INCREASED OXYGENATION OF SEDIMENT IN LAMÈQUE BAY (NEW BRUNSWICK) FOLLOWING REMOVAL OF ALGAE AND REDUCTION OF NUTRIENT INPUTS FROM A SEAFOOD PROCESSING PLANT

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2008

**Canadian Technical Report of
Fisheries and Aquatic Sciences 2805**

Pêches et Océans Canada Fisheries and Oceans Canada

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Canadian Technical Report of Fisheries and Aquatic Sciences

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Increased oxygenation of sediment in Lamèque Bay (New Brunswick) following removal of algae and reduction of nutrient inputs from a seafood processing plant

by

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Cat. No. Fs 97-6/2805 ISSN 0706-6457

Published by:

Fisheries and Oceans Canada
Gulf Fisheries Centre
343 University Avenue
Moncton, NB E1C 9B6

Correct citation for this publication:

Plante, F. and S.C. Courtenay. 2008. Increased oxygenation of sediment in Lamèque Bay (New Brunswick) following removal of algae and reduction of nutrient inputs from a seafood processing plant. Can. Tech. Rep. Fish. Aquat. Sci. 2805: v + 36p.

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ABSTRACT

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Lamèque Bay, a shallow temperate bay located in north-eastern New-Brunswick (Canada) has experienced blooms of green macro-algae and ensuing habitat degradation since the late 1990's as a result of anthropogenic nutrient loading. Eutrophication of portions of the bay has resulted in anoxia and H_2S production with ensuing human health and fish habitat concerns. Effluents from the local seafood transformation plant have been identified as a major source of water and sediment enrichment in the bay.

Between 2003 and 2007 steps were taken to remediate Lamèque Bay. Sea lettuce (*Ulva lactuca*) was removed from the affected shoreline and contiguous waters of Lamèque Bay. At the same time, the seafood processing plant undertook a program of water reduction, best management practises to reduce loss of product, and an effluent treatment retrofit.

Measurements of total sulphides and of oxidation-reduction potentials (Eh) in porewater have been used to determine sediment quality between 2001 and 2007. Preliminary results show a consistent reduction in levels of sulphides from 2001 to 2007. Severely anoxic conditions of 2001 and 2002 returned to normal by 2005. Since then, only stations within 10 metres of the fish plant processing outfall indicate anoxic conditions and high sulphide concentrations. While there are positive signs that the remediation campaign has had positive impact on Lamèque Bay, it is too early to tell if this represents a permanent trend toward normal conditions.

RÉSUMÉ

Plante, F. and S.C. Courtenay. 2008. Increased oxygenation of sediment in Lamèque Bay (New Brunswick) following removal of algae and reduction of nutrient inputs from a seafood processing plant. Can. Tech. Rep. Fish. Aquat. Sci. 2805: v + 36p.

La baie de Lamèque est située au nord-est du Nouveau-Brunswick (Canada). Cette baie peu profonde et tempérée a été le théâtre d'une prolifération de macro algue qui a causée la dégradation de l'habitat depuis la fin des années 1990 suite à un enrichissement d'origine exogène. L'eutrophisation d'une partie de la baie a résulté en condition anoxique et production de H_2S qui ont dégradées l'habitat du poisson et affectées la santé humaine. Les effluents de l'usine locale de transformation de produits marins ont été identifiés comme étant une source majeure d'enrichissement de l'eau et des sédiments dans la baie.

Entre 2003 et 2007, des actions ont été prises afin de restaurer la Baie de Lamèque. La laitue de mer (*Ulva lactuca*) a été récoltée sur le rivage ainsi que dans les eaux peux profondes de la baie. En parallèle, l'usine de transformation de produits marins a entrepris un programme de réduction d'utilisation d'eau en plus de mettre en œuvre un plan de meilleures pratiques de gestion des rejets. De plus, ils ont procédé à des améliorations de leur système de traitement des eaux usées.

Les mesures de sulphides totaux et du potentiel d'oxido-réduction (Eh) dans les eaux interstitielles ont été utilisées pour déterminer la qualité du sédiment entre 2001 et 2007. Nos résultats préliminaires montrent une réduction constante des niveaux de sulphides entre 2001 et 2007. Les conditions d'anoxie sévère rencontrées en 2001 et 2002 sont revenues à la normale en 2005. Depuis, seules les stations situées à moins de 10 mètres de l'exutoire présentent des conditions anoxiques et des concentrations élevées en sulphides. Toutefois, même si les efforts pour améliorer la situation semblent avoir eu des impacts positifs sur les conditions de la baie, il est encore trop tôt pour affirmer que cette tendance représente un retour permanent vers les conditions normales.

1.0. INTRODUCTION

Canada's southern Gulf of St. Lawrence is characterised by sheltered embayments with warm and shallow waters. These productive waters act as nursery and rearing habitats for several fish and shellfish species which support important commercial fisheries in Canada's Southern Gulf of St. Lawrence.

Nutrients enter the coastal waters of the Southern Gulf of St. Lawrence from a number of sources. Effluents from seafood processing plants have been identified as a major source of water and sediment enrichment (Morry *et al.* 2003, Lalonde *et al*. 2007). One of the largest seafood processing plants in New Brunswick is located in the town of Lamèque (north-eastern New-Brunswick, Canada; Figure 1). This town has experienced noxious odour and accumulation of marine algae along the shoreline in the summers of recent years. The fish plant in Lamèque is run by the *Association Coopérative des Pêcheurs de L'Île Ltée*, Lamèque, NB, hereafter called the Co-op.

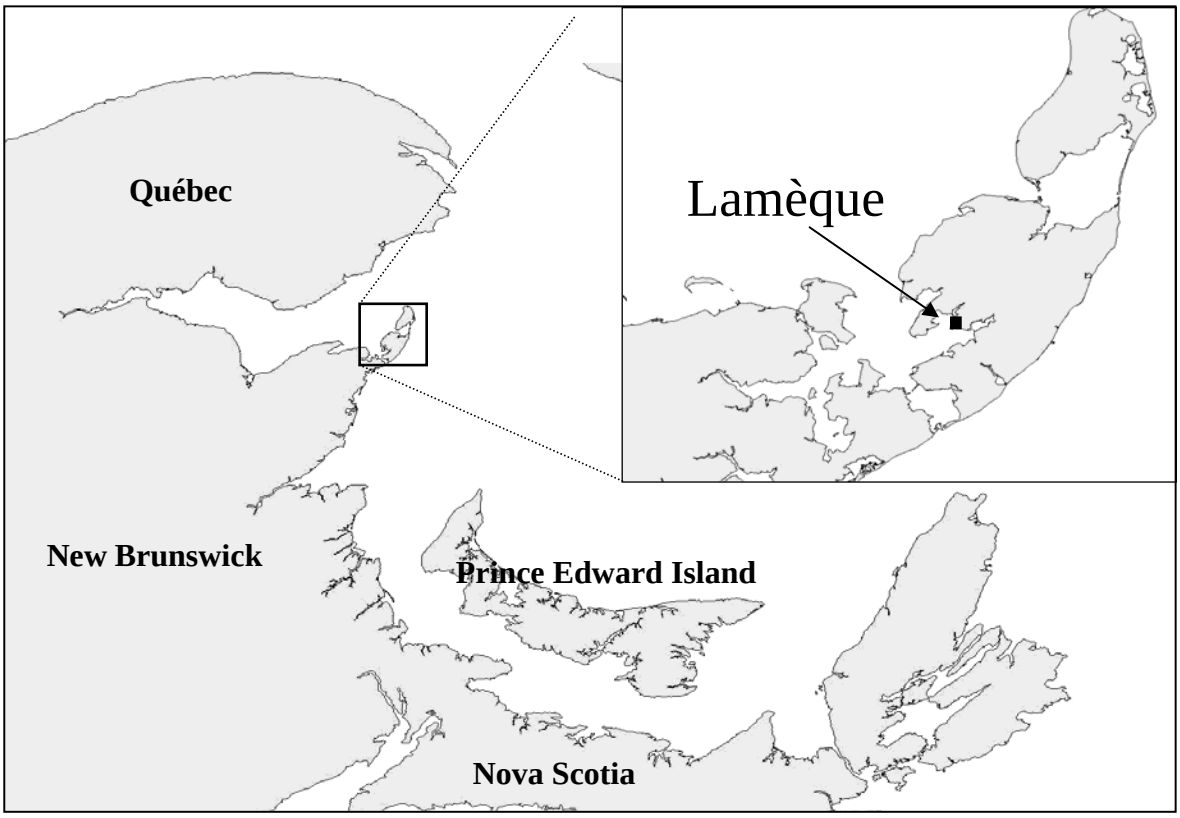

Figure 1: Location of the Lamèque Bay, north-eastern New Brunswick, Canada.

Complaints about odours began being registered in the early 1990's. In July 2002 the Regional Medical Health Officer issued a warning bulletin that residents of the area who are sensitive to strong odours should limit their time spent outdoors. While the odours should not affect human health, they can cause nausea, headaches and irritation of the eyes and throat in certain people. The NB Ministry of Environment and Local Government had recorded elevated levels of total reduced sulphur in the air of the Lamèque region. Odours were particularly strong during low tide when the algae on the beach were exposed. A combination of increased sewage discharge, installation of blue mussel aquaculture facilities, extension of the fishing fleet harbour and fish processing plant discharge into this low-flushing, shallow bay appeared to have resulted in high nutrient loading, algal blooms, anaerobic degradation, and production of hydrogen sulphide (H_2S) (Morry *et al.* 2003).

Sea lettuce (*Ulva lactuca*) is a green macro-algae which is widely distributed from the Tropics to the Arctic (Taylor, 1972). It is found at all levels of the intertidal zone, although in more northerly latitudes and in brackish habitats it is found in the shallow sublittoral. This fast growing algal species can increase in size by more than 30% per day (Pederson and Borum, 1996). In very sheltered conditions, plants that have become detached from the substrate can continue to grow, forming extensive floating communities. The link between luxuriant growth of *Ulva* and sewage effluent is well known since the beginning of the 20th century (Letts and Richards, 1911).

The overgrowth of algae is not the cause but only part of the problem in Lamèque. Large concentrations of nutrients, particularly nitrogen (N) and phosphorus (P), encourage the growth of *Ulva* (Foster, 1914). High Biological Oxygen Demand (BOD) due to the effluent also reduces the oxygen (O_2) available for marine life, which is further compounded when the algae die and decompose, consuming even more of the available oxygen. On the shore, the accumulation of rotting algae results in a noxious odour problem experienced by local residents. This decaying sea lettuce has been identified as the major source of odour in the area and it was therefore postulated that removing the bulk of it would mitigate the odour issue.

