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Benthic Conditions in the Jackfish Bay Area of Concern in Recovery 2013 and Trends from 2003 to 2013

Prepared by:

Danielle Milani and Lee C. Grapentine

Environment and Climate Change Canada
Water Science and Technology Directorate
867 Lakeshore Road, Burlington, Ontario, L7S 1A1

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EXECUTIVE SUMMARY

To evaluate current benthic conditions in the Jackfish Bay Area of Concern in Recovery and whether they are improving over time, sediment contaminant concentrations, benthic invertebrate tissue contaminant concentrations (dioxin and furans), the benthic macroinvertebrate community structure, and the toxicological response of four benthic invertebrates (*Hyalella azteca*, *Chironomus riparius*, *Hexagenia* spp. and *Tubifex tubifex*) in laboratory bioassays were assessed. Spatial differences between current conditions (2013) at contaminated (Jackfish Bay) and reference (Great Lakes) sites were examined using multivariate (ordination) techniques. Temporal differences in conditions from 2003 to 2013 or 2006 to 2009 were also examined using both multivariate and univariate techniques. In 2013, 15 sites were sampled throughout the bay from Moberly Bay (8 sites), south of Moberly Bay (far-field – 3 sites), at the south end of Jackfish Bay (far far-field – 2 sites) and Tunnel Bay (local background for Moberly Bay – 2 sites).

Surficial (0-10cm) sediment metal concentrations mostly fell between low and high sediment quality guideline guidelines (Threshold Effect Level and Probable Effect Level) and were within the range observed for Lake Superior reference sites except for a few metals in Moberly Bay (e.g., Cd, Zn). Over time, metal concentrations have remained stable or have decreased slightly since 2003.

Sediment dioxins and furans (PCDD/Fs) were detected at all sites; the higher chlorinated dioxin homologue groups dominated the samples whereas the tetrachlorofurans were generally the highest of the furan homologue groups. The most toxic dioxin, 2,3,7,8-TCDD, was detected at all sites and was most elevated in Moberly Bay (≤ 22.1 pg/g), followed by the far-field area (≤ 12.4 pg/g), Tunnel Bay (≤ 3.2 pg/g), and far far-field area (≤ 0.44 pg/g). Under the mid-point scenario (non-detected values assigned half the detection limit), sediment PCDD/Fs, expressed in toxic equivalents (TEQs), ranged from 0.7 to 53.4 ng·TEQ/kg in 2013. The TEQs for the dioxin-like PCBs were ≤ 0.165 pg/g and represented very little of the total TEQ. In 2013, the TEQs exceeded the Probable Effect Level (21.5 pg/g) at 7 of the 8 Moberly Bay sites, by ≤ 2.5 times, and at 1 of the 2 far-field sites by 1.3 times; all TEQs were above those observed for Lake Superior reference sites except those in the far far-field area. (Tunnel Bay TEQs were only marginally above.) The TEQs have been relatively stable or decreasing since 2003 with both

increases and decreases observed which likely represents natural variability and perhaps small scale heterogeneity. Petroleum hydrocarbons (PHCs) and total oil and grease concentrations were also elevated in Moberly Bay compared to other areas of the bay and showed a decreasing gradient from Moberly Bay, where heavy hydrocarbons were present (e.g., oils), to the far-field area. Concentrations of total PHCs were mostly stable since 2006. Although the contaminant concentrations were generally stable over time, more recent deposits (from 0-2 cm) would not be reflected in the samples, e.g., contaminant concentrations would be influenced by the deeper sediment where higher concentrations would be expected to occur.

Benthic invertebrates were collected for PCDD/F and dioxin-like PCBs residue analysis at a subset of 7 of the 15 sites: 3 in Moberly Bay, 2 in the far-field area, 1 in the far far-field area and 1 in Tunnel Bay. From 2 to 3 taxa were collected from each site (amphipods, chironomids, and oligochaetes). The higher chlorinated dioxins and the lower chlorinated furans were mostly dominant in the tissues, similar to that seen for sediments. The congener 2,3,7,8-TCDD was detected in only 2 samples, 1 in Moberly Bay and 1 in the far-field area (≤ 8.56 pg/g). Biota-sediment accumulation factors for PCDD/Fs for the 2013 samples were mostly < 1 with occasional values between 1 and 2 and for the dioxin-like PCBs were well below 1, indicating that these contaminants have a low potential to bioaccumulate in benthic invertebrates. The BSAFs should be interpreted with caution since it is possible that some organisms (e.g., amphipods) collected for tissue analysis may not have been exposed to the full 10 cm of sediment which could obscure the BSAF results. The biota TEQs in pg/g for Moberly Bay, far-field, far far-field, and Tunnel Bay were ≤ 34.2, ≤ 48.9 ng/kg, ≤ 28.8 ng/kg and ≤ 8.4, respectively. As a screening level assessment of potential risk, the TEQs were compared to a modified avian TRG (7.3 ng TEQ/kg) and the maximum TEQ for Lake Superior reference samples collected in 2008 (10.4 pg TEQ/kg); exceedences of these criteria occurred with a greater certainty in Moberly Bay and south of Moberly Bay (far-field) for 1 - 2 taxa per site while exceedences in the far far-field area (1 taxon) carried more uncertainty. The biota TEQs were overall lower in 2013 compared to 2008.

The macroinvertebrate community composition and abundance in Jackfish Bay varied from area to area. Moberly Bay was dominated by tubificid worms (mostly unidentified immature worms), followed by chironomids whereas in the far-field and Tunnel Bay, the pontoporeiid amphipods were a dominant group and while tubificids were prevalent, they were in far lower

abundance in these areas than in Moberly Bay. In the far far-field area, there were no tubificids present, and the pontoporeiids were dominant followed by enchytraeid worms, more indicative of oligotrophic conditions. Based on a whole community assessment (multivariate analysis), 11 of the 15 sites were not different from reference ($p > 0.1$); 3 sites were different ($0.10 \geq p > 0.01$) – located in Moberly Bay and far far-field; and 1 site was very different ($p \leq 0.01$) – located in Moberly Bay. Other than far far-field sites, which showed differences in whole community and Tubificidae abundances, effects were restricted to Moberly Bay. Based on individual descriptors, all 8 Moberly Bay sites were different or very different from reference based on 1 to 5 descriptors: total benthos (2 sites), evenness (3 sites), tubificid abundance (6 sites), naidid abundance (1 site) and asellid abundance (5 sites). Most Moberly Bay sites (5 of the 8) had multiple individual benthic descriptors that were different to those from reference sites but on a whole community basis, major differences were restricted to 2 sites that were those closest to the mouth of Blackbird Creek. Overall, the benthic community response varied from very different closest to the mouth of BBC to not different in the far-field area of Jackfish Bay. Temporal trends for 5 co-located sites sampled from Moberly Bay (4 sites) and the far-field area (1 site) from 2006-09 showed some inter-year variability. Conditions in the far-field have improved and remained stable since 2007, whereas Moberly Bay sites showed more variability fluctuating back and forth from different to not different. Overall, benthic invertebrate communities in Moberly Bay were different from those at reference sites, driven mainly by increased tubificid densities and while inter-year variability was apparent, conditions in Moberly Bay have remained relatively stable.

Acute toxicity was evident to the amphipod *Hyalella* at 5 of the 8 sites in Moberly Bay (52-63% survival), in the far far-field (0.7-11.3% survival) and in Tunnel Bay (16.7-35.3% survival). Reduced *Hexagenia* survival and/or growth were also evident in parts of Moberly Bay. Based on the multivariate assessment of integrated endpoints, 5 sites were non-toxic (far-field and Moberly Bay), 4 sites were potentially toxic (Moberly Bay), 2 sites were toxic (Moberly Bay), and 4 sites were severely toxic (far far-field and Tunnel Bay). Although conditions seemed to improve in 2008, the 2013 results closely resembled those from 2003, indicating relatively little change since 2003 with toxicity prevalent in 3 to 4 of the 5 areas in the bay. Examination of *Hyalella* toxicity-contaminant relationships indicated that while no contaminant could be identified as the singular cause, toxicity was partially explained by petroleum hydrocarbons (r^2 =

38.7%, p = 0.02) and a physical toxicity, due to heavy oils present, could not be precluded. Sites in the far far-field area, where sediment contamination was low, were consistently toxic across 2 of the 3 sampling years. The cause of this toxicity was unclear although there could be a substrate-related factor involved in some cases.

Overall, this study shows conditions in Jackfish Bay to be relatively stable, with improvements in some cases since 2003 or 2006. This study can assist in determining the sampling frequency and other long term monitoring options for the Jackfish Bay Area of Concern in Recovery.

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ABBREVIATIONS, ACRONYMS AND SYMBOLS

[X]	concentration of X
AOC	Area of Concern
BBC	Blackbird Creek
BSAF	biota-sediment accumulation factor
BTEX	benzene, toluene, ethylbenzene and xylene
CABIN	Canadian aquatic biomonitoring network
CCME	Canadian Council of Ministers of the Environment
CV	coefficient of variation
DL-PCBs	dioxin-like polychlorinated biphenyls
dw	dry weight
GL	Great Lakes
HpCDD/CDF	heptachlorodioxin/heptachlorofuran
HxCDD/CDF	hexachlorodioxin/hexachlorofuran
IE	identification error
JFB	Jackfish Bay
LEL	lowest effect level
MOE	Ministry of the Environment (Ontario)
MDL	method detection limit
MLR	Multiple linear regression
NMDS	Nonmetric multidimensional scaling
OCD	octachlorodioxin
OCF	octachlorofuran
PAH	polycyclic aromatic hydrocarbon
PCB	polychlorinated biphenyl
PCDD/F	polychlorinated dibenzo-p-dioxin/dibenzofuran (dioxins and furans)
PeCDD/CDF	pentachlorodioxin/pentachlorofuran
PEL	probable effect level
PHC	petroleum hydrocarbon
PSQG	provincial sediment quality guideline
PWQO	provincial water quality objective
QA/QC	quality assurance/quality control
RPD	relative percent difference
SD	standard deviation
SEL	severe effect level
SSTL	Safe Sediment Target Level
TCDD/TCDF	tetrachlorodioxin/tetrachlorofuran
TEF	toxic equivalency factor
TEL	threshold effect level
TEQ	toxic equivalency unit
TKN	total Kjeldahl nitrogen
TOC	total organic carbon
TP	total phosphorus
WHO	World Health Organization
wt	weight

1 INTRODUCTION

Jackfish Bay (JFB) was designated as an Area of Concern (AOC) due to degraded water and sediment quality and environmental health which included impairment to benthic communities (Environment Canada 2014a). From 2003 to 2009 several sampling surveys were undertaken in order to define the general status of sediment contamination and/or to assess benthic recovery over time. In 2003 and 2008, 15 sites were sampled and information within and among 3 or 4 lines of evidence were integrated using the sediment decision-making framework to determine environmental risk (Milani and Grapentine 2007, 2009). These studies indicated that conditions in Moberly Bay (the western arm of Jackfish Bay) were indicative of a polluted environment, characterized by elevated sediment contaminant concentrations (PCBs, dioxins and furans), toxicity, and the absence of pollution sensitive benthos (Milani and Grapentine 2009). In Moberly Bay and south of Moberly Bay (known as the far-field area), benthic invertebrate communities were different from those of Great Lakes (GL) reference sites and toxicity (primarily reduced growth to the amphipod *Hyalella*) was evident. In 2006-2009, a separate benthic recovery study was conducted which involved multiyear assessment of benthic conditions at 5 co-located sites that were classified as having impaired benthic communities in order to determine yearly changes in zoobenthic and surficial sediment physicochemical conditions.

Information on environmental conditions in the Jackfish Bay AOC is provided in the Stage 1 and 2 RAP documents (Jackfish Bay RAP Team 1991, 1998). In 2011, JFB was formally recognized by the governments of Canada and Ontario as an AOC in recovery (EC and MOE 2014). As part of a long term monitoring plan of natural recovery, EC plans to monitor and evaluate conditions in the bay on a regular basis. In 2013, EC conducted the first post-management decision benthic study in the bay in support of the Great Lakes Action Plan. This study involved revisiting 12 test sites sampled previously in 2003 and/or 2008 and the addition of 3 new sites that allowed for improved sampling coverage in certain parts of the bay. Surficial sediment contaminant concentrations, toxicity, benthic invertebrate community composition and benthic invertebrate tissue PCDD/F residues were assessed and the degree to which these conditions differed from those of reference locations were determined using multivariate and univariate techniques. This report describes the current state of conditions in JFB from 2013 and

the temporal trends in benthic conditions from 2003 to 2013 or from 2006-2009. The objectives of the JFB studies were twofold:

1) To determine the current state of benthic conditions in the JFB AOC (2013), based on sediment contaminant concentrations, toxicity, benthic invertebrate community structure, and benthic invertebrate PCDD/F tissue residues; and
2) To determine if, and by how much, benthic conditions in the AOC were recovering from impairment, and to gain an understanding of the year-to-year variation in the structure of macroinvertebrate communities.

2 EXPERIMENTAL DESIGN

2.1 Sampling Design

The 2013 sampling design mostly repeated the array applied in 2008 by Milani and Grapentine (2009); 11 of the 15 sites sampled in 2008 were repeated and site 6956 (Tunnel Bay) sampled in 2003 was repeated (Table 1). To better characterize the spatial extent of contaminants in the far-field and far far-field areas of Jackfish Bay, 3 additional sites were added: EEM8B (Moberly Bay), 2M6 (far field) and 4M4 (far far-field) (Table 1). Six reference sites were also sampled in Lake Superior in 2013 to provide background levels of sediment contaminant concentrations and benthic community structure. Sampling site positions and depth are provided in Table 1 (2003-2013), and sampling locations in JFB are shown in Figure 1. This sampling design allowed for the analyses of both spatial patterns and temporal trends in benthic conditions.

2.2 Measurement Endpoints

At all sites, sediment was obtained from surficial 0 - 10 cm layer of lake bed for: (a) chemical and physical analyses, (b) benthic invertebrates for analysis of community structure, and (c) laboratory whole sediment toxicity tests. At a subset of 7 sites, benthic invertebrates were also collected for measurements of dioxins and furans (PCDD/Fs) and dioxin-like PCB concentrations in their tissues.

Benthic invertebrate community structure (taxonomic composition and abundance) was described based on family-level identifications of macroinvertebrates. Sediment toxicity was quantified based on acute and chronic responses of four invertebrate taxa (10 endpoints in total) in laboratory tests. For the assessment of PCDD/F bioaccumulation, numerically dominant invertebrate taxa were targeted for collection from each location. Amphipods, chironomids and oligochaetes were collected from all sites. In addition, isopods were collected at 3 sites and leeches from 1 site. Analyses of PCDD/Fs was performed on samples composited from organisms within each taxon (i.e., taxa were analyzed separately) without gut clearing.

3 METHODS

3.1 Sample Collection and Handling

In September 2013, 15 sites were sampled within the Jackfish Bay AOC according to sample collection and handling procedures described in Milani and Grapentine (2007, 2009, 2013). Overlying water samples (0.5 m above the bottom) were collected for determining nutrients and buffering capacity (alkalinity). Surficial sediment samples (0-10 cm) were collected for analysis of physicochemical properties, sediment toxicity testing and benthic macroinvertebrate community structure. At 7 of the 15 sites, resident invertebrate tissue was collected for the analysis of PCDD/F and dl-PCBs. In 2006-09, samples were collected at 5 co-located sites to assess benthic community recovery trends (sediment samples were not collected for toxicity tests or tissue analysis purposes).

Sites were positioned using a CD-GPS or WAAS-enabled GPS receiver and an attempt made to sample as close as possible to previous locations, although this proved difficult in the more open areas of Moberly Bay and JFB. The 2013 site positions are provided in Table 1 and all sampling locations from 2003-2013 are shown in Figure 1.

3.2 Sample Analysis

The list of analytes measured in each environmental matrix is provided in Table 2. Analyses of overlying water alkalinity, total phosphorus (TP), nitrates/nitrites-N, ammonia-N and total Kjeldahl nitrogen (TKN) were performed using procedures outlined in Environment Canada (2013). Sediments (freeze dried) were analyzed by Caduceon Environmental Laboratories

(Ottawa, Ontario) for total mercury by cold-vapor atomic absorption (EPA method 7471A); trace metals (hot aqua regia extracted) by ICP-AES (Inductively Coupled Plasma-Atomic Emission Spectroscopy) (EPA method 6010) or by ICP-MS (Mass Spectrometry) (EPA method 6020) (USEPA 2010a); whole rock (major oxides) by lithium borate fusion followed by ICP-AES (SOP D-ICP-02); total carbon by loss on ignition @ 1000°C; total organic carbon (TOC) by combustion method using a Leco carbon analyzer; total phosphorus by automated colorimetry (EPA method 365.4) (USEPA 1983); and total Kjeldahl nitrogen by semiautomated colorimetry (EPA method 351.2) (USEPA 1993). Sediments were also analyzed for dioxins and furans (PCDD/Fs), PCBs (dioxin-like and total), petroleum hydrocarbons (PHCs), oil and grease and polycyclic aromatic hydrocarbons (PAHs) by ALS Laboratory Group (Burlington and Waterloo, ON) (2008-2013 samples) and Maxxam Analytics (Mississauga, ON) (2006-2007 samples). Benthic invertebrate tissue samples were analyzed for PCDD/Fs and dl-PCBs by ALS Environmental (Burlington, ON). PCDD/Fs and dl-PCB analyses were performed by high resolution mass spectrometry (HRMS) (EPA methods 1613B and 1668C, respectively) (USEPA 1994a; 2010b). PHCs were analyzed by GC/FIC based on CCME Canada-Wide Standards (CCME 2008). Total oil and grease was determined by the partition-gravimetric method (standard method 5520B) - samples were extracted with an acetone:hexane mixture and the extract was then evaporated and residue weighed to determine total oil and grease (APHA 2005). PAHs (18 parent compounds) were analysed by GC/MS (Method SW846 3510/8270) (USEPA 1996; 2007). Particle sizes of sediment samples were determined by EC's Sedimentology Laboratory (Burlington, Ontario) for 2006-2009 samples and by EC's laboratory for Environmental testing (Edmonton, Alberta) for the 2013 samples. The 2006-2009 samples were analyzed using sieving apparatus and a Sedigraph analyzer. A sodium metaphosphate solution was added to 5-10 g of freeze dried sediment sample, mixed for 15 minutes, and poured through a 4.0 Phi sieve (62.5 µm). The material retained on the sieve (sand and gravel) was dried and weighed. If the weight was more than 10% of the sample, the material was sieved using sieve stack procedures described in Duncan and LaHaie (1979). For the 2013 samples, percents gravel, sand, silt and clay were determined using sieving apparatus and a Horiba Partica Laser Diffraction Particle Size Analyzer (LA-950). Samples were sieved and then soaked in a hydrogen peroxide solution, dried in the oven overnight, and then soaked in a sodium metaphosphate before entering the Horiba laser analyzer. The solution that passed through the

sieve (silt and clay) was analyzed using the laser analyzer and the computer software programs Merge (Frazer 1990) and Sedi Web Page Gorrie (2008) to convert the light scattering to particle size. Note: the Sedigraph analyser measures the sedimentation rates of different size particles (gravity induced) suspended in a liquid with known properties and therefore would not be directly comparable to the laser analyzer.

3.3 Taxonomic Identification

The sorting, identification, verification and enumeration of benthic invertebrate samples was performed by the following: 2013 samples by Craig Logan Consultants (Troy, Ontario); 2009 samples by EcoAnalysts, Inc. (Moscow, Idaho, USA), and; 2006-2008 samples by Environmental Services and Consulting, Inc. (Blacksburg, VA, USA). Laboratory processing of samples followed the Canadian Aquatic Biomonitoring Network (CABIN) protocols (Environment Canada 2014b). Certain taxa and microinvertebrates (e.g., poriferans, nematodes, copepods, and cladocerans) were excluded. Material was sorted under a dissecting microscope (minimum magnification = 10×), and organisms were enumerated and placed in separate vials by family for identification and verification to lowest practical level by taxonomists certified by the Society of Freshwater Science Taxonomic Certification Program (www.sfstcp.com).

3.4 Whole Sediment Toxicity Tests

Sediments were initially sieved through a 250-µm mesh sieve prior to testing to eliminate native organisms which have been shown to interfere with toxicity responses (Reynoldson et al. 1994). For each replicate treatment, 600 mL of sediment was wet sieved with 2 L of carbon filtered, aerated and dechlorinated City of Burlington (Ontario) tap water (water characteristics (means): conductivity 312 µS/cm; pH 8.2; hardness 127 mg/L; alkalinity 84 mg/L; chloride ion 26 mg/L). Sediment was allowed to settle for a minimum of 24 hours and water decanted; decanted water was saved and used as the overlying water in the toxicity tests.

