)	Temp. (°C)	Salinity (o/oo)	D.O. mg/L	D.O. % saturation
Surface						
1	-	-	-	-	-	-
2	-	-	-	-	-	-
3	-	-	-	-	-	-
4	-	-	-	-	-	-
5	10:10	0	15.5	30.6	3.55	42.3
6	10:15	0	15.5	30.6	3.97	47.2
7	10:30	0	15.2	30.9	4.44	51.7
8	10:45	0	15.4	31.1	1.46	63.7
9	11:00	0	15.0	31.3	6.49	75.8
10	11:20	0	14.2	31.8	8.31	96.4
Bottom						
1	-	-	-	-	-	-
2	-	-	-	-	-	-
3	-	-	-	-	-	-
4	-	-	-	-	-	-
5	10:10	2.13	15.8	30.7	3.83	45.5
6	10:15	4.27	15.4	31.0	5.18	60.5
7	10:30	5.79	15.3	31.0	4.76	55.7
8	10:45	8.53	14.0	31.7	7.42	31.4
9	11:00	9.14	13.9	31.7	7.94	92.1
10	11:20	20.42	13.5	31.9	8.40	97.4

Appendix 3. Hydrographic parameters in the Lower L'Etang for HW on 15.07.77 and LW on 22.08.77. Unreported data collected by H. M. Akagi and A. J. Wilson.

Time (AST)	Temp. (°C)	Depth (m)	A250 x 10^3	Suspend. solids (mg/L)	D.O.
HW					
09:40	17.5	0	1551	14	0
	15.1	4.5	201	4	2.2
10:40	19.5	0	1500	15	0
	16.8	5.0	151	3	3.2
11:40	19.0	0	827	16	0
	17.0	5.0	127	3	4.2
12:40	18.5	0	898	9	0
	17.0	4.5	125	2	4.4
13:40	18.7	0	860	13	0
	15.6	3.5	143	4	4.2
LW					
09:30	16.8	0	1076	5	0
	15.8	1.8	335	6	0.2
10:40	18.3	0	1423	15	0
	-	0.5	-	-	-
11:50	18.8	0	1410	8	0
	-	0.5	-	-	-
12:50	19.0	0	1160	13	0
	-	1.5	-	-	-
13:55	18.8	0	1171	9	0
	17.8	3.0	597	4	0.2

Appendix 4. Hydrographic data obtained on 21 August 1985 at Station #7 (Fig. 1) for (A) surface- and (B) bottom- seawater. Saint John HW = 1515; LW = 2140, AST.

Time AST	Temp. (°C)	Salinity (o/oo)	A250	D.O. mg/L	D.O. % sat.	ATP
(A)						
07:30	14.5	310	229	5.23	61.0	20
08:30	14.7	308	200	5.41	63.2	280
09:30	15.0	309	197	5.41	63.2	260
10:30	15.3	309	202	5.41	63.2	630
11:30	15.4	309	193	4.99	58.2	330
12:30	16.4	310	155	5.88	70.0	970
13:30	16.4	312	137	6.54	77.6	1020
14:30	15.3	314	69	7.28	85.0	300
15:30	15.0	315	49	8.03	93.7	210
16:30	15.0	316	35	8.40	98.0	180
17:30	15.2	316	34	7.89	93.1	260
18:30	15.0	313	92	6.91	80.7	170
(B)						
07:30	14.4	312	136	5.84	66.8	70
08:30	14.7	310	182	4.85	56.7	440
09:30	15.0	310	199	5.41	63.2	550
10:30	15.0	310	190	5.32	62.2	520
11:30	15.2	310	186	5.23	61.0	410
12:30	14.5	315	72	7.33	85.5	-
13:30	14.6	316	48	7.84	91.5	500
14:30	14.5	318	8	8.31	98.2	80
15:30	14.0	317	6	8.50	98.5	90
16:30	14.4	318	4	8.73	101.2	130
17:30	14.0	317	9	8.40	97.4	120
18:30	14.2	317	20	8.03	93.1	110

Apendix 5. Hydrographic measurements made in the L'Etang from 17-18 September 1985 with station numbers referring to Fig. 1.