Growing public protests and decreasing air quality led government agencies to undertake a targeted campaign to curb the source and effects of this eutrophication starting in 2003. The seafood processing plant underwent significant water reduction and an effluent treatment retrofit. Meanwhile the municipality of Lamèque in association with a community group (*la Coalition pour la viabilité de l'environnement de Shippagan et des Îles Lamèque et Miscou*) undertook the task of forcefully removing decaying plant material along the affected shoreline (on land) and from identified reservoirs in the water (at sea).

First attempts to remove decaying algae from the shoreline were made by hand. Local people, equipped with rakes and shovels, rapidly realized that they had to work on a larger scale. In order to facilitate access by heavy machinery and to minimize damage to the environment during harvesting operations on land, construction of a rocky platform on the shoreline was authorized by DFO. Trials were carried out by the Town and community group with several tools including a modified excavator's bucket and custom made trawl attached to the excavator's boom (Appendix A). However, despite the fact that the algae removal was beneficial for the aeration of the sea bed in the intertidal zone, it was decided to attack the algae accumulation problem

directly at the source. Because of the lack of expertise with this kind of problem, several methods were tested. The rental of an aquatic vegetation harvester from Ontario was expensive and not cost efficient due to the size of the area to be covered. Use of shrimp trawls and scallop drags was efficient but limited by the size of the boat needed to operate those heavy gears. Since the area of the bay affected by algae accumulation was less than 2 metres deep at low tide, it was only possible to work a few hours per day during the high tide. Furthermore, extensive utilisation of these gears was potentially damaging to the bottom of the bay. It was therefore decided to join two pieces of equipment to tackle the job: an amphibious excavator and a homemade perforated bucket. This method was identified as the most efficient to scoop out the algae without negative impacts on the environment. Harvested algae was rinsed in fresh water for 24 hours and then transported to a local compost site. Pictures of modified pieces of equipment and quantities of algae harvested are presented in Appendix A.

At the same time, a monitoring program was initiated to measure the oxygenation of sediments throughout Lamèque Bay. These surveys were done in collaboration with *La Coalition pour la viabilité de l'environnement de Shippagan et des Îles Lamèque et Miscou* (Bertin Gauvin, Directeur général, 28, rue de l'Hôpital, C.P. 2037, Lamèque (Nouveau-Brunswick) E8T 1C3, comite.havre@nb.aibn.com). The purpose of this report is to present the results of that sediment monitoring.

2.0. MATERIAL AND METHODS

Measurements of total sulphides in surface sediment and oxidation-reduction potentials (redox; Eh) in porewater were collected to determine sediment quality (Whitfield, 1971). Redox and sulphide were selected as the most cost-effective monitor of the sedimentary environment (Wildish *et al.*, 2001) to determine whether decreased levels of dissolved oxygen and increased levels of sulphide in porewater had occurred. The organic enrichment gradient zones (Table 1) proposed by Wildish *et al*. (1999) were used to group and analyse redox and sulphide readings. Redox (Eh) readings are expressed in mV relative to normal hydrogen electrode (NHE) and sulphide (S) readings are expressed in μM.

Table 1: Organic enrichment gradient zones based on Redox (Eh) and reduced Sulphides (S^{2-})
(Modified from Wildish *et al.* 1999)

Criteria	Normal	Oxic	Hypoxic	Anoxic
Eh_{NHE} (mV)	> 100	100 to 0	0 to -100	< -100
S^{2-} (μM)	< 300	300 to 1 300	1 300 to 6 000	> 6 000

On the advice of Dr. Barry Hargrave (formerly of Bedford Institute of Oceanography, Dartmouth, Nova Scotia) a consultant (Dominator Marine Services Inc., P.O. Box 6191, Saint John, New Brunswick, E2L 4R6, www.DominatorMarine.com) was contracted for the field sampling and laboratory analyses. A total of three samples were collected at every station by a scuba diver using 35 cm lexan core tubes (5 cm inside diameter, drilled at 2 cm intervals and sealed with duct tape) inserted vertically into the substrate under constant pressure. Once a representative sample was retrieved the core tube was capped at each end and returned to the surface where each sample set was videotaped and prepared for sediment analysis.

2.1. REDOX ANALYSIS

Redox measurements were taken with a Hanna electrode (part no. HI3230B). Redox measurements were made within 2 hours of sample collection or within 24 hours if samples were stored in an ice-bath. One redox measurement of each core sample was taken by inserting the electrode through the tape into the hole closest to the sediment-water interface, within the top 2 cm of sample, and twisting the electrode between the thumb and forefinger. The temperature of each sample was measured and recorded. Redox measurements were recorded as millivolts relative to the normal hydrogen electrode (mV_{NHE}) using the equation $mV_{NHE}=E_o+(224-T)$, where E_o=mV of unknown and T=temperature of unknown (^oC) or as millivolts (mV), once the value has stabilized (drift < 10 mV/minute) or 2 minutes after commencement of measurement. The redox electrode was rinsed with distilled water and dried between measurements.

2.2. REDOX ELECTRODE ACCURACY CHECK

The accuracy of the redox electrode was checked using the Hanna 240 mV test solution (part no. HI7021), in which the electrode should read between 220-260 mV. Hanna pre-treatment oxidizing (part no. HI7091) and reducing (part no. HI7092) solutions were used to adjust the accuracy of the redox electrode within the recommended acceptable range.

2.3. SULPHIDE ANALYSIS

For sulphide analysis a 5 ml sediment sub-sample was collected from the top 2 cm of each core immediately after redox analysis. The 5 ml sub-sample was analyzed immediately or stored on ice in an air-tight container with no head-space and analyzed within 72 hours. Sulphide

measurements were taken with a calibrated Thermo Orion Silver/Sulphide electrode (model 9616). Each sub-sample was mixed with 5 ml of a solution of L-ascorbic acid and sulphide anti-oxidant buffer (SAOB) prepared within the past 3 hours. Once the solution of L-ascorbic acid and SAOB were mixed with the sub-sample, the sample was brought to the same temperature at which the electrode was calibrated, and then the sulphide was measured once the value has stabilized or within 2 minutes. The sulphide electrode was rinsed with distilled water and dried between measurements.

2.4. SULPHIDE ELECTRODE CALIBRATION

The sulphide electrode was filled with Orion Optimum Results B (cat. No. 900062) at least 24 hours before use. Three sulphide standards were used for calibration (100 µM, 1000 µM and 10000 µM). The 10000 µM sulphide standard was prepared using de-aerated water and stored in the dark, bottled under nitrogen, and opened immediately before use. The temperature of the sulphide standards had been brought to the same temperature as the samples when analyzed. Regardless of the number of samples analyzed, the calibrated sulphide electrode was used for a maximum of 3 hours from the time of first measurement. Then, the electrode was recalibrated before further readings were taken.

Six surveys were carried out between fall 2001 and winter 2007 by Dominator Marine Services Inc. Nine stations ranging from the fish plant outfall pipe to 1 400 meters away were sampled 3 times in each survey (Figure 2). In addition, a further 11 stations were sampled in years 2005-2007 to describe areas of uncertainty identified in the earlier surveys.

Since three samples were collected at every station, the average for each station was used for the spatial analysis of redox and sulphide conditions. Original data sets from 2001 to 2007 are presented in Appendix B. Mapping and data analyses were conducted with MapInfo, version 3.1, using the natural neighbourhood tool. This method creates natural neighbourhood regions for each data point and each grid cell. Cell values are derived using a point-weighting system based on the area of overlap of the grid cells natural neighbourhood region and the regions of surrounding data points. This method provides a continuous grid from non-continuous data points.

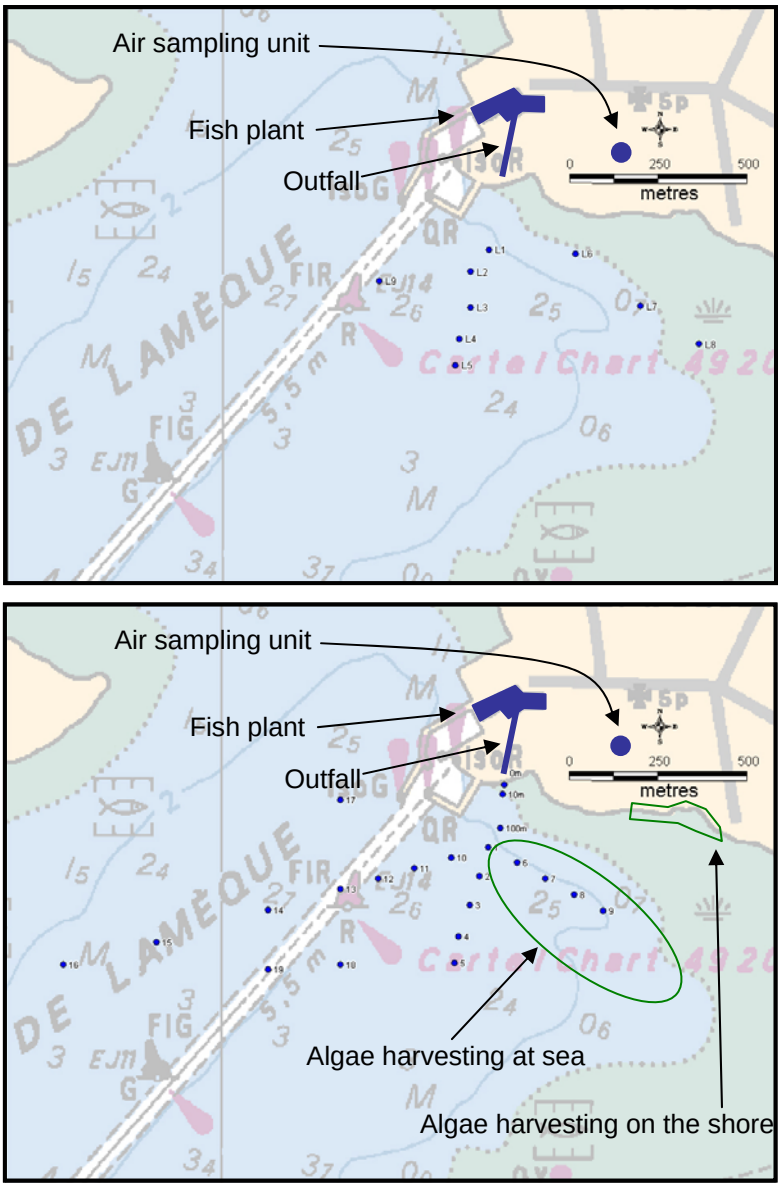

Figure 2: Location of the fish processing plant, air quality sampling unit, algae harvesting areas, and sampling stations in Lamèque Bay (Top map, stations sampled in 2001 and 2002; Bottom map, stations sampled in 2005 to 2007).

