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THE APPLICATION OF *BEAST* SEDIMENT QUALITY GUIDELINES TO THE JACKFISH BAY AREA OF CONCERN

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SUMMARY

This report describes sediment quality in Jackfish Bay, identified as an Area of Concern (AOC) due to degraded water quality, sediment contamination and impacted fish and benthic communities. As part of the Great Lakes 2020 Action Plan, the Benthic Assessment of Sediment (BEAST) methodology was applied to 15 sites throughout the AOC in September 2003. The BEAST methodology involves the assessment of sediment quality based on multivariate techniques using data on benthic communities, the functional responses of laboratory organisms in toxicity tests, and the physical and chemical attributes of the sediment and overlying water. Data from test sites were compared to biological criteria developed for the Laurentian Great Lakes. Additionally, toxicity-contaminant relationships were examined using regression analysis.

Conditions in Moberly Bay (western arm of Jackfish Bay) are indicative of a polluted environment, characterized by elevated sediment contaminant concentrations and the presence of pollution tolerant benthic communities. Several metals and organic contaminants (PCBs, dioxins and furans) are elevated above Sediment Quality Guidelines in Moberly Bay and are elevated compared to the other sampled areas of the AOC. In the whole bay, from 2 to 10 metals exceed the provincial Lowest Effect Level, and exceedences of the Severe Effect Level are limited to a few sites for manganese. Dioxin and furans, expressed in toxic equivalents, are elevated above the federal Probable Effect Level in Moberly Bay and in the area south of Moberly Bay. Benthic communities are different or very different from reference conditions at 6 of the 15 sites. Communities in Moberly Bay are characterized by increased tubificid worms (up to 124,000 per m^2) and the absence or low abundance of a predominant reference group amphipod taxon (haustoriid). These results are consistent with historical data from Moberly Bay with some slight improvement in sediment quality since 1987, indicated by the presence of previously absent amphipods. Generally, conditions in Jackfish Bay are consistent with results from Environmental Effects Monitoring studies performed between 1996 and 2002. Nine sites throughout the bay are severely toxic due to low survival of the amphipod *Hyalella*, and in some cases there is also reduced growth in the mayfly *Hexagenia* (sites in Moberly Bay). Toxicity is partially related to organic contaminants; however, the presence of oily, odorous sediment in Moberly Bay may be a factor in toxicity.

According to the decision-making framework for sediment assessment, developed under the Canada-Ontario Agreement respecting the Great Lakes Basin Ecosystem, management actions are indicated for three sites in Moberly Bay due to elevated sediment contaminants above guidelines and concurrence of severe sediment toxicity and altered benthic communities.

SOMMAIRE

Ce rapport décrit la qualité des sédiments dans la baie Jackfish, désignée secteur préoccupant (SP) en raison de la dégradation de la qualité de l'eau, de la contamination des sédiments et de l'altération des communautés benthiques et halieutiques. Tel qu'énoncé dans le Plan d'action du bassin des Grands Lacs 2020, on a eu recours, en septembre 2003, à la méthode d'évaluation des sédiments benthiques (BEAST) à 15 sites du secteur préoccupant. Cette méthode consiste à évaluer la qualité des sédiments à l'aide de techniques multivariées en utilisant les données sur les communautés benthiques, les réactions fonctionnelles des organismes de laboratoire aux tests de toxicité et les attributs physiques et chimiques des sédiments et des eaux sus-jacentes. On a comparé les données des sites soumis aux essais aux critères biologiques élaborés pour les Grands Lacs laurentiens. En outre, on a étudié la relation qui existe entre les contaminants et la toxicité par l'application de l'analyse de régression.

Les conditions de la baie Moberly (bras ouest de la baie Jackfish) sont celles d'un environnement pollué qui se caractérise par des concentrations élevées de contaminants dans les sédiments et par la présence de communautés benthiques tolérantes à la pollution. Plusieurs métaux et contaminants organiques (PCB, dioxines et furannes) sont présents à des taux supérieurs aux lignes directrices sur la qualité des sédiments dans la baie Moberly, et sont élevés comparativement à d'autres zones d'échantillonnage du secteur préoccupant. Dans l'ensemble de la baie, les concentrations de 2 à 10 métaux sont supérieures à la concentration provinciale minimale avec effet, et on a constaté des dépassements de la concentration avec effet grave à quelques sites seulement pour le manganèse. Les concentrations de dioxines et de furannes, exprimés en équivalents toxiques, dépassent la concentration fédérale avec effet probable dans la baie Moberly et dans la région au sud de la baie Moberly. Les communautés benthiques sont différentes ou très différentes des conditions de référence à 6 des 15 sites. Les communautés de

la baie Moberly se caractérisent par une abondance de tubificidés (jusqu'à 124 000 par m^2) et une quantité faible ou nulle d'un taxon d'amphipodes de référence prédominant (haustoridés). Ces résultats concordent avec les données antérieures de la baie Moberly avec une légère augmentation de la qualité des sédiments depuis 1987, révélée par la présence d'amphipodes précédemment absents. En général, l'état de la baie Jackfish concorde avec les résultats des études sur le suivi des effets sur l'environnement de 1996 à 2002. Neuf sites de la baie sont très toxiques, comme l'indique le faible taux de survie de l'amphipode *Hyalella* et, dans certains cas, le taux de croissance de l'éphémère commune *Hexagenia* (sites de la baie Moberly). La toxicité est partiellement liée à des contaminants organiques; toutefois, la présence de sédiments huileux et odorants dans la baie Moberly peut en être un facteur.

Selon le cadre de prise de décisions pour l'évaluation des sédiments, élaboré en application de l'Accord Canada-Ontario sur l'écosystème du bassin des Grands Lacs, les mesures de gestion doivent s'appliquer à trois sites de la baie Moberly en raison du taux élevé de contaminants dans les sédiments qui est supérieur aux lignes directrices, ainsi que de la toxicité importante des sédiments et de l'altération des communautés benthiques.

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1 INTRODUCTION

1.1 Background and Environment Canada Mandate

In the 1970s, 42 locations in the Great Lakes where the aquatic environment was severely degraded were identified as "problem areas" by the International Joint Commission (IJC). Of these, 17 are along Canadian lakeshores or in boundary rivers shared by the US and Canada. The IJC's Great Lakes Water Quality Board recommended in 1985 that a Remedial Action Plan (RAP) be developed and implemented for each problem area. The RAP approach and process is described in the 1987 Protocol to the Great Lakes Water Quality Agreement (GLWQA). The goal is to restore the "beneficial uses" of the aquatic ecosystem in each problem area, which were now called "Areas of Concern" (AOCs). Fourteen possible "impairments of beneficial use", which could be caused by alterations of physical, chemical or biological conditions in the area, are defined in Annex 2 of the GLWQA.

The Canadian government's commitment to the GLWQA was renewed in 2000 with the Great Lakes Basin 2020 (GL2020) Action Plan, under which the efforts of eight federal departments to "restore, conserve, and protect the Great Lakes basin" over the next five years were to be co-ordinated. Environment Canada's contribution included the funding of detailed chemical and biological assessments of sediments in Canadian AOCs. The National Water Research Institute in Burlington, Ontario was given the responsibility of conducting and reporting on these assessments.

Under the terms of reference for Environment Canada's mandate, the Benthic Assessment of Sediment (BEAST) methodology of Reynoldson et al. (1995; 2000) was to be applied to the AOC assessments (see description below). The study described in this document was conducted to supplement existing data to complete an overall assessment of sediments in Jackfish Bay that are, or have been, exposed to industrial effluents.

1.2 Benthic Assessment of Sediment (BEAST)

The BEAST is a predictive approach for assessing sediment quality using multivariate techniques (Reynoldson et al. 1995; 2000; Reynoldson and Day 1998). The approach utilizes data from nearshore reference sites that were sampled from the Laurentian Great Lakes over a three-year period. Information includes benthic community structure (the type and number of invertebrate taxa present), selected habitat variables, and responses (survival, growth and reproduction) of four benthic invertebrates in laboratory toxicity tests. The reference sites establish normal conditions for selected endpoints, and determine the range of 'normal' biological variability. As a result, expected biological conditions are predicted by applying relationships developed between biological and habitat conditions.

This assessment method has been used to assess the condition of benthic invertebrate communities and toxicity in a number of AOCs, e.g., Collingwood Harbour, St. Lawrence River (at Cornwall), Bay of Quinte, Peninsula Harbour and Hamilton Harbour (Reynoldson et al. 1995; Reynoldson 1998; Reynoldson and Day 1998; Milani and Grapentine 2004, 2005, 2006).

1.3 Jackfish Bay Area of Concern

Jackfish Bay, located on the north shore of Lake Superior approximately 250 km northeast of Thunder Bay, was identified as an AOC due to contaminated sediments and impacted biota as a result of discharges from pulp and paper mill operations at Terrace Bay, Ontario. Discharges enter the AOC via Blackbird Creek, which flows 14 km from Terrace Bay and enters at the northern tip of Moberly Bay. The Jackfish Bay AOC has been the subject of two major remedial action plan (RAP) reports – Stage 1: Environmental Conditions and Problem Definition (Jackfish Bay RAP Team 1991) and Stage 2: Remedial Strategies for Ecosystem Restoration (Jackfish Bay RAP Team 1997). The RAP Stage 1 report identified the following environmental issues of concern:

- Degraded water quality including elevated levels of metals, organics, nutrients, and bacteria,
- Sediment contamination (trace metals, organics, organic material),
- Presence of pollution tolerant benthic communities, and
- Changes in fish community structure.

The beneficial use impairments listed in the RAP Stage 2 report are:

- Loss of fish habitat,
- Degradation of fish populations (dynamics of fish populations and fish body burdens),

- Fish tumours and other deformities (liver neoplasms),
- Degradation of aesthetics (foam and dark coloured water in Blackbird Creek and Moberly Bay), and
- Degradation of benthos (dynamics of benthic populations and body burdens).

Additionally, "restriction on fish consumption" was identified as requiring further assessment. Currently, there are restrictions in place for Lake trout and Whitefish for dioxins and for Lake trout for PCBs (MOE 2005). Whitefish consumption restrictions for dioxins begin for fish at 40 cm length, with complete restriction for the sensitive population at 40 cm. Lake trout consumption restrictions for dioxins begin for fish at 45 cm in length and complete restriction for both general and sensitive populations for fish ≥50 cm in length. For PCBs, Lake trout consumption restrictions (4 meals per month) begin for fish ≥45 cm in length (MOE 2005). There have been several upgrades in mill effluent processes and treatments, including the addition of a secondary treatment facility, which came on line in 1989 (Stantec 2004). While mill upgrades have resulted in reduced contaminants entering Jackfish Bay (e.g., reductions in BOD, TSS, chlorinated compounds) as well as reduced toxicity and improvements to aquatic communities over time, contaminated sediments are still in place (RAP Stage 2). The RAP Stage 2 document identifies that prior to the delisting of Jackfish Bay, sediment conditions and aquatic communities that use the sediment must be addressed with respect to beneficial use impairments. In September 2003, Environment Canada undertook a sampling program in Jackfish Bay to define the general status of the sediment contamination. This report presents the results of these investigations and provides a description of the spatial extent and degree of sediment contamination.

2 METHODS

2.1 Sample Collection

Fifteen sites were sampled September 16 – 17, 2003. Site locations were as follows:

1. Near-field (4 sites); Moberly Bay, western arm of Jackfish Bay. Mill effluent enters Moberly Bay via Blackbird Creek. Historically, this is the area where the greatest sediment contamination and biological effects have been observed. Both the 100% and

part of the 5% effluent plumes (based on general effluent plume patterns; Stantec 2004) are within Moberly Bay.

2. Far-field (3 sites); South of Moberly Bay, approximately 500 m southeast of Cody Island. This area may be within the 1 to 5% effluent plume based on general effluent plume patterns (Stantec 2004).
3. Far far-field (5 sites); 3 sites approximately 750 m south of St. Patrick Island and 2 sites 200 m southwest of Cape Victoria. General effluent plume patterns have indicated that 1% effluent plume travels along the western shoreline of Jackfish Bay with the furthest extent to Cape Victoria (Stantec 2004); however, sites in the far far-field areas may be outside the 1% effluent plume.
4. Tunnel Bay (3 sites); eastern arm of Jackfish Bay. This area was sampled as the most appropriate reference area within Jackfish Bay in previous studies (Stantec 2004); however, Tunnel Bay biota quality has been affected by mill effluent with decreased *Diporeia hoyi* densities evident between 1969 and 1987.

Near-field, far-field and far far-field designations are the same as those used in the Environmental Effects Monitoring Cycle 1 and 2 reports prepared for Kimberley Clark Inc. by Stantec Consultants Ltd. Station co-ordinates and site depth are provided in Table 1 and site locations are shown in Figure 1. Site positions were established in the field using a Magnavox MX300 differential Global Positioning System receiver. Differential corrections were received from Coast Guard beacons signals.

At each test site, samples were collected for chemical and physical analyses of sediment and overlying water, benthic community and whole sediment toxicity tests. Environmental variables measured or analyzed are shown in Table 2. Details on sampling techniques and methods for sample collection are described in Reynoldson et al. (1998a; 1998b). Prior to sediment collections, water samples were obtained using a van Dorn sampler, taken 0.5 meters from the bottom. Temperature, conductivity, pH, and dissolved oxygen were measured on site with Hydrolab water quality instruments. Samples for alkalinity, total phosphorus, total Kjeldahl nitrogen, nitrates/nitrites (NO_3/NO_2), and total ammonia (NH_3) were dispensed to appropriate containers and stored (4°C) for later analysis.

A 40 cm × 40 cm mini-box corer was used to obtain the benthic community and sediment chemistry samples. Benthic community samples were subsampled from the mini-box core using 10 cm length × 6.5 cm diameter acrylic tubes. Samples were sieved through a 250-μm mesh screen and the residue preserved with 5% formalin for later identification. The remaining top 10 cm of sediment from each box core was removed, homogenized in a Pyrex dish, and allocated to containers for chemical and physical analyses of the sediment. Sediment samples were kept at 4°C with the exception of the organic contaminant samples, which were frozen (-20°C).

Five mini-Ponar grab samples were collected per site for the laboratory toxicity tests (approximately 2 L sediment per replicate). Each of the five sediment grabs was placed in separate plastic bag, sealed, and stored in a 10-L bucket at 4°C.

2.2 Sediment and Water Physico-Chemical Analyses

Overlying water

Analyses of alkalinity, total phosphorus, nitrates/nitrites (NO_3/NO_2), total ammonia (NH_3), and total Kjeldahl nitrogen (TKN) were performed by the Environment Canada's National Laboratory for Environmental Testing (NLET) in Burlington, Ontario, by procedures outlined in Cancilla (1994) and NLET (2003).

Particle size

Percents gravel, sand, silt, and clay were determined by the Sedimentology Laboratory (Burlington, ON) following the procedure of Duncan and LaHaie (1979).

Trace metals and nutrients

Freeze dried sediment was analyzed for trace elements (hot aqua regia extracted), major oxides (whole rock), loss on ignition, total organic carbon, total phosphorus, and total Kjeldahl nitrogen by Caduceon Environmental Laboratories (Ottawa, ON), using USEPA/CE (1981) standard methodologies or in-house procedures.

Organic contaminants

Sediments were analyzed for polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), organochlorines (OCs), dioxins and furans, and solvent extractables (oil and grease) by the Laboratory Service Branch of the Ontario Ministry of the Environment (Etobicoke, ON), following standard protocols (MOE 1994a; 1994b; 1995).

2.3 Taxonomic Identification

Benthic community samples were transferred to 70% ethanol after a minimum of 72 hours in formalin. Invertebrates in the benthic community samples were sorted, identified to the family level, and enumerated at the Invertebrate Laboratory (Burlington, ON). Slide mounts were made for Oligochaeta and Chironomidae and identified to family using high power microscopy.

2.4 Sediment Toxicity Tests

Four sediment toxicity tests were performed: *Chironomus riparius* 10-day survival and growth test, *Hyalella azteca* 28-day survival and growth test, *Hexagenia* spp. 21-day survival and growth test, and *Tubifex tubifex* 28-day adult survival and reproduction test. Sediment handling procedures and toxicity test methods are detailed elsewhere (Borgmann and Munawar 1989; Borgmann et al. 1989; Krantzberg 1990; Reynoldson et al. 1991; Reynoldson et al. 1998b; 1998c). All tests passed acceptability criteria for their data to be used in the site assessments. The criteria are based on percent control survival in a reference sediment (Long Point Marsh, Lake Erie): i.e., ≥ 80% for *H. azteca* and ≥70% for *C. riparius* (USEPA 1994; ASTM 1995); ≥ 80% for *Hexagenia* spp., and ≥75% for *T. tubifex* (Reynoldson et al. 1998b). Toxicity tests were performed by the Ecotoxicology laboratory (Burlington, ON).

Water chemistry variables (pH, dissolved oxygen (mg/L), conductivity (μS/cm), temperature (° C), and ammonia (mg/L)) were measured for each test in each replicate test beaker on day 0 (start of test – prior to introduction of organisms) and at completion of the test. Tests were run under static conditions in environmental chambers at 23 ± 1 °C, under a photoperiod of 16L: 8D and an illumination of 500 - 1000 lux. The *T. tubifex* test was run in the dark.

***Hyalella azteca* 28-day survival and growth test**

The *H. azteca* test was conducted for 28 days using 2 – 10 day old organisms. On day 28, the contents of each beaker were rinsed through a 250-μm screen and the surviving amphipods were counted. Amphipods were dried at 60 °C for 24 hours and dry weights recorded. Initial weights were considered zero.

Chironomus riparius 10-day survival and growth test

The *C. riparius* test was conducted for 10 days using first instar organisms. On day 10, the contents of each beaker were wet sieved through a 250-µm screen and the surviving chironomids were counted. Chironomids were dried at 60 °C for 24 hours and dry weights recorded. Initial weights were considered zero.

Hexagenia spp. 21-day survival and growth test

The *Hexagenia* spp. test was conducted for 21 days using preweighed nymphs (5 – 8 mg wet weight/nymph). On day 21, the contents of each jar were wet sieved through a 500-µm screen and surviving mayfly nymphs were counted. Nymphs were dried at 60 °C for 24 hours and dry weights recorded. Initial mayfly wet weights were converted to dry weights using the following equation from a relationship for nymphs from the Ecotoxicology Lab that was previously determined by regression analysis: Initial dry weight = [(wet weight + 1.15)/ 7.35]. Growth was determined by final dry weight minus initial dry weight.

Tubifex tubifex 28-day reproduction and survival test

The *T. tubifex* test was conducted for 28 days using sexually mature worms (gonads visible). On day 28, the contents of each beaker were rinsed through a 500-µm and 250-µm sieve sequentially. The number of surviving adults, full cocoons, empty cocoons, and large immature worms were counted from the 500-µm sieve and the numbers of small immature worms were counted from the 250-µm sieve. Survival and reproduction were assessed with four endpoints: number of surviving adults, total number of cocoons produced per adult, percent of cocoons hatched, and total number of young produced per adult.

2.5 Data Analysis

BEAST analysis

Test sites were assessed using BEAST methodology (Reynoldson and Day 1998; Reynoldson et al. 2000). The BEAST model predicts the invertebrate community group that should occur at a test site based on natural environmental conditions. Multiple discriminant analysis was used to predict the test sites to one of five reference community groups using a previously computed relationship between five environmental variables (latitude, longitude, depth, total organic carbon, and alkalinity) and the community groups (Reynoldson et al. 1995; 2000). For each test site, the model assigned a probability of it belonging to each of five reference faunal groups. Benthic community assessments were conducted at the family level, as this taxonomic detail is shown to be sensitive for the determination of stress (Reynoldson et al. 2000). Community data for the test sites were merged with the reference site invertebrate data of the matched reference group (group to which the test site has the highest probability of belonging) only and ordinated using hybrid multidimensional scaling (HMDS; Belbin 1993), with Bray-Curtis distance site × site association matrices calculated from raw data. Toxicity data were analysed using HMDS, with Euclidean distance site × site association matrices calculated from standardized data. Toxicity endpoints for the test sites were compared to those for all reference sites. (There are no distinct groups as with the community assessment.) Principal axis correlation (Belbin 1993) was used to identify relationships between habitat attributes and community or toxicity responses. This did not include organic contaminant data, which were not measured in the reference sediments. Significant endpoints and environmental attributes were identified using Monte-Carlo permutation tests (Manly 1991). Test sites were assessed by comparison to confidence bands of appropriate reference sites. Probability ellipses were constructed around reference sites, establishing four categories of difference from reference: equivalent /non-toxic (within the 90% probability ellipse), possibly different/ potentially toxic (between the 90 and 99% ellipses), different/toxic (between the 99 and 99.9% ellipses), and very different/severely toxic (outside the 99.9% ellipse) (Figure 2). Test site toxicological responses were also compared to numerical criteria previously established for each category (non-toxic, potentially toxic and toxic) and species from reference site data (Reynoldson and Day 1998).

Test data were analysed in subsets to maintain the ratio of test: reference sites ≤0.10. Multiple discriminant analysis was performed and probability ellipses (Figure 2) were produced using the software SYSTAT (Systat Software Inc. 2002). HMDS, principal axis correlation, and Monte-Carlo tests were performed using the software PATN (Blatant Fabrications Pty Ltd. 2001).

Sediment toxicity and contaminant concentrations

As the BEAST assessment does not incorporate any information on organic contaminants in the sediment (organic contaminant concentrations were not measured in reference sediments), additional analyses of relationships between sediment toxicity and contaminant concentrations for Jackfish Bay sites were conducted. These should aid in identifying causes of toxicity (e.g., organic contaminants, inorganic compounds, sediment grain size).

Relationships between sediment toxicity and sediment contamination for the Jackfish Bay sites were assessed graphically and by regression analysis. Initially, to examine general and dominant patterns in the data, comparisons between the toxicity responses and contaminant conditions were made based on integrative, compound variables (from either summation or multivariate ordination of measurement variables). After this, to better detect less dominant (though significant) relationships between two or a few variables, analyses were conducted using the original measurement variables (i.e., toxicity endpoints and concentrations of individual compounds).

The sediment toxicity data for Jackfish Bay sites were ordinated again by HMDS, as a single group and without the reference site data. To identify and relate the most important of the toxicity endpoints to the HMDS axes, principal axis correlation was conducted. Concentrations in sediment of 10 metals (As, Cd, Cr, Cu, Fe, Hg, Mn, Ni, Pb, Zn) were ordinated by principal components analysis (PCA). The eigenanalysis was performed on the correlation matrix. The PAH data were integrated by summing the concentrations of the individual 16 compounds. Data for all variables were log(x)-transformed.

The integrated descriptors of sediment toxicity (axes scores from the HMDS) and the most important individual toxicity endpoint (survival of *Hyalella*) were plotted against the integrated contaminant descriptors (from PCA and summation of organic contaminants) as well as individual log(x)-transformed sediment contaminants, nutrients and grain size. To determine whether toxicity was better explained by joint consideration of the contaminant descriptors, multiple linear regression involving the contaminant descriptors as predictors was calculated with each toxicity descriptor as the response variable. The degree to which individual sediment variables account for individual toxicity response was assessed by fitting regression models using "best subset" procedures (Draper and Smith 1998; Minitab 2000). Models were fitted for (a) PCB congeners, (b) metals, (c) nutrients and grain size, (d) dioxin and furan isomers, and then (e) all combinations of the best predictors from the four groups. (This procedure was used to avoid computational difficulties arising from working with multiple predictors simultaneously.) The best models were those having maximum explanatory power (based on $R^2_{adjusted}$), minimum number of nonsignificant predictors, and minimum amount of predictor multicollinearity.

2.6 Quality Assurance/Quality Control

Field variability

Triplicate overlying water, sediment and benthic invertebrate samples were collected at two randomly selected sites (1M2, 4M3) for the determination of within-site and among-sample variability. Variability in a measured analyte was expressed as the coefficient of variation (CV = standard deviation / mean × 100). Variability in community composition between site replicates was examined by their location in ordination space. The proximity of the site replicates in ordination space was an indication of their similarity/dissimilarity.

Laboratory

Quality control procedures employed by laboratories included control charting of influences, standards, and blanks (Caduceon Environmental Laboratory). Reference material was used in each analytical run. Calibration standards were run before and after each run. Run blanks and reference standards were run 1 in 20 samples, while duplicates were run 1 in 10 samples. Sample duplicate measurements of sediment metals, major oxides and nutrients were expressed as the relative percent difference: $(x_1 - x_2) / ((x_1 + x_2)/2) \times 100$

Quality control measures for the MOE laboratory included matrix spikes. Percent recoveries were determined for three internal PAH standards (d10-phenanthrene, d12-chrysene, d8-naphthalene).

Benthic community sorting

To evaluate control measures for benthic invertebrate enumeration, each month, a randomly selected sample that was already sorted was re-sorted, and the number of new organisms found counted. The percent of organisms missed (%OM) was calculated using the equation:

%OM = # Organisms missed / Total organisms found × 100

The desired sorting efficiency is a %OM ≤ 5% (or >95% recovery). If the %OM was > 5%, two more replicate samples were randomly selected and the %OM calculated. The average %OM was calculated based on the three samples re-sorted, and represents the standard sorting efficiency for that month. The average %OM is based on only one replicate sample if %OM is < 5%.

3 RESULTS AND DISCUSSION

3.1 Sediment and Water Physico-Chemical Properties

Overlying water

Variables measured in the overlying water (0.5 m above the sediment) are similar for sites outside of Moberly Bay, suggesting some homogeneity in water mass across most sampling sites (Table 3). Across all sites variable ranges are 9.7 mg/L for alkalinity, 35 µS/cm for conductivity, 12.2 mg/L for dissolved oxygen, 0.36 mg/L for NO_3/NO_2, 0.04 mg/L for NH_3, 0.9 for pH, 10.2 °C for temperature, 0.21 mg/L for total Kjeldahl nitrogen, and 38 mg/L for total phosphorus. Sites in near-field Moberly Bay are dissimilar to the rest of the sites, with the highest alkalinity, conductivity, NO_3/NO_2, dissolved oxygen and temperature. Phosphorus in near-field Moberly Bay (range: 23 to 41 µg/L) is elevated above the interim Provincial Water Quality Objective of 20 µg/L. Total phosphorus ranges from 5 to 9 µg/L at remaining sites. These results are similar to those found in 2002, where phosphorus in Moberly Bay ranged from 13 to 59 µg/L (Stantec 2004). Some overlying water variables were also compared to Lake Superior reference sites (n=31) collected over a 3-year period (Unpublished data, Environment Canada 2006). Test site variables that are outside of the upper range observed at the Lake Superior reference sites include dissolved oxygen and total phosphorus in Moberly Bay and NO_3/NO_2 concentrations throughout most of Jackfish Bay (Table 3).

Sediment particle size

Percents sand, silt, clay, and gravel are shown in Table 4. Sediments consist mainly of silt, ranging from 6.4 to 76.1% (median 60.5%), and clay, ranging from 0 to 74.5% (median 19.7%), or silt and sand, ranging from 3.7 to 93.6% (median 9.3%). An exception is 4M3 (far far-field), which consists mostly of clay (74.5%). Moberly Bay site M701 (located closest to the mouth of Blackbird Creek) consists of mostly sand (93.6%) and the two far far-field sites near Cape

Victoria (6972, 6973) have a high percentage of sand as well (65.8%, 67.5%). There is no gravel at any site except a minimal amount (0.2%) at 4M3.

Sediment nutrients and trace metals

Sediment nutrient and trace metal concentrations are shown in Table 5. Nutrients ranged from 0.3 to 7.5% (median 3.0%) for total organic carbon (TOC); 406 to 4400 μg/g (median 2160 μg/g) for total Kjeldahl nitrogen, and 568 to 1500 μg/g (median 865 μg/g) for total phosphorus. Near-field Moberly Bay sites have the highest total organic carbon (5.1 to 7.5%, mean 6.7%), followed by far-field sites (2.5 to 4.2%, mean 3.4%) and Tunnel Bay (mean 2.9%). The far far-field sites have TOCs below the LEL mostly (mean TOC = 0.7 %). Visual inspections at the time of sampling noted a large amount of organic matter content in sediment from Moberly Bay at M701 (Table 1). Similar trends in TOC were observed in 2002, where mean TOC in near-field, far-field and far far-field were 5.2%, 2.8%, and 0.9%, respectively (EEM Cycle 3; Stantec 2004). There is also a gradient in nitrogen concentration from Moberly Bay (mean 3510 μg/g), to far-field sites (mean 2850 μg/g) and far far-field sites (667 μg/g). Tunnel Bay has similar nitrogen concentrations as the far-field (mean 2237 μg/g).

There are exceedences of the provincial Lowest Effect Level (LEL; Persaud et al. 1992) for 2 to 10 metals per site. Sites in Tunnel Bay (6956, 3M2, 3M3) have the greatest number of metal LEL exceedences (7 to 10 metals), while near-field and far field sites have up to 5 and 8 exceedences, respectively. The site closest to the mouth of Blackbird Creek has only 2 LEL exceedences (Cr, Ni), likely due to the high sand content at this site (94%). Far far-field sites have up to 5 LEL exceedences. The Severe Effect Level (SEL) is exceeded only for manganese at 4 sites (2 far-field, 1 far far-field and 1 Tunnel Bay site; Table 5).

The Jackfish Bay RAP 1 report suggests that metal elevations may reflect the regional geology and are typical for the Lake Superior basin. When comparing metal contaminant data from Jackfish Bay to Lake Superior reference sites (Unpublished data, Environment Canada 2006), most test site metal concentrations are within the range observed at Lake Superior reference sites. An exception is Zn, where near-field Moberly Bay sites are slightly above background reference. Nutrient levels in Jackfish Bay (phosphorus, nitrogen and total organic carbon) are also greater than Lake Superior background levels, mainly in the near-field (Moberly Bay) and far-field (south of Moberly Bay) areas.

Organic contaminants

Select organic contaminant concentrations are shown in Figure 3. A complete list of all contaminant concentrations is provided in Appendix A, Table A1.