Four sediment toxicity tests were conducted: the amphipod, *Hyalella azteca* 28-day survival and growth test; the chironomid, *Chironomus riparius* 10-day survival and growth test; the oligochaete worm, *Tubifex tubifex* 28-day reproduction test; and the mayfly, *Hexagenia* spp. 21-day survival and growth test. Tests were conducted in 250-mL beakers containing 50-100 mL of sediment and 125-150 mL of overlying water, with the exception of the mayfly test, which were

conducted in 1-L jars with 125 mL of sediment and 650 mL of overlying water. Tests were aerated for 7 to 10 days prior to the introduction of test organisms. All tests were run under static conditions in environmental chambers at 23°C ±1°C, under a photoperiod of 16:8-hour light:dark and an illumination of approximately 500 lux, with the exception of the *T. tubifex* test which was run in the dark. Temperature, conductivity, pH, dissolved oxygen and total ammonia (ionized and un-ionized) were measured in the overlying water at the beginning and end of tests. Tests were initiated with the random addition of 15 organisms per beaker for *H. azteca* (juveniles 3-10 days old) and *C. riparius* (1st instar), 10 organisms per jar for *Hexagenia* spp. (5-10 mg wet weight, weighed prior to addition to jar), and 4 organisms (sexually mature adults) per beaker for *T. tubifex*. Feeding was as follows: *H. azteca* and *C. riparius* beakers received 8 mg crushed Nutrafin® fish food flakes twice per week over the course of the exposure period; *Hexagenia* jars received 50 mg mixture of crushed Nutrafin® fish flakes, cereal grass and brewer's yeast once per week, and; *T. tubifex* beakers received 80 mg crushed Nutrafin® fish flakes mixed directly into the sediment prior to the introduction of worms. Tests were terminated after 10 and 21 days for *C. riparius* and *Hexagenia* spp., respectively, and 28 days for both *H azteca* and *T. tubifex*. At test termination, sediment was passed through a 250-µm screen for *C. riparius* and *H. azteca*, 500-µm screen for *Hexagenia* and through a 500-µm and 250-µm sieve sequentially for *T. tubifex* to collect large worms and cocoons (500 µm) and small worms (250 µm). Amphipods, chironomids and mayflies were dried at 60°C to a constant weight. Test endpoints included percent survival and growth (increase in mg dry weight per individual) for *H. azteca*, C. *riparius* and *Hexagenia*. Initial weights of *H. azteca* and *C. riparius* were considered negligible. Initial mayfly wet weight was predicted to dry weight using a statistical model derived specifically for mayflies and growth was estimated as the difference between the initial and final dry weight. Test endpoints for *T. tubifex* included adult survival and reproduction, which was assessed with three endpoints: total number of cocoons produced per adult, percent of cocoons that hatched, and total number of young produced per adult.

3.5 Data Analysis

3.5.1 Sediment chemistry

A. Contaminant concentrations in 2013

Concentrations of the individual chemical variables measured in the sediments were compared to the Canadian Sediment Quality Guideline (SQG) Threshold Effect Level (TEL) and Probable Effect Level (PEL) (CCME 2001a) or, if there was no TEL/PEL available, to the Provincial SQG Lowest Effect Level (LEL) and Severe Effect Level (SEL) (Fletcher et al. 2008). The low guidelines define the concentration below which adverse biological effects are expected to occur rarely or which no effect on the majority of the sediment-dwelling organisms is expected. The high guidelines are levels above which are frequently associated with adverse effects on the health of benthic organisms or with adverse effects on the majority of benthic dwelling organisms. Between the low and high guideline represents the range where effects may occasionally occur (CCME 2001a). Sites in which contaminants in sediment were significantly elevated above those at GL reference locations were also identified by comparing test site concentrations to the range in concentrations observed at the reference sites.

PCDD/F concentrations in sediment were expressed in dry weight (pg/g or ng/kg) and in toxic equivalents (TEQs). The TEQ was calculated using the following equation:

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

Each of the 7 dioxin and 10 furan congener concentrations as well as the 12 dl-PCB congener concentrations were multiplied by its respective TEF (toxic equivalency factor to 2,3,7,8- TCDD) and all products were summed to give the TEQ value. The World Health Organization (WHO) fish TEFs were used in the calculation (Van den Berg et al. 1998). For values that were below method detection limit (MDL) the TEQs were calculated by: 1) assigning a value of zero to the non-detected values (lower bound TEQ); 2) assigning the MDL for non-detected values (upper bound TEQ); and 3) assigning half the MDL to non-detected values (mid-point TEQ). The TEQ was compared to the CCME PEL for dioxins/furans of 21.5 ng TEQ/kg (CCME 2001a).

B. Trends in contaminant concentrations from 2003 to 2013

Comparisons of the concentrations of PCDD/F TEQs, PAHs, PHCs, metals (As, Cd, Co, Cu, Cr, Fe, Mn, Ni, Pb, Zn), as well as sediment nutrients (TOC, TP, TKN) were made by graphical assessments of time series data, showing concentrations from 2003 through to 2013 along with the range in concentrations for Lake Superior reference sites collected from 2006-2013 (n=52).

3.5.2 PCDD/F and dl-PCB distribution in biota

A. Tissue contaminant concentrations in 2013

Sites in which concentrations of PCDD/Fs in benthic invertebrates were significantly elevated above reference levels were identified by comparing concentrations at JFB test sites to the 99th percentile value (~maximum) for Lake Superior reference sites. PCDD/F and dl-PCB concentrations in invertebrates were also expressed as toxic equivalents (TEQs) as described above for sediments but using the WHO avian TEFs (Van den Berg et al. 1998). The TEQ was compared to a modified avian Tissue Residue Guideline (TRG) of 7.3 ng TEQ/kg ww for PCDD/Fs and 3.8 ng TEQ/kg ww for dl-PCBs. These TRGs were calculated using the food ingestion to body weight ratio (FI: bw) of the common tern (0.61) (CCME 1999). The avian TRGs for PCDD/Fs and dl-PCBs of 4.75 ng TEQ/kg ww and 2.4 ng TEQ/kg ww, respectively, (CCME 2001b, c), were not used as this value is based on the FI: BW of the Wilson's storm-petrel, a seabird not found in JFB. An avian TRG was used since an avian receptor (e.g., diving duck) could feed directly on benthic invertebrates. The mammalian TRGs for PCDD/F and dl-PCBs (0.71 and 0.79 ng TEQ·kg^{-1} diet ww), while lower, were not used in this case as there would not likely be a direct feeding relationship between benthic invertebrates and a mammalian receptor for Jackfish Bay.

The bioavailability of PCDD/F and dl-PCBs was quantified through the calculation of biota-sediment accumulation factors (BSAFs). The BSAF was defined as:

$$BSAF = (C_o/f_l) / (C_s/f_{toc})$$

where C_o = the congener concentration in the organism, f_l is the lipid fraction in the organism, C_s is congener concentration in the sediment, and f_{toc} is the fraction of total organic carbon in the sediment. The BSAFs assume that the concentration of contaminant in the organism is a linear function of the contaminant concentration in the sediment. The BSAFs were calculated with co-detected tissue and sediment congeners which included 6-11 PCDD/F congeners and 6-8 dl-PCB congeners for the 2013 samples. Lipid values used in the calculations were from two previous field studies where lipids were analyzed in tissue samples; these were 5.74%, 8.59%, and 15.86% for amphipods, chironomids, and oligochaetes, respectively.

B. Trends in tissue contaminant concentrations from 2008 to 2013

Trends in invertebrate tissue contaminant concentrations, expressed as TEQs were examined for two sampling periods. Comparison of the PCDD/F TEQs were made by graphical assessments of time series data, showing tissue concentrations in 2008 and 2013 (tissue was not collected in 2003). Trends were examined for each invertebrate taxon collected. This was not done for dl-PCBs as there are no data prior to 2013.

3.5.3 Benthic invertebrate community structure

A. Conditions in 2013

Benthic communities from the 15 Jackfish Bay sites sampled in 2013 were assessed by comparison to site-specific reference conditions. Each Jackfish Bay site was matched to a subset of sites selected from 91 sites in Lakes Superior and Huron that were sampled once from 2006 to 2012. The number of reference sites used in the assessments varied from site to site, and ranged from 42-57. Reference sites were selected to be similar to the test site in terms of habitat variables that account for variation in benthic community structure. The procedure is described in App. A, but in brief involved:

- Ordinating all the reference site benthos data (log[x+1]-transformed macroinvertebrate family counts) by nonmetric multidimensional scaling (NMDS) applied to a Bray-Curtis distance matrix;
- Developing multiple linear regression (MLR) models relating reference site habitat variables and benthic community descriptors (NMDS axes);
- Predicting the expected range of NMDS axis values (in the absence of any stressor disturbance) for each individual test site using the test site habitat conditions and the MLR models; and
- Selecting reference sites whose NMDS axis values lie within the prediction intervals.

The benthos data for each Jackfish Bay test site and its reference sites were then ordinated again. The test site score was compared to 90% and 99% probability ellipses for the reference site scores. These ellipses indicate three categories of difference from reference:

- not different from reference ($p > 0.10$),
- different from reference ($0.10 \geq p > 0.01$) and
- very different from reference ($p \leq 0.01$).

NMDS was performed using PC-ORD (McCune and Mefford, 2011). Probability ellipses were constructed using Systat (Systat Software Inc. 2007).

Univariate analyses were also conducted on a series of additional benthic community descriptors: total benthos, family richness, Pielou's evenness, and densities of 7 dominant taxa. For each descriptor, the value for each Jackfish Bay community in 2013 was compared to the 5th and 95th percentile interval and the range (i.e., minimum to maximum) for the site-specific reference data.

Three categories of difference from reference were defined:

- not different from reference ($p > 0.10$) for within the 5th – 95th percentile interval,
- different from reference ($0.10 \geq p > \sim 0.02$) for outside the 5th – 95th percentile interval, and
- very different from reference ($p < \sim 0.02$) for outside the range.

The estimated p-value for being outside the reference range depended on the number of reference sites in the subset (range of 42 to 57 reference sites).

B. Trends in conditions from 2003 to 2013

Benthic communities at 5 Jackfish Bay sites (1M1, 1M2, 1M3, 2M1, M701) sampled 5-6 times during 2006-2009 were compared to 27 reference sites mostly sampled 3 times during 1998-2009. These references sites were selected from 61 sites in Lake Superior and the North Channel as the most similar in overall habitat conditions (defined by 20 variables) to 20 AOC sites from Nipigon Bay, Jackfish Bay, Spanish Harbour and St. Marys River AOCs (5 per each). This set of reference sites is better than the subsets used in the analyses of 2013 conditions for assessing temporal trends in the Jackfish Bay because they were contemporaneously sampled with the AOC sites yearly during 2006-2009.

As in the analyses of 2013 benthos condition, temporal variability of the Jackfish Bay sites was determined in terms of ordination scores and the additional community descriptors. For the whole community analyses, the 20 Jackfish Bay benthos samples (from 5 sites each sampled annually in 2006-2009) were compared to 52 samples from the 27 benthic recovery reference sites (sampled 2 times 2006-2009, except 2 sites sampled once). The reference data were ordinated by NMDS (log[x+1]-transformed family densities, Bray-Curtis distance matrix). The

Jackfish Bay samples were then fitted into the NMDS space using the "NMS Scores" procedure of PC-ORD. In this procedure scores along the reference NMDS axes for each Jackfish Bay sample are calculated independent of the other Jackfish Bay samples, and the fitting of 20 new samples into the NMDS space does not alter the scores for the 52 reference samples. The Jackfish Bay sample scores were then compared to 90% and 99% probability ellipses constructed for the reference sample scores to determine the difference-from-reference status.

The additional community descriptors for the Jackfish Bay and reference sites were plotted in time series to show comparative temporal variation. Statistical comparisons between Jackfish Bay and reference site conditions were made for 3 time periods: < 2004, 2006-7, and 2008-9. For each of these periods, 5th – 95th percentile intervals for reference samples were calculated and plotted with Jackfish Bay samples. Samples outside of the intervals differed from reference conditions at $p < 0.1$. Reference sample numbers were insufficient for testing for $p < 0.01$ differences.

3.5.4 Sediment toxicity

A. Toxicity conditions in 2013

Data analysis to assess sediment toxicity were made by comparisons of JFB sites to 66 GL reference sites using NMDS applied to relative Euclidean distance site × site distance matrix. NMDS was first run using the GL reference data. Dimensionality was determined by the stress value (stress >25 are rejected) and whether the stress value fell within the range of randomized runs for the dimension accompanied by a randomization test ($p>0.05$ are rejected) (Peck 2010). The JFB data were then fitted into the ordination space constructed with the GL reference sites and for each site (one at a time), the best fit (lowest stress) position was determined on each of the existing (calibration) axes. Stress was calculated, and once the lowest stress position was determined, it became the ordination score for the site. To evaluate how the toxicological responses influenced the resulting pattern, the endpoints were overlain into the ordinations space and correlation coefficients determined between axes scores and each endpoint response. The relationship between habitat variables (inorganic contaminants, nutrients, particle size) and ordination axes scores were also examined by regression analysis. Ordination site scores were then assessed by graphical comparison to confidence bands for the 66 GL reference site scores (Reynoldson et al. 2000, 2002). Three probability ellipses (90%, 99%, 99.9%) were constructed

around the 66 GL reference site scores, establishing four toxicity bands: Band 1 (within the 90% probability ellipse) = non-toxic; Band 2 (between the 90 and 99% ellipses) = potentially toxic; Band 3 (between the 99 and 99.9% ellipses) = toxic; and Band 4 (outside the 99.9% ellipse) = severely toxic. To examine potential influence of organic contaminants (e.g., PHCs, PCDD/Fs and dl-PCBs) on toxicity, toxicity-contaminant relationships were assessed using simple linear regression analysis (ordinary least squares method). NMDS was performed using PC-ORD (McCune and Mefford 2011) and probability ellipses constructed with SYSTAT (Systat Software Inc. 2007). Simple linear regression analysis (ordinary least squares method) was performed in MINITAB (Minitab Inc. 2007).

B. Trends in toxicity conditions from 2003 to 2013

Individual toxicity endpoints were plotted in time series to examine conditions over time. The key feature of the representations is the change through time in how the Jackfish Bay sites compared to the mean and variation (2 standard deviations (SD)) from the mean for the GL reference sites.

3.6 Quality Assurance/Quality Control

In each sampling survey, 1 in every 10 sites was randomly selected as a QA/QC station, where triplicate overlying water, sediment and benthic invertebrate community samples were collected for determination of within-site and among-sample variability. Three unique field replicate samples were collected during the sampling phase of the program and treated as separate samples throughout the rest of the sample preparation and analysis phases. The variation among the field-replicated analytical data was examined using the coefficient of variation (CV) which is the ratio between the SD and the mean multiplied by 100.

Laboratory analysis

Quality control procedures for the analytical work included the analysis of method blanks, matrix spikes, surrogate spikes, certified reference material (CRM), laboratory control samples (LCS), laboratory standards, and sample duplicates, which were used in each analytical run (generally every 1 in 10 or 20 samples). Calibration standards were run before and after each run. The precision of sample duplicates was evaluated using the relative percent difference (RPD),

defined as RPD = $(\times_1 - \times_2)/ ((\times_1 + \times_2)/2) \times 100$. An acceptable range of values for the quality control results is indicated for each analyte by laboratories conducting the analysis.

Taxonomy

For the benthic invertebrate identification and enumeration performed by Craig Logan Consultants and Environmental Services and Consulting, Inc., 10% of samples were re-sorted and checked by a different sorter than the original. For identification and enumeration performed by EcoAnalysts, Inc., 20-25% of every sample was resorted and checked by a different sorter. If a 95% level sorting efficiency was not achieved, the sample was resorted until a minimum of 95% was achieved. At least one specimen of each taxon encountered was kept in a separate vial to comprise a project reference collection. Internal quality assurance of the identifications involved examination of the reference collection by a second taxonomist to verify accuracy of all taxa identified. Additionally, 10% of samples were randomly selected and re-identified by a QA taxonomist and identification errors (IEs) recorded. If the IE was > 5%, then corrective measures were implemented according to CABIN protocols (Environment Canada 2014b). Data entry involved visual confirmations of the taxonomic identification and number of specimens in each taxon. Benthic data was entered directly or bulk uploaded on the CABIN database.

Toxicity tests

For toxicity tests, bias was assessed through the use of control sediment, which contained only background quantities of the analytes of interest. This control sediment was collected from Long Point Marsh, Lake Erie (42°35.213′ N, 80°27.130′ W) and was included in each test set. An organism's response from the control sediment was used to establish test validity; data that were within the bias window, i.e., mean plus or minus 2 SDs and percent survival greater than a set limit established for Long Point sediment, were carried forward for data analysis. Warning charts were constructed for each of the chronic responses using a minimum of seven points. Tests that did not pass set criteria were repeated.

4 RESULTS AND DISCUSSION

4.1 Quality Assurance/Quality Control

Sample site variability

Among-site variability in a measured analyte can be broken down into three sources: natural within-site heterogeneity in the distribution of the analyte in sediment or water, differences in handling among samples, and laboratory measurement error. Among-site variability indicates the overall error associated with conditions at a site based on a single sample. In 2013, triplicate field sediment samples were collected at sites NF5 (NF500, NF501, and NF502) and 1M4 (1M400, 1M401, 1M402) in 2013. At these sites, 3 unique field replicate samples were collected during the sampling phase of the program and treated as separate samples throughout the rest of the sample preparation and analysis phases. The individual sets of samples are used to assess the overall (laboratory plus field) accuracy. Variability in field-replicate sample measurements, expressed as the coefficient of variation (CV), is provided in App. B, Tables B1-B4. Where analytes were not detected in the sediments, the CVs were not calculable. For trace metals, metal oxides and nutrients, variability was quite low with CVs ranging from 0 to 57.7% (median: 6.3%); most samples (93%) had CVs < 20%, which was very good for field replicated samples (App. B, Table B1). Variability was higher for the organic contaminants. The CVs ranged from 0.6 to 52.3% (median: 20.9%) for PCDD/Fs (App. B, Table B2) and from 16.9 to 63.7% (median: 26.9%) for the dl-PCBs (App. B, Table B3). The CVs for petroleum hydrocarbons (F1-F4) ranged from 5.9-47.8% (median: 28.5%) and for PAHs ranged from 1.1-63.3% (median: 26.3%) (App. B, Table B4). Typically higher CVs are seen where analytes are present in low concentrations and significant variability can exist in the field which may make interpretation of the results of the field replicates difficult (USEPA 1994b). Generally, a failure to meet the measurement quality objectives for the field replicates would result in only a minor concern, indicating the existence of minor uncertainty in the data (assuming that the laboratory replicates show no major problem with analytical variability) (USEPA 1994b). Such concerns should not be used in isolation to disqualify data from the sample or sample batch (Papp et al. 1989). While there were differences in variability were seen among the various parameters, overall results indicated relatively consistent results between box cores taken from the same site and low within-site variability (samples were taken from three separate drops of the box core).

Laboratory duplicates

Analytical precision was measured by analyzing subsamples in duplicate (intralaboratory split samples). For trace metals, metal oxides and nutrients, a relative percent difference (RPD), < 20% indicated that the measurements were within precision standards. Sample duplicates showed good agreement, with the RPD for metals and nutrients ranging from 0 to 140% (median: 3.5%); only 2 analytes had RPDs above 20% - chromium dioxide and silver, which were quite low in concentration (App. B, Table B5). The RPDs for PCDD/Fs ranged from 1.1 to 24.2% (median: 10.3%) and for dl-PCBs they ranged from 5.6 to 36.2% (median: 16.5%) (App. B, Table B6). About half the PCDD/Fs results were below detection limits; therefore, the RPD was not calculable. For petroleum hydrocarbons (F2-F4), PAHs, and PCB aroclors, the RPDs were quite low, ranging from 0 to 19% (median: 3.8%) (App. B, Table B7). Overall, these results indicated generally good agreement between sample duplicates and that a high level of precision achieved for sample measurements.

Laboratory control samples

Laboratory control samples (LCS) have known analytes and concentrations and are used to quantify the variance and bias of the chemical preparation and instrumental testing stages without matrix interference. Percent recoveries of target analytes in the LCS were compared to established control limits and indicated whether the laboratory was capable of making accurate and precise measurements at the required reporting limit. The LCS recoveries are provided in App. B, Tables B8-B14. Recoveries were 101-110% for F2-F4 petroleum hydrocarbons (Table B8), 83-116% for PAHs (Table B9) and 89-107% for PCB aroclors (Table B10); all recoveries were within control limits. For sediment samples, the LCS recoveries for PCDD/Fs and dl-PCBs were very good, ranging from 96 to 111% and from 95 to 118%, respectively (Tables B11-B12). For tissue samples, the LCS recoveries for PCDD/F and dl-PCBs were also very good, ranging from 87 to 107% for PCDD/Fs (Table B13) and from 103 to 119% for dl-PCBs (Table B14).

Method blanks

A method blank (MB) is an analyte-free matrix that was subjected to the same preparation and analytical procedure as other samples and is used to document contamination resulting from the analytical process. The MBs were included with the analysis of every organic contaminant

sample preparation batch and results should generally be below the reporting limit (RL) for most analytes being tested. Results for MBs are provided in App. B, Tables B8, B10-B15). The MBs were all below RLs with the exception of OCDD (Table B11) and PCB 77 (Table B12); however, MBs specifically with PCB congeners detected is almost unavoidable (Ron McLeod pers. Comm.).