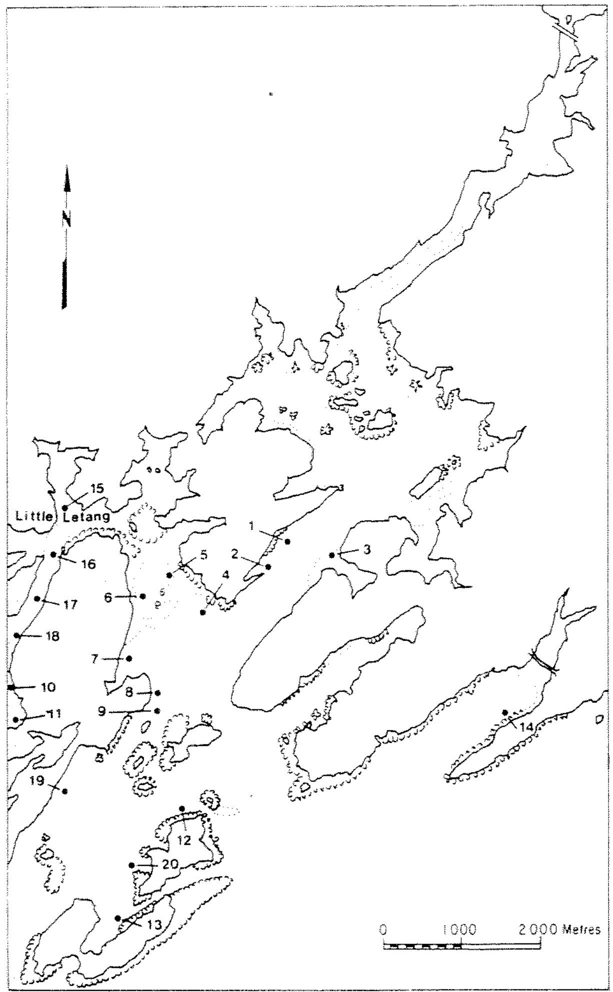
Station #	Time	Depth (m)	Temp. (°C)	Salinity (o/oo)	mg/L	% saturation	ATP (ng/L)	A250 absorbance x 10^3
29	11:25	0	13.2	32.3	8.54	97.2	5.89	28
		12.2	13.0	32.3	8.50	96.7	5.31	27
12	12:00	0	12.9	32.3	8.17	93.0	8.07	28
		18.3	12.9	32.3	8.26	94.1	7.22	22
15	12:30	0	12.4	32.3	8.40	93.8	9.38	16
		11.0	12.8	32.4	8.82	100.4	11.44	15
17	1:00	0	12.4	32.3	8.59	95.9	17.25	17
		12.2	12.8	32.4	8.59	97.8	17.49	16
27	1:40	0	12.2	32.4	8.45	94.3	12.60	13
		18.3	12.8	32.4	8.68	98.8	12.22	16
19	2:00	0	12.8	32.3	8.45	96.2	14.11	18
		20.1	12.8	32.4	8.92	101.5	22.32	14
18	10:30	0	12.5	-	8.59	97.8	13.36	-
		7.6	12.7	-	8.82	100.4	11.83	-
28	11:30	0	12.8	32.3	8.54	97.2	8.17	26
		9.1	13.5	32.3	8.68	100.6	11.25	28
27	12:15	0	12.6	32.3	8.87	100.9	12.60	28
		9.1	13.0	32.4	8.59	97.8	12.29	19
26	12:35	0	12.3	32.4	8.87	99.0	17.76	17
		18.3	12.5	32.4	8.54	97.2	17.69	16
25	1:00	0	12.5	32.3	8.54	97.2	15.86	20
		18.3	12.9	32.4	8.54	97.2	12.89	17
24	10:30	0	12.2	32.4	8.73	97.5	10.62	13
		14.6	13.1	32.5	8.64	98.3	7.08	13
20	11:10	0	12.5	32.4	8.59	97.8	9.27	12
		12.2	12.8	32.5	8.54	97.2	8.08	13
21	11:30	0	12.3	32.4	8.68	96.9	9.54	14
		12.2	12.3	32.5	8.31	92.8	4.59	13
22	11:55	0	12.6	32.4	8.36	95.1	7.82	13
		14.6	12.4	32.5	8.40	93.8	9.89	13
23	12:45	0	13.0	32.4	8.82	100.4	10.18	12
		12.8	13.0	32.4	8.54	97.2	8.97	15

Appendix 6. Sediment redox potential in mV relative to the normal hydrogen electrode measured in core tube samples taken 15 Aug., 17-19 Sept. 1985. Station # refers to Fig. 1 with #11-20 as established, and #21-30, as salmonid culture sites proposed for 1986.