Polycyclic aromatic hydrocarbons (PAHs)

Total PAHs are below the LEL (4000 ng/g) at all sites, ranging from < detection (4M3, 4M3, 6972, 6973) to 1872 ng/g in Moberly Bay (Figure 3). There is an overall decreasing gradient of PAHs from near-field Moberly Bay (mean 1268 ng/g) to far-field (mean 510 ng/g) and far far-field (maximum concentration of 27 ng/g); [PAH]s in Tunnel Bay (mean 796 ng/g) are higher than those in the far-field area. Total PAH concentrations in the current study are similar to those found in 1999, where the mean PAH concentration in Moberly Bay (excluding site at the mouth of Blackbird Creek) was 1795 ng/g, and there was a decrease in concentration south of Moberly Bay to 400 ng/g (Richman 2004).

Polychlorinated biphenyls (PCBs)

Total [PCB]s range from < detection (8 sites) to 150 ng/g (Moberly Bay); 3 of the 4 near-field sites in Moberly Bay are above the LEL of 70 ng/g (Figure 3). Overall [PCB]s decrease with distance outward from Moberly Bay, and are below detection at sites in the far far-field area of Jackfish Bay and at 2 of the 3 sites in Tunnel Bay. Total PCBs in Jackfish Bay sediments collected in 1999 were below detection (no measurable response) in all areas of the bay (Richman 2004). Sediments were also analyzed for 12 dioxin-like (coplanar) PCBs, which were detected in Jackfish Bay sediments (Appendix A, Table A1). Of the dioxin-like PCB congeners, sediments consist mainly of PCB 118 (range: 6.7 to 2300 pg/g), PCB 105 (range: 3.7 to 830 pg/g), PCB 156 (range: 0.7 to 300 pg/g), and PCB 167 (range: 0.4 to 110 pg/g) (Figure 3). Concentrations of these PCB congeners are highest in Moberly Bay sediments and decrease with distance southward from Moberly Bay (Figure 3). Tunnel Bay coplanar [PCB]s are similar to those from the far-field sites.

Solvent extractables

Solvent extractables (oils and grease) range from 66 (far far-field) to 7600 mg/kg in Moberly Bay (Figure 3). There is a decrease in solvent extractables with distance southward from Moberly Bay (mean 4875 mg/kg), to far-field sites (mean 1600 mg/kg) and far far-field sites (mean 94 mg/kg). Concentrations in Tunnel Bay (mean 600 mg/kg) are less than those in the far-field area. The presence of odorous, sticky, oily sediment was noted at near-field sites 1M1, 1M2, and 1M3 (Moberly Bay) at the time of sampling (Table 1). In 2002, Stantec (2004) observed oil in samples from all exposure areas.

Dioxins and furans

Concentrations of polychlorinated dibenzodioxins and dibenzofurans are provided in Appendix A, Table A1 and shown in Appendix A, Figure A1. For the dioxin group, octachlorodioxin concentrations are highest at all sites (range: 15 to 280 pg/g) and concentrations are highest in near-field Moberly Bay followed by Tunnel Bay. Generally, dioxin concentrations increase with increasing chlorine atoms from the hexachlorodioxins to the octachlorodioxins. Total tetrachlorodioxin concentrations (range: <0.8 to 36 pg/g), however, are higher than the pentachlorodioxins (range: <0.7 to 13pg/g) at the majority of sites. The percentage of 2,3,7,8-tetrachlorodibenzo-*p*-dioxin to total tetrachlorodioxins (excluding results where it is indicated that the actual values are lower than what is reported) is 34 to 100% (Appendix A, Table A1). For the furan group, total tetrachlorofurans are highest, ranging from 2.4 to 840 pg/g and are highest in Moberly Bay followed by far-field sites (Figure A1). Overall, there is a decreasing gradient for dioxins and furans from Moberly Bay to the far far-field area of Jackfish Bay, and this is more pronounced for the furans (Figure A1).

Dioxin and furan congeners as well as several coplanar (dioxin-like) PCBs have been reported to cause a number of toxic responses similar to the most toxic dioxin (2,3,7,8-tetrachlorodibenzo-*p*-dioxin; TCDD) (Van den Berg et al., 1998). Using toxic equivalency factors (TEFs), the toxicity of dioxin and furan congeners relative to the toxicity of 2,3,7,8-TCDD was determined. The TEFs, in combination with the chemical data of each dioxin/furan congener, were used to calculate toxic equivalent (TEQ) concentrations in Jackfish Bay sediment using the following equation:

$$TEQ=\sum_{i=1}^{n} ([dioxin/furan]_i \times TEF_i)_n$$

Within a sample, each congener concentration is multiplied by its respective TEF and all products are summed to give a TEQ value. This takes into consideration the unique concentrations and toxicities of the individual components within the dioxin or furan mixture. The World Heath Organization (WHO) TEFs for fish were used in the calculation of the TEQ (Van den Berg et al. 1998) and non-detect values were assigned a zero. The TEQs were compared to the CCME Probable Effect Level (PEL) for dioxins/furans (21.5 ng TEQ/kg).

Near-field sites in Moberly Bay have the highest concentrations of dioxin/furan TEQs; 3 of the 4 sites have TEQs above the PEL, ranging from 28 to 57 ng TEQ/kg (Figure 4). The sandy site closest to the mouth of the Blackbird Creek is not above the PEL. The far-field area (southeast of Cody Island) has the second highest TEQs, where two sites (2M1 and 2M3) are just above the PEL at 21.5 and 24 ng TEQ/kg (Figure 4). Remaining sites are below the PEL. Overall, there is a decrease in concentrations from near-field (Moberly Bay) to far far-field area. Tunnel Bay TEQs are similar to those in the far-field area. The coplanar PCBs, which were not included in the TEQ calculation for Figure 4, contribute little to the total TEQ (0.02 to 0.6%; mean 0.2%).

Organochlorine pesticides

Organochlorinated compounds are detected mainly in Moberly and Tunnel Bay sites. Trace amounts of DDT metabolites are found in both bays and trace amounts of aldrin, dieldrin, a-BHC, b-BHC, and a-chlordane are found at some sites in Moberly Bay (Appendix A, Table A1).

3.2 Benthic Invertebrate Communities

All 15 Jackfish Bay sites are maximally predicted to Great Lakes Reference Group 5, based on the BEAST model and five habitat attributes (alkalinity, depth, total organic carbon, latitude and longitude) (Table 6). The probabilities of test sites belonging to Group 5 are very high, ranging from 77.7% to 99.8% (mean 95%). The near-field Moberly Bay sites, (especially M701 nearest to the mouth of Blackbird Creek) are fairly shallow (depth: 11.4 to 19.0 m), compared to the rest of the sites (depth: 29.7 to 69.7 m) (Table 1), which may explain the slightly lower probabilities of reference group membership for these sites. (The mean depth for Group 5 reference sites is 36.6 m.)

Reference Group 5 has a total of 75 sites mainly from Lake Superior (30), as well as Georgian Bay (19), the North Channel (12), Lake Michigan (7), Lake Ontario (5) and Lake Huron (2). This group is characterized by the Haustoriidae (44.3% occurrence in Group 5 - consisting almost entirely of the amphipod *Diporeia hoyi*), as well as the Tubificidae (16.6% occurrence), Sphaeriidae (11.5% occurrence) and Chironomidae (9.9% occurrence). To a lesser degree, Group 5 also consists of Lumbriculidae, Enchytraeidae, and Naididae (oligochaete worms - 1.9 to 6.8% occurrence). With Asellidae, Valvatidae and Gammaridae (0.6 to 1.5% occurrences), these 10 families make up 99% of the total benthos found in Reference Group 5. Table 7 shows the mean abundances (per 33 cm^2 – the area of the sampling core tube) of each of these 10 reference group families for Jackfish Bay sites. Complete invertebrate family counts are provided in Appendix B, Table B1. Species counts are provided in Table B2. In total, 56 taxa were identified in Jackfish Bay samples, similar to the Cycle 2 EEM results (52 taxa) and greater than the number of taxa identified in the Cycle 3 study (43 taxa) (Stantec 2004). In the current study, taxa are largely represented by chironomids (18 taxa) and tubificids (11 taxa) (Table B2), similar to that found in the Cycle 3 EEM survey (15 chironomid taxa, 9 tubificids taxa; Stantec 2004)

Near-field: Moberly Bay

Moberly Bay sites (M701, 1M1, 1M2, 1M3) are characterized by Tubificidae, which are present at all sites in increased abundance (from 11 to 91× reference mean), and Chironomidae, which are close to the reference mean for 3 of the 4 sites and ~5× higher abundance at M701 (Table 7). Tubificids consist primarily of immatures with and without chaetal hairs (unidentifiable) and are in the range of ~15,000 to 124,000 per m^2 (Appendix B, Table B2). Identifiable dominant worms include *Aulodrilus pluriseta*, *Limnodrilus hoffmeisteri*, *Potamothrix bedoti*, and *Spirosperma ferox*. Haustoriidae (predominant reference Group 5 taxon) are either absent or in low abundance (0.01 to 0.02× mean) and Sphaeriidae are present at all sites but in low abundance (0.06 to 0.13× mean). Other than M701, remaining predominant macroinvertebrate taxa that are part of Group 5 are either absent or in low abundance (with some exceptions). The number of macroinvertebrate families (4 or 5) found at 3 of the 4 Moberly Bay sites is lower than the reference mean (6 families), while for M701, the number of families (8) is higher than the mean (Table 7). Site M701 (mouth of Blackbird Creek) has a more diverse community perhaps due to the nature of sediment – high sand / high organic content, which may support other taxa such as naidiids and asellids. Lumbriculidae (*Stylodrilus heringianus*), a pollution intolerant worm, is present at M701 while absent from 1M1, 1M2 and 1M3. Tubificid abundances are similar to those found in a 1987 survey (Beak 1988) where densities exceeded 100,000 per m^2 in western Moberly Bay, but were mostly < 10,000 per m^2 in other areas. In the EEM Program Cycle 1 to 3 surveys (performed in 1996, 1999 and 2002), tubificid densities in Moberly Bay were not as high as the current study. Total invertebrate abundances in Moberly Bay ranged from 6401 to 10803 per m^2 of which tubificids comprised 47 to 65% in Cycle 1 and 2 surveys, respectively. For the Cycle 3 survey, mean tubificid densities were reported as 3496 per m^2 (Stantec 2004). Current findings suggest communities remain impaired in Moberly Bay, with high densities of pollution tolerant tubificids, similar to or higher than that found in 1987 and higher than that found in the 3 EEM surveys. Tubificid densities and the dominance of tubificids were found to be positively related to organic matter, odour, and oil in the 1987 survey (Beak 1988). Chironomids in near-field Moberly Bay are dominated by the pollution tolerant *Procladius* sp. and *Chironomus* sp.; Stantec (2004) found the same results in 2002 in the Cycle 3 EEM survey. In 1987, there were no *D. hoyi* found in Moberly Bay, a decline from 1969, when 20 to 200 per m^2 were found mainly in the western part of the Bay (Beak 1988). In 2002, no amphipods were found in Moberly Bay in the EEM Cycle 3 survey, while in the Cycle 2 survey (1999), 5 amphipods per m^2 were found (Stantec 2004). In the current study, *D. hoyi* were present at 3 of the 4 sites in densities of 30 to 61 per m^2, suggesting some improvement in the Bay since 1987. The low abundance or absence of amphipods in 1999 and 2002 may reflect heterogeneity in methodology (samples were sieved through a 250-µm sieve in the current study and through a 500-µm screen in EEM studies) or differences in actual site location between studies.

Far-field: southeast of Cody Island

The number of taxa present (4 families) is similar to that found in Moberly Bay and below the reference mean of 6 taxa (Table 7). Haustoriids are present at all 3 sites (2M1, 2M2, 2M3) in low abundance (0.02 to 0.05× reference mean); however, *D. hoyi* densities (61 to 182 per m^2) are greater than densities in Moberly Bay, and similar to that found in 2002 (93 amphipods per m^2) in a similar far-field area (EEM Cycle 3, Stantec 2004). Tubificids are much less abundant (0.4 to 1.5× mean) than that seen in Moberly Bay and close to the reference mean, suggesting better sediment quality (indicative of a less polluted environment). Tubificid densities in the current study (545 to 2121 per m^2) are higher than that found in 2002 in a far-field area (mean 386 per m^2; Stantec 2004). Sphaeriids and chironomids are also present in low abundances (0.3 to 0.8× reference means). Remaining predominant macroinvertebrate taxa that are part of Group 5 are absent.

Far far-field: south of St. Patrick Island and Cape Victoria

Sites south of St. Patrick Island (4M1, 4M2, 4M3) and sites southwest of Cape Victoria (6972 and 6973) are similar in community composition and different from the other areas of Jackfish Bay. Haustoriids dominate (0.3 to 1.1× reference mean, 1061 to 3879 amphipods per m^2), followed by chironomids (0.6 to 1.2× mean) and Enchytraeidae (1.1 to 5.4× mean) (Table 7). Tubificidae are absent or in very low abundance (Cape Victoria; mean 121 per m^2). The number of families present range from 4 to 7 (Table 7). Enchytraeidae (*Mesenchytraeus* sp.) and Lumbriculidae (*Stylodrilus heringianus*) are present in these two areas of the bay, but are absent from the near-field (except lumbriculids at M701 in Moberly Bay), far-field and Tunnel Bay areas. These two deepwater areas of Jackfish Bay have benthic communities that are more indicative of oligotrophic conditions. From 1996 to 2002, haustoriids also dominated the benthic communities in far far-field areas, with densities reported as ranging from 196 to 586 per m^2 (EEM Cycles 1 to 3; Stantec 2004). Lumbriculid density in the far far-field area in 2002 (140 per m^2; Stantec 2004) is slightly higher than densities observed in the far far-field area of the current study (up to 121 lumbriculids per m^2).

Tunnel Bay

Taxon diversity is below the reference mean, with 4 or 5 families present (Table 7). These sites (6956, 3M2, 3M3) are characterized by Haustoriidae, Tubificidae, and Chironomidae, which are present at all sites. Haustoriids (*D. hoyi*) are in low abundance (0.2 to 0.5× reference mean) but are more abundant than in Moberly Bay and south of Moberly Bay (far-field). *D. hoyi* densities (909 to 2000 per m^2) are greater than that observed in similar locations in 1987 (up to 500 per m^2), where declines in numbers were evident from 1967 and 1975 surveys (Beak 1988). Tubificids are present in the range of 965 to 1085 per m^2, slightly below the reference mean (1357 per m^2), and chironomids are slightly above the reference mean (1.6 to 1.9× mean). Remaining predominant macroinvertebrate families that are part of Group 5 are absent from sites in this area (as in the far-field area) (Table 7).

Relative taxon abundances

The mean relative abundances of the predominant macroinvertebrate taxa (tubificids, chironomids, amphipods and sphaeriids) are shown in Figure 5. In near-field Moberly Bay, tubificids almost completely dominate, comprising 91 to 98% (mean 96%) of the macroinvertebrate community. Remaining taxa comprise on average from ~0.04 (amphipods) to 3% (chironomids). Benthic communities in Moberly Bay are most dissimilar to mean Great Lakes (GL) reference (Group 5) communities, which are provided in Figure 5 for comparison. Stantec (2004) found that tubificids comprised 71% of the entire Jackfish Bay community (including zooplankton) in the 2002 EEM Cycle 3 survey, and found no amphipods in Moberly Bay. When the entire community is considered in the current study, tubificids comprise on average 69%, very similar to what was found in 2002. In the far-field area, some improvements are evident. Tubificids still dominate, but comprise 33 to 64% of the macroinvertertebrate community (mean 48%). Relative abundances of amphipods (6%), sphaeriids (28%), and chironomids (18%) are higher than the low relative abundances observed in near-field (0.04, 0.19 and 2.9%, respectively). Again, these results are similar to what was found in 2002 (Stantec 2004). In both of the far far-field areas, amphipods dominate, comprising 22 to 63% of the community (overall mean 48%), followed by other taxa (mainly Enchytraeidae). Tubificids are absent or in low relative abundance, comprising a maximum of 2% at sites near Cape Victoria. The relative abundance of chironomids in the far far-field areas (overall mean 14%) is similar to that in the far-field area (mean 18%) and there is a decrease in sphaeriids in far far-field (overall mean 3%) compared to far-field (mean 28%). In Tunnel Bay, chironomids and amphipods dominate; comprising on average 35% and 33% of community, respectively, followed by tubificids, which comprise ~25% of the community. The relative abundance of other macroinvertebrate groups is low in Tunnel Bay (0.6%), consisting of one ceratopogonid midge.

BEAST assessment of benthic community

Results of the BEAST community assessment, performed at the family level, are summarized in Table 7. A map showing the level of benthic community alteration by site is shown in Figure 6. Ordinations are shown in Appendix C, Figures C1 and C2 (stress ≤ 0.16). Two separate ordinations were performed each with a subset of 7 and 8 test sites. Macroinvertebrate families that are most highly correlated to the two sets of ordination axis scores are: Haustoriidae (r^2 = 0.56, 0.79) and Tubificidae (r^2 = 0.55, 0.65), followed by Sphaeriidae (r^2 = 0.24, 0.51), Chironomidae (r^2 = 0.26, 0.28) and Lumbriculidae (r^2 = 0.36, 0.35). Examination of the relationship between environmental variables and ordination axis scores reveals no that the most highly correlated variables are total organic carbon (TOC, r^2=0.26; shown as a vector in Figure C1) and depth (r^2= 0.35; Figure C2).

Jackfish Bay sites fall into the following bands of similarity to reference conditions (Table 7, Figure 6):

Band 1 (equivalent to reference):	6 sites
Band 2 (possibly different):	3 sites
Band 3 (different):	2 sites: 1 Moberly Bay (near-field) site and 1 far-field site
Band 4 (very different):	4 sites: 3 Moberly Bay (near-field) sites, 1 far-field site

Jackfish Bay sites that are different or very different than reference include the 4 sites in Moberly Bay and 2 of the 3 far-field sites (southeast of Cody Island). The BEAST method tends to be more sensitive to changes in abundance rather than diversity. The difference of Moberly Bay sites from reference conditions is associated with increased abundance of Tubificidae (and increased Chironomidae for site M701). These sites are also located along a gradient of increasing total organic carbon (TOC) in the ordination plot (Appendix C, Figure C1). Far-field sites are associated with decreased abundances of certain taxa, but predominantly Haustoriidae (e.g., sites are located along a similar vector line as Haustoriidae but in the opposite direction; Appendix C, Figure C1).

3.3 Sediment Toxicity

Mean survival, growth and reproduction in laboratory toxicity tests are shown in Table 8. The established numerical criteria for each category (non-toxic, potentially toxic and toxic) for each species are included. Toxicity is highlighted and potential toxicity is italicized. Water quality variables (dissolved oxygen, pH, temperature, ammonia and conductivity) measured at the start and end of the tests are provided in Appendix D, Table D1. Water quality in the test beakers was consistent throughout the duration of the exposures and there were no unusual readings. Acute toxicity to *Hyalella* (survival: 8 to 44%) is evident at 9 of the 15 sites (Table 8). Potential toxicity due to reduced *Hyalella* survival is also evident at 1 site (survival: 66.7%); potential toxicity due to depressed *Hexagenia* growth is evident for 3 sites (growth: 0.07 to 0.81 mg), and; toxicity and potential toxicity due to reduced *Tubifex* cocoon production is evident at 2 sites (number of cocoons/adult: 5.4, 6.9). Three of the four sites in Moberly Bay show both low amphipod survival and low mayfly growth. There is no toxicity to *Chironomus* at any site.

BEAST assessment of toxicity

Results of the BEAST toxicity evaluation are summarized in Table 8. A map showing the level of toxicity by site is shown in Figure 7. Ordinations are shown in Appendix E, Figures E1 and E2 (stress < 0.10). Each figure represents a separate ordination of a subset of 7 and 8 Jackfish Bay sites. Seven and nine endpoints are significant in Figures E1 and E2, respectively. Examination of the relationship between environmental variables and ordination axes scores reveals no high correlations ($r^2 \leq 0.22$). The most highly correlated environmental variables are shown in each ordination.

Jackfish Bay sites fall into the following bands of similarity to reference conditions (Table 8, Figure 7):

Band 1 (non-toxic):	4 sites
Band 2 (potentially toxic):	2 sites
Band 3 (toxic):	0 sites

Band 4 (severely toxic): 9 sites

Sites in Band 4 are associated with decreased *Hyalella* survival (sites are located along the same vector line as *Hyalella* in the opposite direction); *Hyalella* survival is maximally correlated (r^2 =0.97, 0.92) to ordination axis scores and is shown as a vector in Appendix E, Figures E1 and E2. Reduced mayfly growth is also associated with Moberly Bay sites (Figure E1).

Increased depth is correlated to some sites (far far-field sites) and some of these sites are also located along an increasing gradient of clay and copper (shown as a vector in Figure E2), although as mentioned, correlations are not high. Percent clay (r^2 =0.09) is high at site 4M3 (74.5%, Table 4), and depth (r^2 =0.12) is > 60m at 4M1, 4M2 and 6973 (Table 1). Copper (r^2 =0.22) is below the SEL at these sites (Cu range: 23 to 50 μg/g; Table 5).

Toxicity-contaminant relationships

Examination of relationships between sediment toxicity and sediment contaminants both graphically and by regression analysis may aid in identifying possible causes of toxicity attributable to organic contaminants (not included in the BEAST analysis) as well as inorganic compounds, sediment nutrients and sediment grain size. The ordination of the multiple measurements of sediment toxicity by HMDS for all the Jackfish Bay sites produced two descriptors of sediment toxicity (Appendix F, Figure F1). The most highly correlated endpoint (r^2 = 0.99) is *Hyalella* survival (Hasu), shown as a vector in Figure F1. *Hyalella* survival is negatively correlated with Axes 1 and 2; therefore, the greater the toxicity, the higher its score for Axes 1 and 2. The environmental variables most significantly ($p \leq 0.05$) correlated to toxicity include total organic carbon (TOC) and total PAHs (r^2 =0.41 for both), and overlying water total Kjeldahl nitrogen (TKN) (r^2 =0.30); however, these variables are not situated along same vector lines as the sites themselves in ordination space.

<u>Integrated toxicity descriptors – contaminant relationships</u>

Ten metals (As, Cd, Cr, Cu, Fe, Hg, Mn, Ni, Pb, Zn) were ordinated by principal components analysis (PCA). The first 3 principal components account for 54%, 26% and 14% of the total variation, respectively. All measurement variables were positively loaded for PC1, and loadings are of a relatively similar magnitude. This component – denoted as "metPC1" – was used as a general descriptor of metal contamination.

The integrated descriptors of sediment toxicity (Axis 1 and 2 scores "*ToxAxis1*" and "*ToxAxis2*" from the HMDS) were plotted against the integrated metal toxicity descriptor (metPC1), log(x) - transformed total PAHs, total PCBs, and total dioxin and furan congeners (Appendix F, Figure F2). Regression analysis reveals that the strongest relationship is for Axis 1, with dioxin and furan congeners explaining ~93% of the variability. Predictors with positive coefficients (hexachlorodioxins, octachlorodioxins, octachlorofurans) are potentially toxic to *Hyalella* survival.

ToxAxis1 = 10.9 - 1.89 log tetrachlorofurans + 1.48 log hexachlorodioxins - 4.34 log heptachlorodioxins + 2.96 log octachlorodioxins + 3.74 log octachlorofurans ($p<0.001$, adjusted $r^2 = 92.7\%$)

Individual toxicity descriptors - contaminant relationships

The relationships among individual toxicological response variable was evaluated by plotting the most significant endpoint, *Hyalella* survival, against integrated contaminant descriptors (Appendix F, Figure F3) as well as concentrations of individual physical and chemical variables (Appendix F, Figures F4 to F7).

The most significant relationship is provided below. Predictor coefficients that are negative (hexachlorodioxin isomer, total phosphorus in the overlying water) indicate that decreased *Hyalella* survival is related to increased concentrations.

Hyalella survival = - 9.17 – log 0.759 1,2,3,6,7,8-Hexachlorodioxin + 0.688 log Mn + 0.700 arcsine square root Sand + 1.19 log total N (sediment) - 0.509 log total P (water) + 0.641 log NO_3/NO_2 (water) ($p<0.001$, adjusted $r^2 = 92.7\%$)

Potential causes of toxicity

Although bulk and extractable concentrations of contaminants in sediment are imperfect indicators of bioavailability (Luoma and Carter 1991), up to 93% of the variability in toxicity of Jackfish Bay sediments is explained by the regression models. Regression of the toxicity descriptor Axis 1 and individual groups of organic contaminants (dioxin and furan congeners) and the regression of individual toxicity response and individual contaminant, grain size and nutrients produce equally strong relationships.

Predictors with coefficients indicating decrease in toxicity with increase in contaminant concentration do not suggest causal relationships. These include negative contaminant coefficients for toxAxis1, and positive coefficients for the survival variable. After excluding predictors not indicative of toxicity relationships, toxicity to *Hyalella* is most strongly associated with organic contaminants (e.g., total hexachlorodioxins, octachlorodioxins and octachlorofurans for toxAxis1, and 1,2,3,6,7,8-hexachlorodioxin for *Hyalella* survival). Grain size, which is known to affect sediment toxicity, is significant for *Hyalella* survival. Sediment manganese and sediment and overlying water nutrients are important factors that may affect contaminant bioavailability.

3.4 Quality Assurance/Quality Control

Variability among field-replicated sites, expressed as the coefficient of variation (CV), is shown in Appendix G, Table G1. The CVs range from 0 to 71.0 % (median 6.8%), not uncommon for field-replicated samples (samples taken from three separate box core drops). Differences in variability are seen among sites and among parameter for the same site. The highest variability is noted for total phosphorus (water) and chromium (as Cr_2O_3, 69.3%) for site 1M2. Quality control results from Caduceon laboratory (i.e., reference standards, sample duplicate measurements) are not available.

The MOE percent recoveries for matrix spikes of internal standards (d10-phenanthrene, d12-chrysene, d8-naphthalene) are generally good, ranging from 46 to 140% (overall mean 90%) (Table G2). Recoveries are lowest for d8-naphthalene (mean 75%) compared to d12-chrysene (mean 92%) and d10-phenanthrene (mean 103%).

Benthic community variability

The replicate sites of 1M2 and 4M3 are in very close proximity to each other in ordination space, indicating good agreement in benthic community composition for the field replicates (Appendix G, Figure G1). All three replicates of 1M2 are in Band 4. For 4M3, two replicates (1 and 3) are in Band 2 and 1 is in Band 1, but replicates are close nonetheless. These results indicate that the benthic invertebrate community is well represented by one box core sample.

Benthic community sorting efficiency

Sorting efficiency was determined by re-sorting 2 samples (or 13% of the samples). The mean percent sorting efficiency for the community samples is 2.2%, which represents the average sorting efficiency of two sorters over a two month period. This is an acceptable low level, indicating that there was a good recovery (>95%) of organisms in the samples.

3.5 Decision-Making Framework for Sediment Contamination

A risk-based, decision-making framework for the management of sediment contamination was recently developed by the Canada-Ontario Agreement Sediment Task Group using four lines of evidence (sediment chemistry, toxicity, benthic invertebrate community and potential for biomagnification). This decision framework was developed from the Sediment Triad and BEAST frameworks, and is described in Grapentine et al. (2002) and Chapman and Anderson (2005). The overall assessment of a test site is achieved by integrating the information obtained both within and among the four lines of evidence. This framework was applied to the Jackfish Bay study using three lines of evidence (potential for biomagnification was not assessed). The decision matrix for the weight of evidence categorization for test sites is shown in Table 9. For the sediment chemistry column, sites with exceedences of a sediment quality guideline (SQG) – low are indicated by "◘"; sites with SQG-high exceedences by "●". Substances exceeding the Lowest Effect Level (LEL), Severe Effect Level (SEL) and Probable Effect Level (PEL) are listed. For the toxicity column, sites where multiple endpoints exhibit major toxicological effects are indicated by "●"; sites where one endpoint exhibits a major effect or multiple endpoints exhibit minor effects are indicated by "◘"; minor toxicological effects observed in no more than one endpoint by "○". For the benthos alteration column, sites determined from BEAST analyses as different or very different from reference are indicated by "●"; sites determined as possibly different from reference by "◘". Sites with no SQG exceedences or benthic communities equivalent to reference conditions are indicated by "○". Interpretation of the overall assessment for management implications considers the degree of degradation for each line of evidence. Some sites that show possible benthos alteration are not recommended for further action. For these sites, the benthos alteration is not judged detrimental (decreased taxon richness, reduced average abundance).

Management actions required

This is indicated at 3 sites: 1M1, 1M2, 1M3 (near-field Moberly Bay).

Five metals and total PCBs are elevated above LELs and dioxins/furans, expressed in toxic equivalents, are above the PEL at these sites. There is concurrence of strong sediment toxicity and altered benthic communities.

Determine reasons for benthos alteration

This is indicated at 4 sites: M701 (near-field Moberly Bay)
2M1, 2M2, 2M3 (far-field)

From 2 to 9 metals are above LELs at all sites and dioxin/furans are above the PEL at 2 of the 3 far-field sites. Benthic communities are different or very different from reference at 3 sites (near-field and far-field) and possibly different from reference at 1 site. There is no strong evidence of toxicity.

Determine reasons for sediment toxicity

This is indicated at 6 sites: 4M1, 4M2, 4M3 (far far-field)
6972, 6973 (Cape Victoria).
3M2 (Tunnel Bay)

Sediment contaminant concentrations are above LELs for several (3 to 10) metals and one or more endpoints exhibit major toxicological effects. Benthic communities are equivalent to reference, or benthos alteration is not judged detrimental. Communities may have acclimated/adapted or there is insufficient stress to cause population-level responses. There is, however, the potential for adverse effects at these toxic sites and thus the benthic community should be monitored for change in status.

No further actions needed

This is indicated at 2 sites: 3M3 and 6956 (Tunnel Bay).

While sediment metal contaminant concentrations are above LELs for 7-8 metals, benthic communities are equivalent to reference and there is no strong evidence of toxicity.