Matrix spikes

A matrix spike sample is used to assess the efficiency of the extraction technique and as a form of accuracy testing (USEPA 1994b). An aliquot of sample is spiked with a known concentration of target analyte(s) prior to sample preparation and analysis. Matrix spiked samples are used to quantify the variance and bias of the chemical preparation and testing stages with matrix interference. Matrix spike recoveries ranged from: 102 to 144% for sediment petroleum hydrocarbons (App. B, Table B8); 86 to 110% for PAHs (Table B10); and 91 to 110% for PCB aroclors (Table B10). All matrix spike recoveries were well within the QC limits.

Reference material

Reference materials/standards are analyzed to assess the bias of measurements being made at the analytical laboratory. Reference materials commonly used include CRMs (certified reference materials) and SRMs (standard reference materials). Bias is determined by comparing the analytical results to the known value of the reference material, plus or minus an established acceptance range either provided with the reference material or agreed upon as part of the data quality objective process. For example for the USEPA ARCS Program, the accuracy requirement for bias in either SRMs or CRMs is that the measured value must be within +/-20 percent of the known concentration (USEPA 1994b). For the trace metals and nutrients analysis, four RMs were processed and analyzed with each batch of samples. Recoveries ranged from 80 to 125% (median: 97%) (App. B, Table B16); all values were within the QC limits specified for each parameter.

Surrogate spikes

Surrogate spikes are compounds that are spiked into blanks, standards, reference materials, routine samples, and matrix spike samples prior to extraction and are used to assess the

efficiency of the extraction technique and as a form of accuracy testing, but without the confounding influence of the analyte of interest already present in the sample. A surrogate spike is an added organic compound that is similar to the analytes of interest in chemical composition, extraction, and chromatography, but that is not normally found in the environmental sample. Acceptable surrogate spike recoveries were set at 100 +/- 30 percent (USEPA 1994b). Surrogate spikes were run for volatile organic compounds such as BTEX (2-Bromobenzotrifluoride) and F1 hydrocarbons (2-Fluorobiphenyl), F2-F4 petroleum hydrocarbons (3,4-Dichlorotoluene), and PAHs (d14-Terphenyl). Recoveries ranged from 71 to 117% (median 99.6%) (App. B, Table B17) and were all within acceptable QC limits. These high recoveries indicate a good ability of the laboratory to analyse these organic compounds.

Extraction standards

All PCDD/F and dl-PCB samples (sediment and tissue) were spiked with a known amount of a series of ^{13}C-labelled standards prior to extraction to ensure that the analytes of interest could be recovered. These extraction standards are used as internal standards for calculation of the target analyte data. These standards are added prior to extraction/clean-up and these isotopically labeled compounds behave chemically and physically essentially identical to the non-labeled targets inherent in the samples; therefore, losses of target analyte during extraction and clean-up are reflected with the same % losses in the extraction standards (Ron McLeod, pers. comm.).

For sediment samples, recoveries for the labelled PCDD/F extraction standards ranged from 59 to 126% (median: 86%) (App. B, Table B11). Recoveries for the ^{13}C-labelled dl-PCB extractions standard were slightly lower, ranging from 56 to 93% (median: 74%) (App. B, Table B12). There is likely little compromise to the actual data as the low recoveries were for dl-PCBs, which contributed very little to the TEQ.

For tissue samples, the recoveries were lower, ranging from 40 to 137% (median: 87%) for PCDD/Fs and from 39 to 75% (median: 52%) for dl-PCBs (App. B, Tables B13 and B14). The target analyte data are automatically recovery corrected for losses during sample processing. As long as the C-13 labeled internal standards are at quantifiable levels, extraction standard recoveries (high or low) have no impact on the accuracy or the precision of the data (Ron McLeod, pers. comm.).

Benthic invertebrate community composition

Sorting efficiencies for 2013 samples are provided in App. B, Table B18. Ten samples and were randomly selected for QC purposes. The overall average sorting efficiency was 99.7%, with only one organism missed in one sample (App. B, Table B15). These efficiencies well exceeded the acceptable level (≥95%), indicating that a good representation of the benthic community was achieved.

The taxonomic IEs for each set of samples are reported in App. B, Table B19. The mean sample IEs was 0.35% for the 2013 samples, meeting CABIN quality objectives of <5%. Errors included misidentifying one immature Tubificinae, and incorrectly recording a Tubificinae identification on a bench sheet. After mutual agreement between taxonomist and auditor, corrective actions were taken for these samples, and all other samples rechecked for accuracy. The data reported herein contains all taxa and abundances for every sample after all re-identifications were done.

Toxicity tests

Toxicity tests had to pass set criteria or quality objectives (QOs) for each organism before they were used in data analysis. While all tests passed QOs, a *Hyalella* test that exhibited high variation between replicates was nonetheless repeated for verification (App. B, Table B20). The rerun test showed similar results to the original test, thus both tests were concluded as being valid and the averages for the two test was carried forward in the data analysis.

4.2 Overlying Water Characteristics

Conditions of overlying water 0.5 m above the sediment were similar across JFB sites outside of Moberly Bay suggesting homogeneity in water mass across these sampling sites. Outside of Moberly Bay, the average differences across sites were 1.1 mg/L for alkalinity, 11 µS/cm for conductivity, 5.4 mg/L for dissolved oxygen, 0.05 mg/L for NO_3/NO_2, 0.005 mg/L for NH_3, 0.2 for pH, 8.6°C for temperature, 0.06 mg/L for TKN, and 0.025 µg/L for total P. The fairly large difference in temperature across sites was due to far far-field site 4M3, which was a lot deeper (61.4 m) compared to the other sites collected in 2013 (≤ 37.5 m) (Table 1). Conditions at these JFB sites were also similar to those at Lake Superior reference sites collected in 2013 (n=6), with overlapping ranges for the most part (Table 3).

The Moberly Bay sites had higher alkalinity, conductivity, NO_3/NO_2, TKN and total P compared to other sites in JFB (Table 3) and these variables were outside of the range observed at the Lake Superior reference sites (Table 3). Total P (range: 11 to 56 µg/L) was elevated above the interim Provincial Water Quality Objective of 20 µg/L at 5 of the 8 Moberly Bay sites which was similar to that found in 2003 and 2008 (Milani and Grapentine 2007, 2009).

Trends in JFB overlying water conditions from 2003 to 2013 are shown in Figs. 2a and 2b. The solid green lines represent the range in values for Lake Superior reference sites (n=52) sampled from 2006-2013. Dissolved oxygen was mostly ≥ 6.9 mg/L across sampling years but lower levels were observed in 2003; a few JFB sites were below the lower range for Lake Superior reference sites but values were nonetheless above provincial water quality objective (PWQO) bottom values of 4 or 5 mg/L for cold or warm water biota, respectively from 2006 on (Fig. 2a). The pH for JFB sites was fairly stable and was neutral to alkaline throughout the sampling period (7.0-8.4); pH was mostly within the range for Lake Superior reference sites (7.1-8.4). Alkalinity was mostly stable across sampling periods; some increases occurred in 2006-2008 at some sites which by 2009 decreased to within the range for Lake Superior reference sites, indicating fairly similar buffering capacities between the AOC and other parts of Lake Superior. Total P showed similar concentrations across years, except for site M701 in 2006, where there was an upward spike (Fig. 2b); [TP] was back down in 2007 to within the range observed at most other sites and remained relatively stable to 2013. Total P at about half the JFB sites was consistently above the PWQO of 20 µg/L (lakes) to prevent the growth of nuisance algae throughout the sampling period although only 2-4 sites were above the upper range value for reference sites (0.03 mg/L) in any given year (Fig. 2b). TKN was generally stable across years except perhaps for site 1M1 in 2013, which spiked upwards from 2009 to above the upper range value of the reference sites (Fig. 2b). Nitrate + nitrite levels were stable across years from 2003 or 2006 on (Fig. 2b); some JFB sites (mostly Moberly Bay) were elevated above the maximum reference site concentration in 2008 and 2013 specifically while total ammonia showed some upward and downward spikes at a few JBG sites (in Moberly Bay) while remaining sites were quite stable from 2003-2013 (Fig. 2b).

4.3 Sediment Chemical Properties

4.3.1 Sediment nutrients

In 2013, sediment nutrients such as TOC, TKN and TP were elevated above their Provincial Sediment Quality Guidelines (PSQG) Lowest Effect Level (LEL) (1% TOC, 550 µg/g TKN and 600 µg/g TP) (Fletcher et al. 2008) at all sites except one in far far-field area (4M4) (Table 4). TOC was highest in Moberly Bay (4.8-10.1%), followed by the far-field (3.2-3.8%), Tunnel Bay (2.5-2.8%) and far far-field (0.3-1.2%) areas (Table 4). TKN followed a similar pattern with highest levels in Moberly Bay (≤ 3,650 µg/g) followed by far-field (≤ 2,920 µg/g), Tunnel Bay (≤ 2,290 µg/g), and far far-field (≤ 933 µg/g) while TP was highest in Tunnel Bay (≤ 1,350 µg/g), followed by far-field (≤ 1,140 µg/g), Moberly Bay (≤ 981 µg/g) and far far-field (≤ 731 µg/g) (Table 4). Exceedences of the Severe Effect Level (SEL) were limited to TOC at one site in Moberly Bay which marginally exceeded (Table 4). Nutrients were generally elevated in JFB compared to reference sites; concentrations of TOC, TKN and TP at reference sites collected from Lake Superior in 2013 (n=5) were ≤ 2.4%, ≤ 1,707 µg/g and ≤ 830 µg/g, respectively (Environment Canada, unpublished) (App. C, Table C1).

Trends in the 3 sediment nutrients from 2003 to 2013 are shown in Fig. 3. Concentrations of nutrients were consistently between the LEL and SEL across years with a few exceptions. One site in Moberly Bay was above the SEL for TOC in 2006 and 2013, and sites in the far-field area were above the SEL for TP in 2003, after which levels were below the SEL from 2006 on (Fig. 3). Sites in Moberly Bay and in the far-field area (south of Moberly Bay) were elevated in TOC compared to Lake Superior reference sites by up to 3.6 times (in 2006 and 2013). Sites elevated above the reference maximum for TKN were mostly restricted to Moberly Bay with concentrations up to 1.4 times greater. Site M701 was the most variable, with levels of TOC (and TKN) showing the most fluctuation throughout the period. Total P remained stable with a few sites in the far-field just marginally above the reference maximum in 2003 (Fig. 3).

4.3.2 Sediment metals

In 2013, there were exceedences of the TEL or LEL for all metals except lead and mercury (Table 4). The number of metal TEL exceedences ranged from 2 to 7 per site with the exception

of Moberly Bay site M701, where there were no exceedences. Site M701 had a higher percentage of sand (60%) compared to remaining sites (≤ 39%) (App. C, Table C2) which likely explains the lower metal levels. Iron and manganese (Mn) were more elevated outside of Moberly Bay and arsenic was most elevated in Tunnel Bay (Table 4). The SEL was exceeded for Mn in Tunnel Bay only, at 1 of the 2 sites (Table 4). These results are very similar to that found in 2008, where metals were between the low and high guidelines except for a few sandy sites (including M701) and SEL exceedances were limited to Mn in Tunnel Bay (Milani and Grapentine 2009). There were also metal TEL or LEL exceedences at 4 of the 6 Lake Superior reference sites sampled in 2013; from 2 to 4 metals were between the low and high guideline and arsenic and Mn were above the high guideline at one site (App. C, Table C1).

Examination of temporal trends for each metal showed concentrations to be quite stable since 2003 with some metals (e.g., Cr, Mn) showing overall slight decreases since 2003 (Figs. 4a-5c). No metals were above the SEL or PEL throughout the time period, with the exception of Mn (Fig. 4b); however, reference site [Mn]s were also elevated above the SEL (the maximum concentration for 52 Lake Superior reference sites was 2,400 µg/g, median 631 µg/g, EC unpublished). Test sites that had [Mn]s elevated above reference and the SEL were limited to Tunnel bay in the later years (Fig. 4b). Most metal concentrations fell between the TEL and the upper guideline (SEL or PEL) throughout the time period and were within the range observed for Lake Superior reference sites with the exception of Cd, and Zn (Figs. 4a, 4c). Test sites with Cd and Zn elevated above the reference maximum (but below PELs) were limited to Moberly Bay. Metals consistently below the TEL since 2003 or 2006 included Pb and Hg (Figs. 4b-4c).

These temporal trends are for the 0-10 cm layer of sediment, in which most of the benthic community inhabits, and may not reflect contaminant concentrations for the most recently deposited sediment layers.

4.3.4 Sediment PCDD/Fs and dl-PCBs

Concentrations of PCDD/Fs (dioxins and furans) in 2013 JFB sediment are provided in Table 5. The most toxic dioxin, 2,3,7,8-TCDD, was detected at all sites and was most elevated in Moberly Bay where it ranged from 6.9 to 22.1 pg/g (cf. to <1.2 to 17.3 pg/g in 2008), followed by the far-field area (8.5 to 12.4 pg/g) and Tunnel Bay (2.7 to 3.2 pg/g); concentrations were lowest in far far-field area (0.21 to 0.44 pg/g) (Table 5). Generally, dioxin concentrations

increased with increasing chlorine atoms from the hexachlorodioxins (HxCDD) to the octachlorodioxins (OCDD) and [OCDD]s were highest at all JFB sites (range: 11 to 252 pg/g) similar to that found in 2008 (9 to 212 pg/g). The tetrachlorofurans were generally the highest of the furan homologue groups; 2,3,7,8-TCDF ranged from 62 to 354 in Moberly Bay (cf. 10 to 239 pg/g in 2008) and were overall highest in Moberly Bay compared to other areas of JFB (0.2 to 174 pg/g) (Table 5).

Concentrations of PCDD/Fs were also expressed in TEQs (toxic equivalents) which takes into consideration the unique concentrations and toxicities of the individual components within the dioxin or furan mixture. Under the mid-point scenario (non-detects assigned ½ the MDL), TEQs were highest in Moberly Bay where they ranged from 12.6 to 53.4 pg/g, followed by the far-field area (19.7 to 27.9 pg/g), Tunnel Bay (≤ 7.1 pg/g), and far far-field (≤ 1.5 pg/g) (Table 5). Congeners 2,3,7,8-TCDD and 2,3,7,8-TCDF most strongly influenced the TEQ in Moberly Bay and the far-field area (≥ 41% and ≥ 25% of the TEQ, respectively), whereas in the far far-field area of JFB, the influence of these two congeners dropped (to ≤ 31% and ≤ 7.5% of the TEQ, respectively) and the influence of 1,2,3,7,8-PeCDD increased (App. C, Table C3). The influence of these specific congeners on the TEQ was very similar to that found in a study conducted in 2012 in JFB for the 0-2 cm of sediment (Dahmer et al. 2015). With the exception of the far far-field area, all TEQs were above those observed for Lake Superior reference sites (n=8) sampled in 2008 (≤ 5.22 pg/g) (Milani and Grapentine 2009); TEQs in Tunnel Bay were only marginally above. In 2013, the TEQs exceeded the PEL (21.5 pg/g) at 7 of the 8 Moberly Bay sites, by 1.1-2.5 times, and 1 of the 2 far-field sites by 1.3 times (Fig. 5). The PCDD/F TEQs for JFB were also compared to Safe Sediment Target Level (SSTL) developed by Richman and George (2014) for the Spanish Harbour AOC. Based on PCDD/F levels found in sediment, mayflies and fish, and the human health consumption restrictions in place for PCDD/Fs, an area-average sediment TEQ of 56 pg/g was estimated as a SSTL, with a range of 40-81 pg/g to account for differences in bioaccumulation potential between fish species. Below 56 pg/g, PCDD/F exposure to mayflies would be reduced so that large White Suckers (> 40 cm) feeding on mayflies would have a tissue concentration below the first human health consumption limit of 2.7 pg/g (Richman and George 2014). Site M701 had a TEQ just below the average SSTL but above the lower SSTL, indicating that this site could potentially pose some risk; however, all other JFB sites were below the lower SSTL (Fig. 5). In a 2012 study, TEQs as high

as 81.4 pg/g were found close to the mouth of Blackbird Creek (BBC) in the top 2 cm of sediment core samples, which based on ^{210}Pb dating, represents ~ 10 years (Dahmer et al. 2015); this is overall higher than that observed for the top 10 cm in the current study for Moberly Bay (53.4 pg/g) (Table 5). Dahmer et al. (2015) found that TEQs decreased with increasing distance from the mouth of the creek and at ≥ 0.42 km from the mouth of the creek dropped to below the PEL, whereas in the top 10 cm, the TEQs were above the PEL to approximately 0.7 km from the mouth of the creek (and was also above the PEL at one site in the far-field area ~2.4 km from mouth of BBC) (Table 5). These higher TEQs in the current study were likely attributed to influence of the deeper sediments (> 2 cm), as Dahmer et al (2015) found higher TEQs lower in the core samples collected from a station in JFB. The TEQs for JFB were lower than those reported for Spanish Harbour AOC, where TEQs ranged from 47 to 301 pg/g from sites collected in 2013 in the depositional area north of Aird Island (Milani and Grapentine 2015).

The dl-PCBs (12 PCB congeners) consisted mainly of PCB 118 (50 to 4,670 pg/g) and PCB 105 (27 to 2,790 pg/g), followed by PCB 156 (20 to 556 pg/g) and PCB 123 (8.2 to 467 pg/g). PCB 169 was not detected at any site and PCB 81, PCB 126 and PCB 114 were detected at less than half the sites (Table 6). The TEQ for dl-PCBs ranged from 0.002 to 0.165 pg/g (mid-point scenario) (Table 6) and represented very little of the total TEQ. The dl-PCBs generally followed the same spatial pattern as PCDD/Fs, with the highest concentrations of total dl-PCBs in Moberly Bay (≤ 9,213 pg/g) followed by the far-field (≤ 1,924 pg/g), Tunnel Bay (≤ 693 pg/g) and the far far-field (≤ 118 pg/g) (Table 6).

Trends for the PCDD/F TEQ from 2003 to 2013 are shown in Fig. 6. The TEQs showed either stable or declining concentrations since 2003, except for site M701 where the TEQ increased sharply in 2006, followed by multi-year declines to 2008 and then multi-year increases to 2013 (Fig. 6). The up and down concentration trends likely represent natural site variability and/or small scale heterogeneity in some cases where it was difficult to revisit the exact locations from previous surveys.

4.3.5 Sediment BTEX, petroleum hydrocarbons, total oil and grease

The volatile organic compounds benzene, toluene, ethylbenzene and xylene (BTEX) were below MDLs (values preceded by "<") at all 2013 Jackfish Bay sites, except for toluene at site M701 (1.92 mg/kg) (App. C, Table C4). Similar results were found in 2008.

The F4G petroleum hydrocarbons (heavy hydrocarbons in the ~C24-C50+), were the greatest fraction found in JFB samples (800 - 14,900 µg/g) followed by the F3 (C16-C34) hydrocarbons (250 – 8,770 µg/g) (Table 7). The F3 and F4G fractions were not detected in the far far-field area and at 1 of the 2 Tunnel Bay sites (Table 7). The F1 fraction was not detected in any samples and the F2 fraction (≤ 790 µg/g) was low compared to higher fractions. The chromatogram did not reach baseline at C50 (i.e., there were PHC with carbon chain lengths >50) at 1 site in Moberly Bay (EEM8B), indicating the presence of very heavy hydrocarbons (e.g., oils) at this site. Total PHCs was determined by the sum of the F1 to F4 or F4G fraction, whichever was greatest (the F4G were greatest). Total PHCs were most elevated in Moberly Bay (range from 3,992 - 24,461 µg/g) followed by the far-field area (3,249 - 3,695 µg/g) and Tunnel Bay (≤ 1,180 µg/g); concentrations were below detection limits in the far far-field area (Table 7).

Trends for the total PHCs from 2006 to 2013 are shown in Fig. 7 (PHCs were not measured in 2003). Concentrations were mostly stable since 2006, with the most fluctuation seen for site M701 (similar to that seen with PCDD/Fs). Site EEM8B, which had the highest concentration observed in JFB throughout the period was a new site in 2013. Total PHCs in JFB were consistently higher the 99th percentile for Lake Superior reference sites sampled from 2008 to 2013 (440 µg/g; n= 24 sites).

Similar to PHCs, total oil and grease was also most elevated in Moberly Bay (10,700 – 74,500 mg/kg; median 15,750) followed by far-field (5,600 - 7,900 mg/kg), and Tunnel Bay (2,000 – 3,300) (Table 7). The large range in Moberly Bay was due to site EEM8B, which was noted as being very oily, odorous and organicy (this sediment could not be sieved as well) and was the only site where they were PHCs with carbon chain lengths >50 (see above); all other sites in Moberly Bay had total oil and grease ≤ 19,900 mg/kg. Concentrations were below detection limits (< 500 or 750 mg/kg) in the far far-field area (Table 7). Moberly Bay concentrations were mostly higher than those found in the St. Marys River AOC, east of Bellevue marine park (2,310 - 15,100 mg/kg; median 8,570) (Milani 2012), but mostly lower than those found in Lyons Creek East (1,660 - 76,900 mg/kg; median 34,400) (Milani and Grapentine 2014). Oil and grease concentrations were not compared to those reported in previous studies (2008 and 2003) due to the different methodologies employed. Regardless, the

pattern was the same in previous studies, with a gradient of decreasing concentrations from Moberly Bay to the far- and far far-field areas of JFB.