3.0. RESULTS

Based on Hargrave *et al*. (1997), bivariate pairs of Eh/total sulphide data generally demonstrate an inverse relationship when total sulphide, plotted on the x-axis is expressed as log10 and Eh

(mV) on the y-axis as an arithmetic scale. A negative Eh indicates anoxia and a positive Eh indicates oxygenated sediment (Figure 3). Samples from 2001 and 2002 present negative Eh values and high sulphide concentrations (>1 000 μM) which are indicators of "Hypoxic" or "Anoxic" conditions (Table 1). Starting in early 2005, analysis shows a migration to positive Eh values and low sulphide concentrations. Severely anoxic conditions of 2001 and 2002 were returning to normal level by 2005. Since then, only stations within 10 metres of the outfall site showed anoxic conditions and high sulphide concentrations. For all the other stations sampled in the bay between 2005 and 2007, results indicate "Oxic" to "Normal" characteristics.

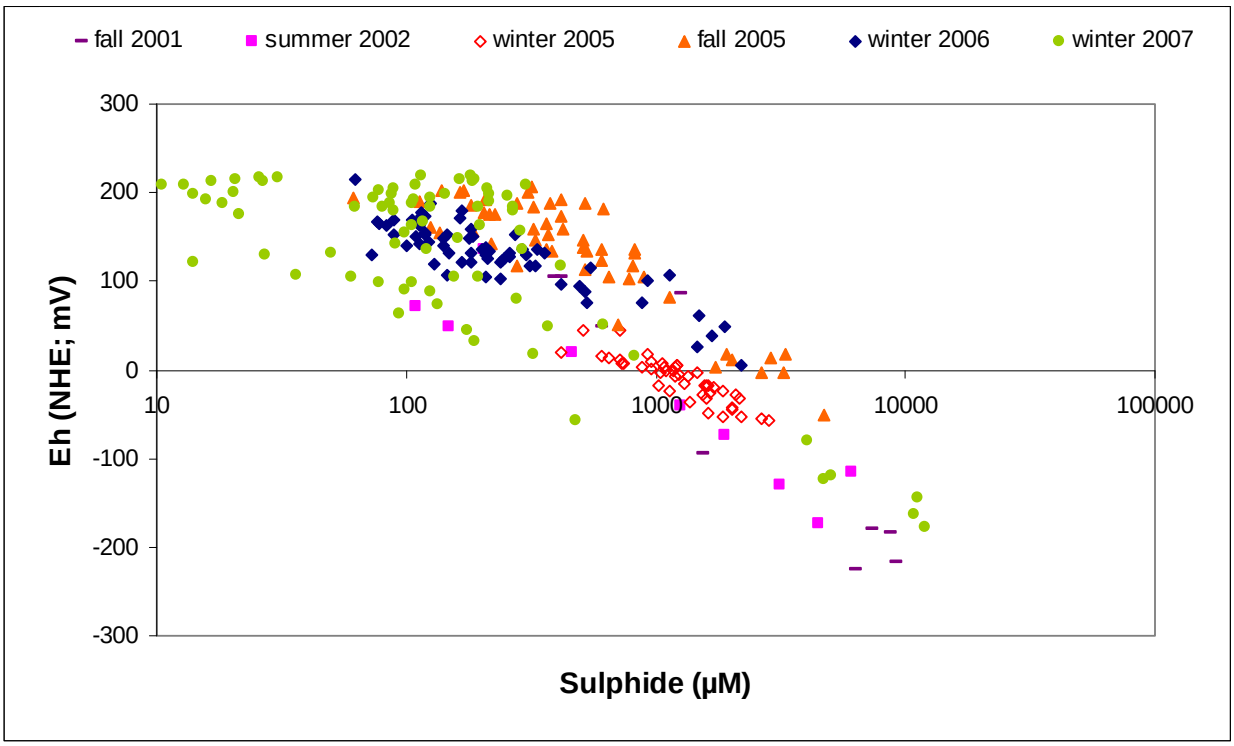

Figure 3: Eh-Sulphide relationship of all samples analyzed between 2001 and 2007

The evolution of the situation related to redox conditions is illustrated in Figure 4. The large anoxic area in 2001 (illustrated in red in Figure 4) slightly reduced in 2002. However, sampling of winter 2005 was the first real confirmation of a trend towards more oxic conditions. Only stations located in the plant outfall surroundings and in the navigation channel were slightly "Hypoxic" (Eh between -100 and 0 mV). Then, the situation rapidly improved.

During winter 2005, only stations within 10 metres of the outfall and a narrow band related to the navigation channel were not characterized as "Normal" (Eh > 100 mV). Furthermore, it was suspected that the band crossing the navigation channel was only an artefact created by the analysis as a result of the lack of data on both sides. Therefore, in 2006, sampling stations were added to the survey to provide additional information in the area previously filled in through

extrapolations. As a result, the area covered by the band was reduced and confined to the channel. Every newly added station presented “Oxic” to “Normal” conditions compared to the extrapolated “Hypoxic” characterization. Again in 2007, every station was characterized as “Oxic” to “Normal” (Eh > 0 mV) with the exception of the two stations located within 10 metres of the outfall.

As expected, the general trend of sulphide concentrations follows the redox picture (Figure 5). In 2001 half of the stations presented severe “Anoxic” conditions (> 6 000 μM). Results from 2002 still showed a large “Hypoxic” area with high concentrations of sulphides (> 1300 μM). As for the redox, the situation rapidly improved during 2005. By the end of the year, most of the samples were characterized as “Oxic” to “Normal” (< 1 300 μM). In 2007, sulphide concentrations at most of the stations were under 300 μM (Normal). Again, only stations within 10 metres of the outfall presented higher concentrations of sulphides. All other stations located at more than 10 metres were characterized as “Oxic” or “Normal”.

Profiles starting at the effluent pipe and following the sampling stations (refer to Figure 2) show significant reduction of sulphides and increase of oxygen in sediment from 2001 to 2007. The impacted area decreased in size to the point that only stations located in the immediate surrounding of the source were considered as anoxic or hypoxic (Figures 6 to 8).

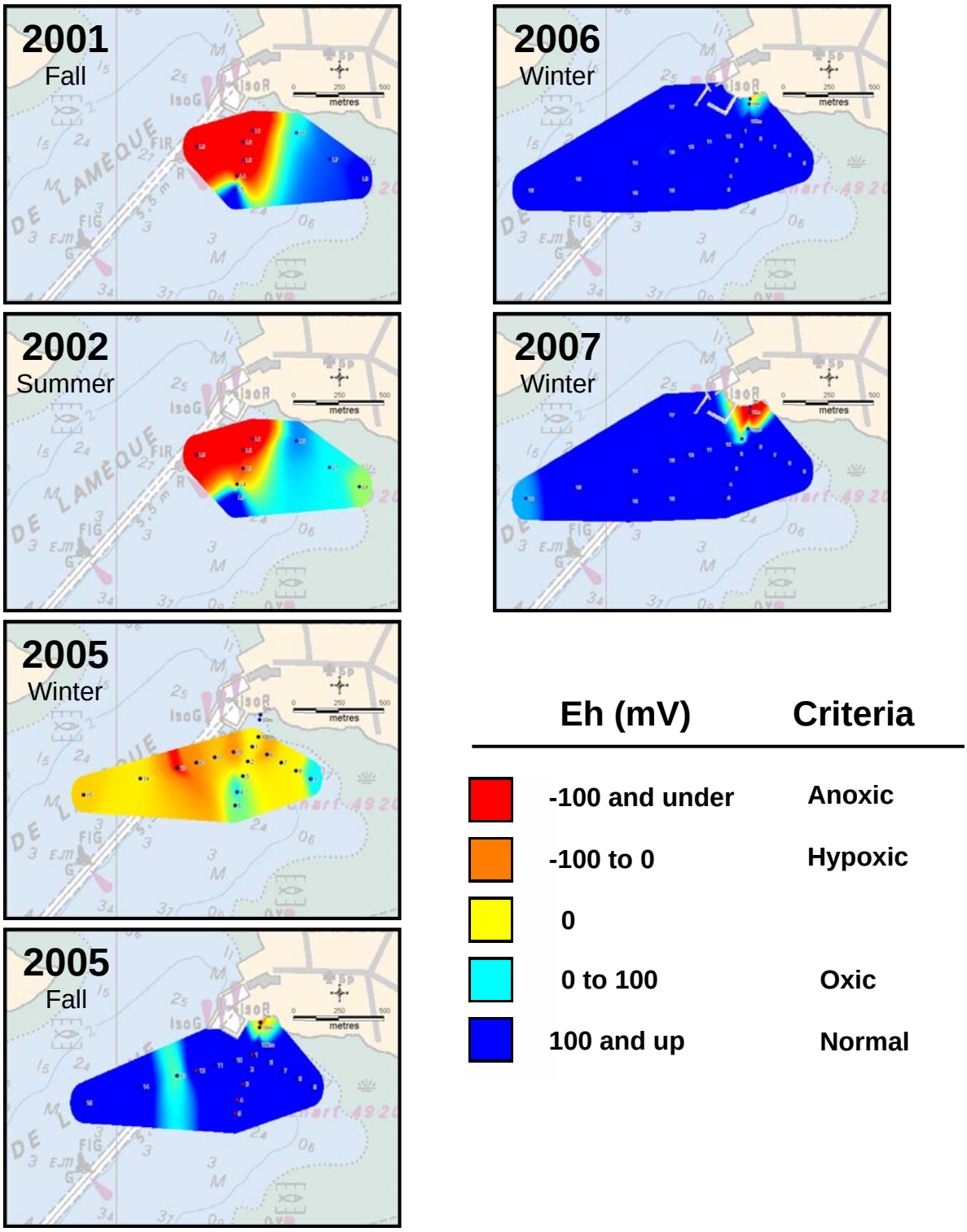

Figure 4: Eh readings illustrating the evolution of the oxygen concentration in the sediment from 2001 to 2007 (illustration prepared with the natural neighbours analysis).