4 CONCLUSIONS

Sediment contaminants

Several sediment contaminants are above Sediment Quality Guidelines in Jackfish Bay. From 2 to 10 metals are above provincial Lowest Effect Levels (LELs) at all sites and total PCBs are above the LEL at 3 of the 4 sites in near-field Moberly Bay. Exceedences of the provincial Severe Effect Level are limited to manganese at four sites in the far-field area (south of Moberly Bay) and in Tunnel Bay. Concentrations of dioxins and furans, expressed in toxic equivalents, are above the federal Probable Effect Level (PEL) in Moberly Bay (up to ~3× the PEL) and are just slightly above the PEL in the far-field area of Jackfish Bay. Moberly Bay has the highest metal and organic contaminant concentrations and sites are organically enriched. Visual inspection of the sediment at the time of sampling noted the presence of odorous, oily sediment at 1M1, 1M2, and 1M3 (all in Moberly Bay); mean solvent extractable (oil and grease) concentration in the near-field area (excluding the sandy site closest to the mouth of Blackbird Creek) is ~4× higher than the far-field area.

Benthic invertebrate community

There are six sites that show evidence of different or very different communities: four in Moberly Bay and two in the far-field area (southeast of Cody Island) (Figure 6). Moberly Bay sites have low (or zero) abundance of haustoriids (key reference site amphipod taxon), and enriched tubificids compared to reference. Tubificid densities in Moberly Bay are indicative of a polluted environment, with > 100,000 tubificids per m^2 at 1 site and 15,000 to 67,000 per m^2 at the other 3 sites. Haustoriidae, which consists entirely of *D. hoyi*, are in lowest abundance in the organically enriched areas of Moberly Bay and the far-field area (south of Moberly Bay). These results are consistent with historical data and suggest a slight improvement in conditions in Moberly Bay since 1987, when *D. hoyi* was absent. Conditions in Moberly Bay are very similar to what was found in the EEM Cycle 1 to 3 surveys in 1996, 1999, and 2002. Altered benthic communities, mainly in the near-field area, reflect historic organic contamination due to pulp and paper mill discharges (Stantec 2004). The far-field area shows some improvement in benthic quality over Moberly Bay with reduced tubificid densities and slight increases in amphipod (*D. hoyi*) densities, but the number of taxa present remains below the reference mean. Taxon diversity in Tunnel Bay is below average but benthic quality is improved over the area south of Moberly Bay, with increased *D. hoyi* densities. Benthic communities in the far far-field area of Jackfish Bay do not appear to be impacted and are more indicative of oligotrophic conditions; densities of *D. hoyi* are highest in these areas and sites are also characterized by the presence of Lumbriculidae and Enchytraeidae.

Sediment toxicity

Toxicity is evident throughout the bay. Nine sites are acutely toxic to the amphipod (*Hyalella azteca*). There is also reduced mayfly (*Hexagenia* spp.) growth in Moberly Bay and reduced worm (*Tubifex tubifex)* cocoon production in far far-field locations. Toxicity is most significantly related to increased organic contaminant concentrations (dioxins and furans). Grains size, sediment and overlying water nutrients and manganese are also significant in individual toxicity - contaminant relationships. Oily sediment may be a factor in toxicity at the Moberly Bay sites. The cause of toxicity at the far far-field sites is unclear and is likely different than the cause of toxicity in the near- and far-field areas; contaminants levels are generally low and effects on *Tubifex* reproduction are only seen in far far-field locations of the bay.

Decision-making framework for sediment contamination

Management actions are indicated for 3 of the 4 sites in Moberly Bay due to elevated sediment contaminants and concurrence of benthos alteration and sediment toxicity. Several sites require the reasons for benthos alteration or the reasons for sediment toxicity to be determined.

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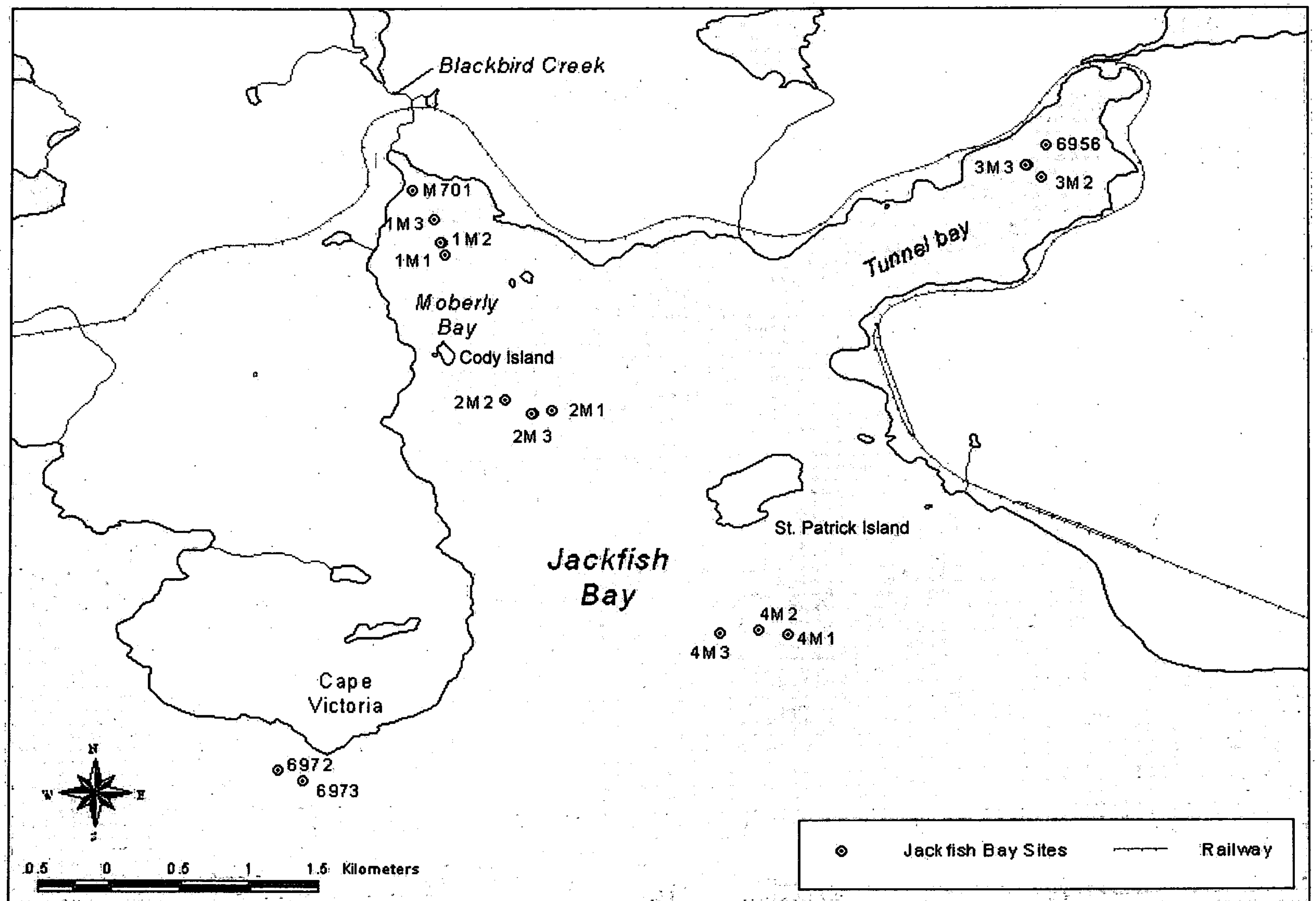


Figure 1. Location of sites in Jackfish Bay, 2003.

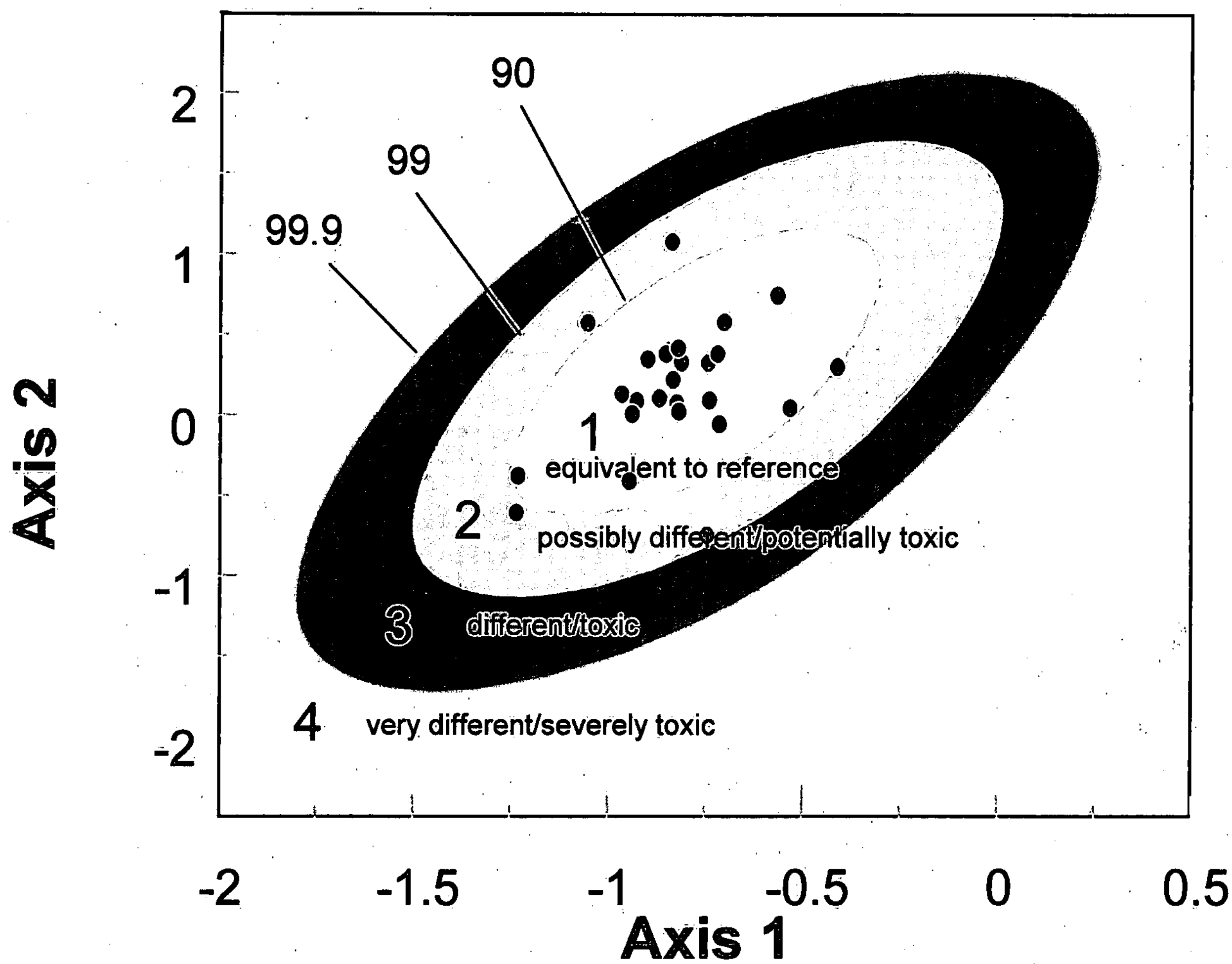


Figure 2. Use of 90, 99, and 99.9% probability ellipses around reference sites in determining the level of departure from reference condition.

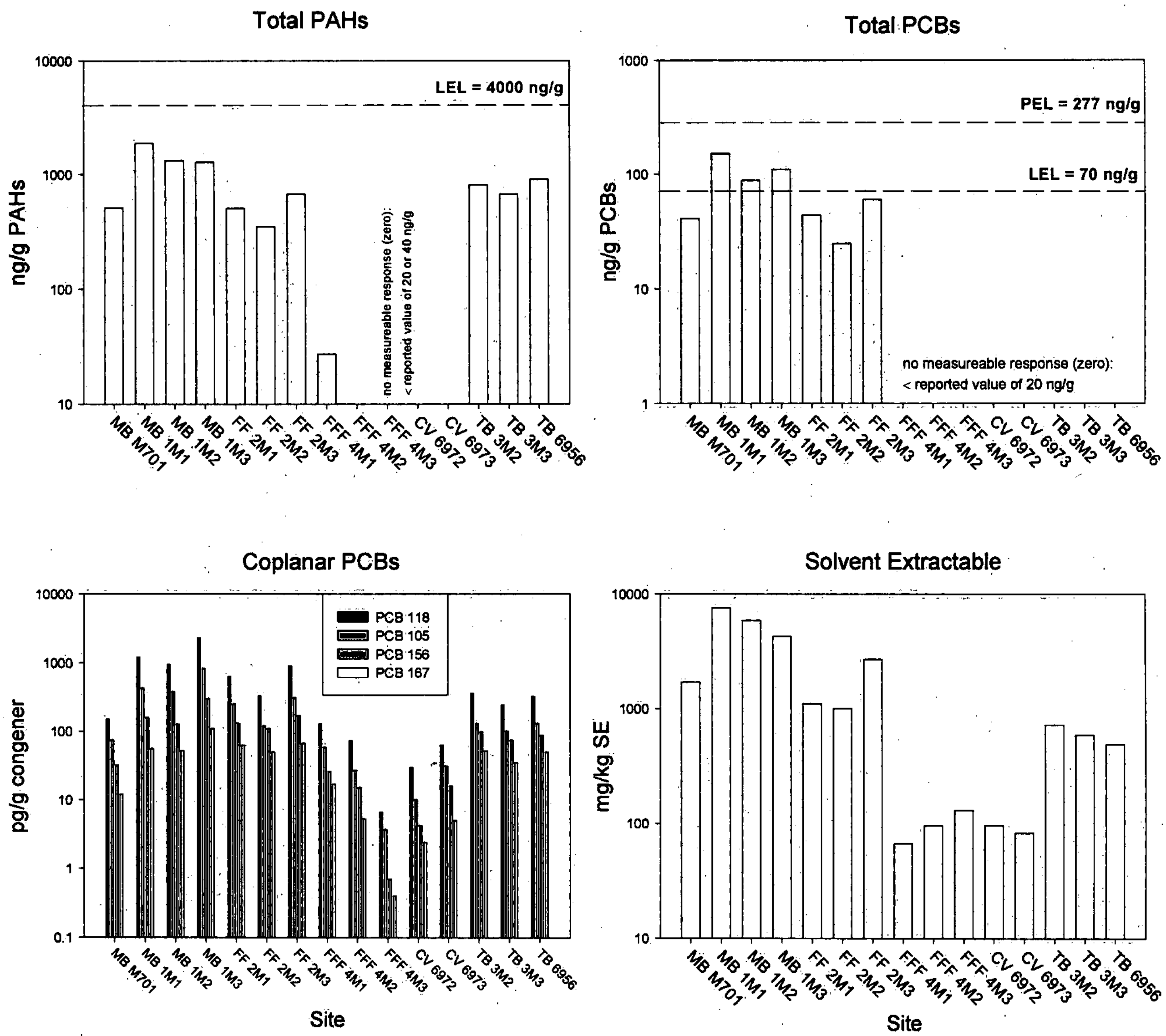


Figure 3. Concentrations of total polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs) and solvent extractable concentrations in Jackfish Bay sediment. The Lowest Effect Level (LEL) and Probable Effect Level (PEL), where available, are shown. (MB = Moberly Bay, FF = far-field, FFF = far far-field, TB = Tunnel Bay, CV = Cape Victoria).

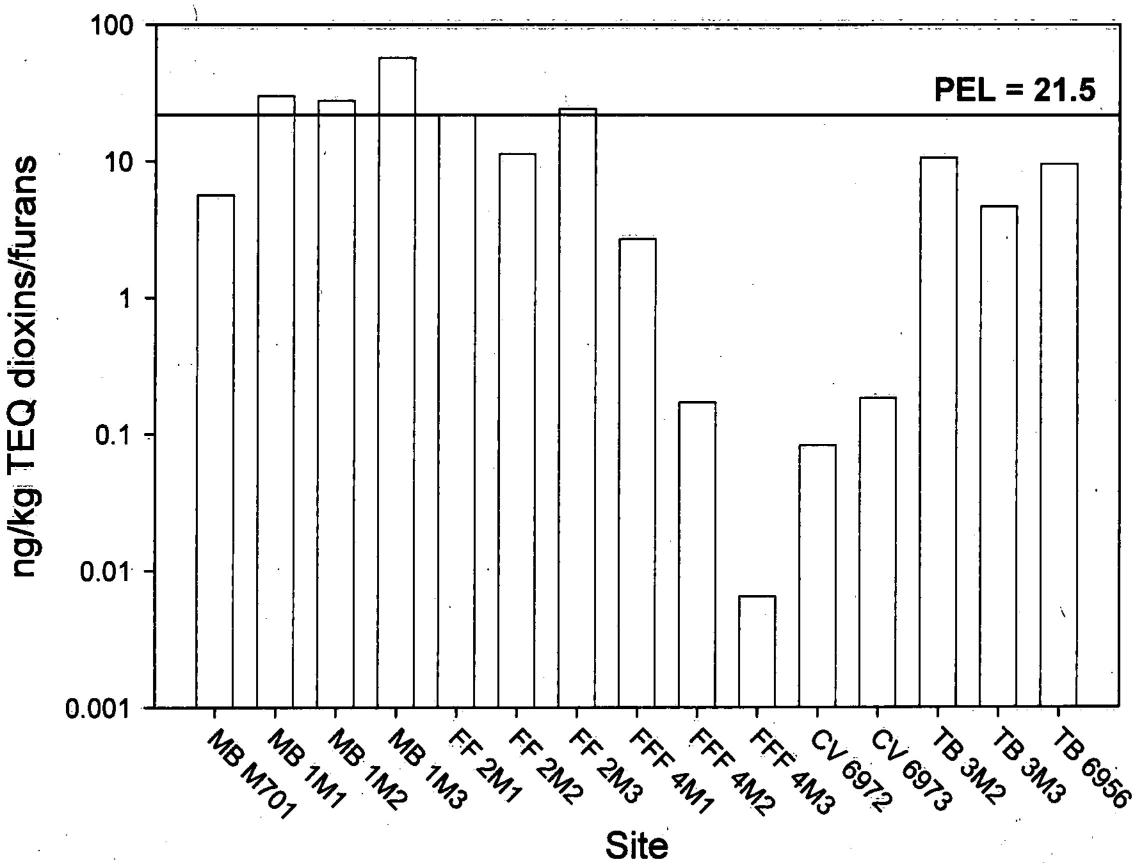


Figure 4. Concentration, expressed in toxic equivalency (TEQ) units, for dioxins and furans relative to 2,3,7,8-TCDD. World Health Organization toxic equivalency factors for fish were used in the calculations (Van den Berg et al. 1998). Non-detect values were assigned a zero in the calculations. The Probable Effect Level (PEL) for dioxins/furans (21.5ngTEQ/kg dw) is shown.

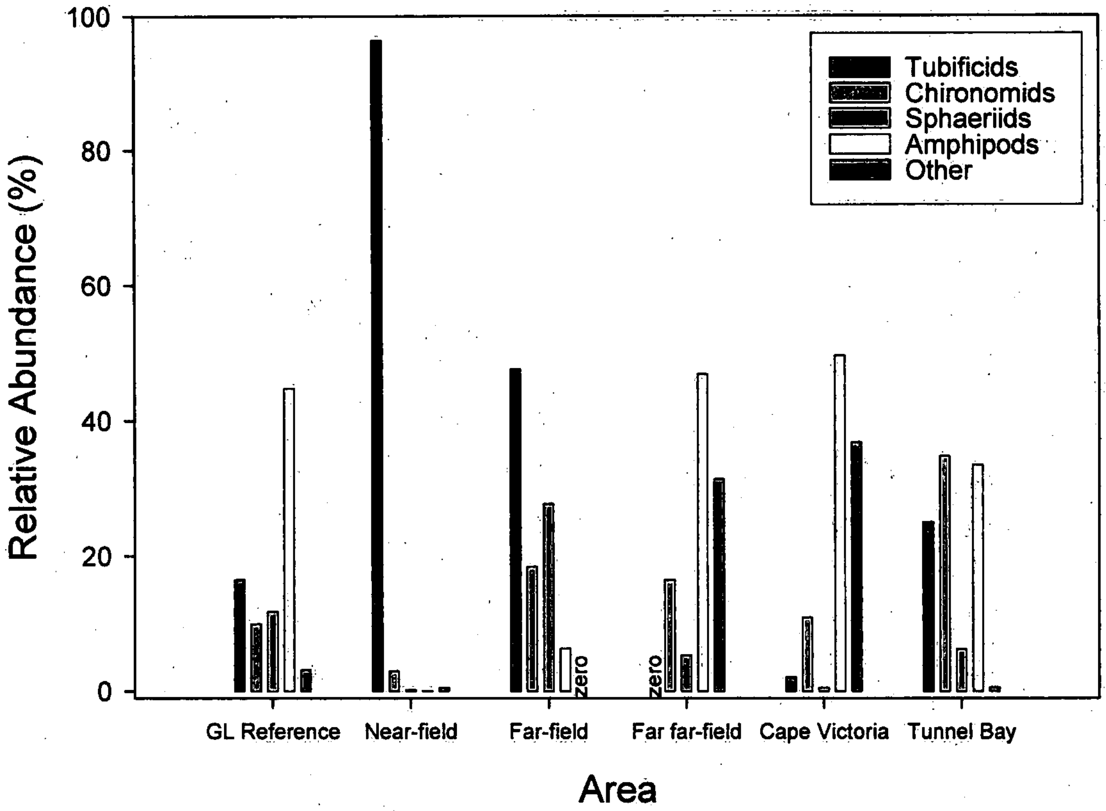


Figure 5. Mean relative abundance of predominant benthic macroinvertebrate taxa from Jackfish Bay areas.

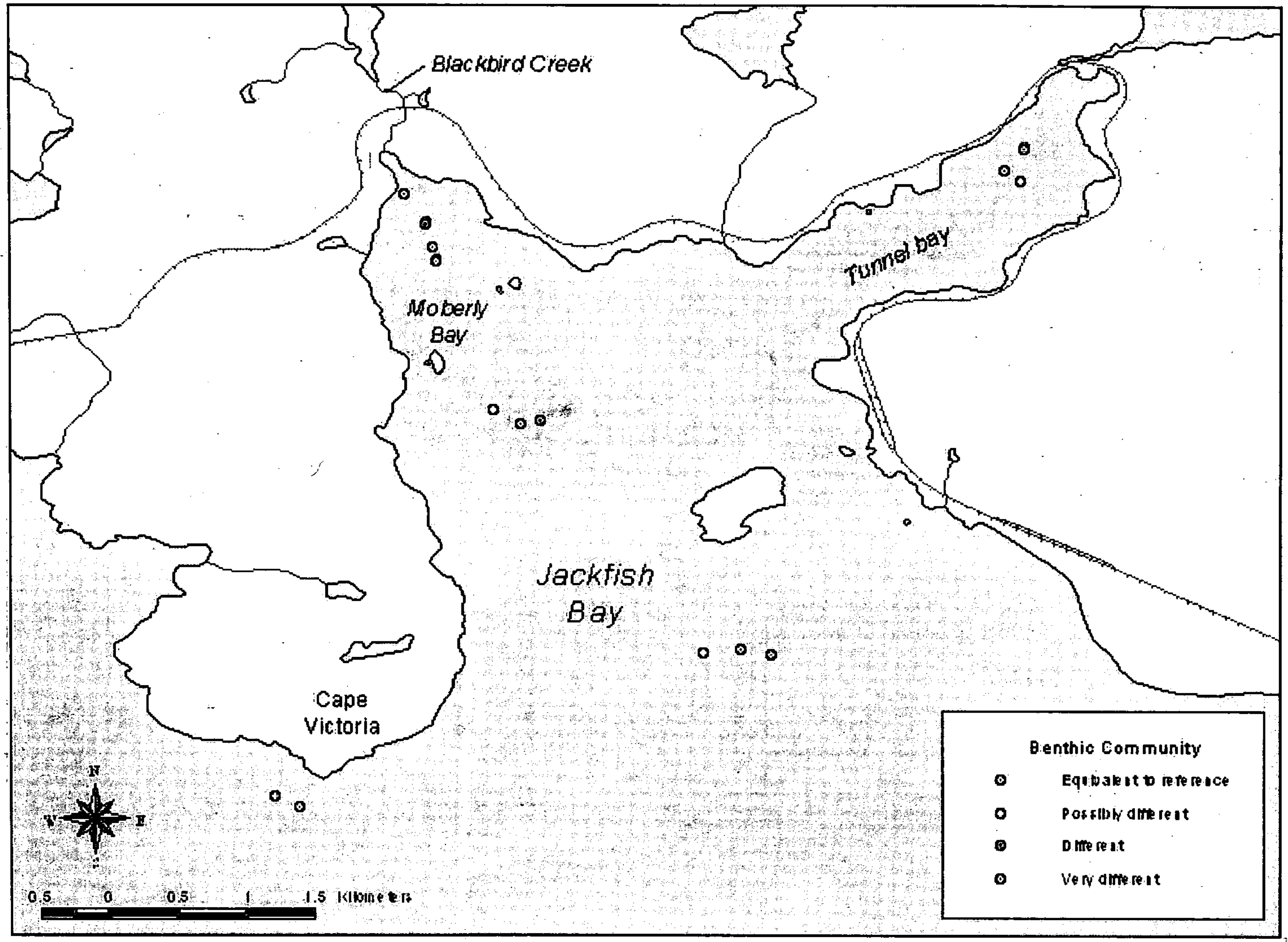


Figure 6. Spatial distribution of Jackfish Bay sites indicating the level of benthic community alteration compared to Great Lakes reference sites.

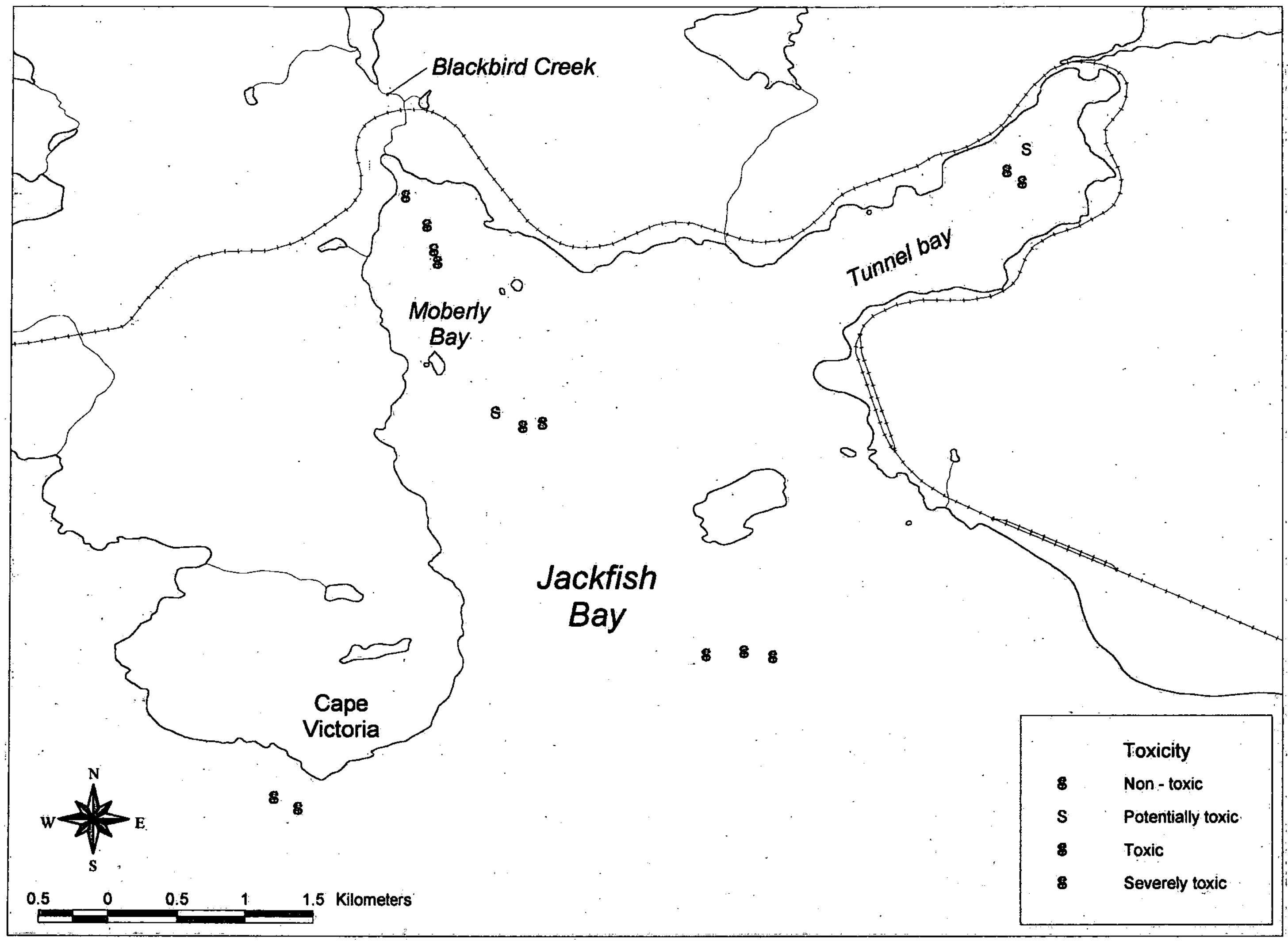


Figure 7. Spatial distribution of Jackfish Bay sites indicating the level of toxicity compared to Great Lakes reference sites.

Table 1. Jackfish Bay site co-ordinates (UTM NAD83), site depth and visual sediment description.

Location	Site	Site Depth (m)	Northing	Easting	Visual Sediment Description
Moberly Bay	M701	11.4	5406393	499874	sandy mud, heavy organic material
Moberly Bay	1M1	19.0	5405905	500030	oily, sticky mud, tar present, smelly
Moberly Bay	1M2	18.9	5405999	500012	oily sticky mud, some tar, smelly
Moberly Bay	1M3	17.1	5406180	499979	oily mud, smelly, some sticky tar
SW Cody Island	2M1	37.1	5404719	500537	fine silty mud over some clay
SW Cody Island	2M2	34.7	5404799	500312	fine silty mud over some clay
SW Cody Island	2M3	39.3	5404695	500443	fine silty mud over some clay
S St. Patrick Island	4M1	68.7	5403003	501648	fine silty soft sediment
S St. Patrick Island	4M2	62.0	5403040	501508	fine silty sediment
S St. Patrick Island	4M3	34.6	5403018	501325	fine clay
Cape Victoria	6972	35.0	5401964	499236	silty sand
Cape Victoria	6973	67.8	5401882	499352	silty sand
Tunnel Bay	3M2	31.2	5406497	502846	fine silty sediment over clay, odourless
Tunnel Bay	3M3	31.0	5406582	502774	fine silty sediment over clay
Tunnel Bay	6956	29.7	5406741	502868	fine silty sand over clay

Table 2. Environmental variables measured at each site.