4.3.6 Sediment PAHs

Concentrations of PAH were low throughout JFB in 2013, with 8 of the 16 compounds below detection limits across all sites (Table 7). PAHs were detected in Moberly Bay for the most part, although the far-field area and Tunnel Bay (3M2) also had 1-4 compounds detected (≤ 0.11 µg/g) (Table 7). Moberly Bay sediments consisted mainly of phenanthrene (≤ 1.19 µg/g), fluoranthene (≤ 0.44 µg/g), and pyrene (≤ 0.60 µg/g), detected at most sites (Table 7). Individual PAHs exceeding LELs included benzo(a)anthracene, chrysene, and pyrene (site EEM8B), and those exceeding PELs included phenanthrene (sites EEM8B and M701) and dibenzo(ah)anthracene (site NF5) (Table 7).

Trends for total PAHs from 2003 to 2013 are shown in Fig. 8. For consistency across sampling years, total PAHs were determined as the sum of 16 parent compounds with the non-detected compounds assigned ½ the detection limit. Total PAHs have remained fairly stable and low (below the LEL), throughout the time period, with the exception of one site (re-located new site EEM8B), which marginally exceeded the LEL in 2013 (Fig. 8). Some sites showed either multiyear increases or decreases depending on the site. In 2008 there was an upward trend in [PAH]s, but was followed by a decrease down to concentrations similar to those seen in 2003 (Fig. 8).

4.4 Bioaccumulation of Contaminants in Benthic Invertebrates

A. Conditions in 2013

Dioxins and furans (PCDD/Fs), measured in resident amphipods, chironomids, and oligochaetes, are provided in Table 8. The higher chlorinated dioxins, e.g., 1,2,3,4,6,7,8-HpCDD (≤ 99 pg/g) and OCDD (≤ 300 pg/g) and the lower chlorinated furans, e.g., 2,3,7,8-TCDF (≤ 170 pg/g), were dominant in the benthos for the most part (Table 8). The most toxic dioxin congener regarded, 2,3,7,8-TCDD, was detected in only 2 of the samples – one from Moberly Bay (1M3; 4.51 pg/g) and one south of Moberly (far-field) (2M6; 8.56 pg/g). From 1 to 6 or 7 PCDD/F congeners were detected in the benthos; amphipods had the highest PCDD/F levels in Moberly

Bay and far-field areas of JFB (Table 8). While the sum of homologue groups (tetra- to octa-groups) was overall higher in Tunnel Bay (≤ 636 pg/g) and the far-field (≤ 587 pg/g) areas compared to Moberly Bay (≤ 403 pg/g), the concentration of 2,3,7,8-TCDF in combination with other detected congeners was higher in Moberly Bay (Table 8). As a result, TEQs were overall higher in Moberly Bay when both the lower and upper bound values were considered (Table 8). For instance, while the TEQs were as high as 98 ng/kg in the far-field area and 58 ng/kg in the far far-field area, these upper bound values are driven by the high detection limits for the congeners in these samples and the range in TEQs were quite wide and thus the TEQs more uncertain. A sample with a narrow TEQ range indicates that more of the congeners were detected in these samples and thus the TEQ would be more reliable; therefore, the TEQs for Moberly Bay and in some cases the far-field sites were more reliable. Under the mid-point scenario, TEQs in ng/kg for Moberly Bay, far-field, far far-field and Tunnel Bay were ≤ 34.2, ≤ 48.9, ≤ 28.8 and ≤ 8.4, respectively, exceeding criteria by 1.4 to 4.7 times (Table 8). As a screening level assessment of potential risk, the TEQs were compared to a modified avian TRG (7.3 ng TEQ/kg) and the maximum (99th percentile) upper bound TEQ for Lake Superior reference samples collected in 2008 (10.4 pg TEQ/kg). At all 3 sites in Moberly Bay and both far-field sites, exceedences of the higher of the two values (10.4) occurred under all scenarios for 1 or 2 taxa whereas in the far far-field area and Tunnel Bay, exceedences occurred only under the mid-point and/or upper bound scenario (worst case scenario) for one taxon (Table 8).

The dl-PCB concentrations in the benthos are provided in Table 9. The dominant PCBs were PCB 118 followed by PCB 105 and PCB 156/157; these congeners were detected in all (PCB 118) or most samples (Table 9). The greatest dl-PCB accumulation (sum of detected 12 congeners) occurred in Tunnel Bay reference area (≤ 8,449 pg/g), followed by far-field (≤ 8,352 pg/g), Moberly Bay (6,392 pg/g) and far far-field (≤ 3,697 pg/g). Amphipods accumulated the most PCBs with the exception of Tunnel Bay where oligochaetes accumulated the most (Table 9). Concentrations of dl-PCBs, expressed in TEQs, are provided in Table 9. Under the mid-point scenario, TEQs for Moberly Bay, and far-field, far far-field were ≤ 1.9 ng/kg, ≤ 3.8 ng/kg, and ≤ 11.1 ng/kg, respectively; TEQs for the Tunnel Bay reference area were ≤ 9.4 ng/kg (Table 9). Exceedences of the modified avian TRG (3.8 ng TEQ/kg) under the mid-point scenarios occurred for one taxon in each of the far far-field and Tunnel Bay areas of JFB (Table 9); exceedences were ≤ 2.9 times the TRG.

B. Temporal trends in TEQs

Trends in tissue PCDD/F TEQs were examined from 2008-2013 (two sampling events) under the mid-point scenario (Fig. 11). The TEQs have decreased in 2013 compared to 2008 for co-located sites. Some 2013 sites were not sampled in 2008 thus trends could not be discerned, however, the mid-point TEQs were overall lower in 2013, ranging from 1.5 to 49 (median: 10.7) compared to 2008, where they ranged from 4.9 to 57 (median: 12.9) (Fig. 11).

4.4.1 Biota-sediment accumulation factors

Bioavailability of individual PCDD/F and dl-PCB congeners were quantified by calculating biota-sediment accumulation factors (BSAFs). The BSAFs reduce site variability due to differences in TOC concentration thus allowing for differences in contaminant bioaccumulation between species to be examined (Ankley et al. 1992). The BSAFs (based on whole-body, uncleared-gut concentrations) were calculated for individual PCDD/F and dl-PCB congeners that were detected in both sediment and tissue samples (paired samples); values > 1 indicates greater potential for the contaminant to accumulate in the tissues.

The PCDD/Fs BSAFs for the 2013 samples were mostly < 1; 87% of samples were < 1 with occasional values between 1-2 (Fig. 9; App. C, Table C5). There was one unusually high BSAF for 1,2,3,7,8,9-HxCDF (36) for amphipods; the BSAF for oligochaetes was lower (2) and this congener was not detected in chironomids (App. C, Table C5). BSAFs were also calculated for samples collected in 2008 (Milani and Grapentine 2009) for 8-9 detected PCDD/F congeners (there was no dl-PCB data for sediments in 2008). In 2008, the BSAFs were overall higher, where they ranged from 0.02 – 7.27; 67% of samples < 1 (App. C, Table C5). The lower chlorinated PCDFs as well as OCDF had higher BSAFs in 2008 than in 2013. These BSAFs indicated that sediment PCDD/Fs generally had a low potential to bioaccumulate in benthic invertebrates and that BSAFs for co-located sites were generally stable or decreasing in JFB. The low potential for PCDD/Fs to bioaccumulate in benthic tissues was also reported by Richman and George (2014) for the Spanish Harbour AOC where BSAFs ranged from 0.01-0.49 and by Pickard and Clarke (2008) whom documented a mean Lake Ontario PCDD/F BSAF of 0.64 based on 28-day laboratory exposures of the oligochaete worm *Lumbriculus variegatus* to field-collected sediment. The dl-PCBs were less bioavailable than the PCDD/Fs with BSAFs consistently well below 1 (≤ 0.3) (Fig. 10, App. C, Table C6), indicating a very low potential for

dl-PCBs to bioaccumulate in benthic invertebrates. PCB 126 had the highest potential to bioaccumulate in 2 of the 3 taxa (amphipods and chironomids), but this was only based on one sample. For oligochaetes, PCB 77 had the greatest potential to accumulate (Fig. 10). The potential for dl-PCBs to accumulate in benthic tissues was lower in Jackfish Bay than that reported by Richman and George (2014) for mayflies collected from the Spanish Harbour Area of Concern, where they ranged from 0.50 to 3.48.

While the above BSAFs were calculated based on the integrated 0-10 cm of sediment, actual exposure to the organisms could be to a narrower layer (e.g., some organisms may not penetrate that deep into the sediment). Thus it is possible that sediment PCDD/F concentrations could be biased higher which would result in lower BSAFs. The BSAFs should therefore be interpreted with caution.

4.5 Benthic Invertebrate Community Structure

A. Conditions in 2013

A total of 16 taxa (families) were found at JFB sites in 2013 (Table 10). Moberly Bay sites were dominated by the oligochaete worm Tubificidae (7,539 - 54,303 m^{-2}), followed by Chironomidae (midge; 804 - 5,547 m^{-2}), Naididae (worm; 49 - 6,594 m^{-2}), and Asellidae (isopod; 60 - 5,232 m^{-2}), which were present at all sites. The Pisidiidae (fingernail clam) were present at 6 of the 8 Moberly Bay sites (≤ 2,226 m^{-2}) and Pontoporeiidae (*Diporeia hoyi*) were absent or in low abundance at 3 sites (≤ 121 m^{-2}). Compared to the other 7 sites in Moberly Bay, site M701 had the greatest taxon richness (12 families, c.f. 4-10) and had an abundance of lumbriculid worms (989 m^{-2}, c.f. ≤ 121 m^{-2}) and gammarid amphipods (204 m^{-2}, c.f. 0) (Table 10). Site M701 had generally lower metal contaminant levels (Table 4) and similar or higher organic contaminant levels (Tables 5-7) compared to the other Moberly Bay sites, but was most dissimilar based on physical sediment characteristics which likely explains the difference in community composition; M701 was located at the mouth of BBC and was sandier (60% sand, 34% silt) than the other siltier sites in Moberly Bay (≤ 39% sand, ≥ 55% silt) (App. C, Table C2).

In the far-field area (south of Moberly Bay), tubificids (422 - 905 m^{-2}) and chironomids (181 - 663 m^{-2}) still dominated but in far less abundance than in Moberly Bay; taxon richness (4-6 families) was similar or lower to that in Moberly Bay (Table 10). (Moberly Bay was more

organically enriched – see section 4.3.1.) Other differences between the far-field and Moberly Bay were the increased abundance of pontoporeiids in the far-field area, which were present at all sites (181 - 784 m^{-2}), and the absence of naidids and asellids (Table 10). In the far far-field area, taxon richness (4-6 families) was similar to that in the far-field area, but there were no tubificids present, and the pontoporeiids now dominated (663 - 1,870 m^{-2}) followed by enchytraeid worms (181 - 362 m^{-2}) and midges (181 - 241 m^{-2}), more indicative of an oligotrophic condition (Table 10). In Tunnel Bay, taxon richness was on the low end of the range for JFB (4 families), and tubificids (1,327 - 1,448 m^{-2}) and chironomids (663 - 1,448 m^{-2}) dominated the benthic community followed by pontoporeiid amphipods (422 - 784 m^{-2}). The benthic community in Tunnel Bay most closely resembled that of the far-field area of JFB.

The 2013 benthic community was identified to lower levels (e.g., genera or species where possible). Most tubificids in Moberly and Tunnel Bays consisted of unidentified immature specimens with and without cap setae; 6 species were identified in Moberly Bay, the most common of which were *Tubifex ignotus*, followed by *Aulodrilus pluriseta*, *Limnodrilus hoffmeisteri*, and *Spirosperma ferox* whereas in Tunnel Bay, 3 species were identified with the most common being *Rhyacodrilus montana* (App. D, Table D1). In the far-field area, most tubificids consisted of identified species (not immatures), with *Rhyacodrilus montana* being the most common (similar to Tunnel Bay) (App. D, Table D1). In Moberly Bay, 13 chironomid genera were identified with *Procladius* and *Chironomus* (mostly *Chironomus decorus*) being the predominant midges (App. D, Table D1). The far-field and Tunnel Bay areas were similar, with 7 and 4 chironomid genera identified, respectively; *Heterotrissocladius changi* and *Protanypus ramosusin* the most prominent species in both areas, whereas in the far far-field area, only two species were present (mostly *Heterotrissocladius changi*) (App. D, Table D1).

The benthic community composition at each 2013 JFB site was assessed by graphical analysis of results from a NMDS of sample invertebrate family densities (see App. A for more details). Benthic communities at JFB sites were compared to communities in their corresponding reference subset sites by NMDS of the merged test and reference sites invertebrate family count data. The status of the test site, determined by its NMDS site score relative to 90 and 99% confidence ellipses for the reference site scores, is demonstrated in individual plots (App. A), and is summarized in Table 11a. Based on the whole community (NMDS axes) the outcomes were the following for the 15 sites:

- 11 sites were not different from reference ($p > 0.1$);
- 3 sites were different ($0.10 \geq p > 0.01$) – 1M4 (Moberly Bay) and 4M3 and 4M4 (far far-field);
- 1 site was very different ($p \leq 0.01$) – M701 (Moberly Bay).

Benthic community descriptors (total benthos, richness, evenness, and 7 dominant taxa) of each 2013 JFB site were also compared to ranges and 5th and 95th percentiles of site-specific reference data, provided as individual box plots in App. A, and summarized in Table 11a. Other than far far-field sites 4M3 and 4M4, which showed differences in whole community and Tubificidae abundances, effects were restricted to Moberly Bay. As mentioned above, tubificids were absent from the far far-field area of JFB which explains the difference from reference, but other oligochaetes that are more indicative of oligotrophic conditions were present (e.g., lumbriculid and enchytraeid worms). In Moberly Bay, all 8 sites were assessed as different or very different from reference based on 1 to 5 descriptors: total benthos (2 sites), evenness (3 sites), tubificid abundance (6 sites), naidid abundance (1 site) and asellid abundance (5 sites) (Table 11a).

Overall, the benthic community response varied from very different closest to the mouth of BBC to not different in the far-field area (Fig. 23). Moberly Bay sites M701 and 1M4, which were closest to the mouth of BBC, were most different from reference based on whole community and 4 descriptors (Table 11a). Sites EEM4, 1M3, and JFB002, located farther out in the central part of Moberly Bay, were borderline different based on whole community, and were different from reference based on asellid and/or tubificid abundances, whereas sites 1M1, NF5, and EEM8B, located farthest south in Moberly Bay, were similar to reference based on whole community but had one or two individual descriptors different from reference (evenness or tubificids) (Table 11a). South of Moberly Bay in the far-field area, benthic communities were similar to reference based on the whole community and individual descriptors (Table 11a; Fig. 23). Differences in tubificid abundances between reference and Moberly Bay sites were the greatest driver, with 6 of the 8 sites showing major differences (Table 11a).

<u>B. Trends in conditions from 2003 to 2013</u>

The temporal variation in whole community similarities of Jackfish Bay to reference sites for the 5 co-located JFB sites (1M1, 1M2, 1M3, 2M1, M701) are summarized in Table 11b. These 5 sites were sampled 5-6 times during 2006-2009 and compared to 27 reference sites mostly sampled 3 times during 1998-2009. There were inter-year differences observed with conditions varying from different to not different or vice versa throughout the time period (Table 11b). Overall, conditions in the far-field (2M1) have improved and remained stable since 2007, whereas Moberly Bay sites showed more variability fluctuating back and forth from different to not different or vice versa.

Trends for three commonly used community descriptors (total abundance, taxon richness and evenness) and the 7 most abundant reference families were examined from the 5 co-located JFB sites sampled from 2003 to 2013 while comparison in densities to the in the range in reference sites was specifically examined from 2003 to 2009. The top 7 abundant families in the reference site samples were Chironomidae, Tubificidae, Pontoporeiidae, Pisidiidae, Naididae, Asellidae, and Lumbriculidae (Fig. 12). While these 7 families were the same most abundant ones in the JFB samples, their order in numerical importance differed, with the Tubificidae comprising the bulk of the samples and the Pontoporeiidae comprising the least of the 7 (Fig. 12). Total benthos has remained stable or has decreased slightly overall since 2003 (some slight increases or decreases depending on the site) (Fig. 13a); reference sites total benthos showed generally decreased total benthos since the late 1990s (Fig. 13a). Total benthos in Moberly Bay was above the upper range for reference sites at 3-4 sites from 2006 on, while in the far-field area remain within the reference range (Fig. 13b). Taxon richness (number of families) at the JFB sites has remained relatively stable since 2003 (Fig. 14a). From 2003-2009, taxon richness was at the lower end of the range or below the range observed for the reference sites; one site in each of Moberly Bay and the far-field area were below the range in 2003, and in 2009, the far-field site was below the range (Fig. 14b). Evenness is a measure of how individuals in a sample are distributed among taxa where a value of 1 indicates all taxa have the same number and the closer to 0 the more uneven the numbers among taxa. Evenness in JFB has fluctuated over the sampling period but overall showed slight increases from 2003 (Fig. 15a). However, from 2003-2009, evenness was quite low in Moberly Bay, with most sites below the lower end of the range observed for the reference sites (< 0.3), while in the far-field, it was within the range of the reference sites (Fig. 15b).

Temporal trends for the 7 numerically important taxa are shown in Figs. 16-22. Chironomid densities have remained stable since 2003 (Fig. 16a) and were within the range observed at the reference sites in the time period assessed (Fig. 16b). Tubificid worms have remained stable or showed overall slight decreased abundance since 2003 (Fig. 17a). From <2004-2009, tubificids were in much greater abundance than reference sites and all 4 sites in Moberly Bay they were outside the upper range for the reference sites from 2006 on (Fig. 17b); in the far-field area, densities were within the range for reference sites. Pontoporeiid amphipods were absent or fluctuated throughout, showing declines and then reverses in declines over time (Fig. 18a). Nearly all reference sites also showed declines in pontoporeiids as well - overall there have been declines since the late 1990s (Fig. 18a). From 2003-2009, pontoporeiids were present in very low abundance in JFB; 2 sites were outside the lower end of the reference range in 2003, and from 2006 on, densities were at the lower end of the reference range (Fig. 18b). Pisidiidae densities showed some fluctuating increases and decreases between 2003 and 2007 depending on the site; 3 of the 5 sites were stable over time, while 2 sites showed sharp declines in 2013 (Fig. 19a); from <2004-2009, pisidids have remained within the range observed for the reference sites however, with the exception of 1 site in each of 2007 and 2009 (Fig. 19b). Naidid worm densities fluctuated over time (repeated increases, then reverses in increase); overall there were declines from 2003 (Fig. 20a). From 2003-2009, naidid densities showed a downward trend from 2006-2008/9, with most 2008/9 sites at the lower end of the reference range (Fig. 20b). Asellids densities also fluctuated throughout the period from 2003-2013 (repeated increases, and reverses in increase). From 2003-2013, asellid densities have remained stable or have increased overall at 3 sites in Moberly Bay; they were consistently absent in the far-field area (Fig. 21a). Asellid densities showed a downward trend from 2006/07 to 2008/9, with most sites at the lower end of the reference range (Fig. 21b). Lumbriculids were consistently absent throughout the time period at 4 of the 5 sites (Fig. 22A); Moberly Bay site M701, showed fluctuating (declines and reverse declines) but overall densities have remained stable since 2003 (Fig. 22A). From 2003 to 2009, lumbriculid densities were consistently at the low end of the reference site range except site M701, which was consistently within the upper range of the reference sites (Fig. 22b).

Overall, benthic invertebrate communities in Moberly Bay remain different from those at reference sites, driven mainly by increased tubificid densities. While there was inter-year variability apparent, results indicated that for the most part conditions in Moberly Bay were

relatively stable. Most Moberly Bay sites (5 of the 8) had multiple individual benthic descriptors that were different to those at reference sites but on a whole community basis, major differences were restricted to 2 of the 8 sites.

4.6 Sediment Toxicity

A. Conditions in 2013

Mean species survival, growth and reproduction for 2013 JFB sediments are provided in Table 12. For each endpoint, potential toxicity and toxicity, based on differing by 2 and 3 SDs from the mean of 66 Great Lakes reference sites, are highlighted blue and red, respectively. The main effect observed was toxicity to the amphipod *Hyalella* with acute toxicity noted in Moberly Bay at 5 of the 8 sites (survival: 52-63%). However, toxicity to *Hyalella* was also observed in the far far-field area (0.7-11.3% survival) and Tunnel Bay (16.7-35.3% survival), where contamination was low. Reduced *Hexagenia* survival and/or growth were also evident in parts of Moberly Bay and the far far-field area and slightly reduced *Tubifex* cocoon production in the far far-field area (Table 12). Toxic effects were noted in previous studies conducted in JFB, specifically to *Hyalella* and *Hexagenia* (Milani and Grapentine 2007, 2009).