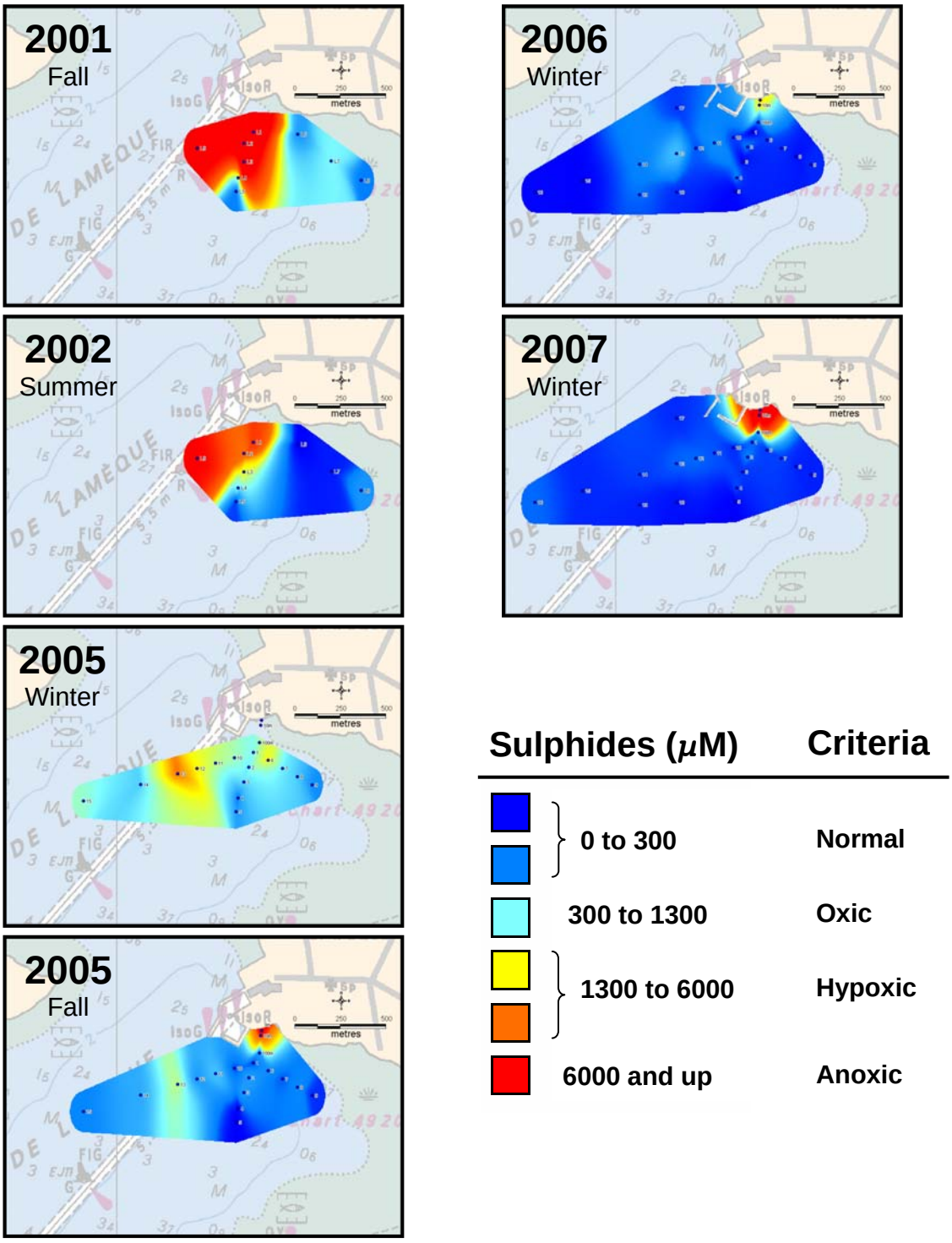

Figure 5: Sulphide readings illustrating the evolution of the oxygen concentration in the sediment from 2001 to 2007 (illustration prepared with the natural neighbours analysis).

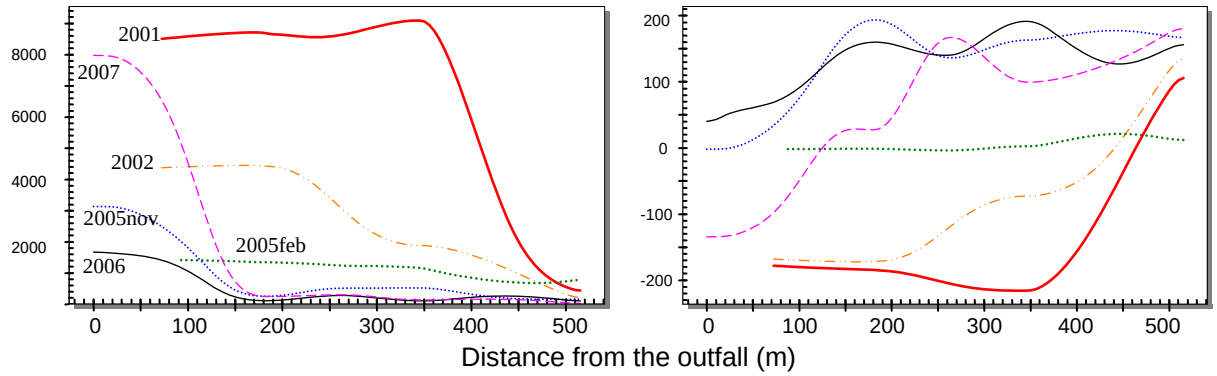

Figure 6: Transcect starting at the fish processing plant outfall and following the sampling stations in a straight line heading south. On left: Sulphides (μM); On right: Redox (mV).

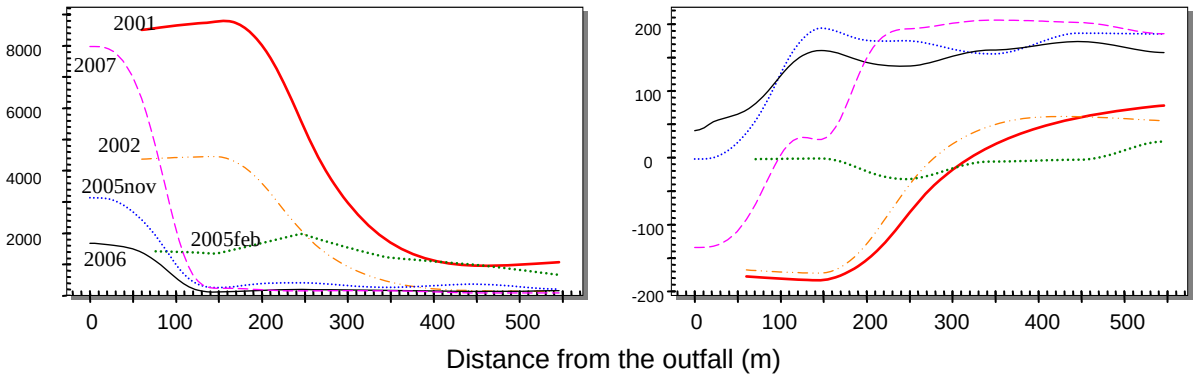

Figure 7: Transcect starting at the fish processing plant outfall and following the sampling stations along the shore line heading south-east. On left: Sulphides (μM); On right: Redox (mV).

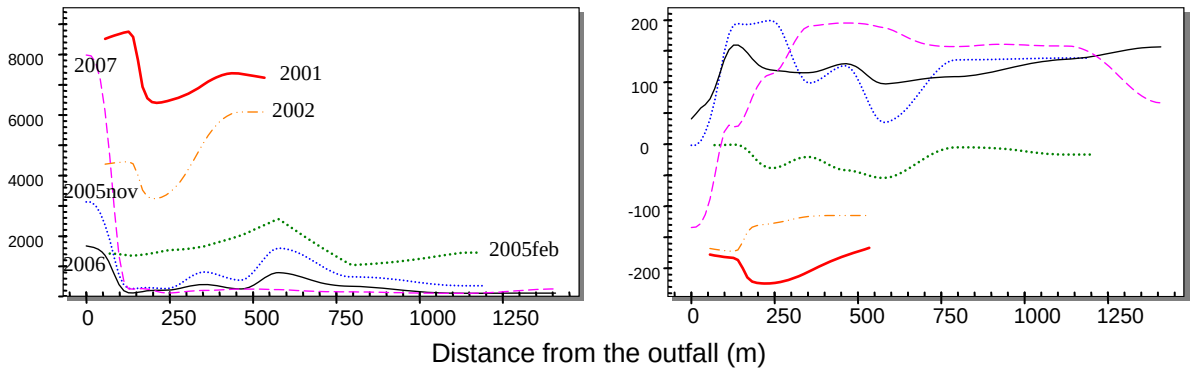

Figure 8: Transcect starting at the fish processing plant outfall and following the sampling stations heading south-west. On left: Sulphides (μM); On right: Redox (mV).

Improvement of sediment quality in the bay had a direct effect on the air quality in town (Table 2). The Air Quality Index is compiled by the New Brunswick Department of Environment. This index is also referred to as the IQUA (Index of the Quality of the Air). Based on Total Reduced Sulphur readings in the air (expressed in parts per billion), the number of "bad air quality" hours decreased significantly from 2002 to 2005. Consequently, complaints of noxious odour from residents reduced to the point that no air monitoring unit was required in 2006 or 2007.

Table 2: Air quality readings in Lamèque based on Total Reduced Sulphur (data from New-Brunswick Department of Environment).

Years	# of hour "poor" (> 10 ppb)	# of hour "very poor" (> 100 ppb)
2002	141	3
2003	119	8
2004	95	2
2005	9	0
2006	No unit deployed by the province	
2007	No unit deployed by the province	

4.0. DISCUSSION

4.1. IMPROVED OXYGENATION OF SEDIMENTS BETWEEN 2001 AND 2007

In 2001 and 2002, areas roughly 750 m X 500 m south of the seafood processing plant outfall in Lamèque Bay showed negative redox (< -100 mV) and high sulphide concentrations (> 6000 μM) characteristic of "anoxic" sediments. This was true in both summer (early July 2002) and fall (September 2001). By early (February) 2005 conditions had improved considerably to fall within the criteria for being "hypoxic" and by late 2005 (November) were within the "oxic" to "normal" range except within approximately 100 m of the outfall. "Normal" conditions, except in the immediate outfall area, were maintained through the winters of 2006 and 2007. The areal extent affected around the pipe outfall was probably quite small. A survey conducted by the same contractor, using the same methods in March 2006 showed "hypoxic" sediments at the pipe outfall and 10 m away but "normal" to "oxic" sediments 100 m away (Courtenay et al. unpublished data).

The muddy sediments of the southern Gulf of St. Lawrence can be "hypoxic" or even "anoxic" naturally (Shaw 1998; Miron et al. 2005). However, Mallet et al. (2006) measured redox and sulphide levels in surficial sediments of St-Simon Bay just to the west of Lamèque Bay approximately bi-monthly from June 2002 to October 2003 and they found generally positive redox levels (mean 226±84 mV) and sulphide levels below the "hypoxic" range (mean 733±30 μM). More recent redox and sulphide data collected by DFO confirmed "normal" to "oxic" conditions in St-Simon Bay (G. Robichaud, Gulf Fisheries Centre, Moncton, unpublished data). These data were collected by the same contractor as was used in the present study and in exactly the same way. Of thirty sites sampled throughout St-Simon Bay in November 2006 all showed "normal" or "oxic" conditions with two exceptions (Eh: -54 mV and sulphide 1230 μM; Eh: -15 mV and sulphide 1410 μM). Therefore the "hypoxic" and "anoxic" sediments within Lamèque Bay in 2001-2002 would not be considered within the range of "normal" conditions. However, Lamèque Bay is not unique among anthropogenically impacted areas of the southern Gulf of St. Lawrence.