Depth (cm)	Station # 11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
0	359		G												H	S				
2.5			R			224		-146	129					109	A	A				344
5.0	359	359	A	104	379		102			104	129	49	119		R	N	329	104	94	
2.5			V			284		-156	129					184	D	D				279
10.0		129	E		279		114			84	139	99	144				109		94	
12.5			L			284		124	154					144						274
15.0		159					184			49	126	129	144						164	
17.5						204		174	169					154						234
20.0							164				194	124	169							
22.5						239		184	184					214						264
25.0							129				144	84	164							
27.5						309		269	194					239						
30.0							182				204	94	164							
32.5						259			184					269						
35.0							182				209	159	209							
37.5						219			214											
40.0							184				224	169								
45.0											234	254								

Appendix 7. Sediment profiling data for L'Etang surveyed on 20.09.85 with the REMOTS® camera. Physical-chemical parameters only. See Rhoads and Germano (1982) for a description of each parameter measured.

Station #	Median phi value	Depth (cm)	Roughness depth (cm)	Mudclasts #	Mudclasts Diam. (cm)	Redox Mean depth	Redox Contrast	Methane pockets #	Low D.O.	Comments
1	4	13.6	0.72	2	1.29	7.6	42	0	No	Amphipod tubes
2	4	8.4	1.85	0	-	6.1	28	0	No	Amphipod tubes
4	3½	4.3	0.8	0	-	4.8	31	0	No	Tube mat RPD > penetration
5	2½	3.1	0.6	0	-	?	24	0	No	Tube mat RPD > penetration
6	3½	3.5	1.1	0	-	?	24	0	No	Tube mat RPD > penetration
7	3½	3.3	1.0	0	-	?	24	0	No	Tubes, hydroids, cobble, shell
8	2½	2.6	0.5	0	-	?	24	0	No	Tube mats, cobbles
9	4	19.9	0.7	4	0.56	8.1	24	0	No	
10	4	17.8	0.5	2	0.48	8.7	26	0	No	
11	4	15.2	1.2	3	0.4	8.8	28	0	No	Large tube at interface
12	1½	2.9	1.0	0	-	?	0	0	No	Dense mats on sand
13	3½	4.3	1.8	0	-	?	0	0	No	Dense mats, cobbles
14	2½	2.7	1.2	0	-	?	21	0	No	Cobbles & hydroids, poor sorting
15	3½	3.3	1.8	0	-	3.8	41	0	No	Tube mat, cobbles
16	3½	6.5	0.8	0	-	5.4	19	0	No	Dense tube mat
17	4	9.7	0.4	2	0.5	0	0	0	Yes	Microbial aggregate
18)	4	8.6	1.0	0	-	4.1	29	0	No	Large polychaete worm
18)	4	10.9	1.8	2	1.0	0.1	4	0	Yes	? relict void
20	4	7.4	0.5	4	0.5	2.8	24	0	No	Dark sediment bands
21	3½	4.1	0.8	0	-	3.1	43	0	No	RPD indistinct
22	3½	3.7	1.7	0	-	?	43	0	No	Mussel bed
23	4	5.7	2.4	0	-	2.7	10	0	No	Mussel bed
24	4	3.1	3.6	0	-	2.2	17	0	No	Mussel bed
25	4	5.3	1.7	0	-	2.2	37	0	No	Mussel bed
26	3½	2.9	1.5	0	-	?	37	0	No	Cobbles, debris, RPD > penetration
27	1½	8.5	0.8	2	0.45	5.7	35	0	No	
28	3½	18.7	0.7	4	0.45	7.0	16	0	No	Amphipods
29	4	13.6	0.8	0	-	9.7	31	0	No	Amphipods, diverse
30	3½	5.4	1.3	0	-	4.7	26	0	No	Amphipods
31	3½	15.4	0.7	4	0.6	7.1	19	0	No	Amphipods
32	3½	9.7	1.4	1	0.4	6.7	26	0	No	Diverse surface fauna
33	4	14.5	0.7	1	0.5	5.8	43	0	No	Amphipod
34										
35	4	10.5	0.5	0	-	6.8	57	0	No	Amphipods, worms
36	3½	7.1	0.8	4	0.4	6.3	48	0	No	Amphipods
37										
38	4	16.2	0.9	0	-	7.2	41	0	No	
39	4	20.1	1.4	2	0.6	8.2	41	0	No	
40	4	9.2	0.5	4	0.9	6.8	32	0	No	Tubes present
41	4	17.3	1.0	0	-	7.9	20	0	No	Epifauna
42										
43										
44	3½	7.9	2.2	0	-	5.1	40	0	No	Cobbles
45	3½	2.1	1.2	2	0.6	?	40	0	No	Epifauna
46	3½	11.9	0.7	0	-	5.4	27	0	No	Epifauna
47										
48	4	13.8	0.3	4	0.3	7.5	26	0	No	
49	4	20.1	1.2	1	0.4	7.0	29	0	No	
50	4	16.4	1.6	2	0.5	7.1	21	0	No	



Appendix 8. Established and approved salmonid aquaculture sites in L'Etang by May, 1986.