Field	Overlying Water	Sediment (top 10 cm)
Northing	Alkalinity	Trace Metals and Major Oxides
Easting	Conductivity	Total Phosphorus, Total Nitrogen
Site Depth	Dissolved Oxygen	Total Organic Carbon, Loss on Ignition
	pH	Percents Clay, Silt, Sand and Gravel
	Temperature	Polychlorinated Biphenyls
	Total Kjeldahl Nitrogen	Polycyclic Aromatic Hydrocarbons
	Nitrates/Nitrites	Organochlorine Pesticides
	Ammonia	Dioxins and Furans
	Total Phosphorus	Solvent Extractables

Table 3. Measured environmental variables in Jackfish Bay overlying water. MB = Moberly Bay, FF = Far-field; FFF= Far far-field; TB = Tunnel Bay; CV = Cape Victoria.

Site	Alkalinity m/L	Conductivity µS/cm	Dissolved O_2	NH_3 m/L	NO_3/NO_2 m/L	pH	Temp °C	Total Kjeldahl N m/L	Total P µg/L
MB M701	48.7	137	14.6	0.016	0.441	7.8	14.9	0.199	26
MB 1M1	51.1	111	17.6	0.020	0.077	7.8	11.5	0.220	41
MB 1M2	48.1	110	17.1	0.026	0.412	7.2	10.9	0.180	32
MB 1M3	46.7	119	14.4	0.031	0.396	7.8	14.1	0.160	23
FF 2M1	42.8	106	5.4	0.020	0.344	7.9	12.7	0.105	5
FF 2M2	42.5	105	5.5	0.021	0.338	7.9	13.6	0.104	5
FF 2M3	42.6	115	9.6	0.019	0.377	7.6	6.7	0.107	7
FFF 4M1	41.7	120	7.1	0.019	0.403	8.0	5.1	0.087	9
FFF 4M2	43.2	110	6.3	0.019	0.406	7.9	4.7	0.084	5
FFF 4M3	41.8	102	5.7	0.022	0.350	8.0	13.8	0.115	3
CV 6972	41.4	103	10.5	0.061	0.353	8.1	13.2	0.297	5
CV 6973	42.2	110	9.3	0.019	0.390	8.0	4.7	0.085	5
TB 3M2	42.4	118	6.2	0.056	0.393	7.4	6.3	0.164	6
TB 3M3	42.7	110	5.6	0.032	0.399	7.5	6.6	0.121	7
TB 6956	43.0	110	5.4	0.050	0.402	7.6	6.6	0.168	6
Lake Superior Reference (n=31)[a]	39-53		10.3-15.0		0.24-0.36	7.5-7.9	5-20	0.031-0.226	3.6-28

[a] Unpublished data, Environment Canada 2006

Table 4. Physical characteristics of Jackfish Bay sediment (top 10 cm). MB = Moberly Bay, FF = Far-field; FFF = Far far-field; TB = Tunnel Bay; CV = Cape Victoria.

Site	% Sand	% Silt	% Clay	% Gravel
MB M701	93.6	6.4	0	0
MB 1M1	4.5	76.1	19.5	0
MB 1M2	4.2	76.1	19.7	0
MB 1M3	9.3	72.0	18.8	0
FF 2M1	7.2	69.2	23.6	0
FF 2M2	28.5	53.4	18.2	0
FF 2M3	7.0	60.5	32.5	0
FFF 4M1	8.9	69.0	22.1	0
FFF 4M2	38.3	47.5	14.2	0
FFF 4M3	10.5	14.8	74.5	0.2
CV 6972	67.5	23.6	8.9	0
CV 6973	65.8	26.4	7.9	0
TB 3M2	4.0	60.4	35.7	0
TB 3M3	10.2	67.4	22.3	0
TB 6956	3.7	75.3	21.0	0

Table 5. Trace metal and nutrient concentrations in Jackfish Bay sediment. Substances > Severe Effect Level are highlighted.

				Lake Superior	Moberly Bay						Far-field: Southwest of Cody Island			Far far-field: South of St. Patrick Island					Far far-field: Cape Victoria		Tunnel Bay		
Parameter	Units	M.D.L.	Reference Method	Reference*	M701	1M1	1M2-01	1M2-02	1M2-03	1M3	2M1	2M2	2M3	4M1	4M2	4M3-01	4M3-02	4M3-03	6972	6973	6956	3M2	3M3
Aluminum (Al)	µg/g	300	SM 3120		6050	10400	10200	9600	9320	9820	14400	9650	13900	10900	8340	23100	18200	21300	8690	9880	12200	14100	11500
Aluminum (Al)	pct				0.605	1.04	1.02	0.96	0.932	0.982	1.44	0.965	1.39	1.09	0.834	2.31	1.82	2.13	0.869	0.988	1.22	1.41	1.15
Antimony (Sb)	µg/g	0.2	SM 3114		0.2	0.4	0.4	0.2	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.2	< 0.2	0.4	0.6	0.5	0.5
Arsenic (As)	µg/g	1	SM 3114	< 25	< 1	2	2	2	2	2	6	5	5	5	3	3	4	2	2	4	9	9	8
Barium (Ba)	µg/g	1	SM 3120		51	76	81	75	74	72	106	61	96	63	47	132	113	134	34	37	98	111	89
Beryllium (Be)	µg/g	0.2	SM 3120		< 0.2	0.3	0.3	0.3	0.2	0.3	0.4	0.3	0.4	0.3	0.3	0.5	0.4	0.6	< 0.2	< 0.2	0.4	0.4	0.4
Bismuth (Bi)	µg/g	5	SM 3120		< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	8	7	7	< 5	< 5	< 5	< 5	< 5
Cadmium (Cd)	µg/g	0.5	SM 3120	0.1-4.3	< 0.5	1.8	1.8	1.7	1.9	1.8	1.4	0.9	1.4	0.9	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	0.6	1.5	1.6	1.2
Calcium	µg/g	100	SM 3120		5810	19600	20300	19400	18900	13700	9360	7460	9900	16900	18200	103000	88300	60200	4780	5640	8960	6800	6490
Calcium (Ca)	pct				0.581	1.96	2.03	1.94	1.89	1.37	0.936	0.746	0.99	1.69	1.82	10.3	8.83	6.02	0.478	0.564	0.896	0.68	0.649
Chromium (Cr)	µg/g	1	SM 3120	8-78	35	58	57	57	58	64	60	43	63	40	34	61	48	59	43	45	44	56	44
Cobalt (Co)	µg/g	1	SM 3120	1-30	7	9	9	9	9	9	13	9	12	10	8	19	16	19	9	10	12	13	11
Copper (Cu)	µg/g	1	SM 3120	3-80	9	37	39	38	39	42	54	32	53	50	30	33	27	34	23	25	56	60	48
Iron	µg/g	300	SM 3120		13000	17000	17100	16400	16100	17500	27000	20300	24800	20000	16200	33100	29000	35400	19200	20600	24800	28000	23200
Iron (Fe)	pct				1.3	1.7	1.71	1.64	1.61	1.75	2.7	2.03	2.48	2	1.62	3.31	2.9	3.54	1.92	2.06	2.48	2.8	2.32
Lead (Pb)	µg/g	5	SM 3120	1-55	< 5	9	10	10	10	11	22	14	23	28	16	11	7	11	8	12	36	39	30
Magnesium	µg/g	100	SM 3120		5130	13200	13600	13100	12700	9830	9070	7160	9590	12700	11500	23100	22300	19200	6530	7690	9000	8360	7530
Magnesium (Mg)	pct				0.513	1.32	1.36	1.31	1.27	0.983	0.907	0.716	0.959	1.27	1.15	2.31	2.23	1.92	0.653	0.769	0.9	0.836	0.753
Manganese (Mn)	µg/g	1	SM 3120		312	403	412	374	384	440	1680	1120	1010	1540	982	685	585	621	346	554	1210	1050	1090
Molybdenum (Mo)	µg/g	1	SM 3120		< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	1	< 1
Nickel (Ni)	µg/g	1	SM 3120	5-107	18	26	35	25	25	30	40	23	35	23	21	41	34	42	26	27	32	32	27
Potassium	µg/g	300	SM 3120		509	1450	1380	1300	1250	1270	1960	1150	1940	1550	1120	4680	3680	4300	767	892	1550	1930	1490
Potassium (K)	pct				0.0509	0.145	0.138	0.13	0.125	0.127	0.196	0.115	0.194	0.155	0.112	0.468	0.368	0.43	0.0767	0.0892	0.155	0.193	0.149
Sodium	µg/g	200	SM 3120		338	461	442	437	414	444	475	362	479	362	323	638	481	519	307	332	348	458	362
Sodium (Na)	pct				0.0338	0.0461	0.0442	0.0437	0.0414	0.0444	0.0475	0.0362	0.0479	0.0362	0.0323	0.0638	0.0481	0.0519	0.0307	0.0332	0.0348	0.0458	0.0362
Silver (Ag)	µg/g	0.5	SM 3120		< 0.5	< 0.5	< 0.5	0.6	0.6	0.8	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
Selenium (Se)	µg/g	0.1	SM 3114		0.1	0.4	0.6	0.6	0.6	0.6	0.5	0.4	0.7	0.3	0.2	0.1	0.1	0.2	0.2	0.1	0.8	0.8	0.6
Strontium (Sr)	µg/g	1	SM 3120		21	26	25	24	23	23	28	22	28	22	21	86	66	55	13	15	21	24	21
Titanium (Ti)	µg/g	1	SM 3120		738	865	746	692	650	759	1260	1100	1240	1010	934	1680	1240	1380	824	1110	852	1040	881
Thallium (Tl)	µg/g	0.02	EPA 6020		< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
Tin (Sn)	µg/g	10	SM 3120		< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
Tungsten (W)	µg/g	200	SM 3120		< 200	< 200	< 200	< 200	< 200	< 200	< 200	< 200	< 200	< 200	< 200	< 200	< 200	< 200	< 200	< 200	< 200	< 200	< 200
Vanadium (V)	µg/g	1	SM 3120		28	37	35	34	34	38	51	41	50	38	32	56	47	59	37	41	43	49	41
Yttrium (Y)	µg/g	0.5	SM 3120		4.4	6.9	6.8	6.4	6.1	6.7	10.2	8.1	9.7	9.2	7.5	12.3	10.4	11.7	6.2	6.4	9.3	10.4	9
Zinc (Zn)	µg/g	1	SM 3120	20-172	93	177	192	185	182	177	137	92	133	78	55	85	72	86	58	74	113	122	101
Mercury (Hg)	µg/g	0.005	SM 3112	0.008-0.26	0.033	0.082	0.058	0.061	0.059	0.09	0.088	0.081	0.091	0.094	0.005	0.04	0.042	0.023	0.02	0.039	0.102	0.114	0.087
Aluminum (Al_2O_3)	%	0.01	IN-HOUSE		11.97	10.34	10.56	10.22	10.8	10.83	12.03	12.2	12.27	11.78	11.44	12.19	12.33	13.84	12.35	12.09	12.41	12.48	12.35
Barium (BaO)	%	0.001	IN-HOUSE		0.06	0.058	0.057	0.058	0.056	0.06	0.069	0.072	0.065	0.065	0.066	0.059	0.055	0.063	0.058	0.06	0.066	0.069	0.07
Calcium (CaO)	%	0.01	IN-HOUSE		2.75	4.44	4.34	4.29	4.2	3.58	2.94	3.1	2.91	4.17	4.35	14.52	13.9	9.12	2.98	2.86	2.82	2.54	2.65
Chromium (Cr_2O_3)	%	0.01	IN-HOUSE		< 0.01	0.01	0.01	0.03	0.01	0.02	0.01	0.01	0.01	0.01	< 0.01	0.01	0.01	0.01	0.01	< 0.01	0.01	0.01	0.01
Iron (Fe_2O_3)	%	0.05	IN-HOUSE		3.11	3.73	3.69	3.68	3.6	3.82	5.14	4.5	4.75	4.19	3.4	5.8	5.7	7.45	4.52	4.31	4.89	5.33	4.74
Potasium (K_20)	%	0.01	IN-HOUSE		1.92	2.2	2.15	2.13	2.09	2.18	2.56	2.5	2.42	2.56	2.47	2.62	2.64	2.92	2.15	2.17	2.45	2.59	2.57
Magnesium (MgO)	%	0.01	IN-HOUSE		1.47	2.99	2.96	2.9	2.87	2.41	2.21	2.02	2.25	2.81	2.47	4.4	4.7	4.25	1.99	2	2.16	2.06	1.97
Manganese (MnO)	%	0.01	IN-HOUSE		0.06	0.07	0.07	0.07	0.07	0.07	0.22	0.17	0.15	0.22	0.14	0.1	0.09	0.11	0.08	0.1	0.17	0.15	0.16
Sodium (NaO)	%	0.01	IN-HOUSE		3.48	2.47	2.41	2.43	2.39	2.61	2.74	3.23	2.6	2.77	3.05	1.91	1.61	2	3.31	3.15	2.55	2.63	2.82
Phosphorus (P_2O_5)	%	0.03	IN-HOUSE		0.13	0.21	0.21	0.2	0.19	0.2	0.25	0.22	0.25	0.18	0.16	0.13	0.13	0.14	0.15	0.13	0.23	0.26	0.23
Silica (SiO_2)	%	0.01	IN-HOUSE		65.04	56.4	56.64	56.16	58.44	57.95	61.1	64.8	62.88	64.12	66.03	43.18	43.89	48.43	69.35	68.16	64.45	62.8	64.12
Titanium (TiO_2)	%	0.01	IN-HOUSE		0.41	0.51	0.5	0.5	0.49	0.51	0.59	0.56	0.56	0.51	0.43	0.52	0.53	0.68	0.56	0.5	0.55	0.58	0.55
Loss on Ignition	%	0.05	IN-HOUSE		9.46	16.54	16.81	16.15	16.7	16.22	9.51	6.25	10.15	6.3	4.87	15.38	15.15	11.2	2.12	2.78	8.87	8.5	7.16
Whole Rock Total	%		IN-HOUSE		99.9	100	100.4	98.8	101.9	100.5	99.4	99.6	101.3	99.7	98.9	100.8	100.7	100.2	99.6	98.3	101.6	100	99.4
Total Nitrogen	µg/g	0.05	EPA 351.2	354-2422	1560	4200	4400	3580	3970	3350	2620	2160	3770	1220	781	412	406	515	476	595	2230	2480	2000
Phosphorus-Total	ug/g	0.01	EPA 365.4	165-1125	581	953	1500	828	953	865	1080	1350	1440	838	805	568	613	722	792	756	1080	1260	1090
Total Organic Carbon	%	0.1	EPA 415.1	0.17-2.93	5.1	6.9	6.6	6.9	6.9	7.5	3.5	2.5	4.2	1.3	0.7	0.8	0.3	0.4	0.5	0.8	3.1	3	2.5

* Environment Canada 2006, Unpublished data, n = 31

Table 6. Probabilities of test sites belonging to Great Lakes faunal groups. The highest probabilities are bolded. (MB = Moberly Bay, FF = Far-field; FFF = Far far-field; TB = Tunnel Bay; CV = Cape Victoria).

Site	Probability of Membership				
	Group 1	Group 2	Group 3	Group 4	**Group 5**
MB M701	0.220	0.001	0.000	0.000	**0.779**
MB 1M1	0.128	0.001	0.000	0.000	**0.871**
MB 1M2	0.134	0.001	0.000	0.000	**0.866**
MB 1M3	0.186	0.001	0.000	0.000	**0.814**
FF 2M1	0.009	0.000	0.000	0.000	**0.991**
FF 2M2	0.010	0.000	0.000	0.000	**0.990**
FF 2M3	0.008	0.000	0.000	0.000	**0.992**
FFF 4M1	0.000	0.000	0.000	0.004	**0.996**
FFF 4M2	0.000	0.000	0.000	0.002	**0.998**
FFF 4M3	0.007	0.000	0.000	0.000	**0.992**
CV 6972	0.008	0.001	0.000	0.000	**0.992**
CV 6973	0.000	0.000	0.000	0.003	**0.996**
TB 3M2	0.017	0.000	0.000	0.000	**0.983**
TB 3M3	0.016	0.000	0.000	0.000	**0.984**
TB 6956	0.021	0.000	0.000	0.000	**0.979**

Table 7. Mean abundance of dominant macroinvertebrate families (per 33 cm^2), taxon diversity (number of families), and BEAST difference-from-reference band. Families expected to be at test sites that are absent are highlighted.

Family	Group 5 Mean	Occurrence in Group 5 (%)	Moberly Bay				Far-field (South of Cody Island)			Far far-Field South of St. Patrick Island			Far far-Field Cape Victoria		Tunnel Bay		
			M701	1M1	1M2[a]	1M3	2M1	2M2	2M3	4M1	4M2	4M3[a]	6972	6973	6956	3M2	3M3
No. Taxa (± 2 SD)	6 (2-9)	-	8	4	5	5	4	4	4	5	4	7	6	5	4	5	4
Haustoriidae	12.1	44.3	0.2	0.2	0.1	0	0.6	0.4	0.2	10.0	7.0	3.5	8.2	12.8	6.6	3.0	4.4
Tubificidae[b]	4.5	16.6	409.6	211.8	207.7	50.0	1.8	7.0	2.2	0	0	0	0.6	0.2	3.6	3.2	3.2
Sphaeriidae	3.1	11.5	0.4	0.2	0.4	0.2	2.0	1.4	1.6	0.8	0.6	0.5	0.2	0	1.0	0.4	1.2
Chironomidae	2.7	9.9	14.6	3.2	3.7	4.2	1.0	2.2	0.8	3.2	2.0	1.5	1.8	2.8	5.2	4.2	4.6
Lumbriculidae	1.8	6.8	1.6	0	0	0	0	0	0	0.4	0	0.3	0.8	0.4	0	0	0
Enchytraeidae	1.4	5.3	0	0	0	0	0	0	0	2.6	1.6	3.1	6.4	7.6	0	0	0
Naididae	0.5	1.9	0.8	0	0.6	0.4	0	0	0	0	0	0.5	0	0	0	0	0
Asellidae	0.4	1.5	2.0	0	0	0.2	0	0	0	0	0	0	0	0	0	0	0
Valvatidae	0.2	0.7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gammaridae	0.2	0.6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BEAST BAND	-	-	4	4	4	3	3	2	4	1	1	2	1	1	1	2	1

[a] QA/QC site; value represent the mean of three field replicates; [b] includes immatures with and without chaetal hairs

Table 8. Mean percent survival, growth (mg dry wt) and reproduction in sediment toxicity tests and BEAST difference-from-reference band. Toxicity is highlighted and potential toxicity is italicized. (MB = Moberly Bay, FF = Far-field; FFF = Far far-field; TB = Tunnel Bay; CV = Cape Victoria).

Site	*C. riparius* %survival	*C. riparius* growth	*H. azteca* %survival	*H. azteca* growth	*Hexagenia* %survival	*Hexagenia* growth	*T. tubifex* %survival	*T. tubifex* No. cocoons/ adult.	*T. tubifex* %hatch	*T. tubifex* No. young/ adult.	**BEAST BAND**
GL Reference Mean	87.1	0.35	85.6	0.50	96.2	3.03	97.9	9.9	57.0	29.0	
MB M701	78.67	0.337	90.67	0.378	100	2.508	100	9.6	53.2	24.9	1
MB 1M1	97.33	0.274	**13.33**	0.266	100	***0.811***	100	9.1	60.3	21.5	**4**
MB 1M2	86.67	0.258	**32.00**	**0.055**	100	***0.069***	100	10.0	55.2	15.4	**4**
MB 1M3	92.00	0.311	**32.00**	0.269	98	***0.591***	100	9.5	64.5	20.6	**4**
FF 2M1	86.67	0.345	90.00	0.711	100	2.290	100	9.0	62.1	19.3	1
FF 2M2	89.33	0.306	93.33	0.689	100	2.412	100	8.2	79.6	19.3	2
FF 2M3	80.00	0.343	90.66	0.374	100	2.666	100	11.0	68.0	28.6	1
FFF 4M1	89.33	0.333	**33.33**	0.408	100	2.016	100	7.2	80.1	12.9	**4**
FFF 4M2	86.67	0.361	**44.00**	0.548	100	2.032	100	8.3	77.0	14.9	**4**
FFF 4M3	85.33	0.305	**8.00**	**0.065**	98	1.087	100	**5.4**	80.2	10.4	**4**
CV 6972	96.00	0.307	**12.00**	***0.220***	98	2.134	100	***6.9***	87.6	13.1	**4**
CV 6973	92.00	0.319	**38.67**	0.649	98	2.234	100	8.0	61.7	20.0	**4**
TB 3M2	84.00	0.378	**44.00**	0.579	100	2.544	100	11.5	66.3	30.9	**4**
TB 3M3	89.33	0.373	82.67	0.549	100	2.776	100	10.9	65.4	29.2	1
TB 6956	86.67	0.388	***66.67***	0.731	100	2.912	100	8.8	68.0	19.6	2
Non-toxic[a]	≥67.7	0.49 – 0.21	≥67.0	0.75 – 0.23	≥85.5	5.0 – 0.9	≥88.9	12.4 – 7.2	78.1 – 38.1	46.3 – 9.9	-
Pot. toxic	67.6 – 58.8	0.20 – 0.14	66.9 – 57.1	0.22 – 0.10	85.4 – 80.3	0.89 – 0	88.8 – 84.2	7.1 – 5.9	38.0 – 28.1	9.8 – 0.8	-
Toxic	**< 58.8**	**< 0.14**	**< 57.1**	**< 0.10**	**< 80.3**	-	**< 84.2**	**< 5.9**	**< 28.1**	**< 0.8**	-

[a] The upper limit for non-toxic category is set using 2 × SD of the mean and indicates excessive growth or reproduction.

Table 9. Decision matrix for weight-of-evidence categorization of Jackfish Bay sites based on three lines of evidence. For the sediment chemistry column, sites with exceedences of the Severe Effect Level (SEL) for metals or the Probable Effect Level (PEL) for organic contaminants are indicated by "●"; sites with exceedences of the Lowest Effect Level (LEL) by "◉". Substances exceeding LELs, SELs and PELs are listed. For the toxicity column, sites where multiple endpoints exhibit major toxicological effects are indicated by "●"; sites where one endpoint exhibits a major effect or multiple endpoints exhibit minor effects are indicated by "◉"; minor toxicological effects observed in no more than one endpoint by "○". For the benthos alteration column, sites determined from BEAST analyses as different or very different from reference are indicated by "●"; and sites determined as possibly different from reference by "◉". Sites with no SQG exceedences or benthic communities equivalent to reference conditions are indicated by "○". Some sites show possible benthos alteration but are not recommended for further action; explanations are provided below for these sites.

Location	Site	Sediment Chemistry	Toxicity	Benthos Alteration	> LEL	> SEL	> PEL	Assessment
Moberly Bay	M701	◉	○	●	Cr, Ni			Determine reasons for benthos alteration[a]
Moberly Bay	1M1	●	●	●	Cd, Cr, Cu, Ni, Zn, total PCBs		Dioxins/Furans	Management actions required
Moberly Bay	1M2	●	●	●	Cd, Cr, Cu, Ni, Zn, total PCBs		Dioxins/Furans	Management actions required
Moberly Bay	1M3	●	●	●	Cd, Cr, Cu, Ni, Zn, total PCBs		Dioxins/Furans	Management actions required
Far-field	2M1	●	○	●	Cd, Cr, Cu, Fe, Mn, Ni, Zn	Mn	Dioxins/Furans	Determine reasons for benthos alteration[a]
Far-field	2M2	◉	○	◉	Cd, Cr, Cu, Fe, Mn, Ni	Mn		Determine reasons for benthos alteration[a]
Far-field	2M3	●	○	●	Cd, Cr, Cu, Fe, Mn, Ni, Zn		Dioxins/Furans	Determine reasons for benthos alteration[a]
Far far-field	4M1	◉	◉	○	Cd, Cr, Cu, Mn, Ni			Determine reasons for sediment toxicity
Far far-field	4M2	◉	◉	○	Cr, Cu, Mn, Ni			Determine reasons for sediment toxicity
Far far-field	4M3	◉	●	◉[c]	Cr, Cu, Fe, Mn, Ni			Determine reasons for sediment toxicity
Cape Victoria	6972	◉	●	○	Cr, Cu, Ni			Determine reasons for sediment toxicity
Cape Victoria	6973	◉	◉	○	Cr, Cu, Fe, Mn, Ni			Determine reasons for sediment toxicity
Tunnel Bay	3M2	◉	◉	◉[c]	As, Cd, Cr, Cu, Fe, Mn, Ni, Pb, Zn	Mn		Determine reasons for sediment toxicity
Tunnel Bay	3M3	◉	○	○	As, Cd, Cr, Cu, Fe, Mn, Ni			No further actions needed
Tunnel Bay	6956	◉	○	○	As, Cd, Cr, Cu, Fe, Mn, Ni, Pb			No further actions needed

[a] Benthos alteration may be due to other factors, either natural (e.g., competition/predation, habitat differences) or human-related (e.g., water column contamination) (Chapman and Anderson 2005)
[b] Most or all individual toxicity endpoints are in the non-toxic categories according to the numerical guidelines.
[c] benthos alteration is not judged detrimental

APPENDIX A: Organic Contaminant Concentrations

Table A1. Organic contaminant concentrations in Jackfish Bay sediment (top 10 cm).