Interestingly though sediments from coastal environments receiving the effluents of four other seafood processing plants in the southern Gulf of St. Lawrence did not show "hypoxic" or "anoxic" sediments (Courtenay et al. unpublished data). These sites were sampled at the end of pipe, 10 metres and 100 metres away in March 2006. One plant showed "hypoxic" sediments at the pipe outfall but the other three did not and all four showed "normal" to "oxic" sediments 10 metres and 100 metres away from the outfall. The fish plants discharging into these four areas were all much smaller than the Co-op in Lamèque and most discharged into better flushed environments. Flushing can make a big difference to the assimilative capacity of a coastal bay or estuary receiving effluent. One other fish plant receiving environment sampled in the March 2006 study was Black's Harbour (Bay of Fundy) which receives effluent from a very large herring processor. Though sediments at the outfall and 10 metres away were actually "anoxic", sediments 100 metres away within the normal range; presumably because of flushing from some of the highest tides in the world.

The rate of improvement in the oxygenation of surficial sediments in Lamèque Bay was much faster than had been anticipated. It was noted at the 2003 Shippagan workshop on fish plant effluents (Morry et al. 2003) that nutrients had entered the sediments through decomposition of sea lettuce and direct deposit of large quantities of oil, grease and suspended solids discharged by the Lamèque Co-op effluent. These nutrients could only be removed, it was suggested, by removing the sediments from the bay. A 2005 proposal for sediment remediation in Lamèque Bay from Dalhousie University's Centre for Water Resource Studies stated that "Regardless of treatment processes implemented in the seafood processing plant, the sediment and algae will continue to be a source for nutrients and anoxia for many years." (Jamieson and Gagnon 2005).

4.2. WHAT CAUSED THE IMPROVEMENT?

So what changed between 2002 and 2005 that might explain this rapid and dramatic improvement in oxygenation of the sediments? There are several sources of nutrients to Lamèque Bay including municipal wastewater but the greatest by far is the Island Fishermen Cooperative fish processing facility (Roy et al. 2003). The plant did not reduce quantity of product processed over the years 2001-2005 and in fact there was a small increase in quantity of

crab, shrimp and herring processed (Gérard Benoît, Special Projects Coordinator, *Association Coopérative des Pêcheurs de L'Île Ltée*, pers. comm.). However, a number of changes did occur within the plant. In 2002 the fish plant analysed the volume and characteristics of its effluent and created an in-plant committee to apply Best Management Practises (Coastal Zones Research Institute Inc. 2003; Morry 2006). Employees were trained to reduce the volume of water used and loss of organic matter which included the testing of a Dissolved Air Filtration (DAF) as a pilot plant. In 2004 a new evaporator system was installed in the fishmeal plant to treat the stick water coming from the herring meal operation and the next year a DAF unit was installed to remove 85% of suspended solids from wastewater leaving the plant. Between 2001 and 2006 water use dropped from approximately 4500 L/min to 2500 L/min and the DAF unit removed over 2 metric tons of solids per day during days of two 9-hour shrimp shifts (Gérard Benoît, Special Projects Coordinator, *Association Coopérative des Pêcheurs de L'Île Ltée*, pers. comm.).

In addition to reducing nutrient inputs to Lamèque Bay from the Co-op fish plant a considerable effort was made by the municipality of Lamèque and the Coalition environmental group starting in 2003 to remove sea-lettuce from the shore and nearshore area as described in the Introduction (see Appendix A for details). This program removed between 90 and 300 cubic metres of sea lettuce per year.

4.3. WHAT EFFECT DID SEDIMENT DEGRADATION HAVE ON THE FLORA AND THE FAUNA OF LAMÈQUE BAY?

Redox potentials and total sulphides have proven to be among the most sensitive indicators of sediment organic enrichment (Hargrave et al. 1997) but what is of real concern is the effect on the plants and animals living in, on and above the sediments. Biomass or species composition of benthic macrofauna may be affected even before redox or sulphide changes are noted (Pearson and Rosenberg 1978; Wildish and Pohle 2005). With mild organic enrichment, the abundance of certain taxa and even the numbers of kinds of animals present (richness) may increase but with pronounced enrichment both the abundance and species richness will decline (McKindsey et al. 2006).

Unfortunately no data have been collected on the benthic invertebrate community of Lamèque Bay. Shellfish harvesting has been prohibited for decades due to bacterial and chemical pollution in the vicinity of the town and port (SEnPAq 1990). With the anoxic conditions near the fish plant outfall it is reasonable to expect that benthic infauna would have been depauperate or even non-existent at the start of this study (early 2000s). It would have been very interesting to see if the community a kilometre away from the outfall more nearly approximated the benthic community typical of unimpacted bays in the southern Gulf of St. Lawrence, or whether enrichment effects extended to the whole of Lamèque Bay. For comparison, benthic infauna data have been collected from other bays and estuaries of the southern Gulf of St. Lawrence through Environmental Effects Monitoring programs of pulp and paper mills since 1992 (e.g., Atholville, Dalhousie, Bathurst, Miramichi), a study of oysters in Caraquet, Miramichi, Buctouche and Cocagne (Milewski and Chapman 2002) and through research programs on environmental effects of bivalve aquaculture (e.g., Shaw 1998; Miron et al. 2005; Mallet et al. 2006). Collection of benthic invertebrate data would also have permitted testing the hypothesis that improvement in sediment geochemistry between 2001 and 2007 near the fish plant was

accompanied by reestablishment of a normal benthic community. That said, instituting such a monitoring program now would still be of value in assessing the health of Lamèque Bay sediments and tracking the success of mitigation measures now in place.

Increase in the biomass of sea lettuce in Lamèque Bay may also have resulted in declines in areal coverage and biomass of eelgrass (*Zostera marina*) (see references cited by Milewski and Chapman 2002 and Lotze et al. 2003). No measures were made in the present study of the relative abundance or health of eelgrass but eelgrass beds covered 51% of Lamèque Bay in 1988 (SEnPAq 1990). There is great interest presently within a working group of DFO and other government partners to assess coverage and health of eelgrass beds throughout the southern Gulf of St. Lawrence. Therefore there may be an opportunity to assess whether the recent degradation of Lamèque Bay has affected its eelgrass beds, and if so, to monitor their recovery now that nutrient inputs have been reduced and sediments appear to be recovering. Recovery of eelgrass following anoxic events has been documented elsewhere and can be surprisingly rapid (Plus et al. 2003).

Lotze et al. (2003) surveyed eelgrass beds in Lamèque Bay in July 2002 and compared them to other estuaries with high nutrient inputs (Cocagne, Buctouche, Baie Ste-Anne) and lower nutrient inputs (Kouchibouguac, Kouchibouguacacis, Tabusintac). Eelgrass beds from the high nutrient estuaries were patchier, covered less area overall, and showed more epiphytic growth than beds from less impacted estuaries. Lamèque and the other nutrient rich estuaries also showed more algae and phytoplankton and signs of anoxic conditions including hydrogen sulphide gas. The associated epibenthic animal community was also different, with more detritivores and less herbivores and predators than in the more pristine estuaries.

To the best of our knowledge there are no historic data on the nekton (nearshore fish and large invertebrates) of Lamèque Bay so we do not know what existed before the Bay became heavily eutrophied. However, such data have been collected in recent years (Weldon et al. 2005, 2007). Beginning in 2003 the Community Aquatic Monitoring Program (CAMP) has been recording the numbers and species of animals caught by beach seine at six stations around the Bay. Data from 2003 showed both lower species richness (fewer taxa) and lower overall abundance in Lamèque Bay than in three other sites sampled around the southern Gulf of St. Lawrence (Scoudouc River estuary in NB, Basin Head lagoon in PEI and Antigonish Harbour in NS; Theriault et al. 2006). Data collected in subsequent years (2004-2007) have confirmed this difference but have also shown similarly low richness and abundance in other northern NB sites. Additional work will be required to determine whether Lamèque Bay's relatively depauperate faunal community is related to the degraded environment or to other factors such as geography. As well, the CAMP database will permit testing of the hypothesis that the nekton community will change as the sediments of Lamèque Bay continue to recover.

4.4. AIR QUALITY

Though the environmental health of Lamèque Bay has probably been in decline for many years, the impetus for remediation and reduction of nutrient inputs was concerns over air quality and human health. Complaints over noxious odours had been received since the early 1990s and in 2002 the NB Department of Environment and Local Government installed an air quality monitoring unit in the centre of the residential area of Lamèque to test the air for signs of hydrogen sulphide, ozone and other chemicals. That same year health advisories were issued twice cautioning people to stay indoors during the periods of poor air quality. The number of hours of poor or very poor air quality decreased over the years 2002-2005 from 144 to 9 following which the province did not feel it necessary to continue monitoring. No complaints of bad air quality were received from residents in 2006. However, during the summer of 2007 several complaints were received about odours and pink-coloured water moving east along the shore from the Co-op effluent discharge pipe. The reason for this is unclear but may be related to the fact that since 2006 the plant has continued processing throughout the year. Previously, the plant shut down between December and March which may have allowed a period of natural remediation for Lamèque Bay.

5.0. CONCLUSION

It has become clear in the last few decades that coastal ecosystems worldwide, including the southern Gulf of St. Lawrence, are more fragile than previously thought. With increasing numbers of people living and working along our estuaries and bays, cumulative impacts are causing unforeseen changes in areas that have sustained people for generations. One major impact is the addition of more nutrients, from sewage, agriculture, industry and the fishing and processing industry, than can be assimilated in low flushing environments. Resulting degradation has caused ecological, aesthetic and even human health concerns. Because of the complexity of these ecosystems, it is difficult to predict their natural recovery as well as the impact of our actions. In the case of Lamèque Bay, efforts made by the town, the community group and the industry improved the oxygenation of the sediments more quickly than had been anticipated. Impacts of reduced nutrient loads on the ecology of the Bay remain to be seen. Furthermore, a recent increase in the quantity of marine product processed and extended processing periods may have a negative impact by exceeding the assimilative capacity of the receiving environment and by decreasing the natural recovery period usually available during winter time. For these reasons we recommend continued monitoring of Lamèque Bay to further our understanding of coastal eutrophication and remediation processes.

6.0. ACKNOWLEDGEMENTS

We would like to thank Dr. Michael Chadwick (DFO, Gulf Region, Oceans and Science Regional Director) for his leadership on the fish plant file since 2003 and his continuing support for this project. We would also like to thank Brad Firth (DFO, GIS Technician) for his assistance and expertise with all the mapping related analysis.