Two GL models were used in the assessment of 2013 JFB sites. Using all 10 toxicity endpoints, a 2-dimensional nonmetric multidimensional scaling (NMDS) solution was recommended for the first GL reference model (minimum stress = 12.3, p = 0.008); 14 of the 15 JFB sites were run through this model (one at a time) (mean stress = 12.1, SD = 0.223) (Fig. 24a). Using 6 toxicity endpoints (because no *Tubifex* endpoints were available), a 3-dimensional NMDS solution was recommended for the second GL reference model (minimum stress = 0.03, p = 0.008); site EEM8B was run through this model (Fig. 24b). With the construction of the probability ellipses, the outcomes were the following for the 15 sites (Figs. 23a, b):

- 5 sites were non-toxic (within 90% ellipse);
- 4 sites were potentially toxic (within 90 and 99% ellipses) – M701, 1M1, 1M3 and JFB002 (Moberly Bay);
- 2 sites were toxic (within 99 and 99.9% ellipses) – 1M4 and EEM4 (Moberly Bay);
    - 4 sites were severely toxic (outside 99.9% ellipse) – 4M3 and 4M4 (far far-field); 3M2 and 6956 (Tunnel Bay).

Sites in Moberly Bay ranged from non-toxic to toxic from Moberly Bay to the far-field area (south of Moberly Bay) (Fig. 25; Table 12). Sites in both the far far-field and Tunnel Bay were also severely toxic. Joint plots showing the relative relationship of endpoints to the NMDS axes scores and the relationship between the explanatory (habitat) variables (inorganic compounds) and NMDS scores are provided in Figs. 26a and 26b, respectively. The direction of the endpoint vector shows its relative association with the axes and the magnitude of that association (the longer the vector the stronger the association) (Fig. 26a). Survival of *Hyalella* was the most influential response and was most strongly associated with axis 2 (r^2 = 0.851), followed by *Tubifex* % hatched cocoons (r^2 = 0.506), which was most strongly associated with axis 1 (Fig. 26a; App. E, Table E1). Examination of the relationships between toxicological response and the habitat (explanatory) variables (excluding organic contaminants for which there are no GL data), showed that alkalinity (r^2 = 0.392), SiO_2 (r^2 = 0.369) and Al_2O_3 (r^2 = 0.286) were most strongly correlated to axes scores (App. E, Table E2) and the test sites were associated with lower levels of these variables (Fig. 26b); however, these variables were still within the range observed at GL reference sites. Median concentrations (range) for alkalinity, Al_2O_3 and SiO_2 for GL reference sites were 76 mg/L (40.8-107 mg/L), 10.7% (3.4-16.1%) and 53.9% (26.1-92.8%), respectively (EC, unpublished data). To examine the potential influence of organic contaminants (e.g., PHCs, PCDD/Fs and dl-PCBs) on toxicity, toxicity-contaminant relationships were also examined using simple linear regression analysis. The regression analysis, conducted on Moberly Bay, far-field, and Tunnel Bay sites (n=13), revealed a significant relationship between *Hyalella* growth and the F3 PHC fraction, although the proportion of variability in growth explained was not large (r^2 = 38.7%, p = 0.023) (App F, Table F1). The PHCs, particularly the heavy hydrocarbons (e.g., oils) were present in elevated concentrations in Moberly Bay. It is possible that there could be a physical effect of oil on benthic invertebrates, as research conducted by the USEPA has suggested (Mount et al. 2009), and which was investigated in the St. Mary River AOC (Milani 2012). The PCDD/Fs and dl-PCBs are unlikely to bioaccumulate in benthic organisms to sufficient concentrations to induce acute or chronic effects in laboratory toxicity tests. The lack of sensitivity of invertebrates to PCDD/Fs and dl-PCBs has been documented in several studies (West et al. 1997; Borgmann et al. 1990; Dillon et al. 1990). The PCDD/F compounds are known to induce aryl hydrocarbon hydroxylase in fish and mammals; however, the aryl hydrocarbon (Ah) receptor does not appear to be present in invertebrates which

could explain their insensitivity (West et al. 1997; Borgmann et al. 1990; Dillon et al. 1990). Previous examination of toxicity-contaminant relationships for JFB showed weak correlations to sediment contaminant concentrations (Milani and Grapentine 2009). Whether the cause of toxicity to *Hyalella* in Moberly Bay was contaminant-related therefore remains unclear. The cause of *Hyalella* toxicity in the far far-field and Tunnel Bay was also not clear as contaminant levels were low and both these two areas support a good abundance of pontoporeiid amphipods (Fig. 13b). Acute toxicity to the amphipod was also found in these two areas in 2003 (survival: 8-44%) while in 2008, there were only slight reductions in amphipod survival in far far-field and Tunnel Bay (survival: 77-79%) (Milani and Grapentine 2007, 2009). It is possible that substrate type was a factor for some test sites. Sediment from the far far-field area, particularly 4M4, which had the highest silt (52 %) (App. C, Table C2), was noted in the laboratory to be quite flocky and did not settle well in the test beakers. *Hexagenia* also showed negative effects at 4M4 (reduced survival and growth) and cocoon and young production were slightly low compared to other sites in JFB (Table 12).

B. Trends in conditions from 2003 to 2013

Changes in individual toxicological response at sites sampled from 2003-2013 are shown in Figs. 26-29. The reference mean and -2 SDs of the mean are shown in each graph; sites with responses that were below -2 SDs of the reference mean are labelled.

Hyalella survival was the most variable endpoint with an acute response evident throughout JFB consistently through time (Fig. 27a). Both increases and decreases in survival were seen from 2003 to 2008; increases were large in some cases and were followed by reverses in 2013 - this occurred throughout the bay except in the far-field area where conditions remained relatively stable (Fig. 27a). Although conditions seemed to improve in 2008, the 2013 results closely resembled those from 2003, with a large number of sites below -2 SDs of the mean, indicating relatively little change since 2003 with toxicity prevalent in 3 to 4 of the 5 areas in JFB. Sites in the far far-field area (low contamination) were consistently toxic across 2 of the 3 sampling years likely indicating some other unknown factor since contamination was low. *Hyalella* growth, also fluctuated, showing both increases and decreases or stable responses throughout the time period depending on the site; areas where very low growth (below -2 SDs of the reference man) was observed included Moberly Bay (all years), the far-field (2008) and the far far-field (2008 and 2013) (Fig. 27b). *Chironomus* survival has mostly remained stable or has improved since 2003

or 2008, with most sites above the reference mean; growth has remained relatively stable and with the exception of 1 or 2 sites (Moberly Bay and far far-field areas) was within 2 SDs of the mean throughout the time period (Figs. 28a, b). *Hexagenia* survival was stable from 2003 to 2008, except for Moberly Bay site M701, which decreased in 2008, followed by a reverse in 2013; survival mostly decreased from 2008 to 2013, in some cases to below -2 SDs of the mean, but has nonetheless remained ≥ 86% (Fig. 29a). Like *Hyalella*, *Hexagenia* survival was lowest in the far far-field area in 2013. *Hexagenia* growth has remained mostly stable since 2003 or has improved slightly in some cases; growth was within 2 SDs of the mean except in Moberly Bay, where lower growth was consistent since 2003 (Fig. 29b). *Tubifex* cocoon production has showed multiyear improvements since 2003 (Fig. 30a); only site(s) in the far far-field area, where contamination was lowest, were below -2 SDs of the mean throughout the time period. The percentage of cocoons that hatched has remained mostly stable and above the reference mean throughout with the exception of 2-4 sites, which dipped below the reference mean but remained nonetheless well above -2 SDs from the mean (Fig. 30b). Young production also showed improvements from 2003 following a similar pattern to cocoon production; the number of sites that fell below the reference mean decreased with each sampling year and by 2013 only a few sites were slightly below the reference mean (Fig. 30c).

Overall the endpoints that were most affected in JFB were *Hyalella* survival and growth of and *Hexagenia* growth, where responses consistently fell below -2 SD of the mean throughout the time period. Toxicity to *Hyalella* and *Hexagenia* was mostly stable since 2003 while for *Chironomus* and *Tubifex*, toxicological responses were mostly stable or showed improvement since 2003.

5 CONCLUSIONS

In the fall of 2013, 15 sites were sampled in Jackfish Bay which included 8 sites in Moberly Bay, 3 sites in a far-field location south of Moberly Bay, 2 sites in a far far-field location and 2 sites in Tunnel Bay (reference area for Moberly Bay). The 0-10 cm layer of sediment was sampled for physico-chemical analyses, benthic invertebrate community structure, toxicity testing, and tissue residue analysis of dioxins and furans and dioxin-like PCBs. A summary of status of benthic conditions for 2013 Jackfish Bay sites relative to reference sites and temporal trends from 2003 to 2013 are provided in Table 13.

Metal contaminant concentrations in the sediments were similar to those for reference sites for most metals (e.g., As, Cr, Cu, Fe, Pb, Mn, Hg, and Ni) while other metals were slightly elevated at half or more sites (e.g., Cd, Zn). Over the period of 2003-2013, metals were fairly stable with perhaps some slightly decreasing concentrations (e.g., Cr). Dioxin and furan concentrations, expressed in toxic equivalents, were elevated compared to the Probable Effect Level in Moberly Bay and in the far-field area south of Moberly Bay. The TEQs have generally remained stable or decreased over time, although there was some high variability exhibited in some cases. The dioxin-like PCBs, while present in similar patterns spatially as PCDD/Fs, contributed a negligible amount to the total TEQ. Petroleum hydrocarbons and PAHs were elevated in Moberly Bay and showed a decreasing concentration gradient from Moberly Bay to the far far-field areas of Jackfish Bay, and have remained relatively stable over time. Total oil and grease concentrations were also elevated in Moberly Bay compared to other areas of the bay. Although contaminant concentrations were generally stable over time, the more recent deposits (e.g., 0-2 cm) would not be reflected in the samples, e.g., contaminant concentrations would be influenced by the deeper sediment where higher concentrations would occur.

Biota-sediment accumulation factors were mostly less than 1 or occasionally between 1 and 2, indicating that sediment dioxins and furans generally had a low potential to bioaccumulate in benthic invertebrates. The dioxin-like PCBs had very low potential to bioaccumulate. The BSAFs should be interpreted with caution since it is possible that some organisms (e.g., amphipods) collected for tissue analysis may not have been exposed to the full 10 cm of sediment which could obscure the BSAF results. As a screening level assessment of potential risk, the TEQs in the benthos were compared to a Tissue Residue Guideline and maximum reference site concentrations; exceedences of the greater of the two values occurred with greater certainty in Moberly Bay and south of Moberly Bay (far-field) while exceedences in the far far-field area carried more uncertainty. The mid-point TEQs (where non-detects were assigned ½ the MDL) were overall lower in 2013 compared to 2008, and have remained stable or have decreased in 2013 for co-located sites.

Benthic communities at most Jackfish Bay sites sampled in 2013 were determined to be similar to those from reference sites based on family composition and abundance. There were different benthic communities evident in parts of Moberly Bay, primarily due to increased abundances of tubificid worms, and in the far far-field area, due to the absence of tubificid

worms. Most Moberly Bay sites (5 of the 8) had multiple individual benthic descriptors that were different to those from reference sites but on a whole community basis, major differences were restricted to 2 sites that were those closest to the mouth of Blackbird Creek. Overall, the benthic community response varied from very different closest to the mouth of Blackbird Creek to not different in the far-field area of Jackfish Bay. Other descriptors that showed differences from reference included evenness and abundances of the isopod Asellidae, which were greatly increased in Moberly bay and absent everywhere else. Examination of trends over time in Moberly Bay and south of Moberly Bay (far-field) revealed inter-year variability, but that for the most part conditions have remained relatively stable since 2006.

Toxicity was evident at less than half the sites sampled in 2013, driven by reduced survival of the amphipod *Hyalella* and in some cases (e.g., sites in Moberly Bay) in combination with reduced *Hexagenia* growth. Moberly Bay sediments ranged from strongly toxic to non-toxic with decreasing toxicity from Moberly Bay to south of Moberly Bay (far-field). Examination of *Hyalella* toxicity-contaminant relationships indicated that no contaminant could be identified as the singular cause of toxicity. Toxicity could perhaps be partially be explained by petroleum hydrocarbons and a physical toxicity due to heavy oils present could not be precluded. Toxicity, however, was most severe in the far far-field area and in Tunnel Bay which were consistently toxic across 2 of the 3 sampling years. The cause of toxicity in these two areas was unclear since sediment contamination was low but it is possible that it could be a substrate-related factor in some cases. Although conditions seemed to improve in 2008, the 2013 results closely resembled those from 2003, indicating relatively little change since 2003 with toxicity prevalent in 3 to 4 of the 5 areas in Jackfish Bay.

Overall, this study shows conditions in Jackfish Bay to be relatively stable, with some improvements in some cases since 2003 or 2006. This study can assist in determining the sampling frequency and other long term monitoring options for the Jackfish Bay Area of Concern in Recovery.

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Figures

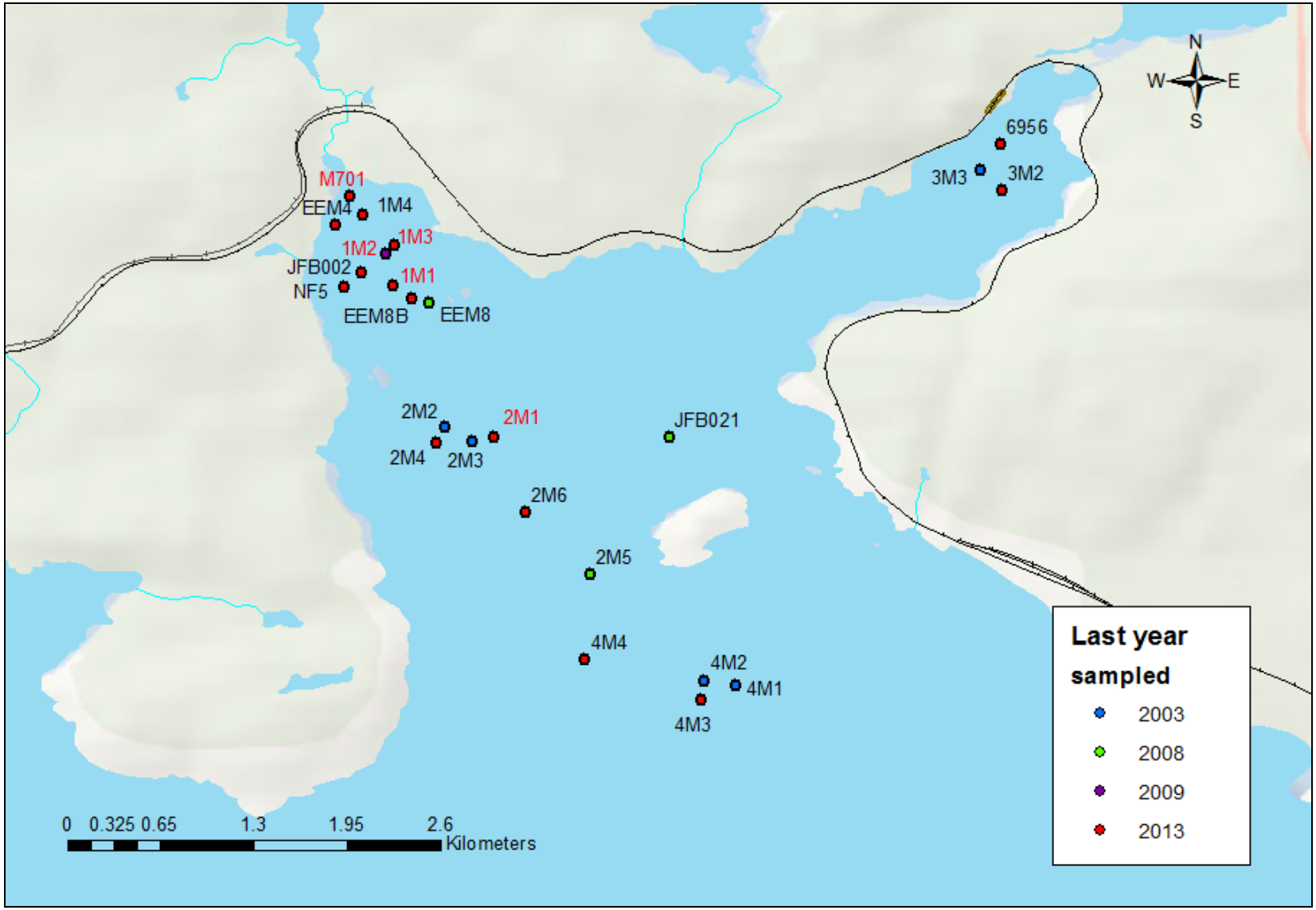


Figure 1. Sampling locations for Jackfish Bay 2003-2013 assessments, colour-coded by last year assessed. The five sites assessed in 2006-2009 for the benthic recovery study are labelled in red.

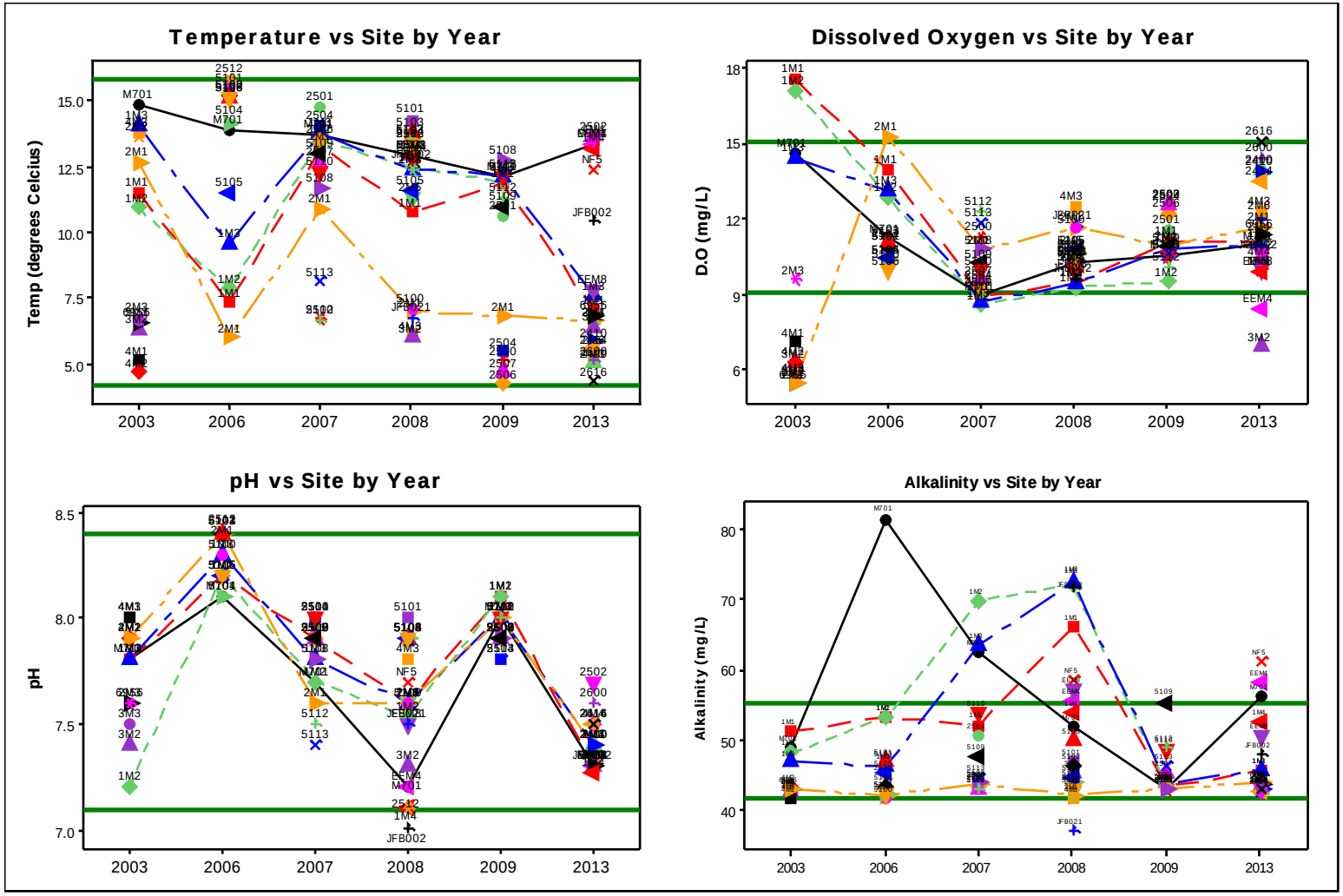


Figure 2a. Trends in overlying water temperature (°C), dissolved oxygen (mg/L), pH, and alkalinity (mg/L) for Jackfish Bay sites from 2003 to 2013. The solid green lines are the maximum and minimum values for the Lake Superior reference sites collected 2006-2013 (n=52).