		Near-field												Far-field					
Parameter Name	Units	M701		1M1		1M2-1		1M2-2		1M2-3		1M3		2M1		2M2		2M3	
PCB; total	ng/g dry	41	P40	110	P40	73	P40	94	P40	97	P40	150	P40	44	P40	25	P40	60	P40
DDT & Metabolites	ng/g dry	5	<T	9	<T	4	<T	21		16	<T	21		3	<T	2	<=W	2	<=W
Aldrin	ng/g dry	1	<=W	2	<T	1	<=W	2	<T	1	<=W	2	<T	1	<=W	1	<=W	1	<=W
a-BHC (hexachlorocyclohexane)	ng/g dry	1	<=W	1	<=W	1	<=W	2	<T	2	<T	1	<=W	1	<=W	1	<=W	1	<=W
b-BHC (hexachlorocyclohexane)	ng/g dry	1	<=W	1	<=W	1	<=W	2	<T	1	<=W	1	<=W	1	<=W	1	<=W	1	<=W
g-BHC (hexachlorocyclohexane)	ng/g dry	1	<=W	1	<=W	1	<=W	1	<=W	1	<=W	1	<=W	1	<=W	1	<=W	1	<=W
a-Chlordane	ng/g dry	2	<=W	2	<=W	3	<T	2	<=W	2	<=W	2	<=W	2	<=W	2	<=W	2	<=W
g-Chlordane	ng/g dry	2	<=W	2	<=W	2	<=W	2	<=W	2	<=W	2	<=W	2	<=W	2	<=W	2	<=W
Dieldrin	ng/g dry	2	<=W	2	<=W	3	<T	2	<=W	2	<=W	4	<T	2	<=W	2	<=W	2	<=W
Methoxychlor	ng/g dry	5	<=W	5	<=W	5	<=W	5	<=W	5	<=W	5	<=W	5	<=W	5	<=W	5	<=W
Endosulphan I	ng/g dry	2	<=W	2	<=W	2	<=W	2	<=W	2	<=W	2	<=W	2	<=W	2	<=W	2	<=W
Endosulphan II	ng/g dry	4	<=W	4	<=W	4	<=W	4	<=W	4	<=W	4	<=W	4	<=W	4	<=W	4	<=W
Endrin	ng/g dry	4	<=W	4	<=W	4	<=W	4	<=W	4	<=W	4	<=W	4	<=W	4	<=W	4	<=W
Endosulphan sulphate	ng/g dry	4	<=W	4	<=W	4	<=W	4	<=W	4	<=W	4	<=W	4	<=W	4	<=W	4	<=W
Heptachlor epoxide	ng/g dry	1	<=W	1	<=W	1	<=W	1	<=W	1	<=W	1	<=W	1	<=W	1	<=W	1	<=W
Heptachlor	ng/g dry	1	<=W	1	<=W	1	<=W	1	<=W	1	<=W	1	<=W	1	<=W	1	<=W	1	<=W
Mirex	ng/g dry	5	<=W	5	<=W	5	<=W	5	<=W	5	<=W	5	<=W	5	<=W	5	<=W	5	<=W
Oxychlordane	ng/g dry	2	<=W	2	<=W	2	<=W	2	<=W	2	<=W	2	<=W	2	<=W	2	<=W	2	<=W
op-DDT	ng/g dry	5	<=W	5	<=W	5	<=W	8	<T	5	<=W	6	<T	5	<=W	5	<=W	5	<=W
pp-DDD	ng/g dry	5	<=W	5	<=W	5	<=W	5	<=W	5	<=W	5	<=W	5	<=W	5	<=W	5	<=W
pp-DDE	ng/g dry	5	<T	9	<T	4	<T	13		16		8	<T	3	<T	1	<=W	1	<=W
pp-DDT	ng/g dry	5	<=W	5	<=W	5	<=W	5	<=W	5	<=W	7	<T	5	<=W	5	<=W	5	<=W
Toxaphene	ng/g dry	50	<=W	50	<=W	50	<=W	50	<=W	50	<=W	50	<=W	50	<=W	50	<=W	50	<=W
Acenaphthene	ng/g dry	20	<=W	20	<=W	20	<=W	20	<=W	20	<=W	20	<=W	20	<=W	20	<=W	20	<=W
Acenaphthylene	ng/g dry	20	<=W	20	<=W	20	<=W	20	<=W	20	<=W	20	<=W	20	<=W	20	<=W	20	<=W
Anthracene	ng/g dry	32	<T	86	<T	160		110		100		63	<T	20	<=W	20	<=W	25	<T
Benzo(a)anthracene	ng/g dry	43	<T	72	<T	46	<T	85	<T	78	<T	120		30	<T	27	<T	38	<T
Benzo(a)pyrene	ng/g dry	40	<=W	47	<T	40	<=W	59	<T	52	<T	81	<T	40	<=W	40	<=W	40	<=W
Benzo(b)fluoranthene	ng/g dry	50	<T	130		100		150		140		200		82	<T	54	<T	110	
Benzo(k)fluoranthene	ng/g dry	20	<=W	39	<T	37	<T	51	<T	36	<T	60	<T	26	<T	20	<=W	39	<T
Chrysene	ng/g dry	62	<T	170		120		190		190		280		68	<T	49	<T	96	<T
Dibenzo(a,h)anthracene	ng/g dry	40	<=W	40	<=W	40	<=W	40	<=W	40	<=W	40	<=W	40	<=W	40	<=W	40	<=W
Fluoranthene	ng/g dry	100		230		150		290		260		340		69	<T	50	<T	93	<T
Fluorene	ng/g dry	20	<=W	30	<T	50	<T	39	<T	25	<T	20	<=W	20	<=W	20	<=W	20	<=W
Benzo(g,h,i)perylene	ng/g dry	40	<=W	40	<=W	40	<=W	40	<=W	40	<=W	61	<T	40	<=W	40	<=W	40	<=W
Indeno(1,2,3-c,d)pyrene	ng/g dry	40	<=W	87	<T	71	<T	100	<T	92	<T	140	<T	63	<T	48	<T	72	<T
Naphthalene	ng/g dry	26	<T	26	<T	21	<T	22	<T	27	<T	27	<T	34	<T	31	<T	24	<T
Phenanthrene	ng/g dry	96	<T	170		120		200		200		230		54	<T	40	<T	67	<T
Pyrene	ng/g dry	100		190		120		240		220		270		81	<T	50	<T	110	
PAH; total	ng/g dry	509		1277		995		1536		1420		1872		507		349		674	
3,3',4,4'-tetrachlorobiphenyl (PCB 77)	pg/g dry	5.2		28		14		27		25		56		18		10		23	
3,4,4',5-tetrachlorobiphenyl (PCB 81)	pg/g dry	0.1	<	0.56		0.4	<	0.67		0.66		0.88		0.46		0.3	<	0.57	
2,3,3'4,4'-pentachlorobiphenyl (PCB 105)	pg/g dry	74		430		220		510		410		830		250		120		310	
2,3,4,4',5-pentachlorobiphenyl (PCB 114)	pg/g dry	2.6		25		12		26		24		41		9.2		5.7		14	
2,3'4,4',5-pentachlorobiphenyl (PCB 118)	pg/g dry	150		1200		570		1300		1000		2300		630		330		910	
2'3,4,4',5-pentachlorobiphenyl (PCB 123)	pg/g dry	9.2		27		21		31		30		62		24		19		25	
3,3'4,4',5-pentachlorobiphenyl (PCB 126)	pg/g dry	1.1		4.9		2.7		5.4		5.2		8.5		5.6		3.7		4.8	
2,3,3'4,4'5-hexachlorobiphenyl (PCB 156)	pg/g dry	32		160		92		150		140		300		130		110		170	
2,3,3'44'5'-hexachlorobiphenyl (PCB 157)	pg/g dry	5	<	29		17		32		27		57		29		16		34	
23',44',55'-hexachlorobiphenyl (PCB 167)	pg/g dry	12		56		39		62		55		110		62		50		67	
3,3'4,4'55'-hexachlorobiphenyl (PCB 169)	pg/g dry	0.2	<	0.5	<	0.2	<	0.4	<	0.6	<	0.44		1		0.4	<	0.54	
233'44'55'-heptachlorobiphenyl (PCB 189)	pg/g dry	5.5		20		15		18		18		45		24		26		29	
2378-tetrachlorodioxin	pg/g dry	3.4		15		9.4		15		14		25		9.4		6.4		12	
2378-tetrachlorofuran	pg/g dry	31		200		130		230		200		400		140		64		160	
12378-pentachlorodioxin	pg/g dry	1	<	2	<	2	<	1	<	1.4		2.8		2	<	1	<	2	<
12378-pentachlorofuran	pg/g dry	0.85		7		5		6.8		7.6		8.4		4		2	<	4.9	
23478-pentachlorofuran	pg/g dry	1.3		8.7		7.4		11		9.2		15		7.6		2.9		7.5	
123478-hexachlorodioxin	pg/g dry	1	<	1	<	3	<	1	<	2	<	1.2		1.5		2	<	2	<
123678-hexachlorodioxin	pg/g dry	1	<	1	<	3	<	2	<	2	<	2.5		2.1		2	<	3	
123789-hexachlorodioxin	pg/g dry	1	<	1	<	4	<	1	<	2	<	3		2.7		2	<	3.1	
234678-hexachlorofuran	pg/g dry	0.9	<	1	<	1	<	1	<	1	<	1	<	1	<	0.9	<	1	<
123478-hexachlorofuran	pg/g dry	0.9	<	1	<	3	<	2	<	2	<	2.7		2		1.4		2	<
123678-hexachlorofuran	pg/g dry	0.8	<	1	<	1	<	1	<	1	<	1.2		1	<	1	<	1	<
123789-hexachlorofuran	pg/g dry	1	<	2	<	1	<	1	<	1	<	2	<	1	<	1	<	2	<
1234678-heptachlorodioxin	pg/g dry	3.9		30		20		28		31		42		25		16		29	
1234678-heptachlorofuran	pg/g dry	1.7		8.9		6.8		8.3		11		12		6.9		4.7		7.3	
1234789-heptachlorofuran	pg/g dry	0.9	<	1	<	1	<	1	<	2	<	1	<	1	<	1	<	1	<
Tetrachlorodioxin; total	pg/g dry	7.1	I2	23	I5	17	I3	21	I4	23	I5	36	I9	13	I3	6.4	I1	16	I3
Tetrachlorofuran; total	pg/g dry	67	I13	440	I16	280	I17	490	I16	430	I16	840	I17	300	I14	130	I13	330	I16
Pentachlorodioxin; total	pg/g dry	1	<	5.7	I4	2	<	5	I2	6.4	I3	12	I5	6.3	I3	3.4	I2	6.5	I2
Pentachlorofuran; total	pg/g dry	4.3	I4	40	I9	31	I8	46	I10	42	I9	63	I11	35	I8	12	I4	41	I11
Hexachlorodioxin; total	pg/g dry	1	<	15	I3	9.6	I3	14	I3	14	I3	21	I6	28	I7	13	I3	30	I6
Hexachlorofuran; total	pg/g dry	2	I2	7.7	I3	3.2	I2	7.5	I3	8.8	I3	16	I7	9.4	I4	4.1	I3	5.2	I1
Heptachlorodioxin; total	pg/g dry	6.9	I2	70	I2	49	I2	62	I2	69	I2	98	I2	70	I2	37	I2	76	I2
Heptachlorofuran; total	pg/g dry	6.1	I2	31	I2	23	I2	27	I2	42	I2	45	I2	16	I2	11	I2	18	I2
Octachlorodioxin	pg/g dry	20		280		130		150		190		240		150		82		140	
Octachlorofuran	pg/g dry	5.4		28		22		24		43		43		12		9.6		12	

< actual result is less than the reported value

<=W no measurable response (zero) : < reported value

<T a measurable trace amount : interpret with caution

Table A1. Continued.

		Far far-field										Tunnel Bay						Cape Victoria			
Parameter Name	Units	4M1		4M2		4M3-1		4M3-2		4M3-3		3M2		3M3		6956		6972		6973	
PCB; total	ng/g dry	20	<=W	20	<=W	20	<=W	20	<=W	20	<=W	25	P40	20	<=W	20	<=W	20	<=W	20	<=W
DDT & Metabolites	ng/g dry	2	<=W	2	<=W	2	<=W	2	<=W	2	<=W	3	<T	3	<T	4	<T	2	<=W	2	<=W
Aldrin	ng/g dry	1	<=W	1	<=W	1	<=W	1	<=W	1	<=W	1	<=W	1	<=W	1	<=W	1	<=W	1	<=W
a-BHC (hexachlorocyclohexane)	ng/g dry	1	<=W	1	<=W	1	<=W	1	<=W	1	<=W	1	<=W	1	<=W	1	<=W	1	<=W	1	<=W
b-BHC (hexachlorocyclohexane)	ng/g dry	1	<=W	1	<=W	1	<=W	1	<=W	1	<=W	1	<=W	1	<=W	1	<=W	1	<=W	1	<=W
g-BHC (hexachlorocyclohexane)	ng/g dry	1	<=W	1	<=W	1	<=W	1	<=W	1	<=W	1	<=W	1	<=W	1	<=W	1	<=W	1	<=W
a-Chlordane	ng/g dry	2	<=W	2	<=W	2	<=W	2	<=W	2	<=W	2	<=W	2	<=W	2	<=W	2	<=W	2	<=W
g-Chlordane	ng/g dry	2	<=W	2	<=W	2	<=W	2	<=W	2	<=W	2	<=W	2	<=W	2	<=W	2	<=W	2	<=W
Dieldrin	ng/g dry	2	<=W	2	<=W	2	<=W	2	<=W	2	<=W	2	<=W	2	<=W	2	<=W	2	<=W	2	<=W
Methoxychlor	ng/g dry	5	<=W	5	<=W	5	<=W	5	<=W	5	<=W	5	<=W	5	<=W	5	<=W	5	<=W	5	<=W
Endosulphan I	ng/g dry	2	<=W	2	<=W	2	<=W	2	<=W	2	<=W	2	<=W	2	<=W	2	<=W	2	<=W	2	<=W
Endosulphan II	ng/g dry	4	<=W	4	<=W	4	<=W	4	<=W	4	<=W	4	<=W	4	<=W	4	<=W	4	<=W	4	<=W
Endrin	ng/g dry	4	<=W	4	<=W	4	<=W	4	<=W	4	<=W	4	<=W	4	<=W	4	<=W	4	<=W	4	<=W
Endosulphan sulphate	ng/g dry	4	<=W	4	<=W	4	<=W	4	<=W	4	<=W	4	<=W	4	<=W	4	<=W	4	<=W	4	<=W
Heptachlor epoxide	ng/g dry	1	<=W	1	<=W	1	<=W	1	<=W	1	<=W	1	<=W	1	<=W	1	<=W	1	<=W	1	<=W
Heptachlor	ng/g dry	1	<=W	1	<=W	1	<=W	1	<=W	1	<=W	1	<=W	1	<=W	1	<=W	1	<=W	1	<=W
Mirex	ng/g dry	5	<=W	5	<=W	5	<=W	5	<=W	5	<=W	5	<=W	5	<=W	5	<=W	5	<=W	5	<=W
Oxychlordane	ng/g dry	2	<=W	2	<=W	2	<=W	2	<=W	2	<=W	2	<=W	2	<=W	2	<=W	2	<=W	2	<=W
op-DDT	ng/g dry	5	<=W	5	<=W	5	<=W	5	<=W	5	<=W	5	<=W	5	<=W	5	<=W	5	<=W	5	<=W
pp-DDD	ng/g dry	5	<=W	5	<=W	5	<=W	5	<=W	5	<=W	5	<=W	5	<=W	5	<=W	5	<=W	5	<=W
pp-DDE	ng/g dry	1	<=W	1	<=W	1	<=W	1	<=W	1	<=W	3	<T	3	<T	4	<T	1	<=W	1	<=W
pp-DDT	ng/g dry	5	<=W	5	<=W	5	<=W	5	<=W	5	<=W	5	<=W	5	<=W	5	<=W	5	<=W	5	<=W
Toxaphene	ng/g dry	50	<=W	50	<=W	50	<=W	50	<=W	50	<=W	50	<=W	50	<=W	50	<=W	50	<=W	50	<=W
Acenaphthene	ng/g dry	20	<=W	20	<=W	20	<=W	20	<=W	20	<=W	20	<=W	20	<=W	20	<=W	20	<=W	20	<=W
Acenaphthylene	ng/g dry	20	<=W	20	<=W	20	<=W	20	<=W	20	<=W	20	<=W	20	<=W	20	<=W	20	<=W	20	<=W
Anthracene	ng/g dry	20	<=W	20	<=W	20	<=W	20	<=W	20	<=W	20	<=W	20	<=W	22	<T	20	<=W	20	<=W
Benzo(a)anthracene	ng/g dry	20	<=W	20	<=W	20	<=W	20	<=W	20	<=W	53	<T	46	<T	58	<T	20	<=W	20	<=W
Benzo(a)pyrene	ng/g dry	40	<=W	40	<=W	40	<=W	40	<=W	40	<=W	44	<T	40	<=W	52	<T	40	<=W	40	<=W
Benzo(b)fluoranthene	ng/g dry	27	<T	20	<=W	20	<=W	20	<=W	20	<=W	110		98	<T	110		20	<=W	20	<=W
Benzo(k)fluoranthene	ng/g dry	20	<=W	20	<=W	20	<=W	20	<=W	20	<=W	40	<T	35	<T	28	<T	20	<=W	20	<=W
Chrysene	ng/g dry	20	<=W	20	<=W	20	<=W	20	<=W	20	<=W	77	<T	66	<T	81	<T	20	<=W	20	<=W
Dibenzo(a,h)anthracene	ng/g dry	40	<=W	40	<=W	40	<=W	40	<=W	40	<=W	40	<=W	40	<=W	40	<=W	40	<=W	40	<=W
Fluoranthene	ng/g dry	20	<=W	20	<=W	20	<=W	20	<=W	20	<=W	120		96	<T	130		20	<=W	20	<=W
Fluorene	ng/g dry	20	<=W	20	<=W	20	<=W	20	<=W	20	<=W	20	<=W	20	<=W	20	<=W	20	<=W	20	<=W
Benzo(g,h,i)perylene	ng/g dry	40	<=W	40	<=W	40	<=W	40	<=W	40	<=W	50	<T	45	<T	59	<T	40	<=W	40	<=W
Indeno(1,2,3-c,d)pyrene	ng/g dry	40	<=W	40	<=W	40	<=W	40	<=W	40	<=W	96	<T	85	<T	74	<T	40	<=W	40	<=W
Naphthalene	ng/g dry	20	<=W	20	<=W	20	<=W	20	<=W	20	<=W	51	<T	41	<T	87	<T	20	<=W	20	<=W
Phenanthrene	ng/g dry	20	<=W	20	<=W	20	<=W	20	<=W	20	<=W	75	<T	79	<T	94	<T	20	<=W	20	<=W
Pyrene	ng/g dry	20	<=W	20	<=W	20	<=W	20	<=W	20	<=W	96	<T	81	<T	110		20	<=W	20	<=W
PAH; total	ng/g dry	27		<		<		<		<		812		672		905		<		<	
3,3',4,4'-tetrachlorobiphenyl (PCB 77)	pg/g dry	9	<	5	<	0.7	<	0.6	<	1	<	20	<	10	<	12		2	<	3	<
3,4,4',5-tetrachlorobiphenyl (PCB 81)	pg/g dry	0.4	<	0.3	<	0.1	<	0.1	<	0.2	<	2	<	1	<	0.76		0.2	<	0.2	<
2,3,3'4,4'-pentachlorobiphenyl (PCB 105)	pg/g dry	58		27		3	<	2	<	6	<	130		100		130		10	<	31	
2,3,4,4',5-pentachlorobiphenyl (PCB 114)	pg/g dry	3	<	1	<	1	<	0.6	<	0.5	<	6.1		5.1		6.9		1	<	0.9	<
2,3'4,4',5-pentachlorobiphenyl (PCB 118)	pg/g dry	130		73		6	<	4	<	10	<	360		240		320		30	<	63	
2'3,4,4',5-pentachlorobiphenyl (PCB 123)	pg/g dry	3.9		2.4		0.6	<	0.5	<	0.8	<	22		12		15		1	<	0.9	<
3,3'4,4',5-pentachlorobiphenyl (PCB 126)	pg/g dry	3	<	1	<	0.3	<	0.3	<	0.3	<	6.2		5.5		5.3		0.8	<	1	<
2,3,3'4,4'5-hexachlorobiphenyl (PCB 156)	pg/g dry	26		15		0.9	<	0.2	<	1	<	98		74		87		4.3		16	
2,3,3'44'5'-hexachlorobiphenyl (PCB 157)	pg/g dry	6.6		5	<	0.2	<	0.2	<	0.2	<	21		13		16		0.94		2.9	
23',44',55'-hexachlorobiphenyl (PCB 167)	pg/g dry	17		5.3		0.4	<	0.2	<	0.6	<	52		35		50		2.4		5	
3,3'4,4'55'-hexachlorobiphenyl (PCB 169)	pg/g dry	0.6	<	0.4	<	0.2	<	0.1	<	0.3	<	2	<	1.3		1.1		0.3	<	0.2	<
233'44'55'-heptachlorobiphenyl (PCB 189)	pg/g dry	5.9		2.4		0.7	<	0.86		0.4	<	23		18		20		1.1		4.2	
2378-tetrachlorodioxin	pg/g dry	1	<	2	<	1	<	0.7	<	2	<	4	<	4	<	3.7		2	<	0.8	<
2378-tetrachlorofuran	pg/g dry	5.1		3.3		1	<	0.3		1	<	43		36		39		1.6		3.6	
12378-pentachlorodioxin	pg/g dry	1.7		2	<	1	<	0.6	<	2	<	4		1.5		2.4		1	<	0.7	<
12378-pentachlorofuran	pg/g dry	1	<	1	<	0.8	<	0.5	<	1	<	3.3		1.4		2		0.9	<	0.6	<
23478-pentachlorofuran	pg/g dry	1	<	1	<	0.8	<	0.5	<	1	<	4.7		2.3		2.3		0.9	<	0.7	<
123478-hexachlorodioxin	pg/g dry	1.2		4	<	1	<	2	<	2	<	2.8		2	<	3	<	2	<	3	<
123678-hexachlorodioxin	pg/g dry	3	<	3	<	1	<	1	<	2	<	4	<	2	<	4		2	<	2	<
123789-hexachlorodioxin	pg/g dry	3.4		4	<	1	<	2	<	2	<	4.4		3	<	4.3		2	<	3	<
234678-hexachlorofuran	pg/g dry	2	<	2	<	0.9	<	0.5	<	1	<	2.6		2	<	2	<	0.8	<	1	<
123478-hexachlorofuran	pg/g dry	2	<	2	<	0.8	<	0.5	<	1	<	4	<	2	<	2	<	0.8	<	1	<
123678-hexachlorofuran	pg/g dry	2	<	2	<	0.8	<	0.5	<	1	<	3	<	2	<	2	<	0.8	<	1	<
123789-hexachlorofuran	pg/g dry	4	<	4	<	1	<	0.7	<	1	<	2	<	3	<	3	<	1	<	3	<
1234678-heptachlorodioxin	pg/g dry	25		10	<	2	<	3	<	4	<	41		27		36		5	<	10	<
1234678-heptachlorofuran	pg/g dry	6.7		4	<	4	<	2	<	4	<	12		7.5		10		2	<	6	<
1234789-heptachlorofuran	pg/g dry	2	<	2	<	2	<	0.7	<	1	<	2.3		1	<	2	<	1	<	1	<
Tetrachlorodioxin; total	pg/g dry	2.1	I1	2	<	5.1	I4	4.1	I3	4.4	I2	8.7	I3	6	I2	11	I4	2	<	0.8	<
Tetrachlorofuran; total	pg/g dry	19	I8	6.4	I4	2.2	I3	3.1	I5	2.7	I3	94	I14	90	I17	98	I17	2.4	I2	7.9	I6
Pentachlorodioxin; total	pg/g dry	5.7	I2	2.5	I1	3.4	I2	3.2	I3	2.5	I1	8.9	I3	5.1	I2	13	I4	1	<	0.7	<
Pentachlorofuran; total	pg/g dry	9.4	I3	5.6	I2	1.5	I1	2.5	I2	2.7	I2	21	I6	18	I5	24	I7	1.9	I2	2.4	I2
Hexachlorodioxin; total	pg/g dry	33	I5	4.1	I1	3.7	I2	2	I1	2.4	I1	42	I6	8.3	I1	39	I6	4.4	I2	6.6	I2
Hexachlorofuran; total	pg/g dry	5.7	I1	3.6	I1	0.7	I1	0.69	I1	2	<	13	I4	6.9	I2	8.3	I2	1	<	3	<
Heptachlorodioxin; total	pg/g dry	56	I2	18	I1	2	<	3	<	4	<	96	I2	67	I2	99	I2	6	<	12	I1
Heptachlorofuran; total	pg/g dry	10	I2	1.6	I1	3	<	2	<	3	<	20	I3	12	I2	17	I2	0.8	I1	6	<
Octachlorodioxin	pg/g dry	120		66		15		13		16		190		130		180		26		40	
Octachlorofuran	pg/g dry	6.1		3.9		2	<	0.9	<	2	<	13		8.9		9.8		1.6		2.3	

< actual result is less than the reported value

<=W no measurable response (zero) : < reported value

<T a measurable trace amount : interpret with caution

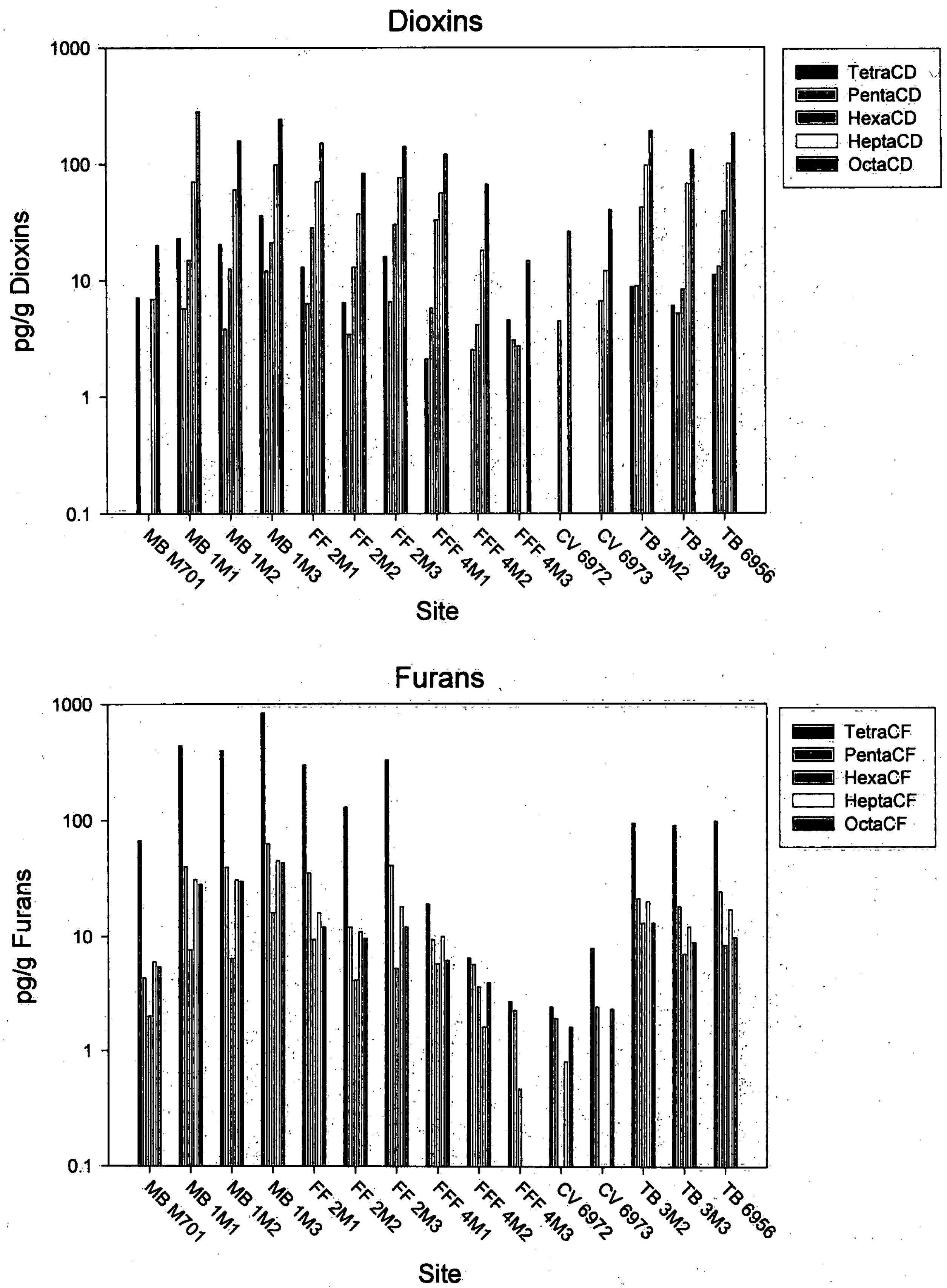


Figure A1. Concentrations of total dioxin [top] and furan [bottom] congeners in Jackfish Bay sediments. (MB = Moberly Bay, FF = Far-field; FFF = Far far-field; TB = Tunnel Bay; CV = Cape Victoria).

APPENDIX B: Invertebrate Abundances

Table B1. Benthic invertebrate family abundance (number per 33 cm²).

Family	Near-field - Moberly Bay						Far-field - South Cody Island			Far far-field - South St. Patrick Island					Cape Victoria		Tunnel Bay		
	69M701	691M1	691M2-1	691M2-2	691M2-3	691M3	692M1	692M2	692M3	694M1	694M2	694M3-1	694M3-2	694M3-3	6972	6973	6956	693M2	693M3
Asellidae	2.0					0.2													
Aturidae				0.2															
Bosminidae		1.6	0.4				0.4	6.2	2.8				0.2				1.6	3.0	1.2
Ceratopogonidae																		0.2	
Cercopagidae							0.2												
Chironomidae	14.6	3.2	3.2	4.6	3.4	4.2	1.0	2.2	0.8	3.2	2.0	2.2	1.2	1.0	1.8	2.8	5.2	4.2	4.6
Chydoridae	2.6	8.2	7.2	6.0	10.0	2.2	0.2	0.6	0.4		0.2	0.2						0.6	0.4
Daphnidae	0.4	0.4		0.2	0.2	1.6		1.8	2.0	2.0	6.2			0.4				4.2	1.2
Enchytraeidae										2.6	1.6	4.0	0.8	4.4	6.4	7.6			
Halicaridae	1.0	0.4	0.8	0.6	0.4	0.2	0.2										0.2		
Haustoriidae	0.2	0.2		0.2			0.6	0.4	0.2	10.0	7.0	2.2	5.0	3.4	8.2	12.8	6.6	3.0	4.4
Hydridae												0.4							
Lebertiidae		0.2											0.2						
Lumbriculidae	1.6									0.4		0.6	0.2	0.2	0.8	0.4			
Macrothricidae	4.6	81.2	103.6	95.2	88.6	29.0		9.4		1.8	2.6	0.4	0.2		1.0	1.0			
Naididae	0.8		1.2	0.2	0.4	0.4							1.2	0.2					
Plagiostomidae														0.2					
Planorbidae	0.4																		
Sphaeriidae	0.4	0.2	0.2	0.6	0.4	0.2	2.0	1.4	1.6	0.8	0.6	0.8	0.4	0.4	0.2		1.0	0.4	1.2
Trhypachthoniidae	0.8				0.2														
Tubificidae	409.6	211.8	209.2	222.0	192.0	50.0	1.8	7.0	2.2						0.6	0.2	3.6	3.2	3.2

Table B2. Benthic invertebrate densities in Jackfish Bay (number per 33 cm^2).

	Near-field - Moberly Bay						Far-field - South Cody Island			Far far-field - South St. Patrick Island					Cape Victoria		Tunnel Bay		
	M701	1M1	1M2-1	1M2-2	1M2-3	1M3	2M1	2M2	2M3	4M1	4M2	4M3-1	4M3-2	4M3-3	6972	6973	6956	3M2	3M3
P. Annelida																			
Cl. Oligochaeta																			
F. Enchytraeidae																			
Mesenchytraeus sp.										2.6	1.6	4	0.8	4.4	6.4	7.6			
F. Lumbriculidae																			
Stylodrilus heringianus	1.6									0.4		0.6	0.2	0.2	0.8	0.4			
F. Naididae																			
Nais communis					0.2														
Nais variabilis	0.2		0.4																
Piguetiella blanci			0.2																
Piguetiella michiganensis	0.4												0.2						
Vejdovskyella intermedia	0.2		0.6	0.2	0.2	0.4							1	0.2					
F. Tubificidae																			
Aulodrilus pluriseta	1.2	6.2	1.2	2.0	1.8	3.8													
Ilyodrilus templetoni			0.2																
Limnodrilus hoffmeisteri	1.4	0.2	0.4		0.4		0.2												0.2
Limnodrilus udekemianus							0.2												
Potamothrix bedoti	8.4	2.4	2.2	3.2	1.8	3.2													
Potamothrix vejdovskyi				0.2															
Spirosperma ferox	5.0	0.4	0.4	0.4	0.6	0.2													
Tubifex tubifex	1.2																	0.2	
Immature Tubificids with cheatal hairs	235.2	148.4	139.2	128.8	106.6	31.2	1.4	6.2	1.8								3	2.4	2.4
Immature Tubificids without cheatal hair	155.2	54.2	65.4	87.4	80.8	11.6		0.8	0.4						0.6		0.6	0.6	0.6
Quistadrilus multisetosus	2.0		0.2													0.2			
P. Platyhelminthes																			
F. Plagiostomidae																			
Hydrolimax sp.														0.2					
P. Arthropoda																			
O. Amphipoda																			
F. Haustoriidae																			
Diporeia hoyi	0.2	0.2		0.2			0.6	0.4	0.2	10	7	2.2	5	3.4	8.2	12.8	6.6	3	4.4
O. Isopoda																			
F. Asellidae																			
Caecidotea sp.	2.0					0.2													
O. Prostigmata																			
F. Halicaridae	1.0	0.4	0.8	0.6	0.4	0.2	0.2										0.2		
F. Trhypachthoniidae	0.8				0.2														
F. Aturidae				0.2															
F. Lebertiidae																			
Lebertia sp.		0.2											0.2						
O. Cladocera																			
F. Cercopagidae																			
Bythotrephes cederstroemii							0.2												

Table B2. Continued.