We are also grateful to Bertin Gauvin (*la Coalition pour la viabilité de l'environnement de Shippagan et des Îles Lamèque et Miscou*), Eric Garnier (Dominator Marine Services Inc.) and their respective teams for the excellent field sampling under extremely rugged winter conditions and for their laboratory analysis. This work would not have been possible without the support of Paul Orel Chiasson (General Director) and Gérard Benoît (Special Projects Coordinator) from the *Association Coopérative des Pêcheurs de L'Île Ltée*, Georges Lindsay, recently retired manager of the Environment Canada New Brunswick regional office in Fredericton, and Dr. Barry Hargrave, recently retired research scientist at the DFO's Bedford Institute of Oceanography in Dartmouth, Nova Scotia.

This manuscript was considerably improved by the suggestions of reviewers Pierre Mallet (DFO, Ecosystem Biologist) and Ernest Ferguson (DFO, Habitat Area Chief in Tracadie-Sheila, New Brunswick).

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APPENDIX A

Table A_1: Results of the algae harvesting operations in Lamèque Bay (in metric tons) during summer (source: Town of Lamèque).

Year	On the shoreline	In the bay	Total
2003	70	20	90
2004	120	12	132
2005	80	70	150
2006	70	120	190
2007	70	147	217

Figure A_1: Algae harvesting from the shoreline with traditional machinery (source: Coalition pour la viabilité de l'environnement de Shippagan et des Îles Lamèque et Miscou).

Figure A_2: Algae harvesting from the platform built on the shoreline. On left, perforated excavator bucket; on right, modified trawl towed by the excavator (source: Coalition pour la viabilité de l'environnement de Shippagan et des Îles Lamèque et Miscou).

Figure A_3: Algae harvesting in the bay (at sea) with modified traditional commercial fishing gear. On left, modified Devism trawl; on right, modified scallop dredge.

Figure A_4: Algae harvesting in the bay (at sea) using an aquatic plant harvester (on left) and an amphibian excavator equipped with a modified perforated bucket (on right).

APPENDIX B

September 10, 2001: Sediment chemistry results and sample station description

Station	Location Lat/long (WGS 84)	Sample	TOC (%)	Moisture (%)	Sediment Redox (mV)	Sediment Redox adjusted (mV)	Sulphide Concentration (μm)	Water depth (m)	Sediment description			
									Thickness	Colour	Consistency	Odour
L1	N 47° 47.354 W 64' 39.396	1	-	-	-	-183.8	8 760	3.0	>8 cm	Black	Fine	H_2S
L2	N 47° 47.320 W 64° 39.437	2	-	-	-	-225.4	6 340	3.1	>8 cm	Black	Fine	H_2S
L3	N 47° 47.266 W 64° 39.437	3	-	-	-	-216.4	9 100	3.2	>8 cm	Black	Fine	H_2S
L4	N 47° 47.218 W 64° 39.462	4	-	-	-	-94.6	1 530	3.0	>8 cm	Grey	Fine	H_2S
L5	N 47° 47.178 W 64° 39.472	5	-	-	-	105.7	420	3.5	2-8 cm	Brown	Coarse	None
L6	N 47° 47.348 W 64° 39.200	6	-	-	-	48.5	610	2.1	2 cm	Brown	Coarse	None
L7	N 47° 47.268 W 64° 39.053	7	-	-	-	85.3	1 260	1.8	2 cm	Brown	Coarse / Fine	None
L8	N 47° 47.210 W 64° 39.920	8	-	-	-	104.3	390	0.8	2 cm	Brown / Grey	Coarse	None
L9	N 47° 47.306 W 64° 39.645	9	-	-	-	-179.1	7 350	3.4	>8 cm	Black	Fine	H_2S

July 2, 2002: Sediment chemistry results and sample station description

Station	Location Lat/long (WGS 84)	Sample	TOC (%)	Moisture (%)	Sediment Redox (mV)	Sediment Redox adjusted (mV)	Sulphide Concentration (μm)	Water depth (m)	Sediment description			
									Thickness	Colour	Consistency	Odour
L1	N 47˚ 47.354 W 64˚ 39.396	1	-	-	-	-172.9	4 450	3.2	>8 cm	Black	Fine	H_2S
L2	N 47˚ 47.320 W 64˚ 39.437	2	-	-	-	-129.9	3 160	3.3	>8 cm	Black	Fine	H_2S
L3	N 47˚ 47.266 W 64˚ 39.437	3	-	-	-	-73.1	1 875	3.4	>8 cm	Black / Grey	Fine / Coarse	Slight H_2S
L4	N 47˚ 47.218 W 64˚ 39.462	4	-	-	-	-41.5	1 260	3.1	>8 cm	Grey	Fine	Slight H_2S
L5	N 47˚ 47.178 W 64˚ 39.472	5	-	-	-	135.1	205	3.6	2-8 cm	Brown	Coarse	None
L6	N 47˚ 47.348 W 64˚ 39.200	6	-	-	-	71.8	110	2.3	>8 cm	Brown	Coarse	None
L7	N 47˚ 47.268 W 64˚ 39.053	7	-	-	-	49.2	148	2.0	>8 cm	Brown	Coarse / Fine	None
L8	N 47˚ 47.210 W 64˚ 39.920	8	-	-	-	20.1	465	1.1	>8 cm	Grey	Coarse	Very Slight H_2S
L9	N 47˚ 47.306 W 64˚ 39.645	9	-	-	-	-115.3	6 100	3.7	>8 cm	Black	Fine	H_2S

February 26-27, 2005: Sediment chemistry results and sample station description

Station	Location Lat/long (WGS 84)	Sample	TOC (%)	Moisture (%)	Sediment Redox (mV)	Sediment Redox adjusted (mV)	Sulphide Concentration (μm)	Water depth (m)	Sediment description			
									Thickness	Colour	Consistency	Odour
1	N 47˚ 47.354 W 64˚ 39.396	1a	1.1	41	-230	-7	1 350	3.3	>8 cm	Grey / black	Fine	H_2S
		1b	1.1	45	-217	6	1 210					
		1c	1.1	41	-226	-3	1 465					
2	N 47˚ 47.310 W 64˚ 39.416	2a	1.1	39	-225	-2	1 170	3.0	>8 cm	Grey / black	Fine / coarse	H_2S
		2b	1.4	36	-218	5	1 220					
		2c	0.98	35	-238	-15	1 290					
3	N 47˚ 47.266 W 64˚ 39.437	3a	1.2	45	-215	8	1 060	3.6	>8 cm	Brown / Grey	Fine / coarse	H_2S
		3b	0.89	44	-228	-5	1 240					
		3c	0.84	41	-219	4	1 185					
4	N 47˚ 47.218 W 64˚ 39.462	4a	0.91	39	-215	8	741	3.6	>8 cm	Grey	Fine / coarse	Slight H_2S
		4b	0.83	41	-178	45	510					
		4c	1.0	35	-203	20	416					
5	N 47˚ 47.178 W 64˚ 39.472	5a	0.94	38	-206	17	920	3.6	>8 cm	Grey	Fine / coarse	Slight H_2S
		5b	0.92	41	-211	12	716					
		5c	1.0	38	-216	7	725					
6	N 47˚ 47.330 W 64˚ 39.331	6a	2.5	60	-268	-45	2 015	3.0	>8 cm	Black	Fine	H_2S
		6b	1.3	49	-246	-23	1 860					
		6c	1.7	56	-252	-29	2 095					
7	N 47˚ 47.306 W 64˚ 39.266	7a	1.4	45	-220	3	1 075	3.0	>8 cm	Grey / Brown	Fine	Slight H_2S
		7b	1.0	42	-241	-18	1 560					
		7c	1.5	34	-226	-3	1 040					
8	N 47˚ 47.282 W 64˚ 39.201	8a	0.98	36	-213	10	964	2.7	>8 cm	Grey / Brown	Fine	Slight H_2S
		8b	0.76	35	-247	-23	1 140					
		8c	0.89	36	-220	3	875					

Feruary 26-27, 2005 (cont'd): Sediment chemistry results and sample station description

Station	Location Lat/long (WGS 84)	Sample	TOC (%)	Moisture (%)	Sediment Redox (mV)	Sediment Redox adjusted (mV)	Sulphide Concentration (μm)	Water depth (m)	Sediment description			
									Thickness	Colour	Consistency	Odour
9	N 47˚ 47.257 W 64˚ 39.136	9a	0.59	35	-179	44	724	2.7	>8 cm	Brown / Grey	Fine / coarse	Slight H_2S
		9b	0.81	28	-208	15	608					
		9c	0.90	33	-210	13	653					
10	N 47˚ 47.338 W 64˚ 39.479	10a	1.6	46	-259	-36	1 380	3.6	>8 cm	Grey / Brown	Fine	H_2S
		10b	0.87	43	-272	-49	1 610					
		10c	1.3	64	-256	-33	1 595					
11	N 47˚ 47.322 W 64˚ 39.562	11a	1.8	52	-243	-20	1 710	3.0	>8 cm	Grey / black	Fine	H_2S
		11b	1.3	46	-240	-17	1 600					
		11c	1.3	51	-249	-26	1 640					
12	N 47˚ 47.306 W 64˚ 39.645	12a	3.4	67	-279	-53	1 870	3.6	>8 cm	Black / grey	Fine	H_2S
		12b	3.5	63	-255	-32	2 150					
		12c	3.5	64	-266	-43	2 035					
13	N 47˚ 47.290 W 64˚ 39.730	13a	4.9	74	-276	-53	2 200	7.0	>8 cm	Black	Fine	H_2S
		13b	5.2	74	-280	-57	2 845					
		13c	5.2	76	-278	-55	2 650					
14	N 47˚ 47.258 W 64˚ 39.894	14a	3.5	69	-221	2	965	3.9	>8 cm	Grey / Brown	Fine	Slight H_2S
		14b	3.4	68	-240	-17	1 030					
		14c	3.2	67	-225	-2	1 100					
15	N 47˚ 47.209 W 64˚ 40.145	15a	2.6	64	-250	-27	1 530	3.7	>8 cm	Grey / Brown	Fine	Slight H_2S
		15b	3.5	70	-230	-7	1 190					
		15c	3.1	65	-241	-18	1 620					