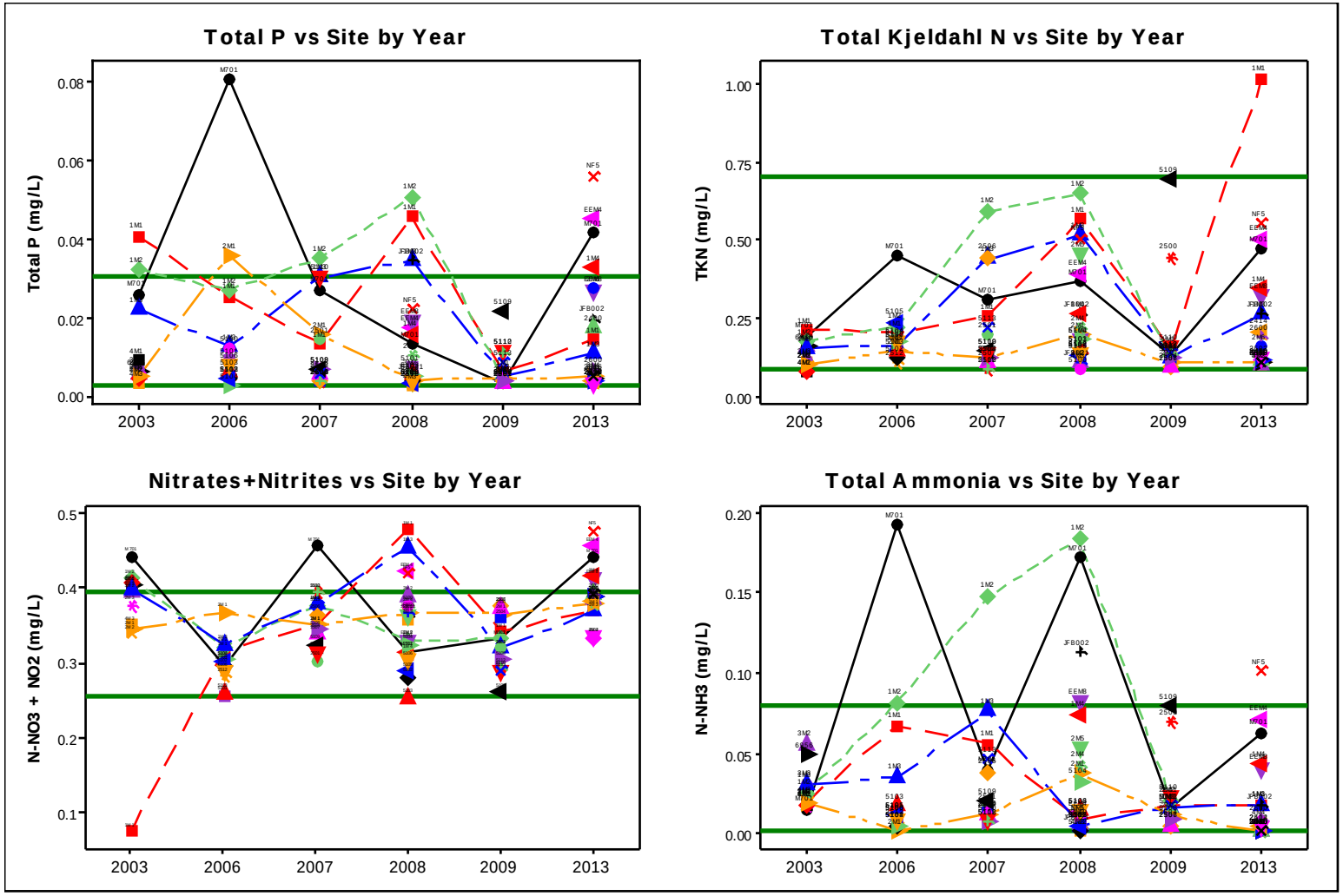


Figure 2b. Trends in overlying water total phosphorus, total Kjeldahl nitrogen, nitrates + nitrites and total ammonia (mg/L) for Jackfish Bay sites from 2003 to 2013. The solid green lines are the maximum and minimum values for the Lake Superior reference sites collected 2006-2013 (n=52).

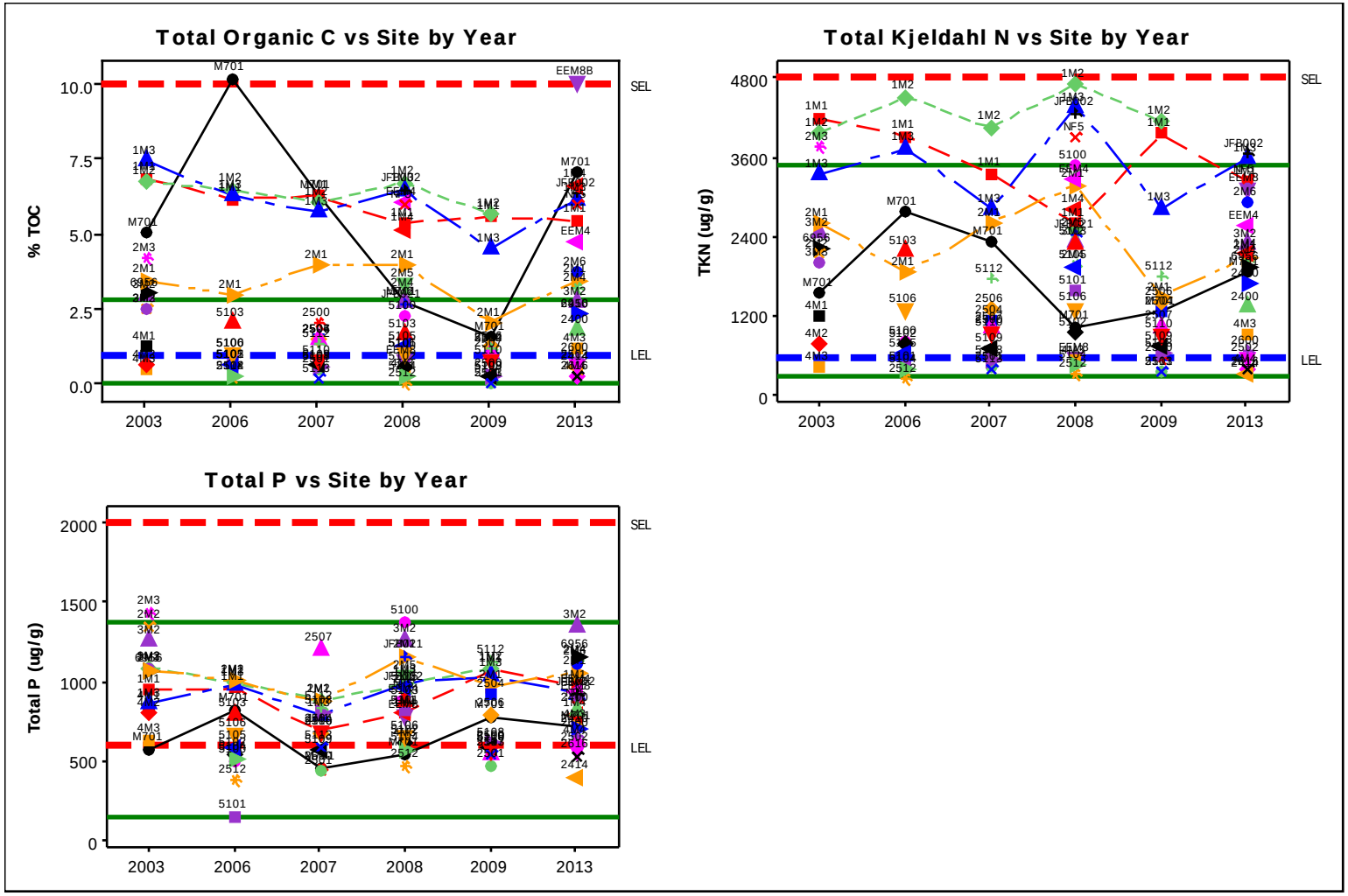


Figure 3. Trends in sediment total organic carbon (%), total Kjeldahl nitrogen, and total phosphorus concentrations (µg/g dw) at Jackfish Bay from 2003-2013. The solid green lines are the maximum and minimum values for the Lake Superior reference sites collected 2006-2013 (n=52). The lowest effect level (LEL) and the severe effect level (SEL) are indicated.

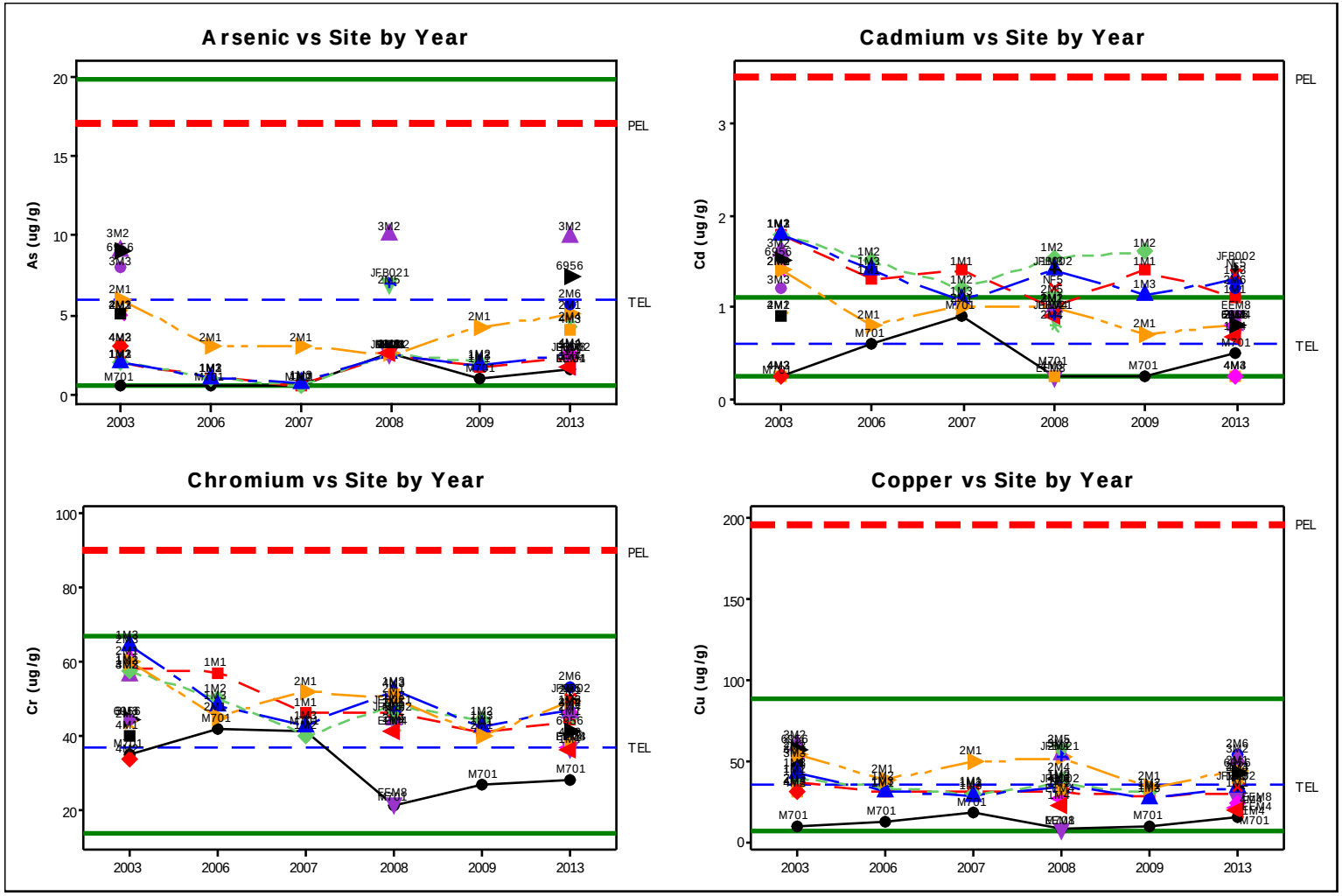


Figure 4a. Temporal trends in sediment arsenic, cadmium, chromium and copper concentrations at Jackfish Bay sites from 2003 to 2013. The solid green lines are the maximum and minimum values for the Lake Superior reference sites collected 2006-2013 (n=52). The blue and red dashed lines represent the Threshold Effect Level (TEL) and Probable Effect Level (PEL), respectively.

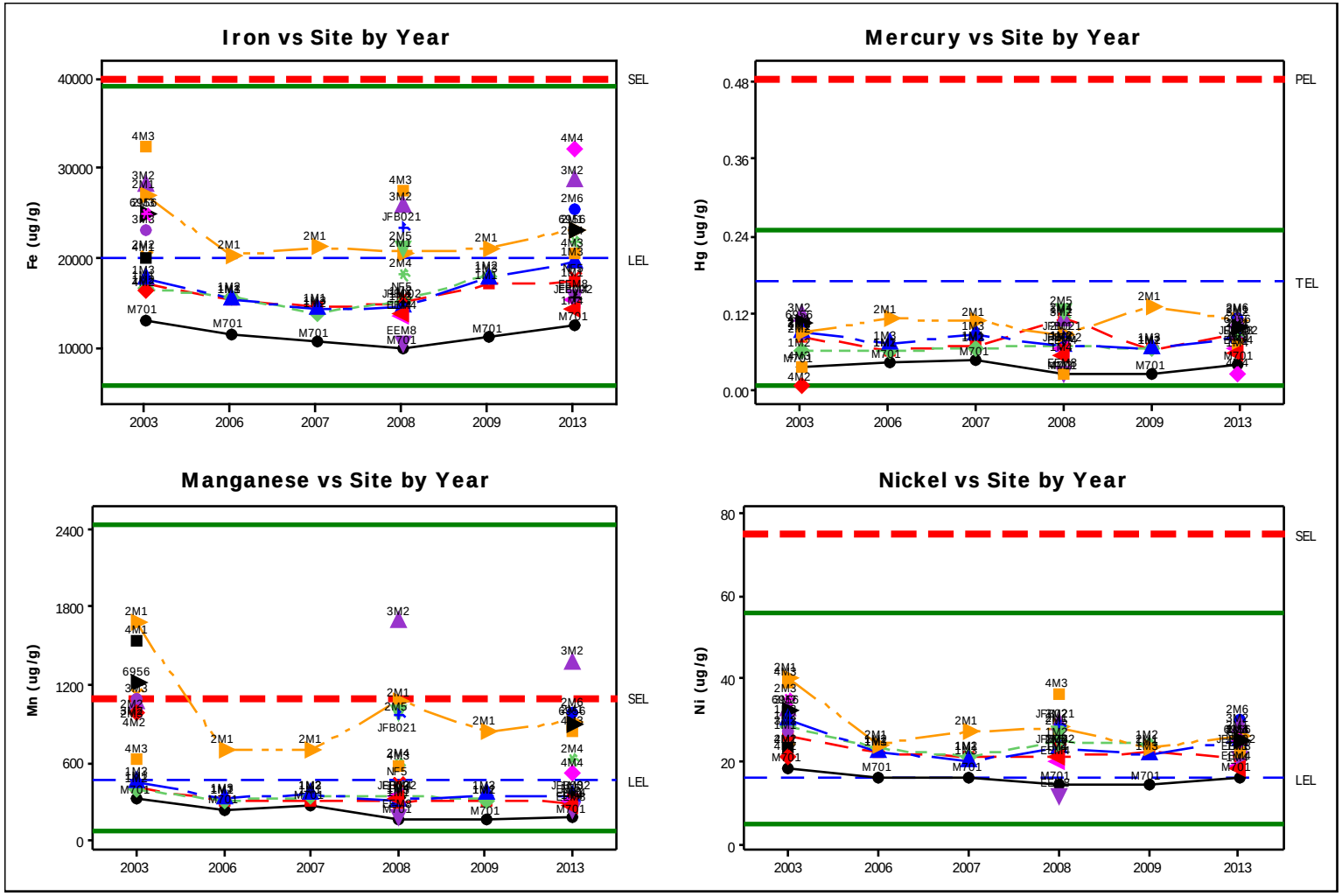


Figure 4b. Temporal trends in sediment iron, mercury, manganese and nickel concentrations at Jackfish Bay sites from 2003 to 2013. The solid green lines are the maximum and minimum values for the Lake Superior reference sites collected 2006-2013 (n=52). The blue and red dashed lines represent the Lowest or Threshold Effect Level (LEL or TEL) and the Severe or Probable Effect Level (SEL or PEL), respectively.

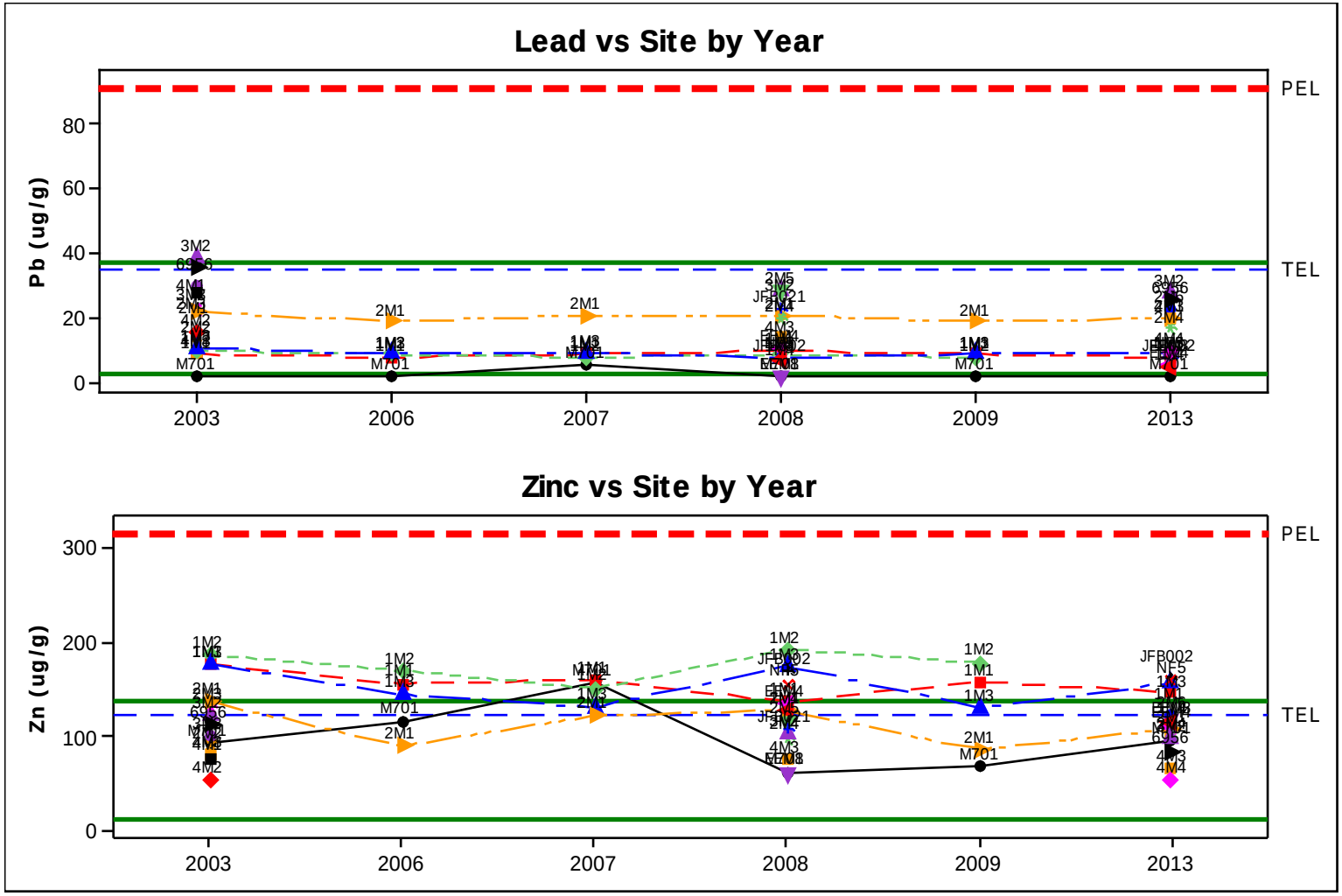


Figure 4c. Temporal trends in sediment lead and zinc concentrations at Jackfish Bay sites from 2003 to 2013. The solid green lines are the maximum and minimum values for the Lake Superior reference sites collected 2006-2013 (n=52). The blue and red dashed lines represent the Threshold Effect Level (TEL) and Probable Effect Level (PEL), respectively.