	Near-field - Moberly Bay						Far-field - South Cody Island			Far far-field - South St. Patrick Island					Cape Victoria		Tunnel Bay		
	M701	1M1	1M2-1	1M2-2	1M2-3	1M3	2M1	2M2	2M3	4M1	4M2	4M3-1	4M3-2	4M3-3	6972	6973	6956	3M2	3M3
F. Macrothricidae	4.6	81.2	103.6	95.2	88.6	29.0		9.4		1.8	2.6	0.4	0.2		1	1			
F. Daphnidae	0.4	0.4		0.2	0.2	1.6		1.8	2.0	2	6.2			0.4				4.2	1.2
F. Chydoridae	2.6	8.2	7.2	6.0	10.0	2.2	0.2	0.6	0.4		0.2	0.2						0.6	0.4
F. Bosminidae		1.6	0.4				0.4	6.2	2.8				0.2				1.6	3	1.2
Cl. Insecta																			
F. Ceratopogonidae																			
Probezzia sp.																		0.2	
F. Chironomidae																			
Chironomus sp.	3.8			1.0	0.6	0.2		0.2			0.2						0.4		2
Conchapelopia sp.															0.2				
Cryptochironomus sp.	0.2																		
Heterotrissocladius oliveri							0.8	1.8	0.4	3.2	1.6	1.2	1.2	1	0.8	2.2		2.2	0.6
Heterotrissocladius sp.		0.4															2.4		0.6
Micropsectra sp.		0.2																	
Microtendipes sp.	0.2																		
Parachironomus sp.												0.2							
Paracladopelma sp.												0.2				0.4			
Parakiefferiella sp.	0.2				0.2	0.2			0.2								1	0.2	0.2
Polypedilum sp.																0.2			
Polypedilum(Tripodura) scalaen	0.2																		
Procladius sp.	7.2	2.2	2.8	3.4	2.6	3.8	0.2	0.2			0.2								
Protanypus sp.			0.2						0.2			0.2					1.4	1.8	1
Stempellinella sp.															0.6				
Stictochironomus sp.	0.4																		
Tanytarsus sp.	1.6	0.4		0.2															
Unknown Chironomidae	0.8		0.2									0.4			0.2				0.2
P. Cnidaria																			
O. Hydrozoa																			
F. Hydridae																			
Hydra sp.												0.4							
P. Mollusca																			
Cl. Bivalva																			
F. Sphaeridae																			
Musculium sp.	0.2						0.6	0.4	0.4		0.4						0.6		
Pisidium casertanum	0.2	0.2								0.4	0.2								
Pisidium equilaterale						0.2							0.4						
Pisidium milium					0.2				0.6										
Pisidium subtruncatum					0.2														
Cl. Gastropoda																			
F. Planorbidae																			
Helisoma anceps	0.4																		

APPENDIX C: BEAST Community Ordinations

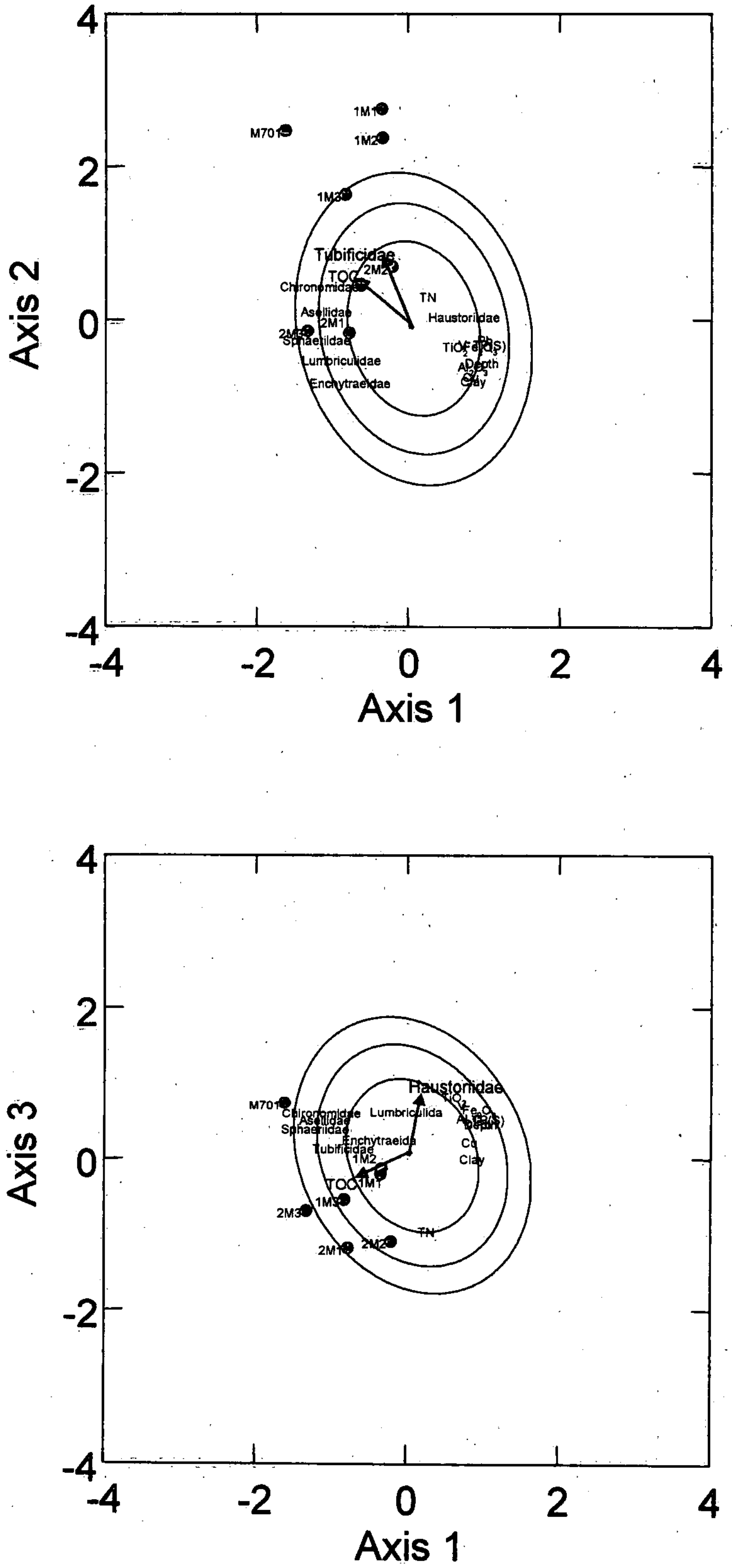


Figure C1. Ordination of the first subset of Jackfish Bay sites using benthic invertebrate community data (family abundance). Site scores are plotted on Axes 1 & 2 (top) and Axes 1 & 3 (bottom), with 90% (smallest ellipse), 99% (middle ellipse), and 99.9% (largest ellipse) probability ellipses around Group 5 reference sites (reference site scores not shown). Maximally correlated Tubificidae (top), Haustoriidae (bottom) and total organic carbon (TOC) are shown as vectors. Stress = 0.14.

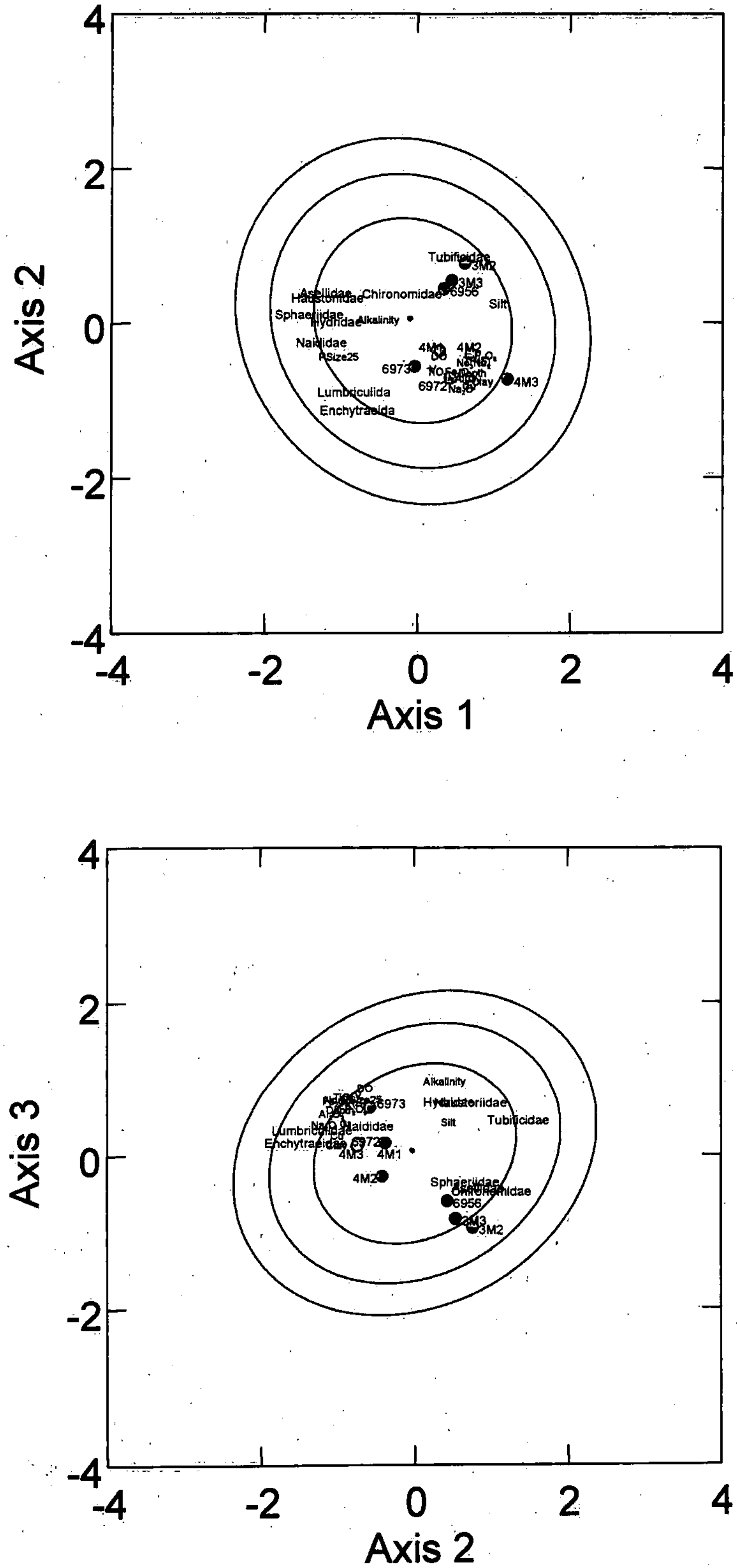


Figure C2. Ordination of the second subset of Jackfish Bay sites using benthic invertebrate community data (family abundance). Site scores are plotted on Axes 1 & 2 (top) and Axes 2 & 3 (bottom), with 90% (smallest ellipse), 99% (middle ellipse), and 99.9% (largest ellipse) probability ellipses around reference sites (reference site scores not shown). Stress = 0.16.

APPENDIX D: Toxicity Test Water Quality Parameters

Table D1. Water quality parameter measurements in laboratory toxicity tests.

Chironomus riparius										
	Day 0					Day 10				
Site	pH	Conductivity	temp	D.O.	Ammonia	pH	Conductivity	temp	D.O.	Ammonia
6956	8.4-8.5	271-346	22.0-22.1	8.0-8.1	0	8.5-8.6	327-342	22.0-22.1	8.1-8.2	0
6972	8.4-8.5	280-301	22.0-22.1	8.2	0	8.5	308-325	22.1	8.1	0
6973	8.4-8.5	269-289	21.9-22.1	8.1-8.3	0	8.5	306-315	22.0-22.1	8.0-8.1	0
2M1	8.4	267-294	21.9-22.0	8.0-8.2	0	8.5	309-319	22.0-22.1	8.1-8.2	0
2M2	8.4	269-334	21.5-22.0	7.9-8.2	0	8.4-8.5	303-318	22.0-22.1	8.0-8.1	0
2M3	8.2-8.4	307-338	21.2-21.5	8.0-8.2	0	8.1-8.2	299-345	22.9	7.8-8.0	0
3M2	8.0-8.1	249-289	21.3-21.4	8.0-8.2	0	7.9-8.0	281-296	22.9-23.1	4.1-7.8	0
3M3	8.0-8.1	248-311	21.1-21.3	8.1-8.3	0	8.3	269-335	22.6-22.8	7.9	0
4M1	8.1-8.4	280-327	21.2-21.3	7.9-8.2	0	8.4-8.5	296-325	22.7-22.8	7.8-8.1	0
4M2	8.4-8.5	269-354	20.7-21.0	8.1-8.2	0	8.5-8.6	314-321	22.7-22.8	7.9-8.0	0
4M3	8.3-8.4	283-319	21.2-21.3	8.2-8.3	0	8.3-8.4	320	22.5-22.6	8.0-8.1	0
M701	7.9-8.2	343-585	21.2-2.3	8.2-8.4	0	7.9	470	22.3-22.4	8.1-8.2	0
1M1	8.1-8.3	540-663	21.3	8.2-8.3	0	7.9-8.1	660	22.3-22.4	8.1-8.2	0
1M2	8.2-8.4	551-602	21.2-21.3	8.1-8.3	0	8.0-8.1	630	22.2-22.4	8.0-8.1	0
1M3	8.1-8.2	487-617	21.1-21.3	8.2-8.4	0	8	610	22.4	7.9-8.0	0

Hyalella azteca										
	Day 0					Day 28				
Site	pH	Conductivity	temp	D.O.	Ammonia	pH	Conductivity	temp	D.O.	Ammonia
6956	8.4	102-341	21.6-21.7	8.2-8.3	0	8.3-8.4	265-344	23.4-23.5	8.4-8.5	0
6972	8.3-8.4	264-286	21.3-21.7	8.3-8.4	0	8.2-8.3	321-342	23.3-23.4	8.4-8.7	0
6973	8.4-8.5	257-306	21.9-22.0	8.2-8.3	0	8.7-9.0	271-306	22.3-22.5	8.3-9.6	0
2M1	8.3	296-321	21.8-22.0	8.1	0	8.5-8.6	319-358	22.3-22.4	8.0-8.2	0
2M2	8.2-8.4	282-332	21.4-21.7	8.1-8.3	0	8.4	341-357	22.1-22.4	7.9-8.3	0
2M3	8.4-8.5	302-331	21.0-21.8	8.2-8.3	0	8.4-8.5	345-377	23.1-23.5	8.6-8.7	0
3M2	8.2-8.3	243-282	21.1-21.6	8.3	0	8.3-8.4	246-341	23.1-23.5	8.6-8.7	0
3M3	8.1-8.2	249-288	21.0-21.2	8.3-8.4	0	8.3-8.4	213-332	22.9-23.3	22.9-23.3	0
4M1	8.5-8.6	253-328	20.8-21.3	8.3-8.4	0	8.2-8.3	216-375	22.6-23.2	8.5-8.8	0
4M2	8.6-8.7	234-290	20.8-21.3	8.3-8.5	0	8.4-8.5	284-367	22.4-23.2	9.0-9.3	0
4M3	8.5-8.6	283-296	21.5-21.9	8.8-8.9	0	8.3-8.6	264-437	21.8-22.4	8.5-9.4	0
M701	8.3-8.5	266-387	21.9-22.0	8.2-8.4	0	8.2-8.3	398-484	22.2-22.5	8.5	0
1M1	8.2-8.3	382-471	21.2-21.4	8.3-8.4	0	8.2-8.3	510-581	21.6-22.0	8.3-8.6	0
1M2	8.1-8.2	432-499	21.9-22.0	8.0-8.3	0	8.4	460-542	22.5-22.8	8.0-8.2	0
1M3	8.2	383-451	20.7-21.3	8.3-8.4	0	8.2-8.5	494-580	21.7-22.0	8.3-8.8	0

Hexagenia spp.										
	Day 0					Day 21				
Site	pH	Conductivity	temp	D.O.	Ammonia	pH	Conductivity	temp	D.O.	Ammonia
6956	8.3-8.5	299-337	22.1-22.3	8.3-8.4	0	8.2-8.3	310-356	23.0-23.2	7.8-8.1	0
6972	8.4-8.5	298-328	21.7-22.3	8.3-8.5	0	8.4-8.5	298-328	21.7-22.3	8.3-8.5	0
6973	8.4-8.6	296-332	21.8-22.2	8.2-8.5	0	8.3-8.4	312-365	22.7-23.1	8.0-8.2	0
2M1	8.4	284-319	21.9-22.0	8.2-8.4	0	8.3	315-326	22.-23.0	7.2-7.8	0
2M2	8.3-8.4	284-316	21.9-22.3	8.1-8.4	0	7.9-8.3	314-337	22.7-23.1	5.1-8.0	0
2M3	8.2-8.4	289-356	22.0-22.6	6.7-8.0	0	8.2	338-351	22.2-22.9	7.7-8.0	0
3M2	8.2	258-297	22.2-22.6	7.6-8.2	0	8.1-8.2	293-328	22.3-23.1	7.7-8.2	0
3M3	8.2-8.3	265-304	21.6-22.3	7.8-8.3	0	8.1-8.2	300-345	22.1-22.7	8.1-8.2	0
4M1	8.4-8.6	309-334	22.0-22.2	8.2-8.3	0	8.0-8.2	337-349	21.4-22.4	7.9-8.4	0
4M2	8.6-8.7	298-354	22.1-22.2	8.1-8.3	0	8.3-8.4	340-375	22.2-22.6	7.8-8.2	0
4M3	8.2-8.3	290-312	22.3-22.7	8.8-8.9	0	8.2-8.3	359-386	22.7-22.9	8.4-8.5	0
M701	8.0-8.1	307-353	22.6-22.9	8.4-8.6	0	8.0-8.1	361-406	22.8-23.2	8.1-8.4	0
1M1	7.9-8.0	400-489	22.5-22.7	8.3-8.5	0	7.8-7.9	474-564	22.7-22.9	8.3-8.4	0
1M2	8	390-466	22.1-22.7	8.0-8.4	0	7.8-8.0	463-532	22.5-23.0	8.1-8.4	0
1M3	7.9-8.1	331-423	22.3-22.7	8.3-8.4	0	7.9	497-534	22.5-22.9	8.3-8.4	0

Tubifex tubifex										
	Day 0					Day 28				
Site	pH	Conductivity	temp	D.O.	Ammonia	pH	Conductivity	temp	D.O.	Ammonia
6956	8.3-8.4	232-357	20.5-20.8	7.9-8.2	0	8.4-8.7	296-306	21.2-21.5	8.2-8.3	0
6972	8.4-8.5	307-344	20.5-20.7	7.7-8.1	0	8.4-8.7	-	21.2-21.4	8.3-8.4	0
6973	-	225-339	-	7.9-8.3	0	8.4-8.7	346-356	21.5-21.6	8.1-8.5	0
2M1	8.3-8.5	259-324	20.4-20.7	8.0-8.2	0	8.4-8.5	3-265-331	21.2-21.5	8.3-8.5	0
2M2	8.3-8.4	293-358	20.4-20.6	7.9-8.2	0	8.4-8.5	267-340	21.5-21.7	8.2-8.3	0
2M3	8.0-8.2	337-396	20.9-21.3	7.3-7.5	0	8.0-8.1	238-348	21.7	8.4-8.5	0
3M2	7.6-7.9	302-341	20.9-21.0	6.7-7.7	0	8.1-8.2	224-303	21.7-21.8	8.0-8.2	0
3M3	7.7-7.9	291-343	20.7-21.1	7.3-7.8	0	8.1	220-287	21.7	8.0-8.4	0
4M1	7.7-8.3	265-355	21.6-22.0	8.0-8.1	0	8.1-8.3	214-362	21.3-21.4	8.3-8.7	0
4M2	8.3-8.4	287-361	21.2-21.8	7.9-8.1	0	8.2	220-279	21.2-21.5	8.5-8.7	0
4M3	8.5-8.6	329-363	21.6-21.8	7.9-8.1	0	8.1-8.2	282-413	20.0-20.5	8.0-8.4	0
M701	8.6-8.7	344-409	21.5-21.6	7.7-8.2	0	8.1-8.3	399-467	20.5-20.8	8.2-8.4	0
1M1	8.5-8.8	389-554	21.6-21.7	7.8-8.0	0	8.2	408-640	20.7-21.0	8.2-8.3	0
1M2	8.5-8.7	414-516	21.5-21.6	8.1-8.2	0	8.3-8.6	403-508	20.7-20.8	8.2-8.4	0
1M3	8.7-8.8	418-529	20.8-20.9	8.2-8.5	0	8.5-8.6	551-587	20.8-20.9	8.2-8.5	0

Note: These numbers represent the range between the 5 replicates used for the tests

APPENDIX E: BEAST Toxicity Ordinations

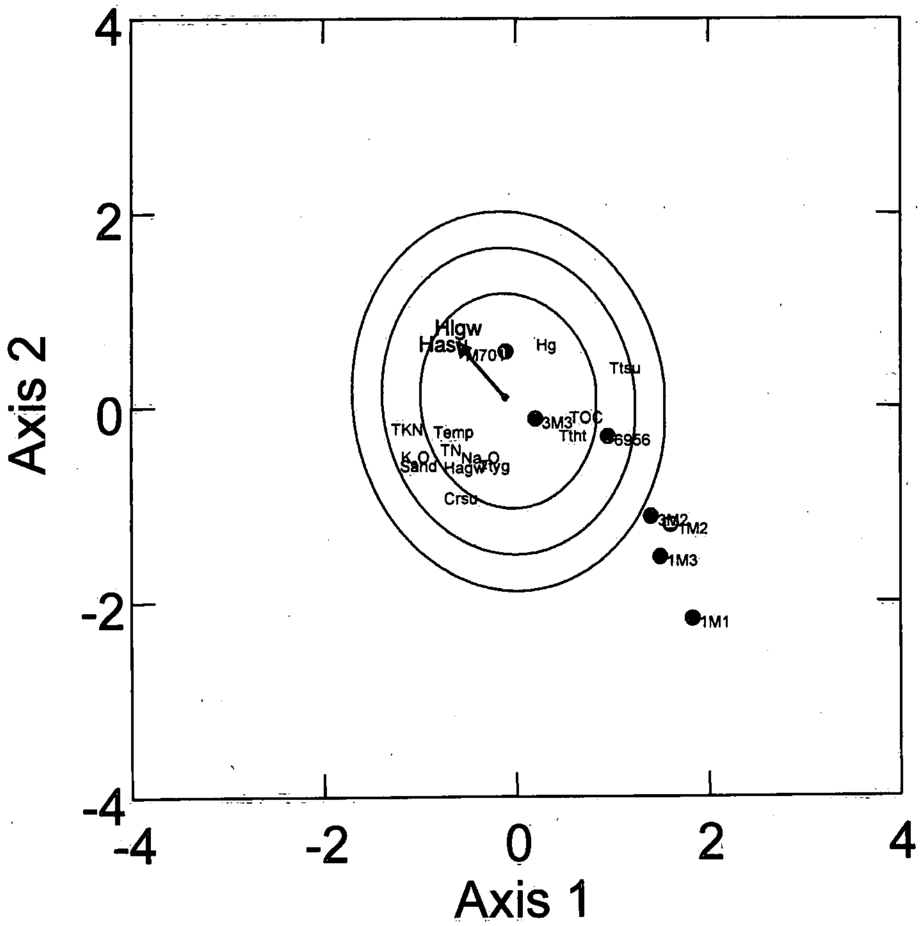


Figure E1. Ordination and assessment of the first subset of test sites using 10 toxicity test endpoints, plotted on Axes 1 and 2, with 90%, 99%, and 99.9% probability ellipses around reference sites (reference site scores not shown). Hasu, Hagw = *Hyalella* survival, growth; Ttsu, Ttht, Ttyg = *Tubifex* survival, hatch, young; Crsu = *Chironomus* survival; Hlgw = *Hexagenia* growth. Stress = 0.095.

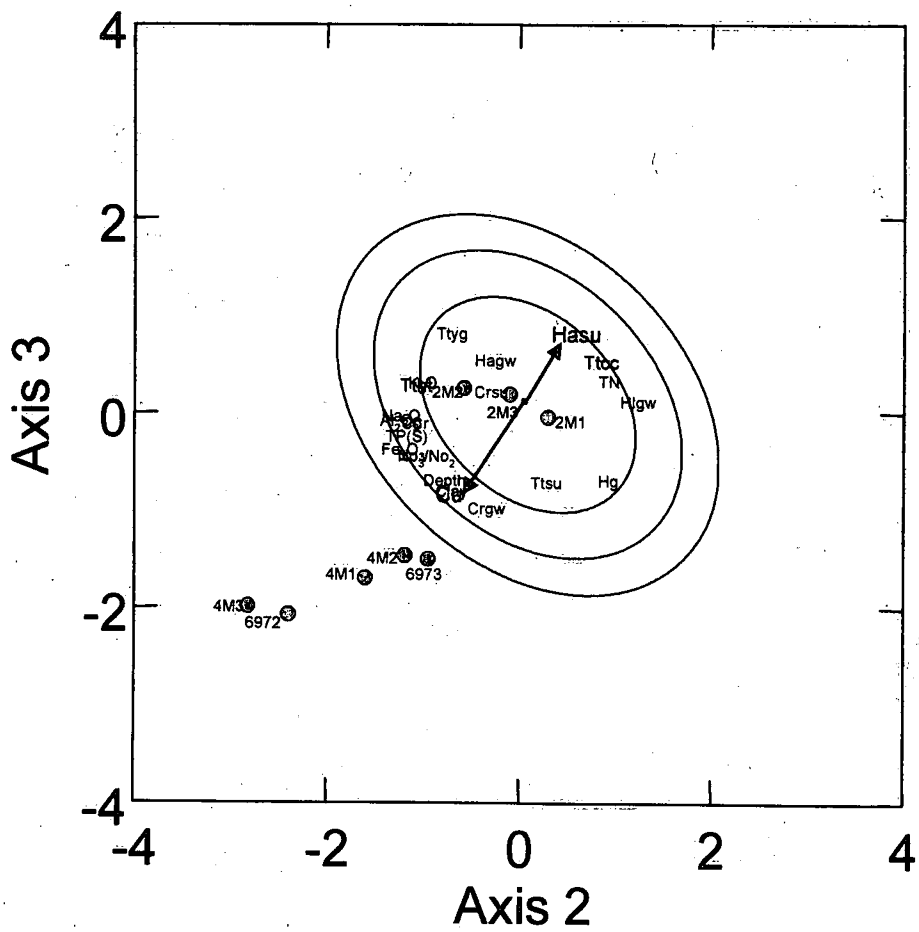


Figure E2. Ordination and assessment of the second subset of test sites using 10 toxicity test endpoints summarized on Axes 2 and 3, showing 90%, 99%, and 99.9% probability ellipses around reference sites (site scores not shown). The contributions of most significant endpoint and environmental variables are shown with arrows. Hasu, Hagw = *Hyalella* survival, growth; Ttsu, Ttht, Ttcc, Ttyg = *Tubifex* survival, hatch, coccons, young; Crsu, Crgw = *Chironomus* survival, growth; Hlgw = *Hexagenia* growth. Stress = 0.098. Note: Site 2M2 is located in Band 2 on alternate axis (Axis 1 – not shown).

APPENDIX F: Toxicity – Contaminant Relationships

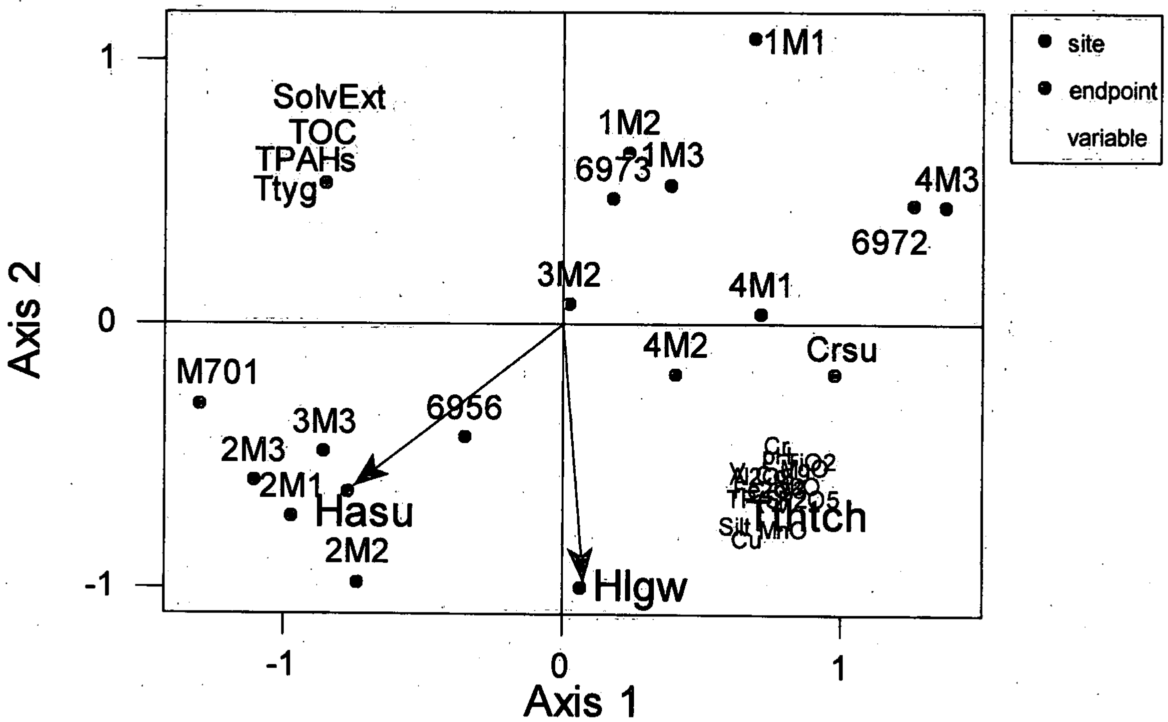


Figure F1. Toxicological response of Jackfish Bay sites represented by 2-dimensional HMDS (stress = 0.04). The direction of maximum correlation of *Hyalella* survival endpoint (Hasu) with sites is shown as a vector. High values for Axes 1 & 2 correspond to sites with low *Hyalella* survival and high values for Axis 2 also correspond to sites with low *Hexagenia* growth.