November 18-19, 2005: Sediment chemistry results and sample station description

Station	Location Lat/long (WGS 84)	Sample	TOC (%)	Moisture (%)	Sediment Redox (mV)	Sediment Redox adjusted (mV)	Sulphide Concentration (μm)	Water depth (m)	Sediment description			
									Thickness	Colour	Consistency	Odour
1	N 47˚ 47.354 W 64˚ 39.396	1a	1.2	52.2	-20.4	199.6	165.0	2.7	>8 cm	Grey	Fine	None
		1b	1.5	54.8	-26.8	193.2	209.0					
		1c	1.9	59.4	-31.2	188.8	375.0					
2	N 47˚ 47.310 W 64˚ 39.416	2a	1.0	43.5	-73.6	146.4	327.0	2.7	>8 cm	Grey	Fine	Very slight H_2S
		2b	1.1	45.5	-117.6	102.4	781.0					
		2c	0.86	44.9	-61.2	158.8	425.0					
3	N 47˚ 47.266 W 64˚ 39.437	3a	1.3	47.9	-85.8	134.2	530.0	2.7	>8 cm	Brown / Grey	Fine	None
		3b	0.83	42.0	-46.2	173.8	416.0					
		3c	0.73	43.2	-39.0	181.0	613.0					
4	N 47˚ 47.218 W 64˚ 39.462	4a	0.82	41.7	-58.4	161.6	126.0	2.7	>8 cm	Brown / Grey	Fine	None
		4b	0.87	42.1	-41.8	178.2	204.0					
		4c	0.95	45.7	-18.2	201.8	138.0					
5	N 47˚ 47.178 W 64˚ 39.472	5a	1.3	50.2	-25.4	194.6	61.9	3.3	>8 cm	Brown / Grey	Fine	None
		5b	1.0	43.9	-102.8	117.2	278.0					
		5c	1.1	46.1	-31.0	189.0	113.0					
6	N 47˚ 47.330 W 64˚ 39.331	6a	0.90	41.6	-67.4	152.6	372.0	3.0	>8 cm	Brown / Grey	Fine	None
		6b	0.93	44.1	-32.0	188.0	524.0					
		6c	1.2	44.7	-36.4	183.6	321.0					
7	N 47˚ 47.306 W 64˚ 39.266	7a	1.1	46.2	-45.2	174.8	216.0	2.7	>8 cm	Brown / Grey	Fine	None
		7b	1.2	44.8	-86.0	134.0	381.0					
		7c	1.2	46.2	-63.8	156.2	185.0					
8	N 47˚ 47.282 W 64˚ 39.201	8a	0.74	36.4	-54.2	165.8	365.0	3.0	>8 cm	Brown / Grey	Fine	None
		8b	0.95	43.1	-28.4	191.6	416.0					
		8c	1.2	45.6	-19.2	200.8	306.0					

November 18-19, 2005 (cont'd): Sediment chemistry results and sample station description

Station	Location Lat/long (WGS 84)	Sample	TOC (%)	Moisture (%)	Sediment Redox (mV)	Sediment Redox adjusted (mV)	Sulphide Concentration (μm)	Water depth (m)	Sediment description			
									Thickness	Colour	Consistency	Odour
9	N 47˚ 47.257 W 64˚ 39.136	9a	0.82	37.6	-44.2	175.8	225.0	2.7	>8 cm	Brown / Grey	Fine / coarse	None
		9b	0.67	34.2	-27.4	192.6	207.0					
		9c	0.84	40.4	-33.6	186.4	182.0					
10	N 47˚ 47.338 W 64˚ 39.479	10a	2.0	52.4	-18.6	201.4	170.0	3.6	>8 cm	Brown / Grey	Fine	None
		10b	1.6	54.9	-14.4	205.6	316.0					
		10c	1.4	50.8	-31.6	188.4	278.0					
11	N 47˚ 47.322 W 64˚ 39.562	11a	1.7	52.8	-168.2	51.8	712.0	3.6	>8 cm	Grey	Fine	Slight H_2S
		11b	2.4	56.0	-115.2	104.8	890.0					
		11c	1.6	52.2	-83.6	136.4	816.0					
12	N 47˚ 47.306 W 64˚ 39.645	12a	4.1	78.6	-65.2	154.8	136.0	5.5	>8 cm	Brown / Grey	Fine	Slight H_2S
		12b	4.9	79.6	-115.0	105.0	648.0					
		12c	4.5	78.8	-102.0	118.0	812.0					
13	N 47˚ 47.290 W 64˚ 39.730	13a	4.1	77.6	-137.4	82.6	1 140.0	5.5	>8 cm	Brown / Grey	Fine	H_2S
		13b	4.7	78.6	-216.6	3.4	1 745.0					
		13c	4.1	77.7	-202.4	17.6	1 910.0					
14	N 47˚ 47.258 W 64˚ 39.894	14a	3.1	69.1	-84.8	135.2	609.0	3.0	>8 cm	Brown / Grey	Fine	None
		14b	3.2	70.8	-81.6	138.4	515.0					
		14c	3.3	71.8	-87.8	132.2	816.0					
15	N 47˚ 47.209 W 64˚ 40.145	15a	3.0	70.2	-106.6	113.4	520.0	3.2	>8 cm	Brown / Grey	Fine	None
		15b	3.1	74.5	-61.8	158.2	321.0					
		15c	3.4	74.6	-77.4	142.6	218.0					
Outfall + 0m	N 47˚ 47.438 W 64˚ 39.360	+0a	0.51	28.8	-223.6	-3.6	3 260.0	0.8	2-8 cm	Black / Grey	Fine / coarse / cobble	H_2S
		+0b	0.83	33.5	-205.6	14.4	2 870.0					
		+0c	1.0	34.7	-209.0	11.0	2 010.0					

November 18-19, 2005 (cont'd): Sediment chemistry results and sample station description

Station	Location Lat/long (WGS 84)	Sample	TOC (%)	Moisture (%)	Sediment Redox (mV)	Sediment Redox adjusted (mV)	Sulphide Concentration (μm)	Water depth (m)	Sediment description			
									Thickness	Colour	Consistency	Odour
Outfall + 10m	N 47˚ 47.439 W 64˚ 39.360	+10a	0.73	30.6	-222.8	-2.8	2 650.0	1.0	2-8 cm	Black	Fine / coarse	H_2S
		+10b	0.64	32.4	-202.2	17.8	3 310.0					
		+10c	0.63	31.2	-270.2	-50.2	4 710.0					
Outfall +100m	N 47˚ 47.383 W 64˚ 39.369	+100a	1.2	41.6	-73.8	146.2	516.0	2.7	>8 cm	Brown / Grey	Fine / coarse	None
		+100b	0.94	41.2	-96.4	123.6	609.0					
		+100c	0.76	37.3	-84.8	135.2	364.0					

March 2-3, 2006: Sediment chemistry results and sample station description

Station	Location Lat/long (WGS 84)	Sample	TOC (%)	Moisture (%)	Sediment Redox (mV)	Sediment Redox adjusted (mV)	Sulphide Concentration (μm)	Water depth (m)	Sediment description			
									Thickness	Colour	Consistency	Odour
1	N 47˚ 47.354 W 64˚ 39.396	1a	1.2	46.6	-69.6	154.4	120.0	3.0	>8 cm	Brown / Grey	Fine	None
		1b	1.1	45.1	-60.0	164.0	113.0					
		1c	1.4	47.5	-61.2	162.8	82.9					
2	N 47˚ 47.310 W 64˚ 39.416	2a	1.0	44.8	-72.2	151.8	275.0	3.0	>8 cm	Brown / Grey	Fine	None
		2b	1.0	40.9	-90.2	133.8	217.0					
		2c	1.0	42.6	-88.0	136.0	336.0					
3	N 47˚ 47.266 W 64˚ 39.437	3a	0.91	42.6	-50.0	174.0	119.0	3.0	>8 cm	Brown / Grey	Fine	None
		3b	1.1	43.6	-36.8	187.2	125.0					
		3c	1.0	42.3	-9.0	215.0	62.2					
4	N 47˚ 47.218 W 64˚ 39.462	4a	0.83	41.9	-135.4	88.6	517.0	3.3	>8 cm	Brown / Grey	Fine	None
		4b	0.89	40.4	-92.6	131.4	181.0					
		4c	0.90	37.8	-95.0	129.0	208.0					
5	N 47˚ 47.178 W 64˚ 39.472	5a	1.1	44.4	-59.4	164.6	78.4	3.3	>8 cm	Brown / Grey	Fine	None
		5b	1.1	43.5	-70.8	153.2	118.0					
		5c	0.97	42.6	-73.2	150.8	109.0					
6	N 47˚ 47.330 W 64˚ 39.331	6a	1.3	46.5	-103.4	120.6	239.0	3.0	>8 cm	Brown / Grey	Fine / coarse	None
		6b	1.2	46.0	-74.4	149.6	185.0					
		6c	1.2	47.3	-84.0	140.0	140.0					
7	N 47˚ 47.306 W 64˚ 39.266	7a	1.1	43.5	-70.4	153.6	145.0	3.0	>8 cm	Brown / Grey	Fine / coarse	None
		7b	1.1	44.7	-65.6	158.4	181.0					
		7c	1.3	46.9	-53.2	170.8	164.0					
8	N 47˚ 47.282 W 64˚ 39.201	8a	0.97	43.1	-45.2	178.8	168.0	3.0	>8 cm	Brown / Grey	Fine / coarse	None
		8b	0.83	36.6	-50.0	174.0	115.0					
		8c	0.92	37.5	-55.6	168.4	89.3					

March 2-3, 2006 (cont'd): Sediment chemistry results and sample station description

Station	Location Lat/long (WGS 84)	Sample	TOC (%)	Moisture (%)	Sediment Redox (mV)	Sediment Redox adjusted (mV)	Sulphide Concentration (μm)	Water depth (m)	Sediment description			
									Thickness	Colour	Consistency	Odour
9	N 47˚ 47.257 W 64˚ 39.136	9a	0.61	34.8	-98.4	125.6	248.0	2.7	>8 cm	Brown / Grey	Fine / coarse	None
		9b	0.79	37.6	-55.0	169.0	105.0					
		9c	0.89	38.7	-47.2	176.8	115.0					
10	N 47˚ 47.338 W 64˚ 39.479	10a	1.7	56.0	-118.2	105.8	209.0	1.8	>8 cm	Brown / Grey	Fine	None
		10b	1.4	51.7	-92.4	131.6	261.0					
		10c	1.4	50.5	-104.2	119.8	129.0					
11	N 47˚ 47.322 W 64˚ 39.562	11a	1.4	51.1	-106.0	118.0	315.0	2.4	>8 cm	Brown / Grey	Fine	None
		11b	1.4	47.8	-92.0	132.0	360.0					
		11c	0.87	40.5	-129.2	94.8	494.0					
12	N 47˚ 47.306 W 64˚ 39.645	12a	3.5	69.6	-96.8	127.2	261.0	3.0	>8 cm	Brown / Grey	Fine	None
		12b	3.2	71.3	-94.2	129.8	302.0					
		12c	3.4	68.5	-92.6	131.4	149.0					
13	N 47˚ 47.290 W 64˚ 39.730	13a	4.8	79.0	-148.6	75.4	878.0	4.5	>8 cm	Grey / Brown	Fine	Slight H_2S
		13b	4.6	79.1	-123.2	100.8	922.0					
		13c	5.0	79.7	-109.6	114.4	550.0					
14	N 47˚ 47.258 W 64˚ 39.894	14a	3.5	70.7	-147.4	76.6	528.0	2.4	>8 cm	Brown / Grey	Fine	Very slight H_2S
		14b	3.1	71.6	-99.2	124.8	213.0					
		14c	3.1	73.7	-100.0	124.0	241.0					
15	N 47˚ 47.209 W 64˚ 40.145	15a	3.1	74.1	-95.2	128.8	72.9	3.0	>8 cm	Brown / Grey	Fine	None
		15b	2.8	71.8	-81.6	142.4	113.0					
		15c	3.4	74.4	-84.4	139.6	101.0					
16	N 47˚ 47.173 W 64˚ 40.357	16a	2.2	63.2	-74.6	149.4	142.0	3.0	>8 cm	Brown / Grey	Fine	None
		16b	2.2	66.1	-70.8	153.2	89.4					
		16c	2.3	61.3	-57.2	166.8	76.1					