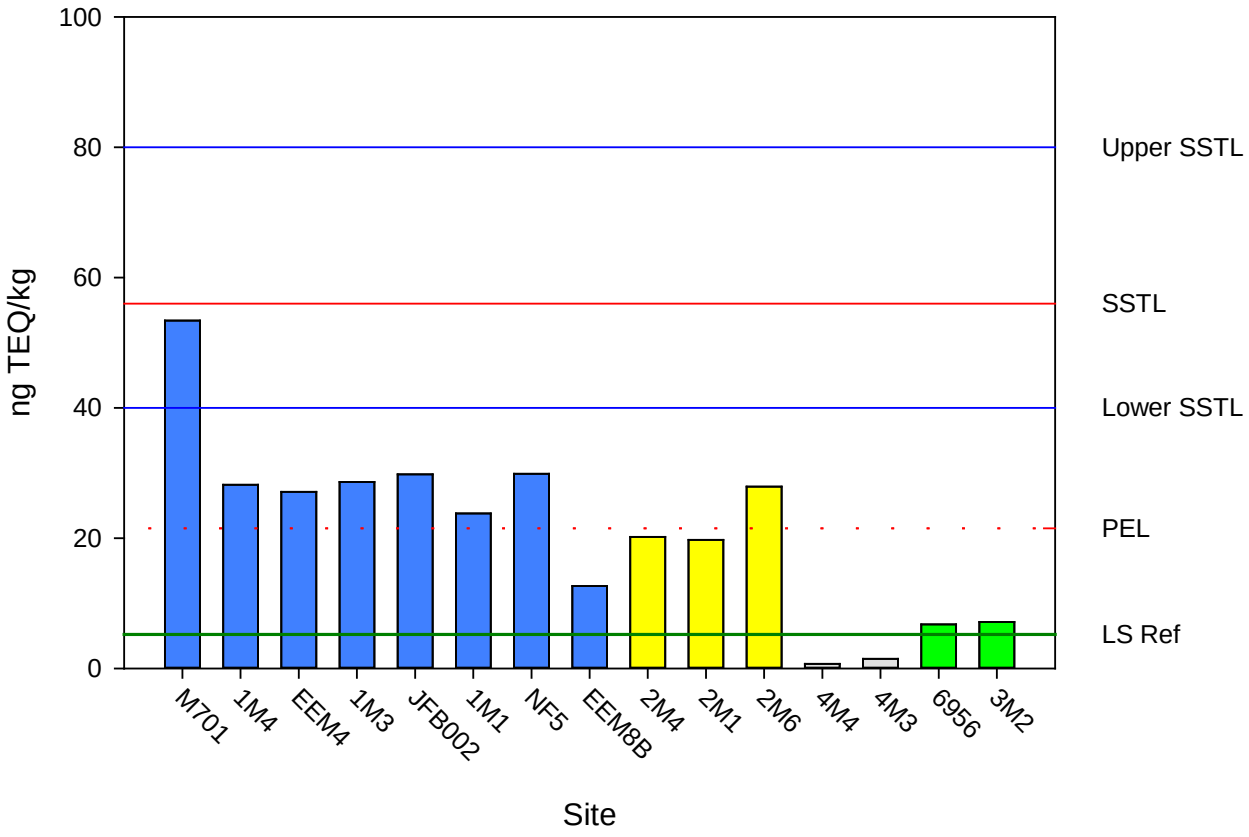


Figure 5. Sediment dioxin and furan concentrations expressed in toxic equivalents (TEQ) for 2013 Jackfish Bay sites. World Health Organization toxic equivalency factors for fish were used in the calculations (Van den Berg et al. 1998). Non-detect values were assigned half the detection limit (mid-point TEQ). The Probable Effect Level (PEL; 21.5ng·TEQ/kg) is indicated by the red dashed line and the area average Safe Sediment Target Level (SSTL; <56 ng TEQ/kg) and upper and lower SSTL levels (81 and 40 ng TEQ/kg, respectively) estimated by Richman and George (2014) are indicated by the solid red and blue lines. The solid green line represents the highest TEQ for Lake Superior sites (n=8) sampled in 2008 (5.22 pg/g). Bars are colour-coded for areas: blue = Moberly Bay, yellow = far field; grey = far far-field; green = Tunnel Bay.

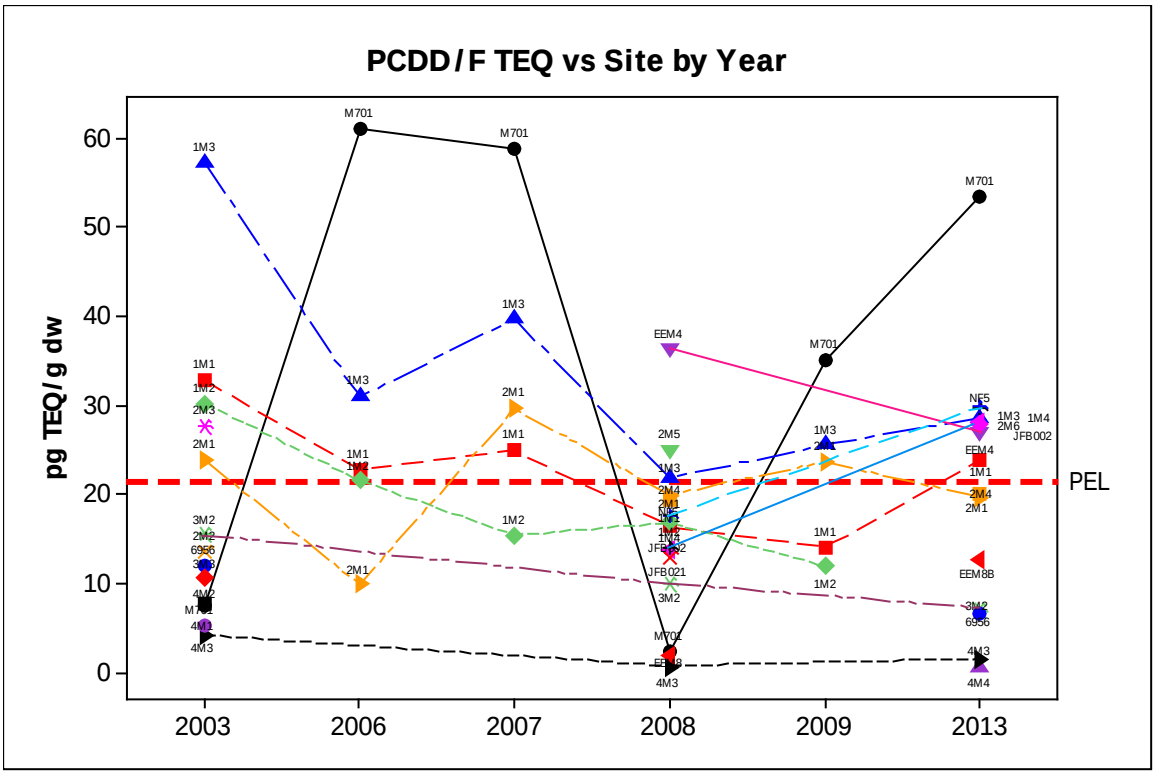


Figure 6. Temporal trends in sediment dioxins and furans (PCDD/F) toxic equivalents (TEQ) at Jackfish Bay sites from 2003 to 2013. The red dashed line represents the Probable Effect Level (PEL) of 21.5 pg/g.

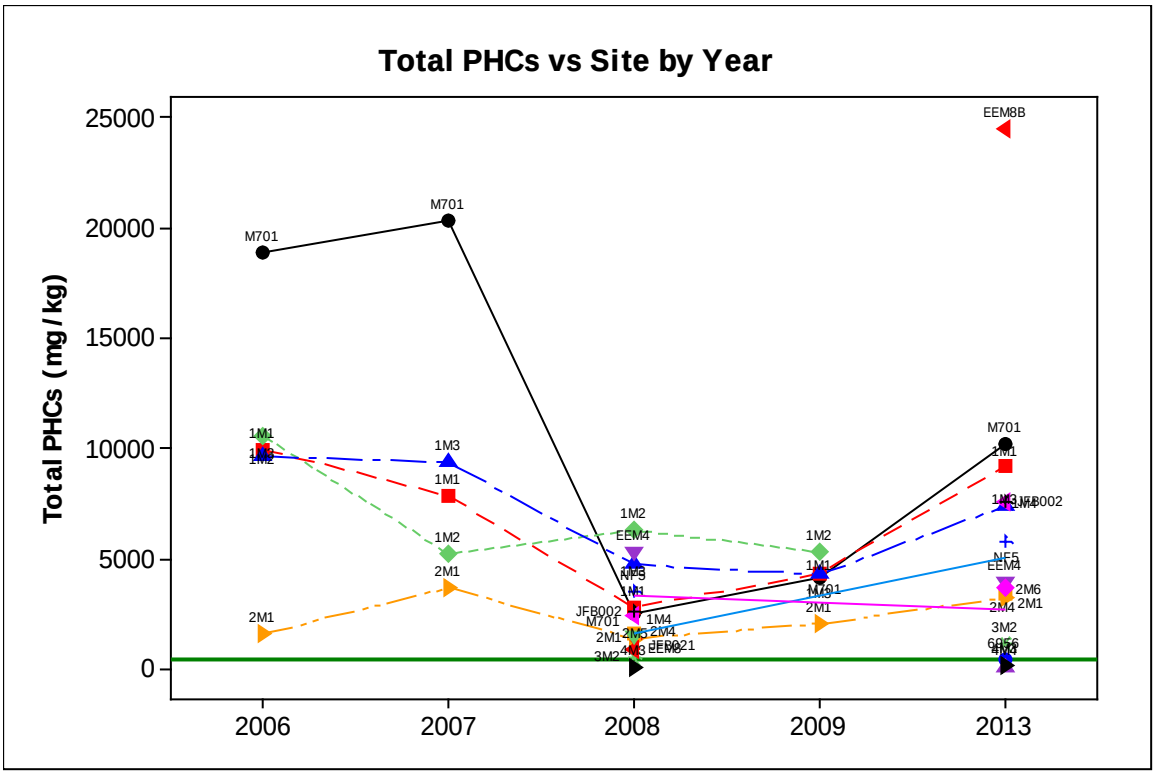


Figure 7. Temporal trends in sediment total petroleum hydrocarbons (PHC) at Jackfish Bay sites from 2003 to 2013. The 99th percentile for Lake Superior reference samples collected from 2008-2013 is indicated by the green horizontal line.

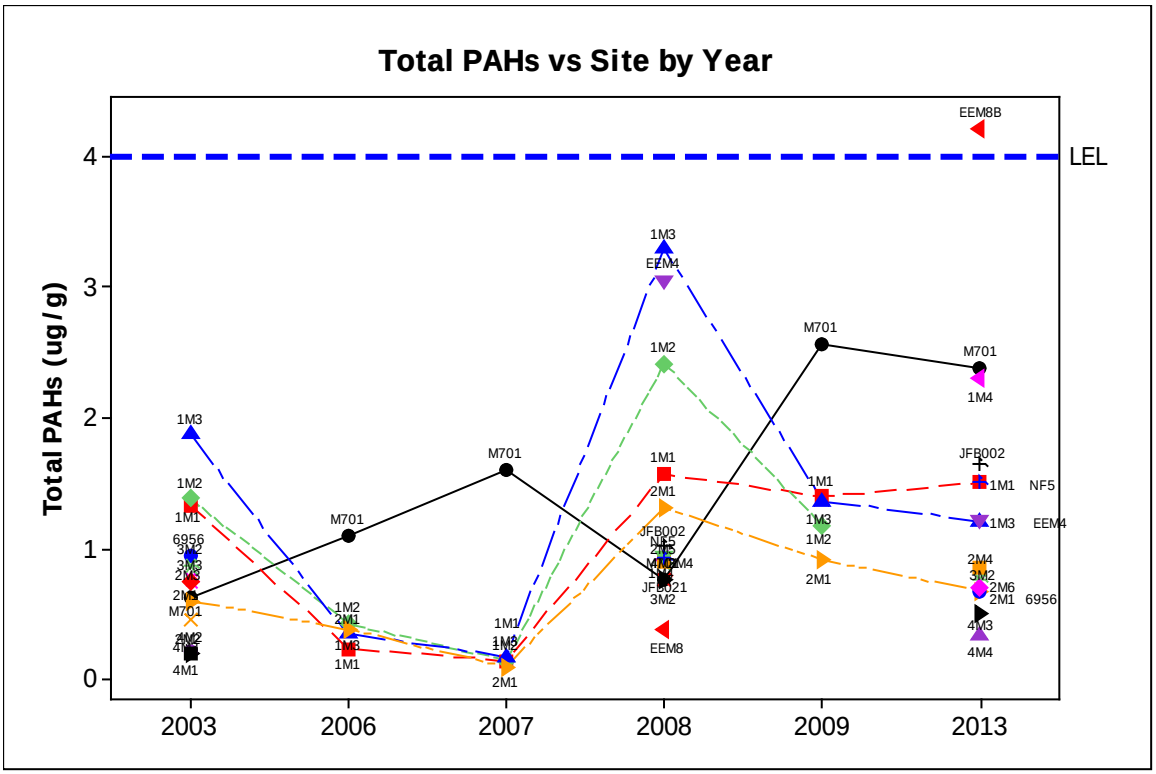


Figure 8. Temporal trends in sediment PAHs at Jackfish Bay sites from 2003 to 2013. The blue dashed line represents the Lowest Effect Level (LEL).

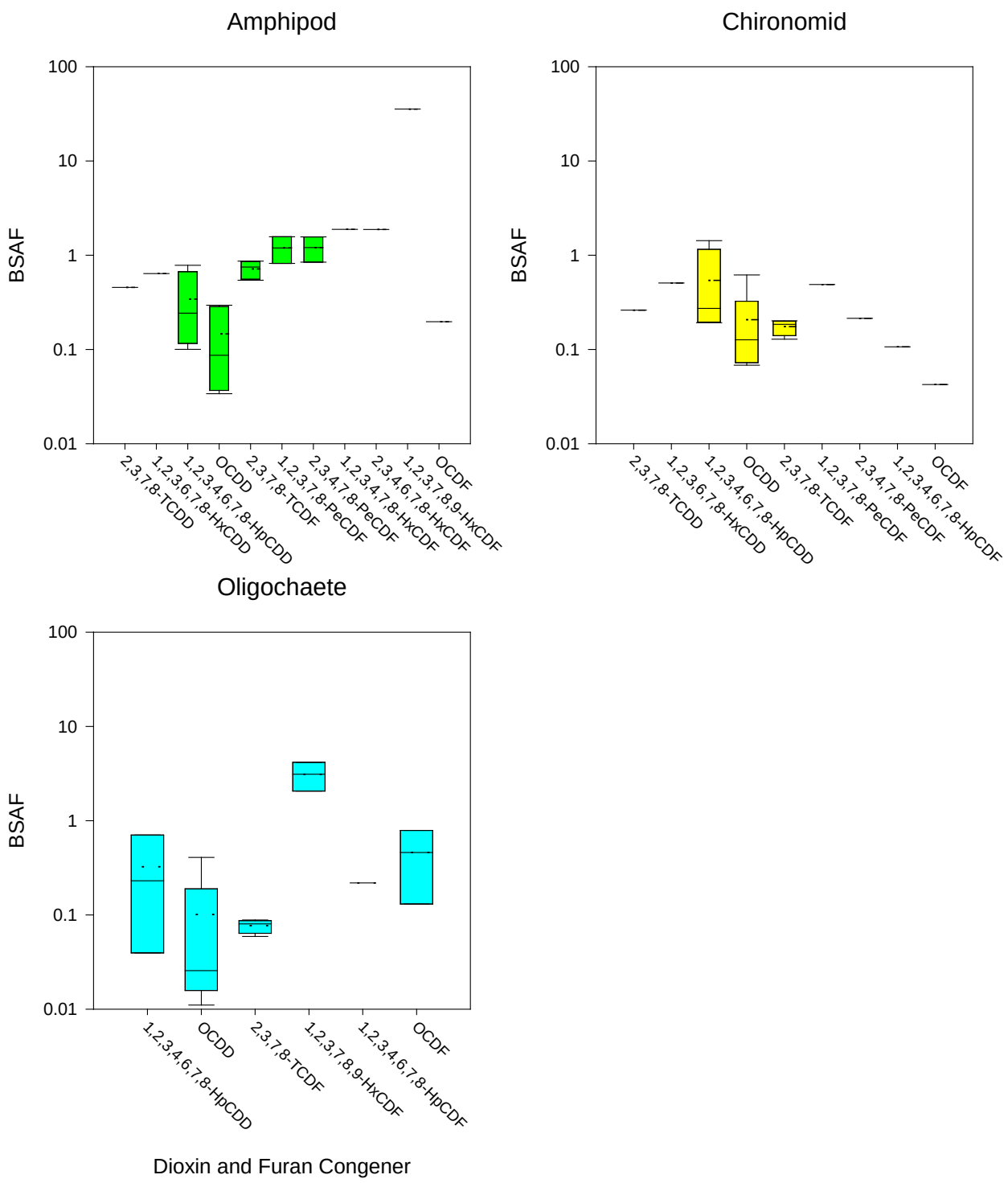


Figure 9. Biota-sediment accumulation factors (BSAF) for dioxin and furan congeners that were detected in paired 2013 Jackfish Bay samples.

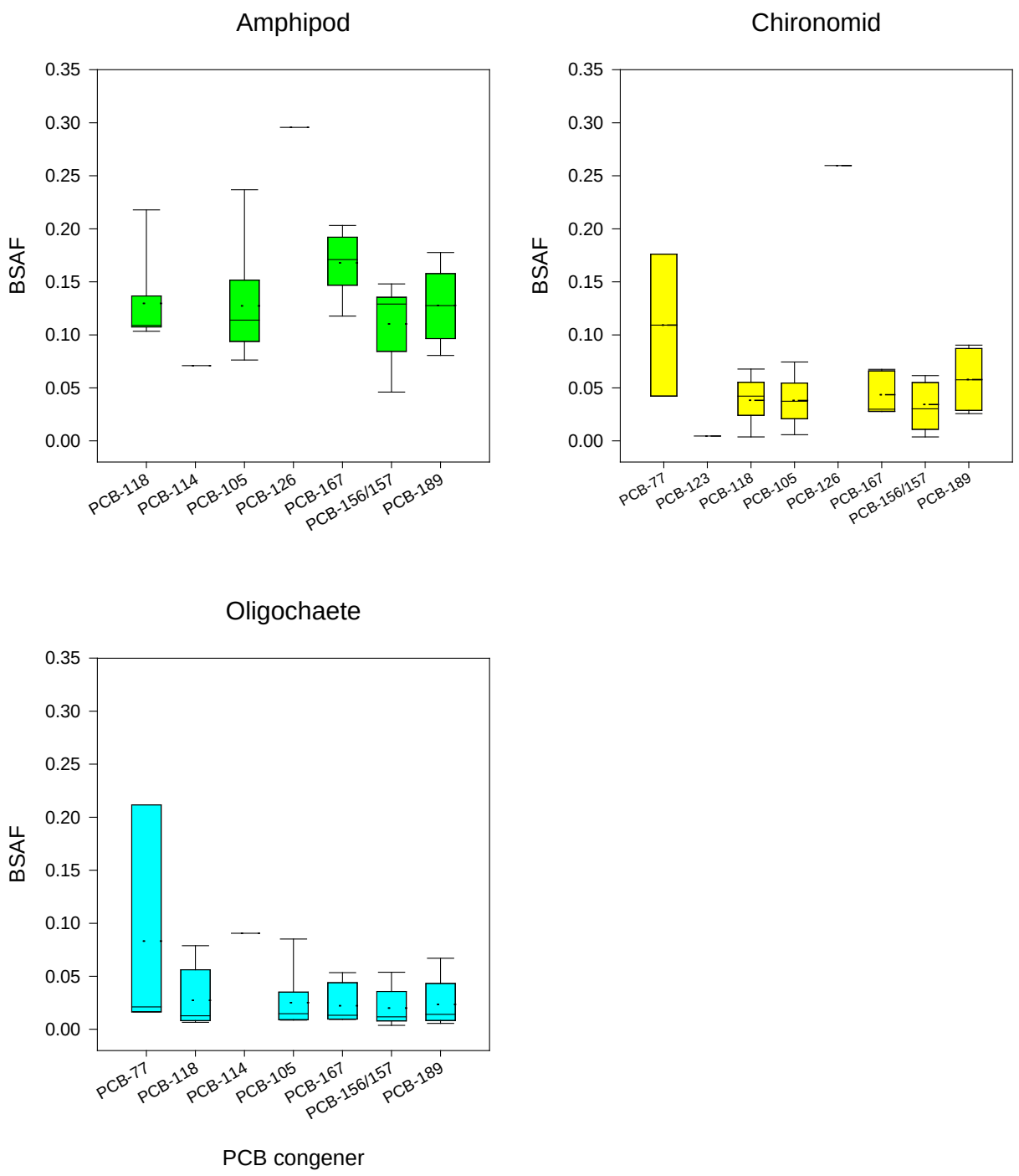


Figure 10. Biota-sediment accumulation factors (BSAF) for dioxin-like PCBs that were detected in paired 2013 Jackfish Bay samples.