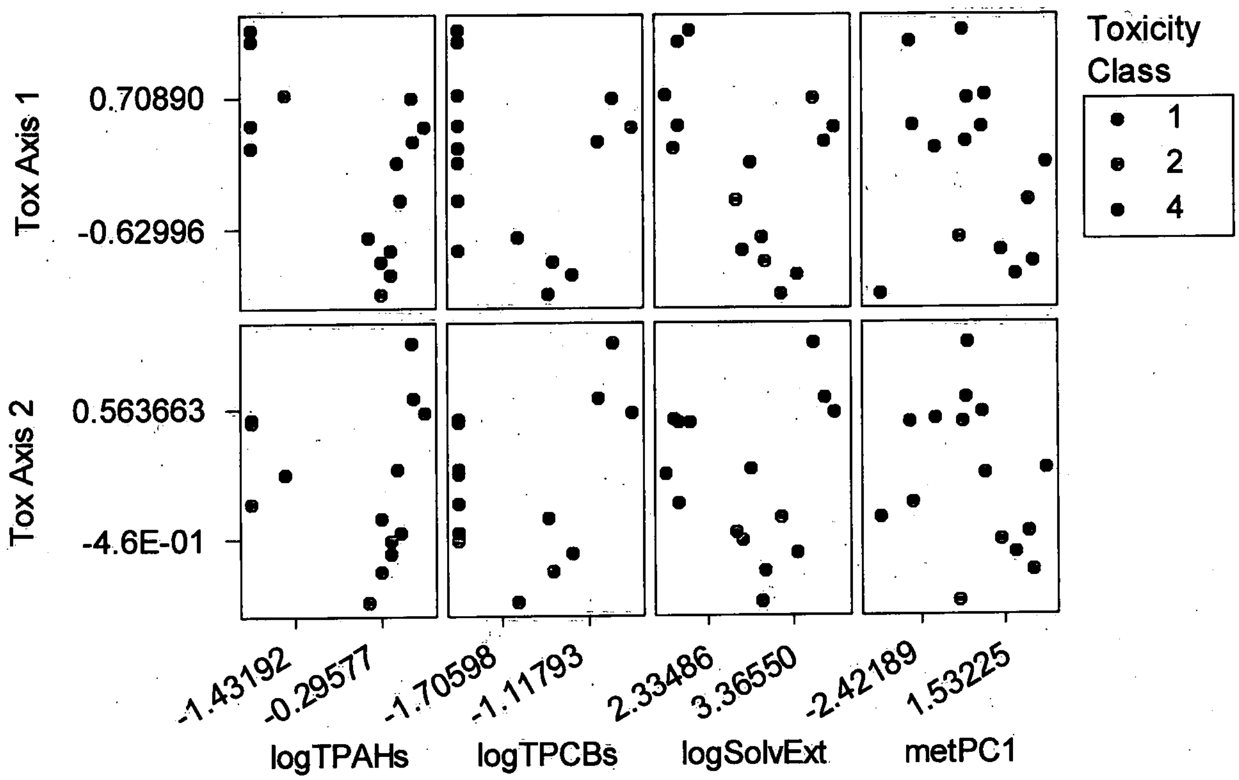
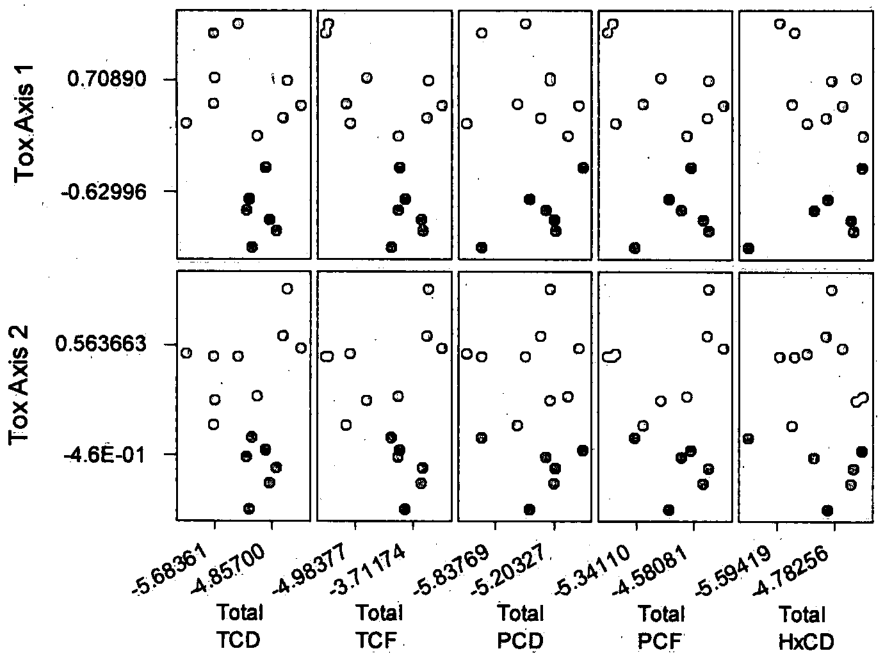


Figure F2. Jackfish sediment toxicity relationships to contaminant concentrations based on integrated toxicity descriptors (HMDS axes) and integrated metal and organic contaminant descriptors (see text for derivation of variables). Sites are colour-coded by toxicity class as determined by BEAST assessment with reference sites. High values for Axis 1 correspond to sites with low *Hyalella* survival; high values for Axis 2 correspond to sites with low *Hyalella* survival and *Hexagenia* growth. (See text for derivation of variables.)



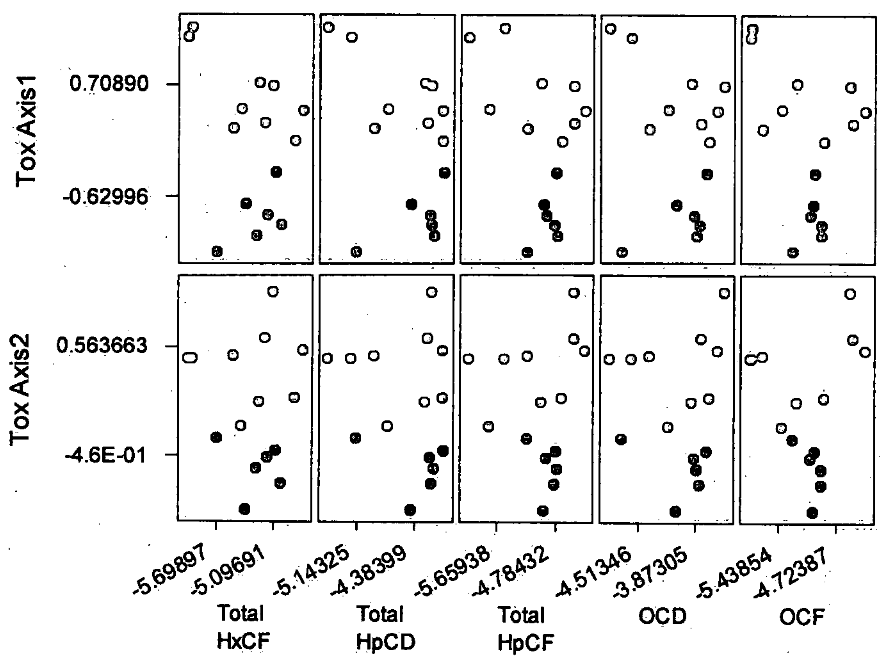


Figure F2. Continued.

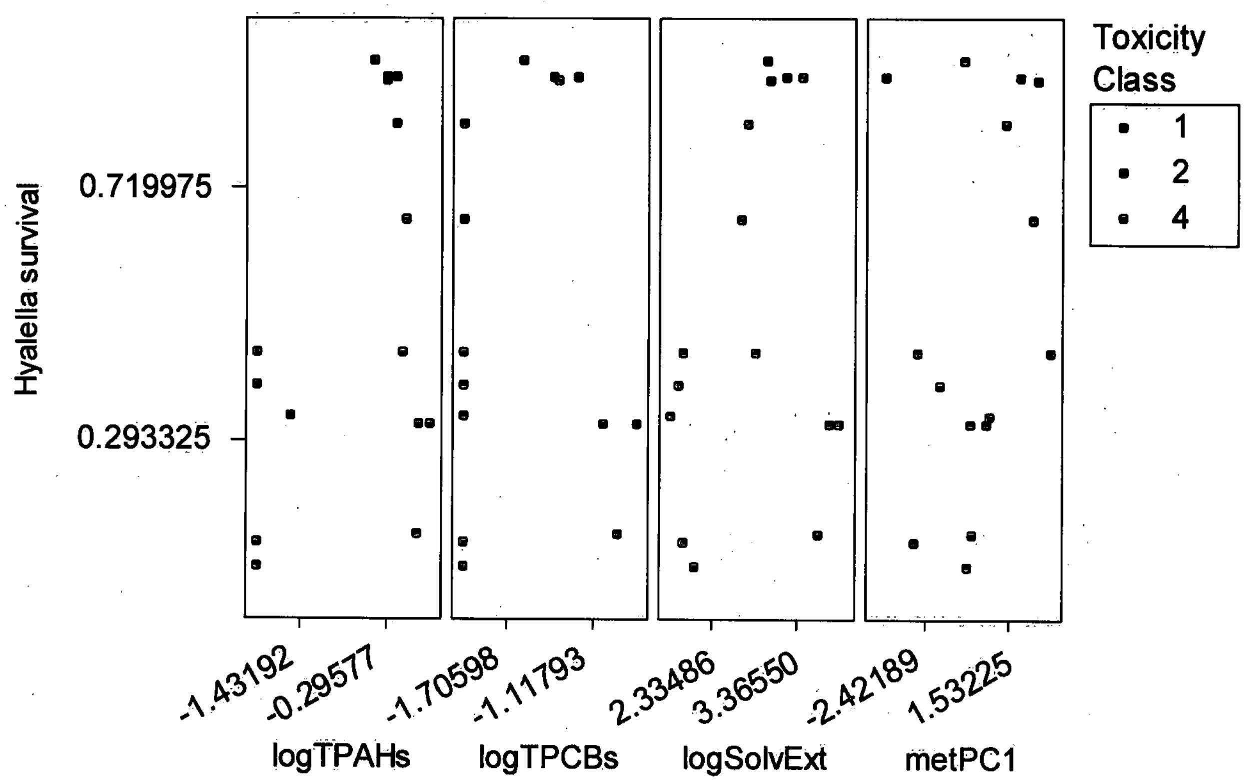
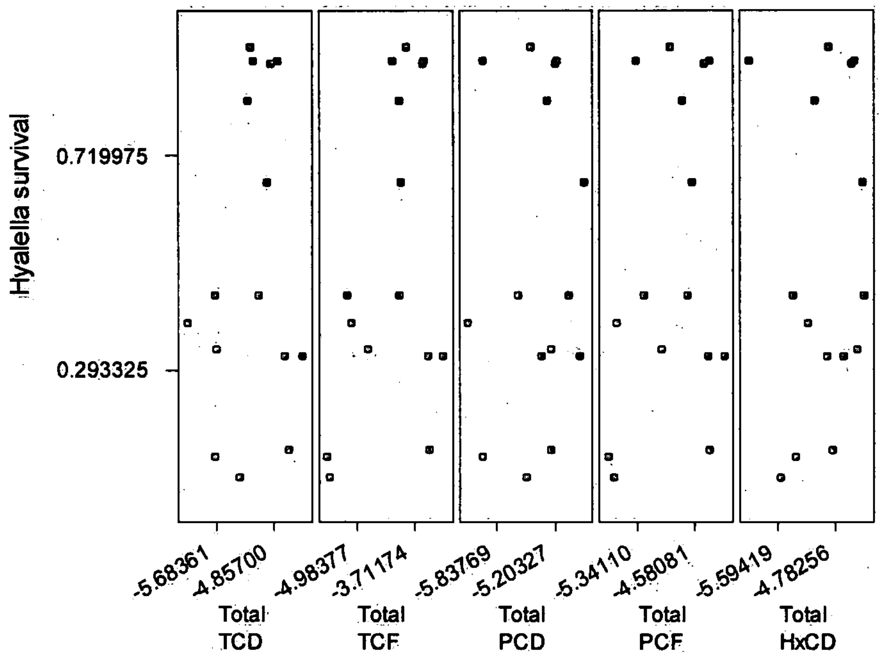


Figure F3. Jackfish sediment toxicity relationships to contaminant concentrations based on individual toxicity endpoint and integrated metal and organic contaminant descriptors (see text for derivation of variables). Sites are colour-coded by toxicity class as determined by BEAST assessment with reference sites.



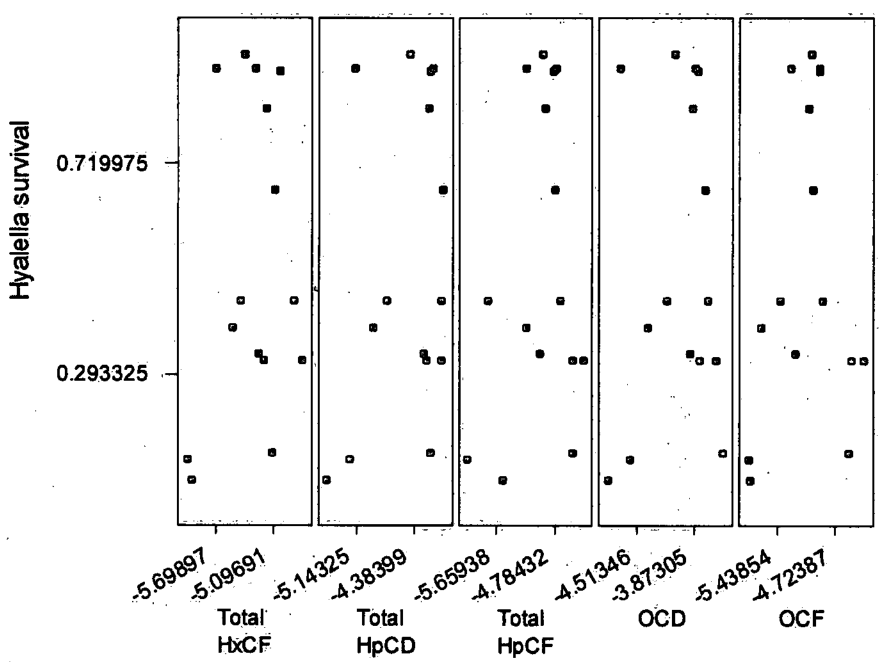


Figure F3. Continued.

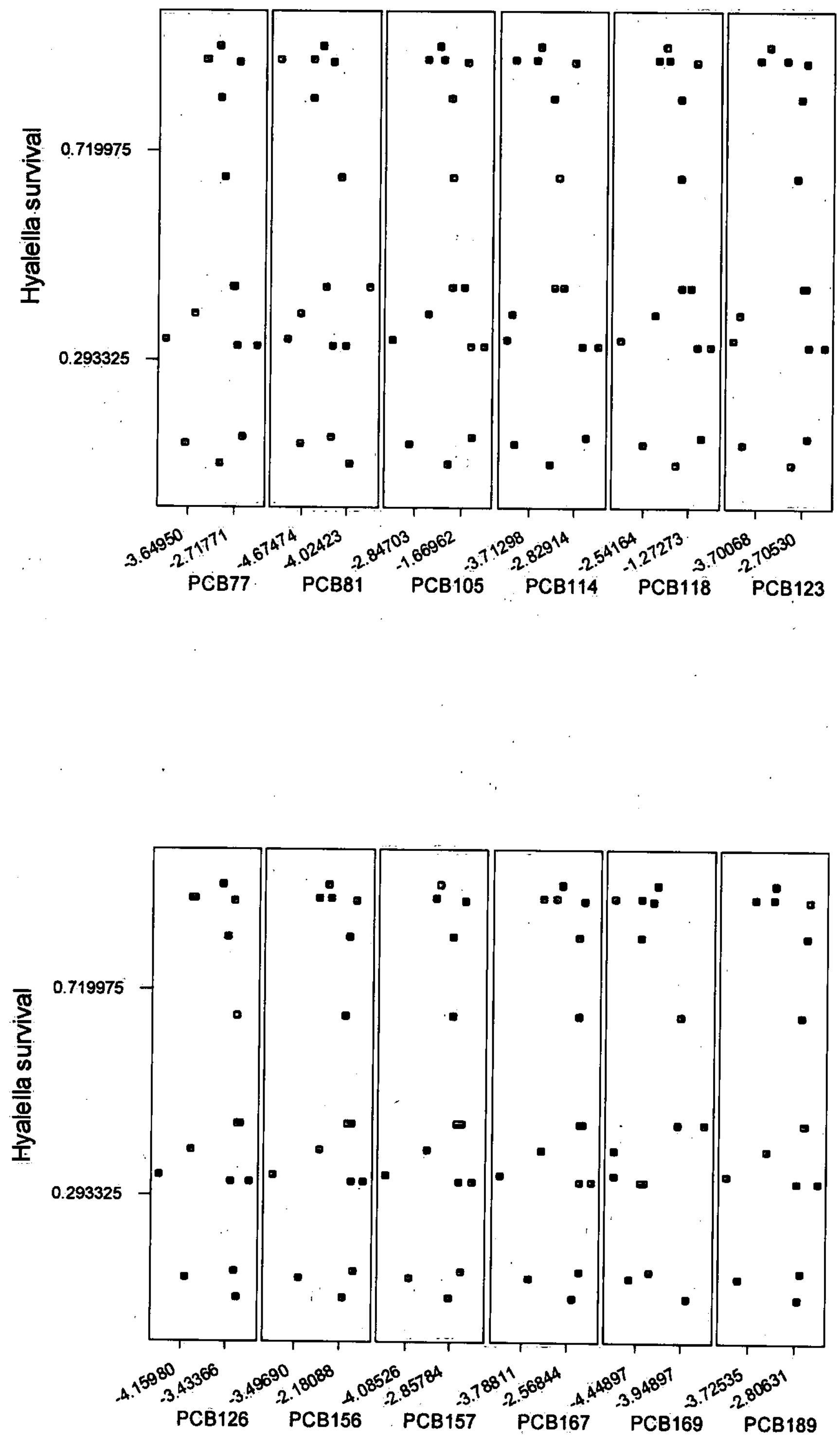
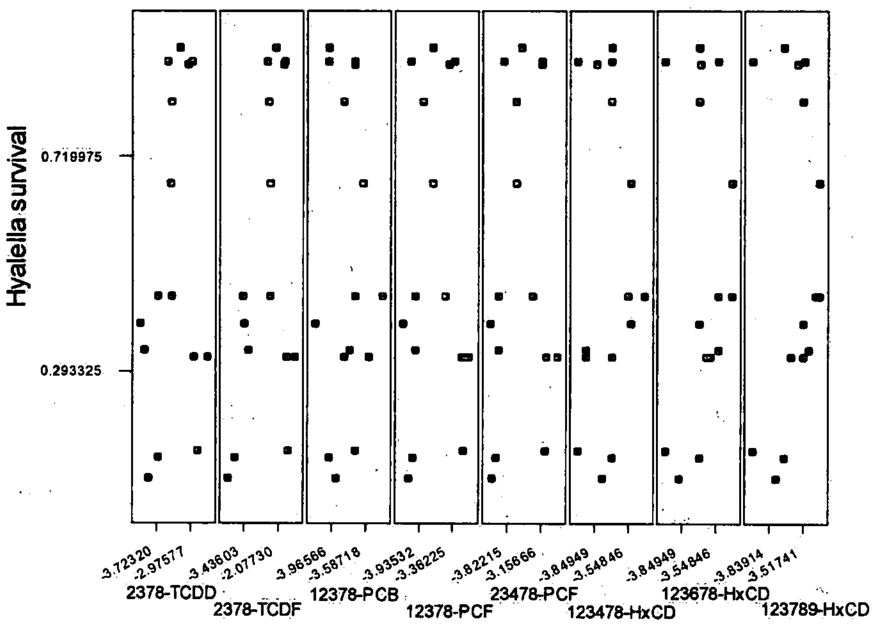


Figure F4. Jackfish sediment toxicity relationships to contaminant concentrations based on individual toxicity endpoint and individual coplanar PCB congeners. Sites are colour-coded by toxicity class as determined by BEAST assessment with reference sites (see Figure F3).



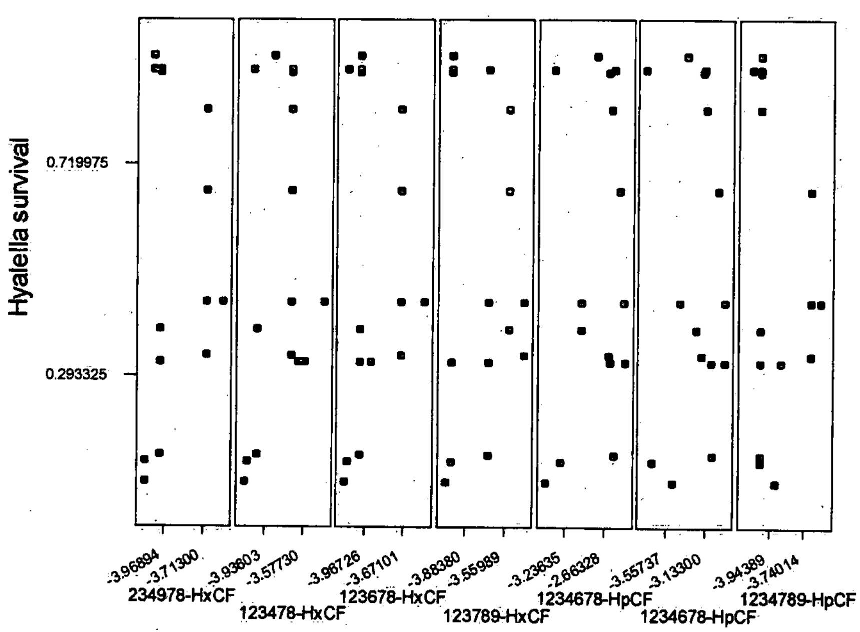
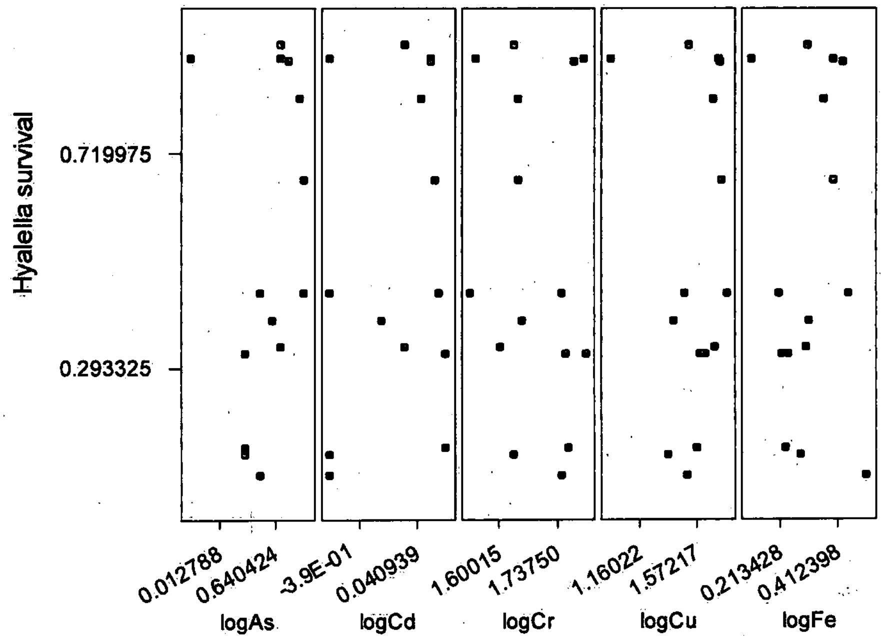


Figure F5. Jackfish sediment toxicity relationships to contaminant concentrations based on individual toxicity endpoint and individual dioxin and furan isomers. Sites are colour-coded by toxicity class as determined by BEAST assessment with reference sites (see Figure F3).



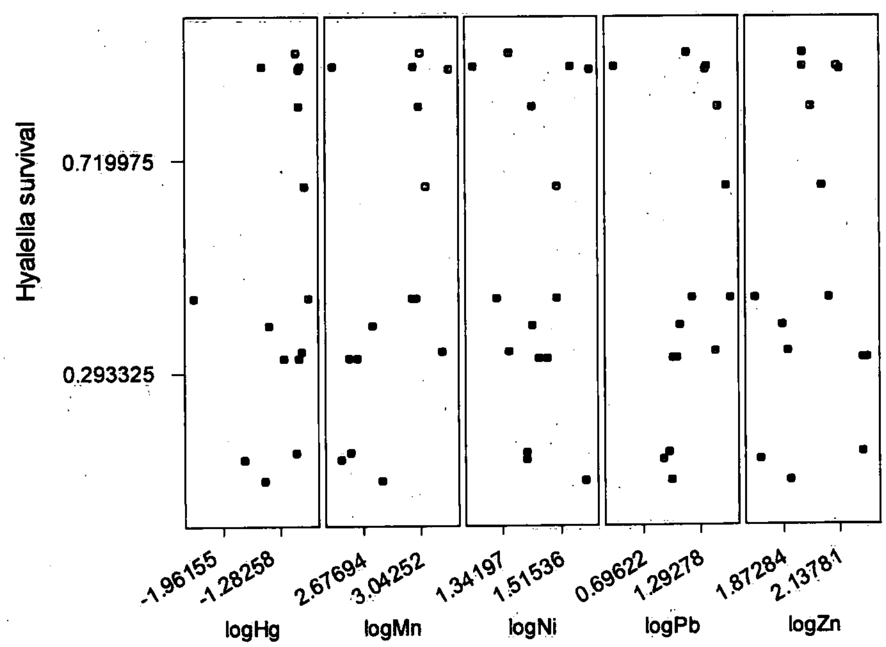


Figure F6. Jackfish Bay sediment toxicity relationships to contaminant concentrations based on individual toxicity endpoint and individual metal concentrations. Sites are colour-coded by toxicity class as determined by BEAST assessment with reference sites (see Figure F3).

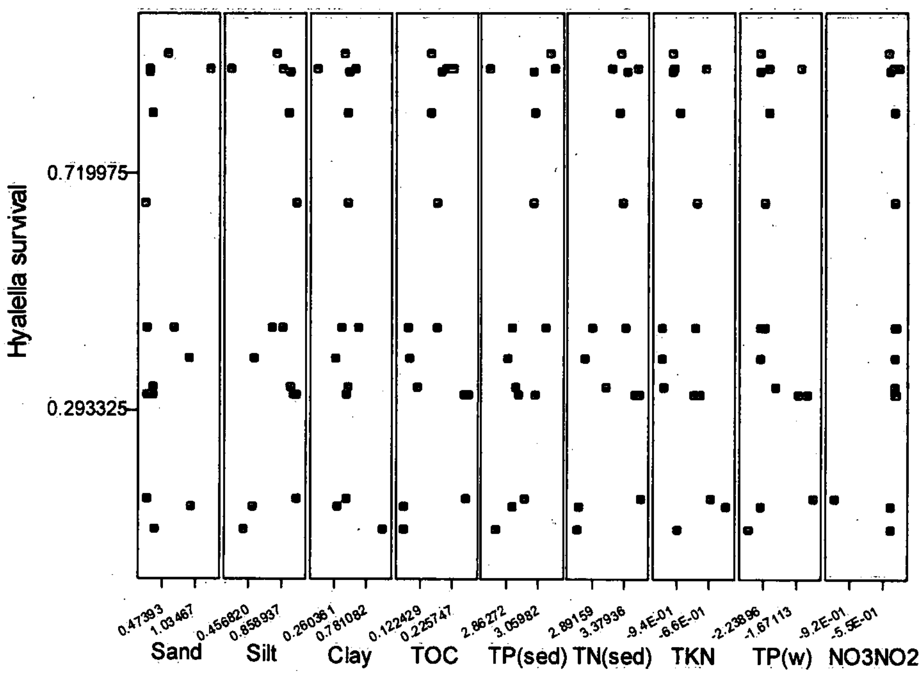


Figure F7. Jackfish Bay sediment toxicity relationships to contaminant concentrations based on individual toxicity endpoint and individual nutrient concentrations and particle size. Sites are colour-coded by toxicity class as determined by BEAST assessment with reference sites (see Figure F3).

APPENDIX G: Quality Assurance/Quality Control

Table G1. Coefficients of variation for field-replicated sites.

Parameter	Coefficient of Variation 1M2	Coefficient of Variation 4M3
Al (%)	4.6	11.9
Al_2O_3 (%)	2.8	7.2
Alkalinity (mg/L)	3.5	0.7
As (ppm)	0.0	33.3
Ba (ppm)	4.9	9.2
BaO (%)	1.8	6.8
Be (ppm)	21.7	20.0
Bi (ppm)	0.0	7.9
Ca (%)	3.6	25.9
CaO (%)	1.7	23.6
Cd (ppm)	5.6	0.0
Co (ppm)	0.0	9.6
Cr (ppm)	1.0	12.5
Cr_2O_3 (%)	69.3	0.0
Cu (ppm)	1.5	12.1
Fe (%)	3.1	10.0
Fe_2O_3 (%)	1.3	15.6
Hg (ppm)	2.6	29.8
K (%)	5.0	12.0
K_2O (%)	1.4	6.2
LOI (%)	2.1	16.9
Mg (%)	3.4	9.6
MgO (%)	1.6	5.1
Mn (ppm)	5.1	8.0
MnO (%)	0.0	10.0
Na (%)	3.5	15.0
Na_2O (%)	0.8	11.1
NH_3 (mg/L)	7.7	12.0
Ni (ppm)	20.4	11.2
NO_3/NO_2 (mg/L)	6.9	0.7
P_2O_5 (%)	5.0	4.3
Pb (ppm)	0.0	23.9
Sb (ppm)	34.6	34.6
Se (ppm)	0.0	43.3
SiO_2 (%)	2.1	6.3
Sr (ppm)	4.2	22.8
Ti (ppm)	6.9	15.7
TiO_2 (%)	1.2	15.5
TKN (mg/L)	47.6	8.9
Tl (ppm)	0.0	43.3
TN (ppm)	10.3	13.8
TOC (%)	2.5	52.9
TP(Sed) (ppm)	32.7	12.5
TP(Wat) (mg/L)	71.0	3.5
V (ppm)	1.7	11.6
Whole Rock (%)	1.5	0.3
Y (ppm)	5.5	8.5
Zn (ppm)	2.8	9.6

range: 0 - 71%
median: 6.8%

Table G2. Percent recovery in matrix spikes (MOE).