March 2-3, 2006 (cont'd): Sediment chemistry results and sample station description

Station	Location Lat/long (WGS 84)	Sample	TOC (%)	Moisture (%)	Sediment Redox (mV)	Sediment Redox adjusted (mV)	Sulphide Concentration (μm)	Water depth (m)	Sediment description			
									Thickness	Colour	Consistency	Odour
17	N 47˚ 47.425 W 64˚ 39.733	17a	2.9	69.1	-102.4	121.6	182.0	3.0	>8 cm	Brown / Grey	Fine	Very slight H_2S
		17b	3.2	72.6	-120.6	103.4	238.0					
		17c	3.1	68.5	-118.0	106.0	145.0					
18	N 47˚ 47.179 W 64˚ 39.733	18a	1.6	53.4	-90.6	133.4	209.0	3.0	>8 cm	Brown / Grey	Fine	Very slight H_2S
		18b	1.5	52.5	-80.4	143.6	124.0					
		18c	1.7	51.5	-103.0	121.0	168.0					
19	N 47˚ 47.167 W 64˚ 39.895	19a	4.0	79.5	-85.0	139.0	209.0	6.1	>8 cm	Brown / Grey	Fine	Very slight H_2S
		19b	4.1	81.5	-75.4	148.6	178.0					
		19c	3.9	80.8	-127.6	96.4	417.0					
Outfall + 0m	N 47˚ 47.438 W 64˚ 39.360	+0a	0.31	22.3	-175.8	48.2	1 900.0	0.9	2-8 cm	Black	Fine / coarse / cobble	H_2S
		+0b	0.4	23.7	-185.6	38.4	1 690.0					
		+0c	0.4	21.8	-197.4	26.6	1 455.0					
Outfall + 10m	N 47˚ 47.439 W 64˚ 39.360	+10a	0.38	29.5	-117.8	106.2	1 140.0	1.8	2-8 cm	Grey / Black	Fine / coarse	Slight H_2S
		+10b	0.44	30.2	-162.6	61.4	1 495.0					
		+10c	0.40	30.1	-218.4	5.6	2 200.0					
Outfall +100m	N 47˚ 47.383 W 64˚ 39.369	+100a	0.81	36.8	-105.8	118.2	328.0	3.3	2-8 cm	Grey / Brown	Fine / coarse	None
		+100b	0.96	36.6	-87.0	137.0	290.0					
		+100c	0.72	33.7	-88.6	135.4	200.0					

March 2-3, 2007: Sediment chemistry results and sample station description

Station	Location Lat/long (WGS 84)	Sample	TOC (%)	Moisture (%)	Sediment Redox (mV)	Sediment Redox adjusted (mV)	Sulphide Concentration (μm)	Water depth (m)	Sediment description			
									Thickness	Colour	Consistency	Odour
1	N 47˚ 47.354 W 64˚ 39.396	1a	4.20	71.51	-161	63.0	94.6	3.9	>8 cm	Brown / Grey	Fine	Slight H_2S
		1b	4.30	73.52	-150	74.0	135.0					
		1c	4.10	70.85	-281	-57.0	482.0					
2	N 47˚ 47.310 W 64˚ 39.416	2a	1.50	45.92	-88	136.0	291.0	3.9	>8 cm	Brown / Grey	Fine	Slight H_2S
		2b	1.50	52.16	-67	157.0	286.0					
		2c	1.10	43.72	-15	209.0	34.0					
3	N 47˚ 47.266 W 64˚ 39.437	3a	1.10	41.84	-126	98.0	106.0	4.2	>8 cm	Brown / Grey	Fine	None
		3b	1.20	45.01	-69	155.0	98.3					
		3c	0.72	38.35	-180	44.0	176.0					
4	N 47˚ 47.218 W 64˚ 39.462	4a	0.82	40.17	-144	80.0	276.0	4.2	>8 cm	Brown / Grey	Fine	None
		4b	0.77	38.89	-62	162.0	106.0					
		4c	0.83	38.45	-89	135.0	121.0					
5	N 47˚ 47.178 W 64˚ 39.472	5a	0.93	46.01	-16	208.0	12.9	3.9	>8 cm	Brown / Grey	Fine	None
		5b	1.00	46.70	-12	212.0	26.8					
		5c	1.10	43.42	-103	121.0	14.1					
6	N 47˚ 47.330 W 64˚ 39.331	6a	1.40	48.46	-12	212.0	185.0	4.2	>8 cm	Brown / Grey	Fine / coarse	None
		6b	1.50	49.51	-6	218.0	115.0					
		6c	1.60	52.52	-76	148.0	162.0					
7	N 47˚ 47.306 W 64˚ 39.266	7a	1.10	44.07	-40	184.0	126.0	3.9	>8 cm	Brown / Grey	Fine / coarse	None
		7b	1.20	44.71	-9	215.0	164.0					
		7c	1.10	45.42	-6	218.0	181.0					
8	N 47˚ 47.282 W 64˚ 39.201	8a	1.00	44.89	-20	204.0	89.4	3.6	>8 cm	Brown / Grey	Fine / coarse	None
		8b	0.91	43.94	-16	208.0	110.0					
		8c	0.80	39.06	-29	195.0	73.8					

March 2-3, 2007 (cont'd): Sediment chemistry results and sample station description

Station	Location Lat/long (WGS 84)	Sample	TOC (%)	Moisture (%)	Sediment Redox (mV)	Sediment Redox adjusted (mV)	Sulphide Concentration (μm)	Water depth (m)	Sediment description			
									Thickness	Colour	Consistency	Odour
9	N 47˚ 47.257 W 64˚ 39.136	9a	0.73	38.25	-31	193.0	107.0	3.3	>8 cm	Brown / Grey	Fine / coarse	None
		9b	0.74	37.59	-45	179.0	88.9					
		9c	0.71	37.05	-40	184.0	62.5					
10	N 47˚ 47.338 W 64˚ 39.479	10a	1.70	62.02	-192	32.0	187.0	3.9	>8 cm	Brown / Grey	Fine	None
		10b	1.70	54.80	-7	217.0	30.6					
		10c	1.60	52.68	-135	89.0	126.0					
11	N 47˚ 47.322 W 64˚ 39.562	11a	1.80	56.83	-60	164.0	198.0	3.9	>8 cm	Brown / Grey	Fine	None
		11b	1.90	57.72	-34	190.0	216.0					
		11c	2.30	57.78	-9	215.0	187.0					
12	N 47˚ 47.306 W 64˚ 39.645	12a	3.90	72.40	-27	197.0	254.0	4.2	>8 cm	Brown / Grey	Fine	None
		12b	3.80	71.97	-20	204.0	211.0					
		12c	3.50	68.50	-41	183.0	267.0					
13	N 47˚ 47.290 W 64˚ 39.730	13a	5.10	79.82	-26	198.0	214.0	6.1	>8 cm	Grey / Brown	Fine	Very slight H_2S
		13b	5.00	80.48	-45	179.0	267.0					
		13c	4.80	79.22	-40	184.0	196.0					
14	N 47˚ 47.258 W 64˚ 39.894	14a	3.40	70.98	-57	167.0	116.0	3.9	>8 cm	Brown / Grey	Fine	None
		14b	2.90	67.59	-120	104.0	196.0					
		14c	3.20	70.43	-25	199.0	143.0					
15	N 47˚ 47.209 W 64˚ 40.145	15a	3.10	69.58	-36	188.0	86.4	3.9	>8 cm	Brown / Grey	Fine	None
		15b	3.20	70.97	-29	195.0	125.0					
		15c	3.50	73.76	-134	90.0	99.2					
16	N 47˚ 47.173 W 64˚ 40.357	16a	2.30	63.53	-207	17.0	326.0	3.9	>8 cm	Grey	Fine	Slight H_2S
		16b	2.20	63.79	-175	49.0	370.0					
		16c	2.20	61.05	-92	132.0	49.9					

March 2-3, 2007 (cont'd): Sediment chemistry results and sample station description

Station	Location Lat/long (WGS 84)	Sample	TOC (%)	Moisture (%)	Sediment Redox (mV)	Sediment Redox adjusted (mV)	Sulphide Concentration (μm)	Water depth (m)	Sediment description			
									Thickness	Colour	Consistency	Odour
17	N 47˚ 47.425 W 64˚ 39.733	17a	2.60	66.24	-81	143.0	90.4	4.2	>8 cm	Brown / Grey	Fine	None
		17b	2.70	65.94	-120	104.0	156.0					
		17c	2.50	65.25	-25	199.0	87.4					
18	N 47˚ 47.179 W 64˚ 39.733	18a	2.00	56.16	-95	129.0	27.4	4.5	>8 cm	Brown / Grey	Fine	None
		18b	1.80	56.60	-125	99.0	78.5					
		18c	1.90	52.98	-120	104.0	60.2					
19	N 47˚ 47.167 W 64˚ 39.895	19a	4.00	79.21	-40	184.0	80.9	6.4	>8 cm	Brown / Grey	Fine	Very slight H_2S
		19b	4.00	79.92	-36	188.0	106.0					
		19c	4.00	78.51	-21	203.0	77.5					
Outfall + 0m	N 47˚ 47.438 W 64˚ 39.360	+0a	16.00	84.09	-388	-164.0	10 900.0	1.5	2-8 cm	Black	Semi-liquid / Fine / coarse / cobble	H_2S
		+0b	17.00	83.57	-369	-145.0	11 200.0					
		+0c	17.20	83.31	-401	-177.0	12 000.0					
Outfall + 10m	N 47˚ 47.439 W 64˚ 39.360	+10a	0.51	32.88	-344	-120.0	5 050.0	2.4	2-8 cm	Black	Fine / coarse	H_2S
		+10b	0.46	34.25	-347	-123.0	4 690.0					
		+10c	0.43	28.27	-303	-79.0	4 040.0					
Outfall +100m	N 47˚ 47.383 W 64˚ 39.369	+100a	0.91	39.09	-209	15.0	816.0	3.9	2-8 cm	Grey / Brown	Fine / coarse	Slight H_2S
		+100b	0.81	38.01	-173	51.0	620.0					
		+100c	1.00	38.09	-106	118.0	415.0					