	Parameter		
Site	d10-phenanthrene	d12-chrysene	d8-naphthalene
M701	100	74	68
1M1	97	81	70
1M2-1	110	91	68
1M2-2	110	78	68
1M2-3	100	88	120
1M3	100	82	64
3M2	110	98	61
3M3	100	96	59
6956	110	95	85
2M1	100	89	83
2M2	100	100	74
2M3	110	95	65
4M1	100	100	87
4M2	98	100	83
4M3-1	110	81	59
4M3-2	140	120	99
4M3-3	67	69	46
6972	100	110	64
6973	100	110	97
mean	103	92	75

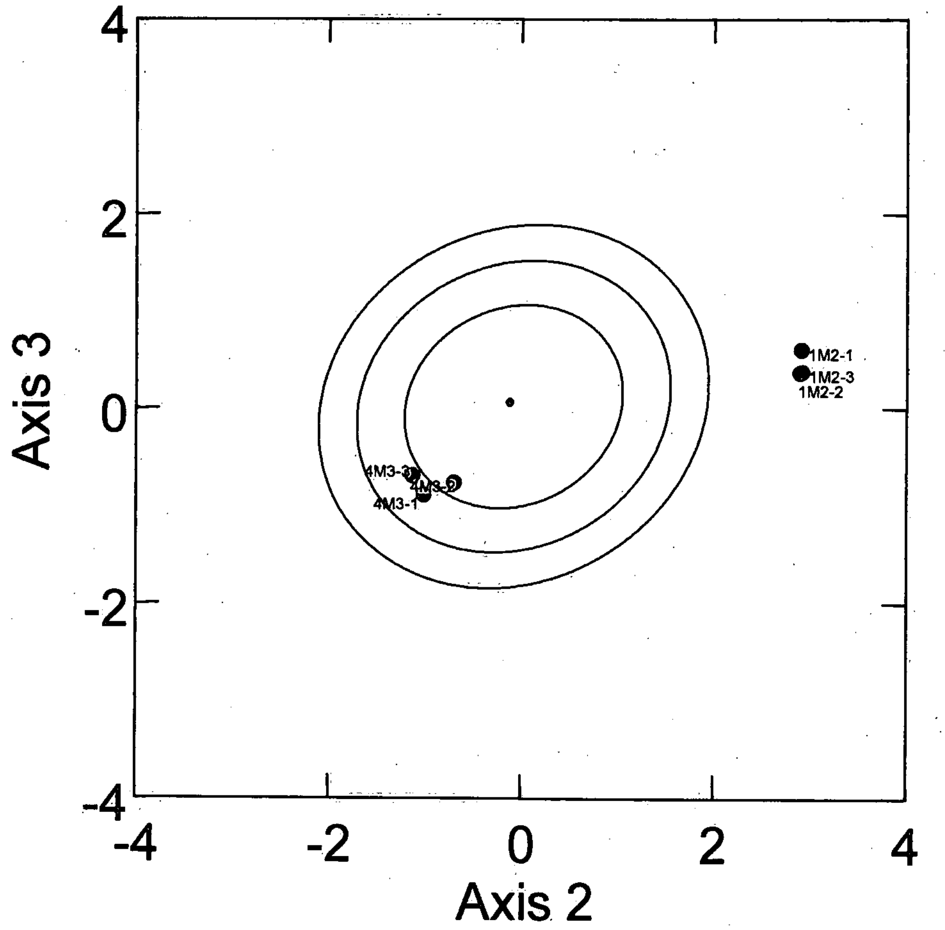
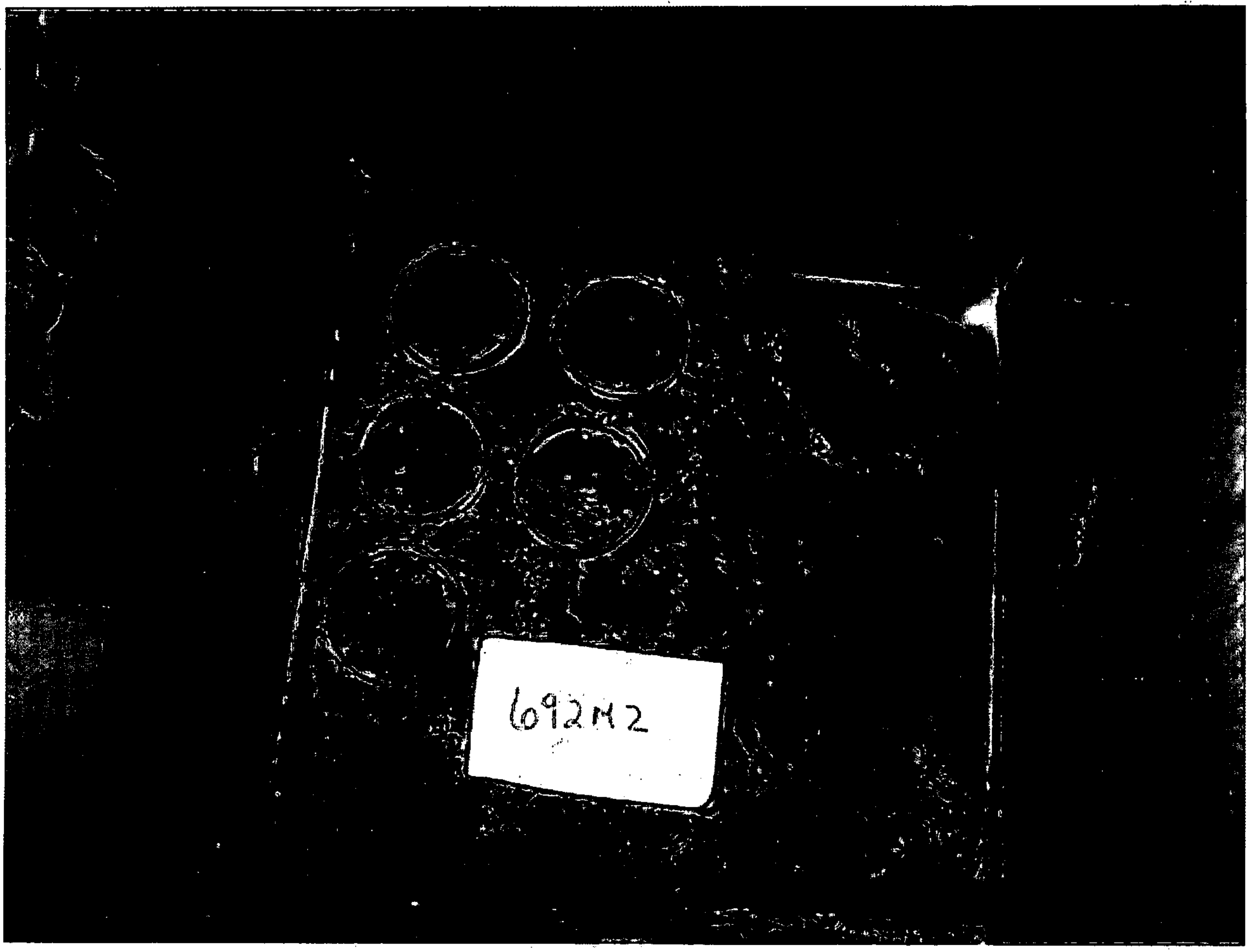


Figure G1. Location of field-replicated QA/QC sites in ordination space.

APPENDIX H: Sediment Sample Photographs

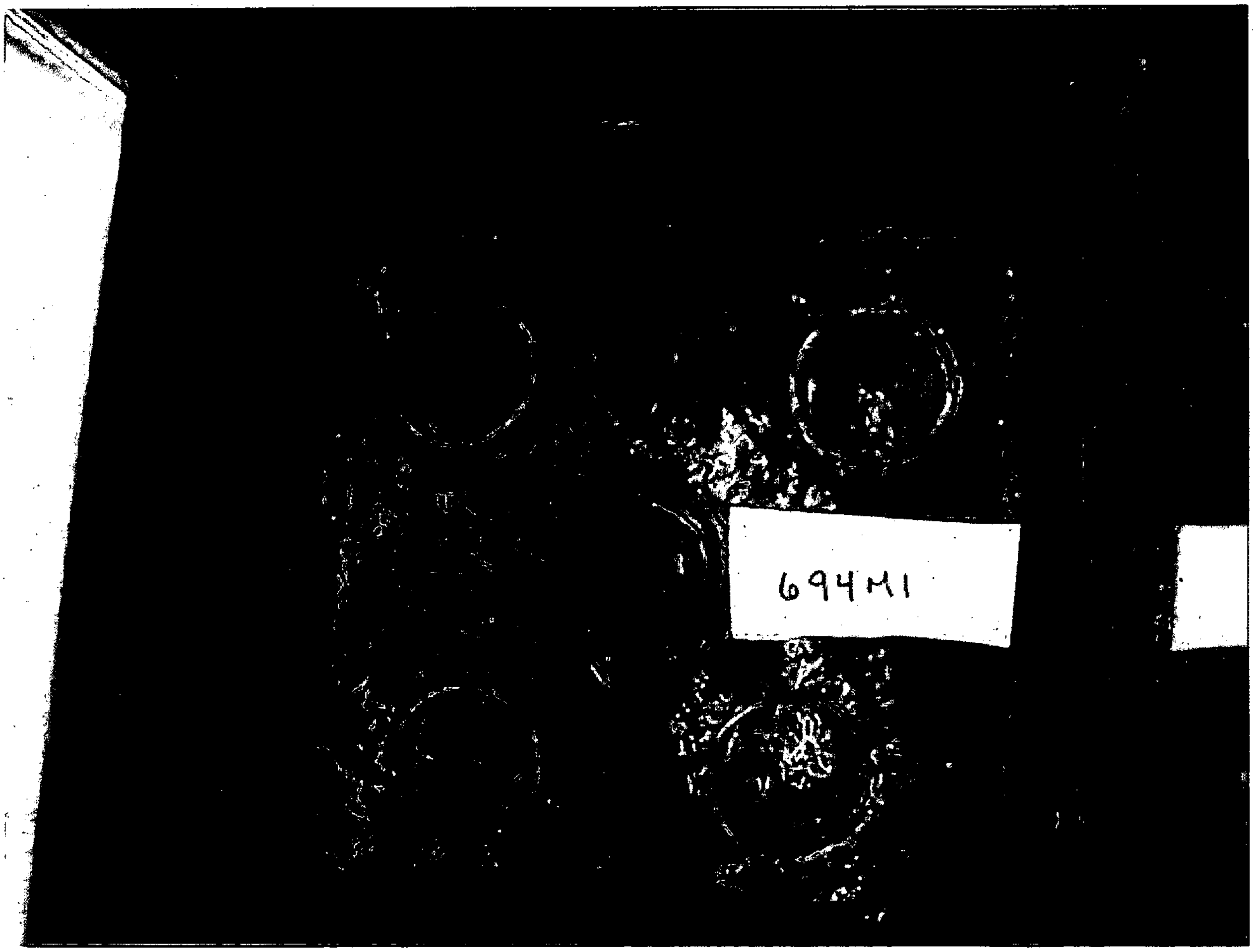
Moberly Bay – Site M701
(Note: there are no pictures are available for Sites 1M1, 1M2 and 1M3 in Moberly Bay)

Far-field (South of Cody Island) – Site 2M1

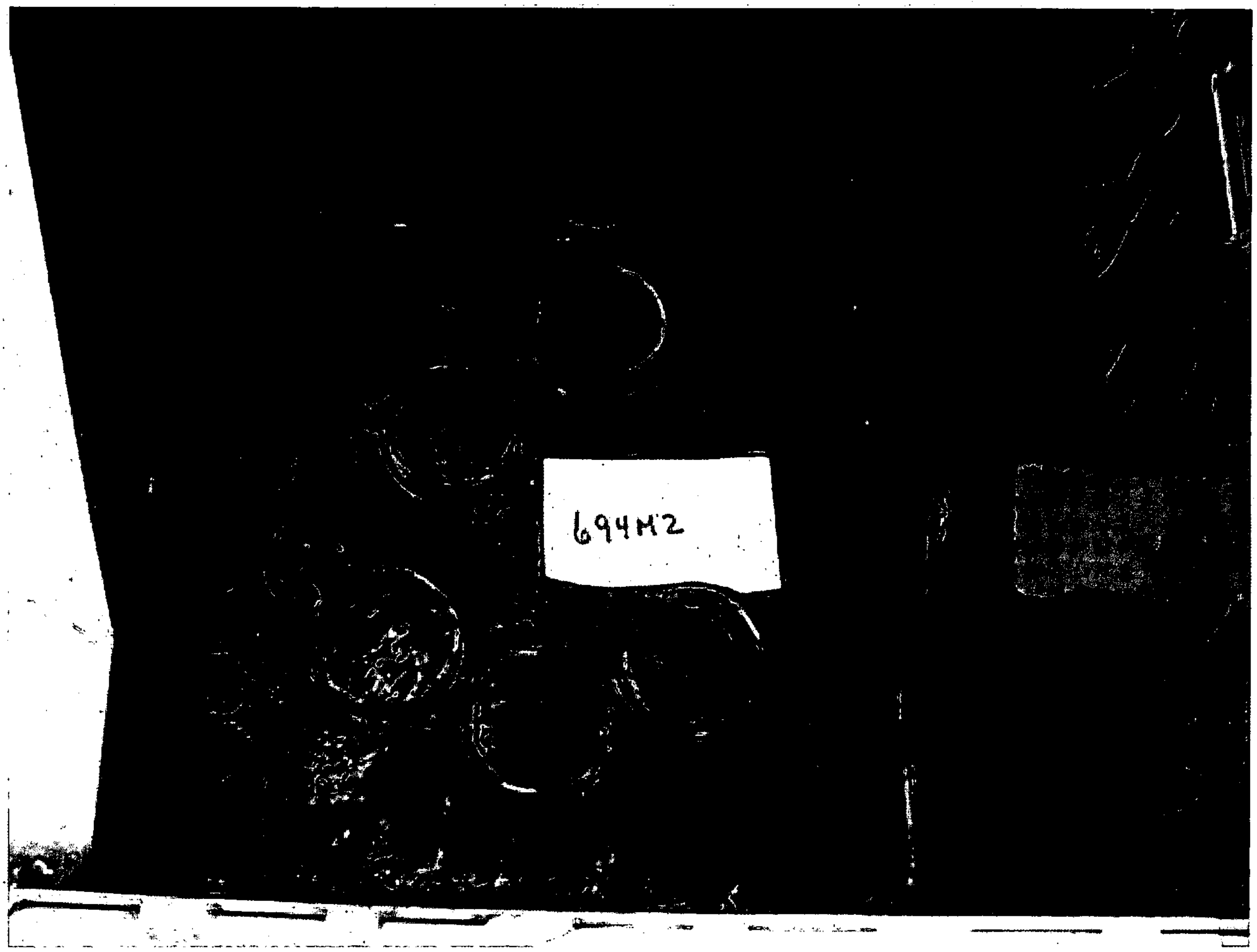


Far-field (South of Cody Island) – Site 2M2

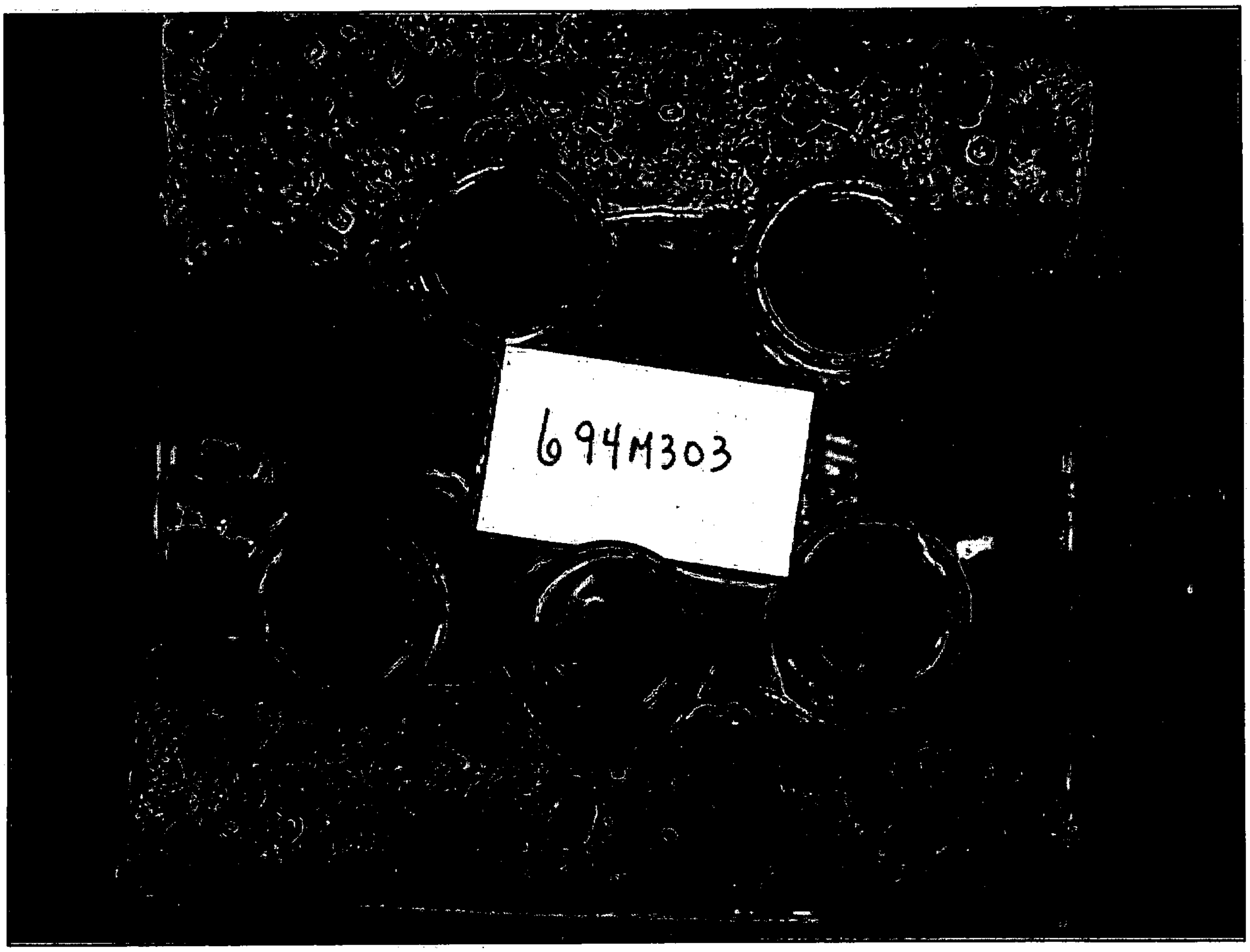
Far-field (South of Cody Island) – Site 2M3



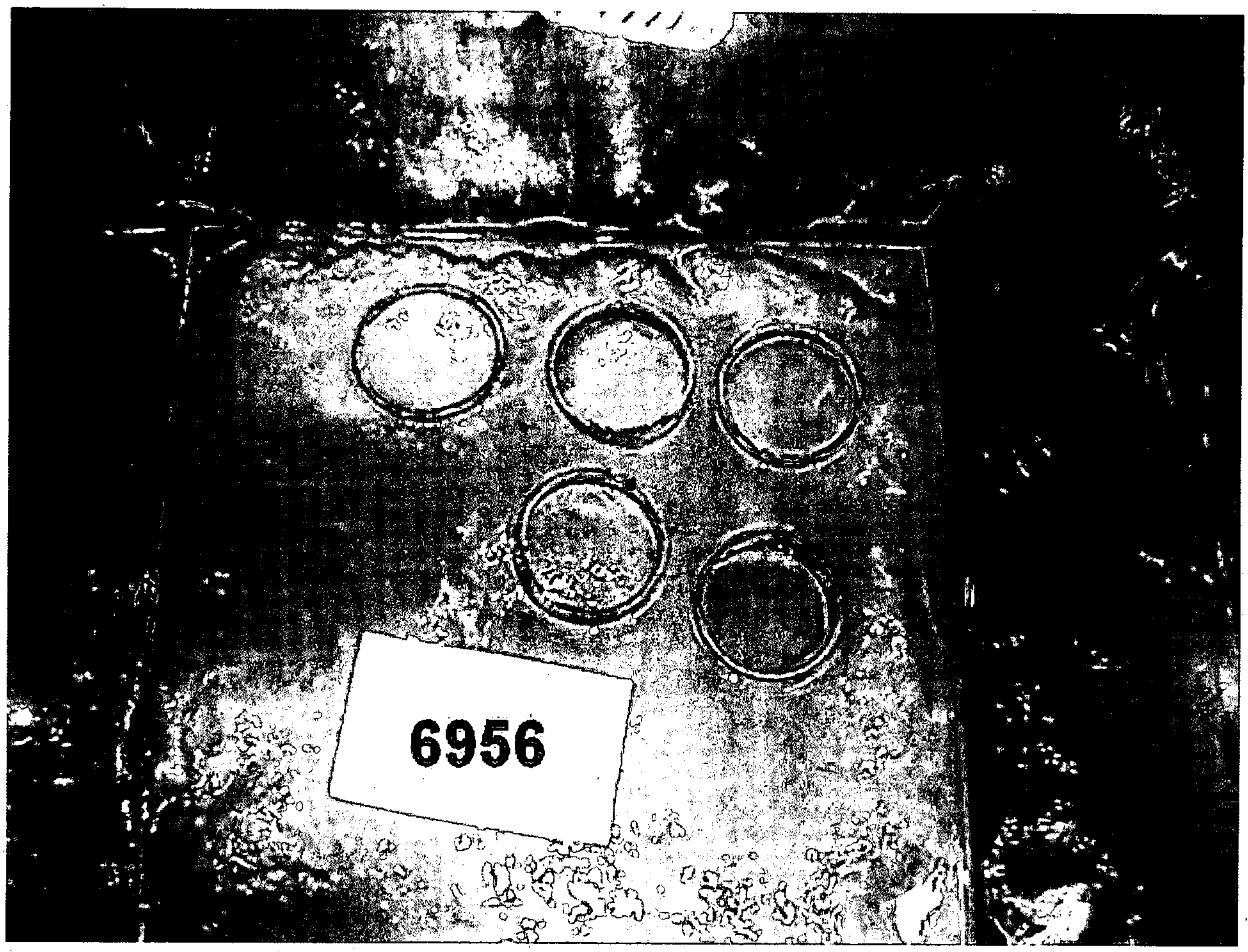
Far far-field (South of St. Patrick Island) – Site 4M1



Far far-field (South of St. Patrick Island) – Site 4M2

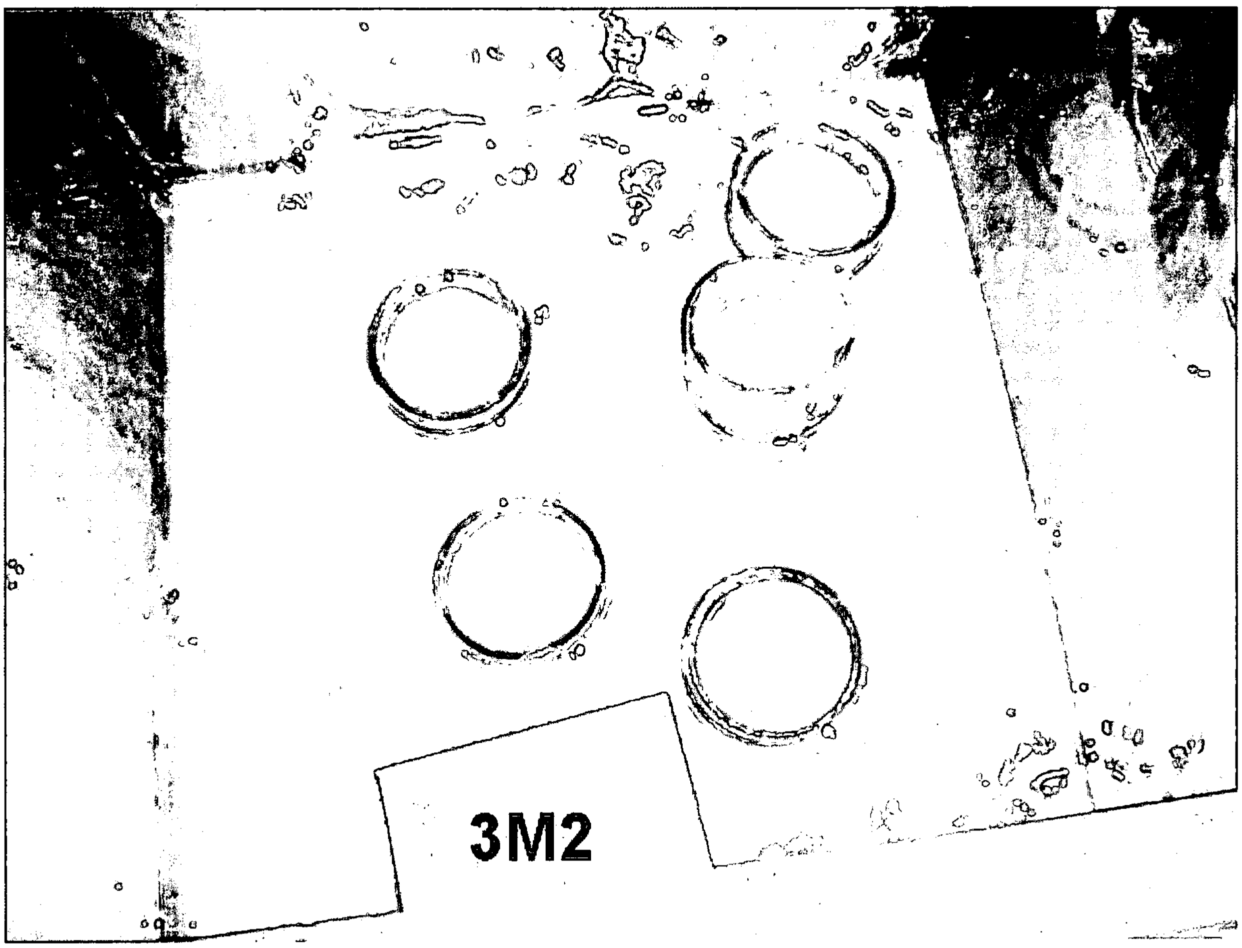


Far far-field (South of St. Patrick Island) – Site 4M3



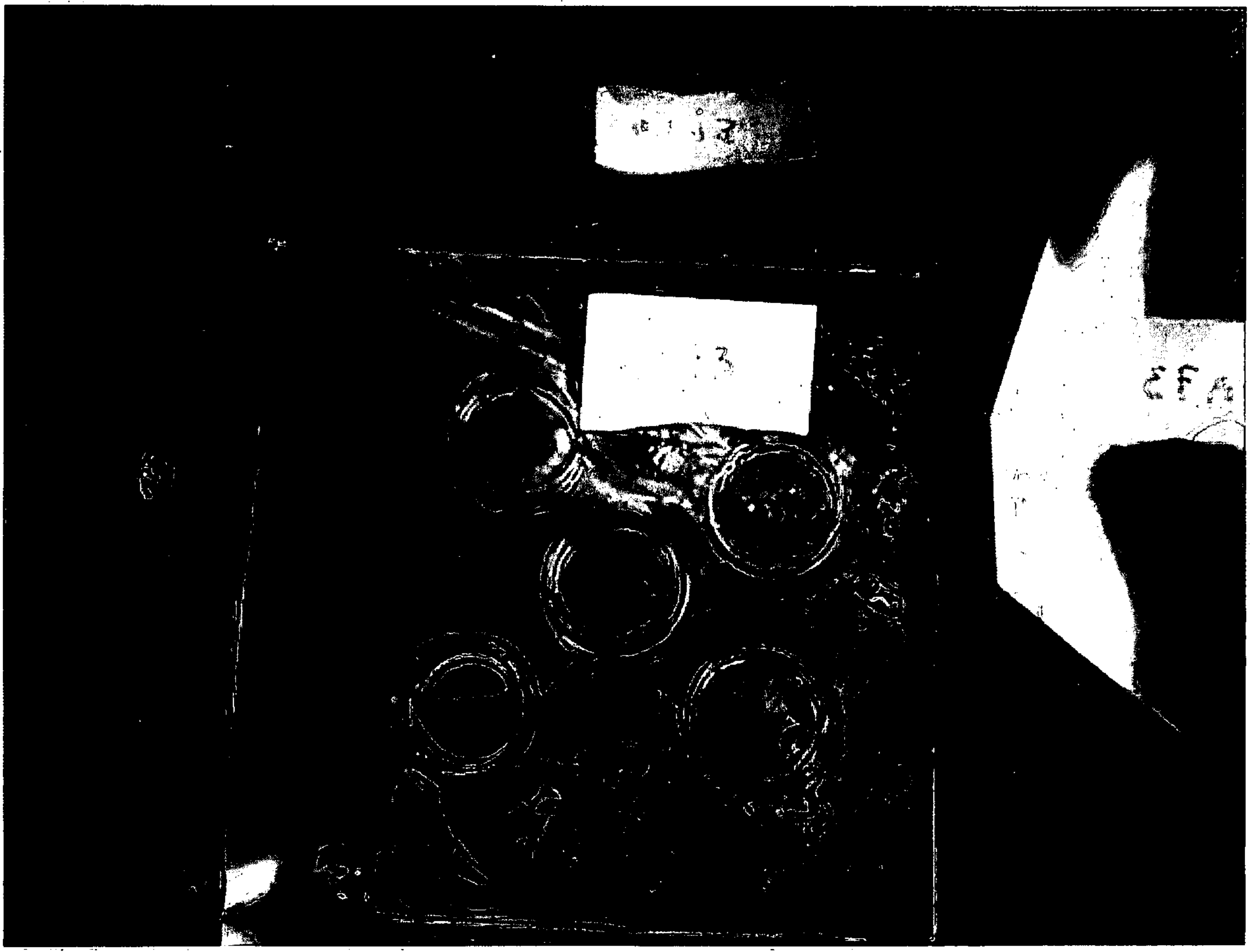
Tunnel Bay – Site 6956

Tunnel Bay – Site 3M3



Tunnel Bay – Site 3M2

Off Cape Victoria – Site 6972



Off Cape Victoria – Site 6973

Environment Canada Environnement Canada

Canada

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St. Lawrence Centre
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Montreal, Quebec
H2Y 2E7 Canada

Place Vincent Massey
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