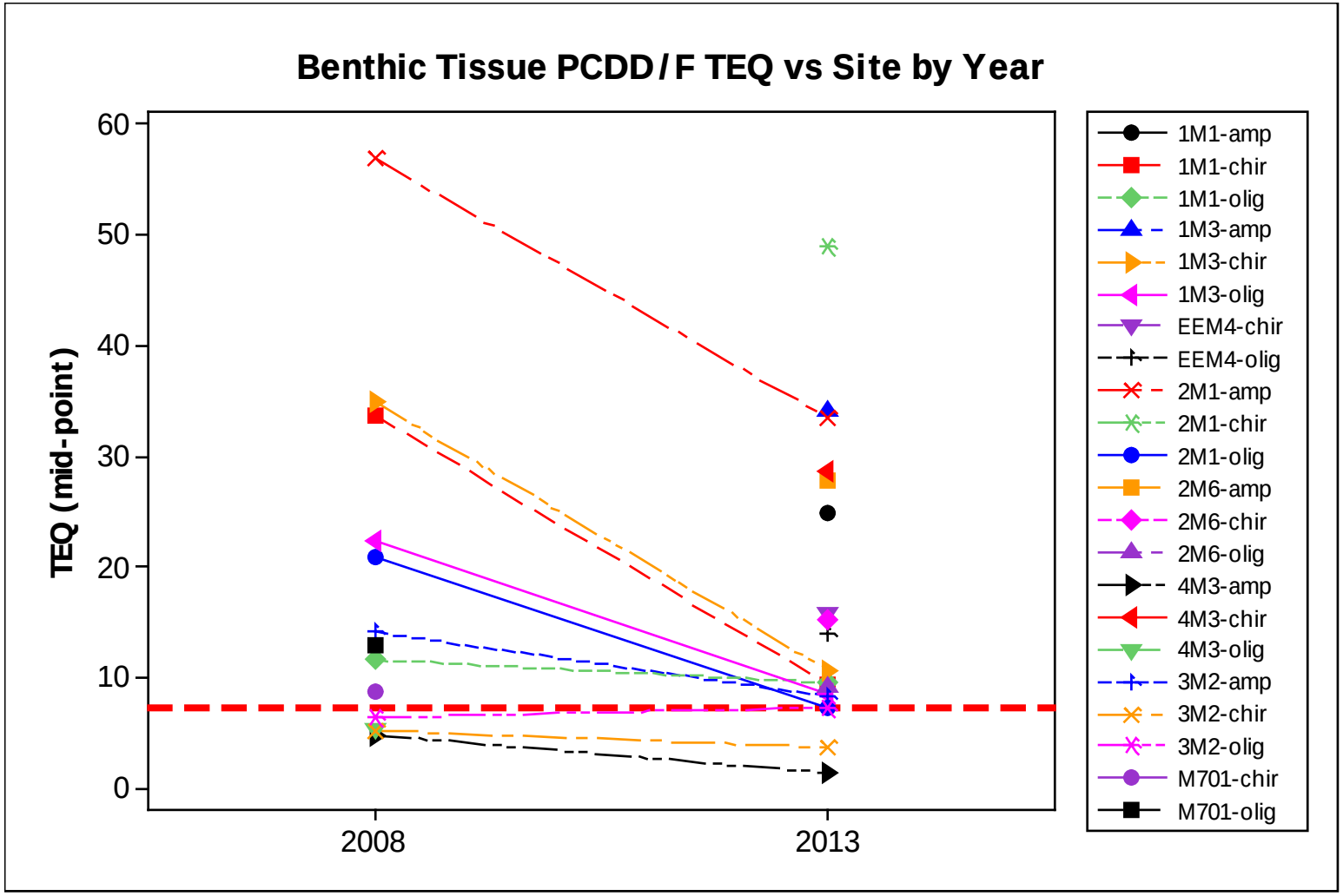


Figure 11. Temporal trends in Jackfish Bay invertebrate tissue dioxin and furan (PCDD/F) concentrations, expressed in toxic equivalents (TEQ) from 2008 to 2013. The TEQ was calculated using ½ the method detection limit for non-detects (mid-point TEQ). The red dashed line represents a modified Tissue Residue Guideline (TRG) of 7.3 pg TEQ/g ww (see text for details).

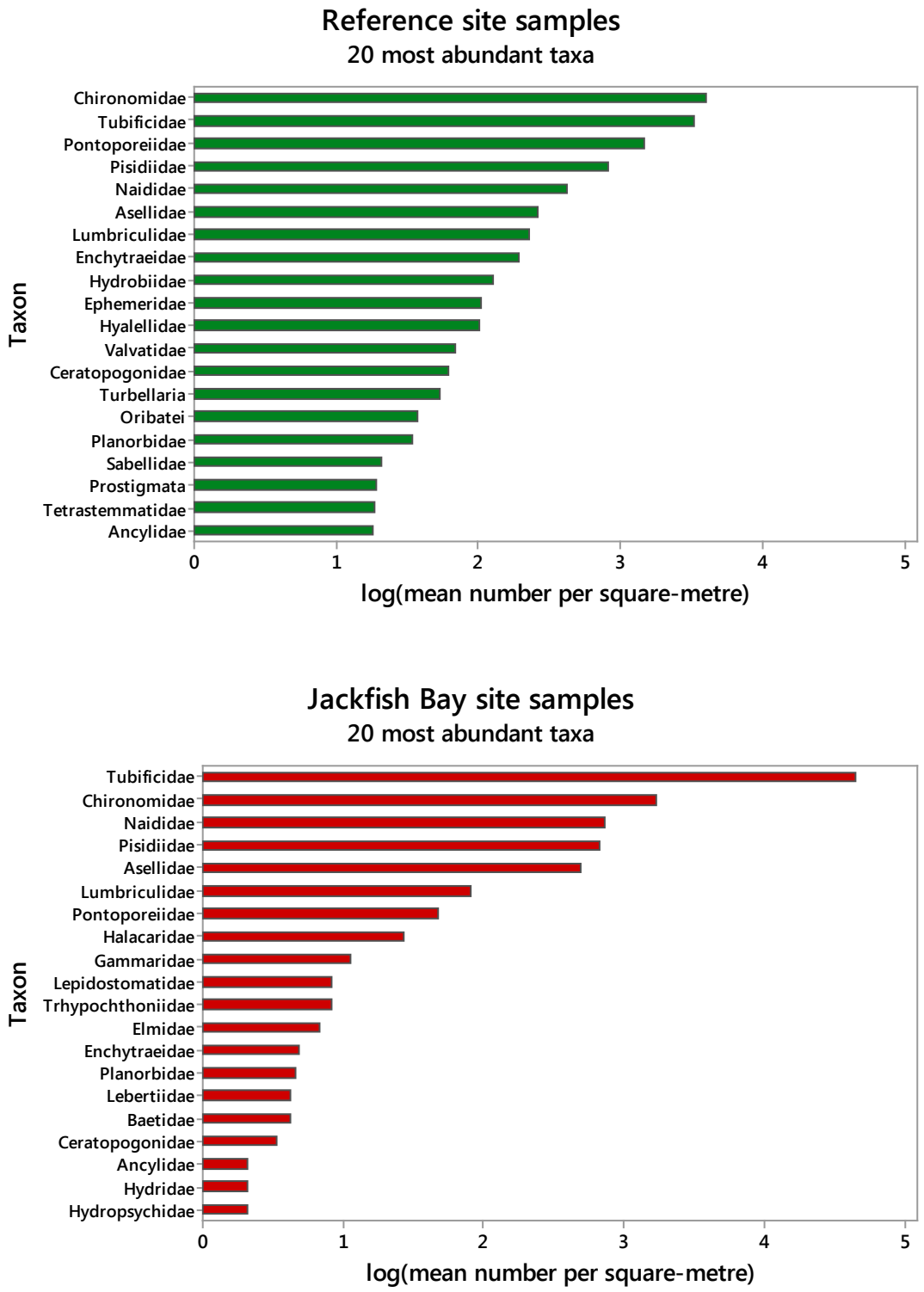


Figure 12. Most abundant (dominant) invertebrate taxa (20 most abundant) from Great Lakes reference sites (green) compared to 2013 Jackfish Bay sites (red).

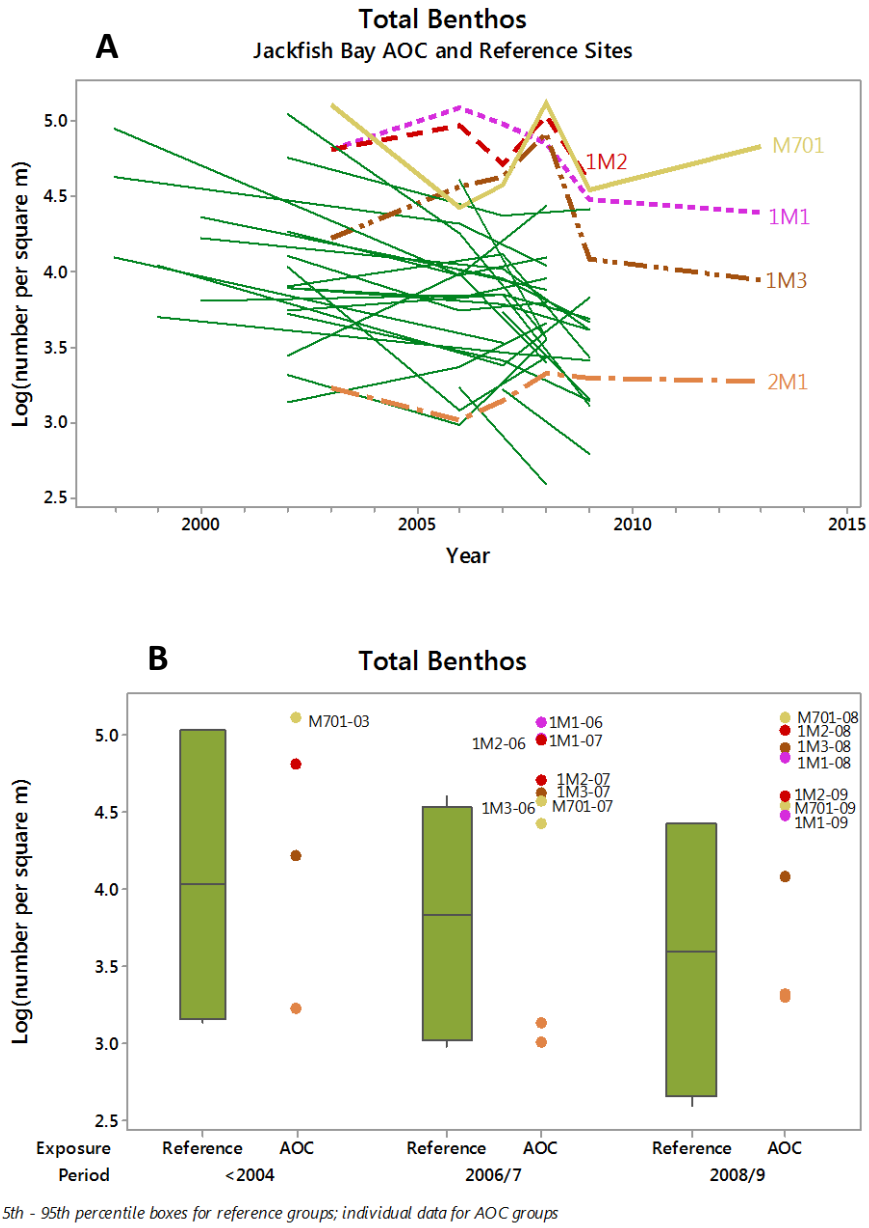


Figure 13. **A.** Temporal trends in total benthos for Jackfish Bay (labelled lines) and reference site (green lines) benthic communities sampled 1998-2013. **B.** Comparisons of total benthos for Jackfish Bay samples (circles) to 5th – 95th percentile intervals (boxes) for reference site samples (green boxes) within 3 periods. Jackfish Bay samples outside of the boxes are labelled.

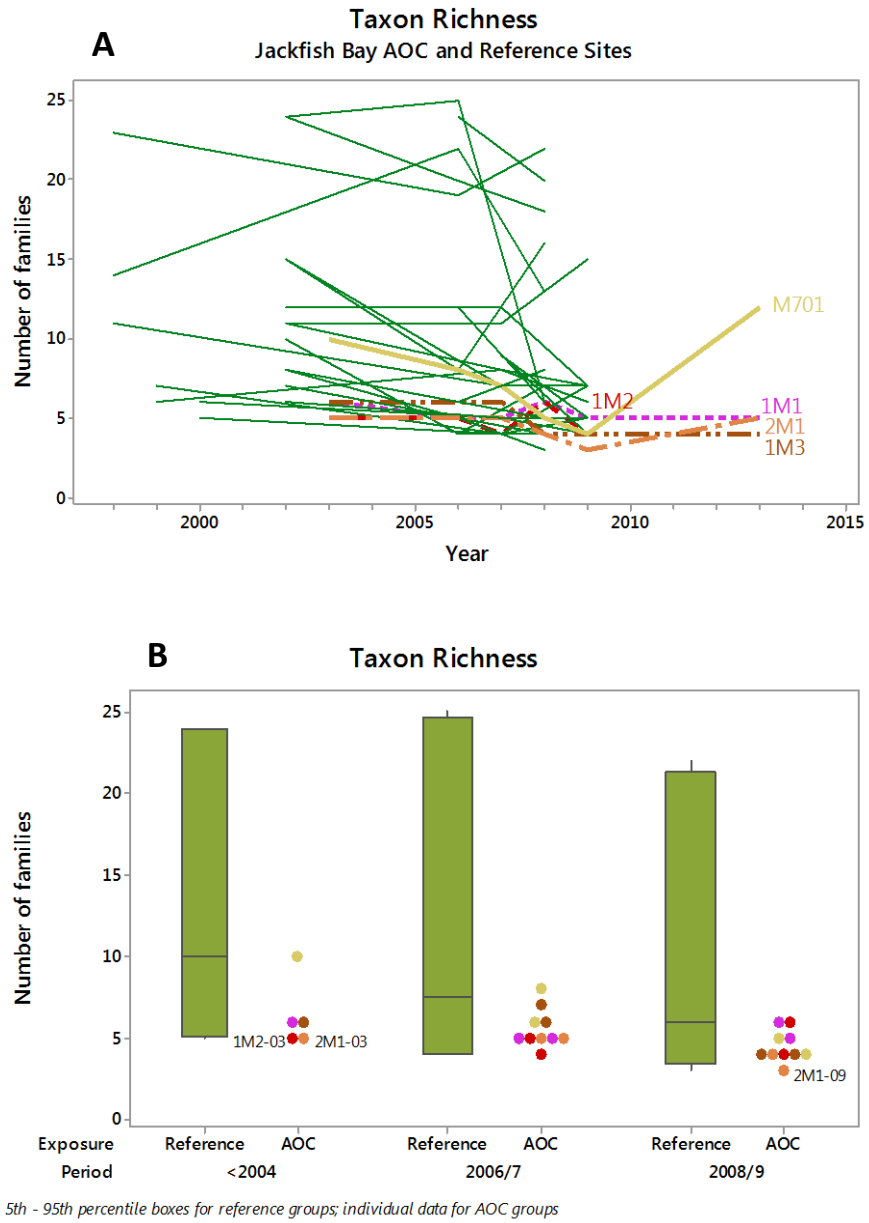


Figure 14. Temporal trends (**A**) and statistical comparisons (**B**) for taxon richness of Jackfish Bay and reference site benthic communities. See caption for Fig. 13 for explanation.

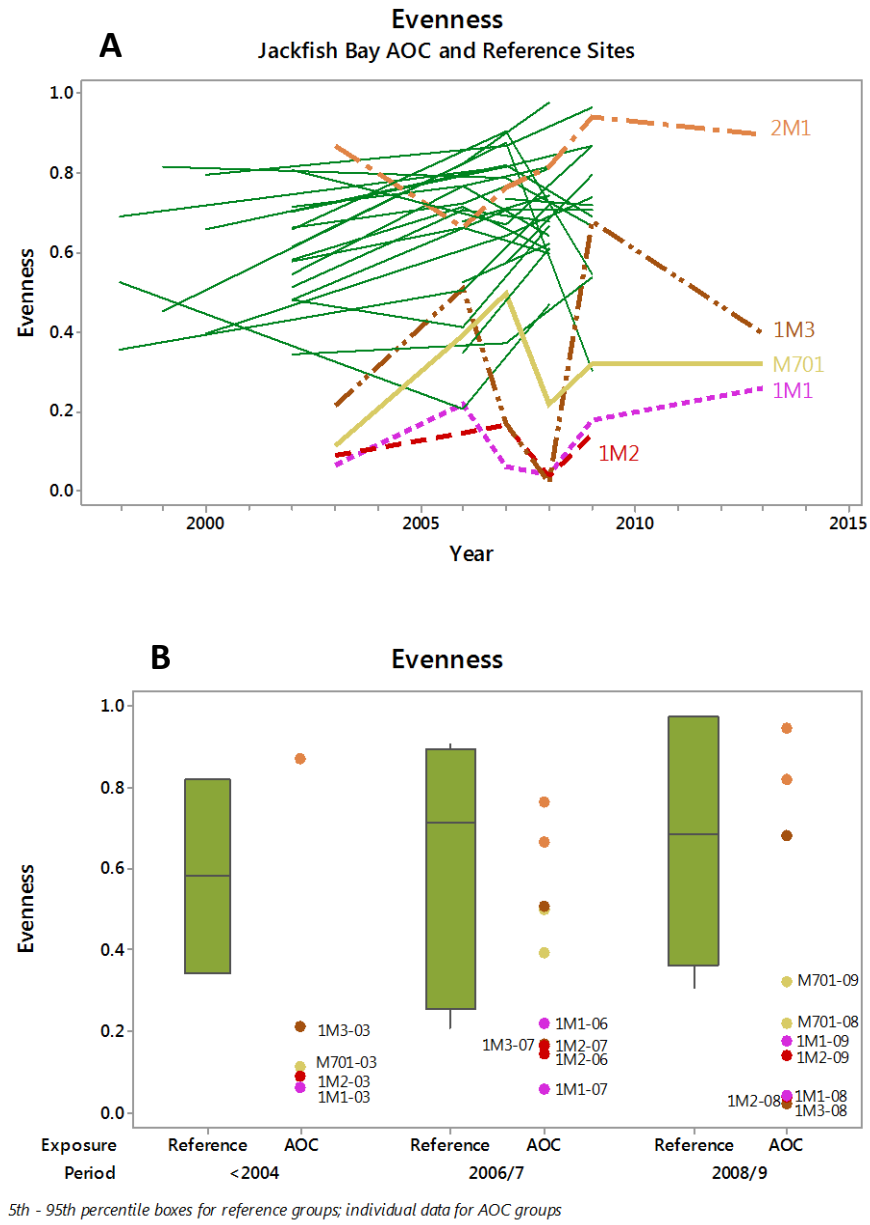


Figure 15. Temporal trends (**A**) and statistical comparisons (**B**) for evenness of Jackfish Bay and reference site benthic communities. See caption for Fig. 13 for explanation.

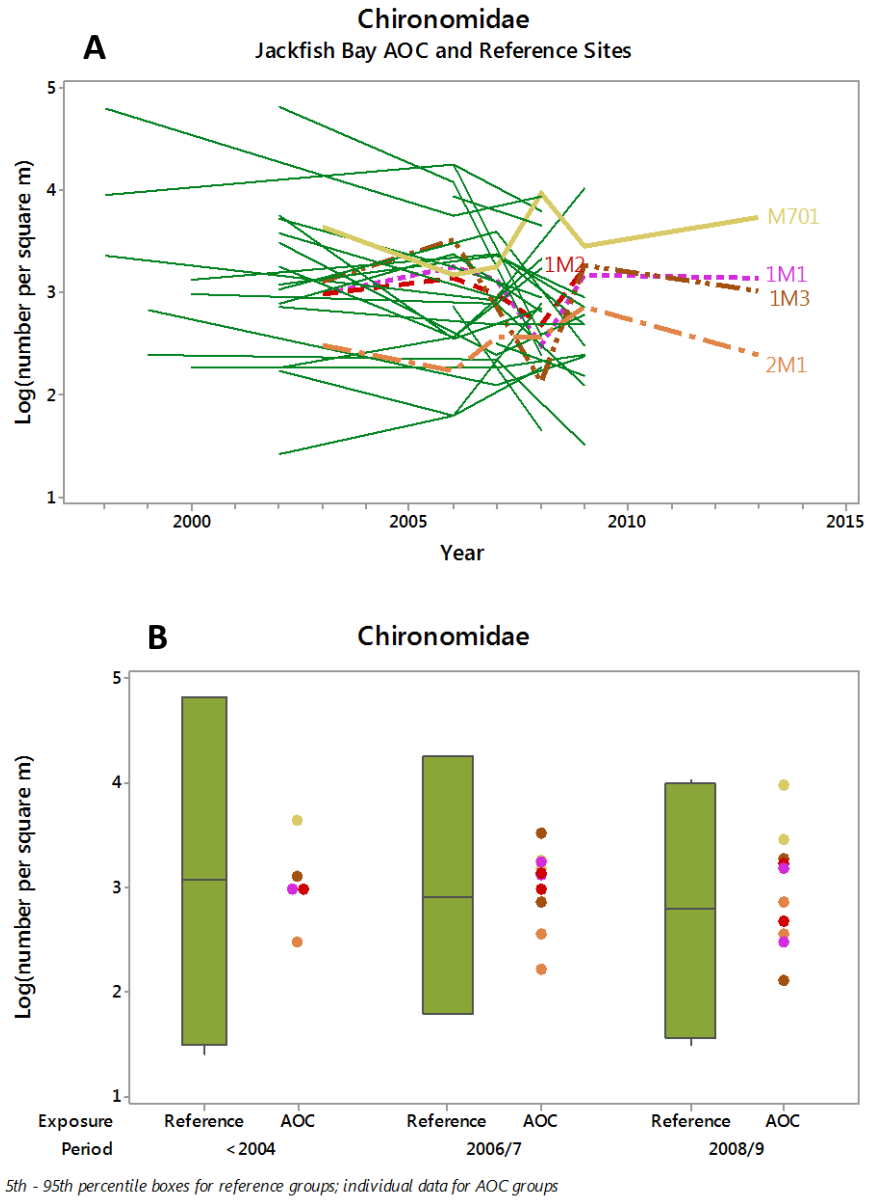


Figure 16. Temporal trends (**A**) and statistical comparisons (**B**) for Chironomidae of Jackfish Bay and reference site benthic communities. See caption for Fig. 13 for explanation.

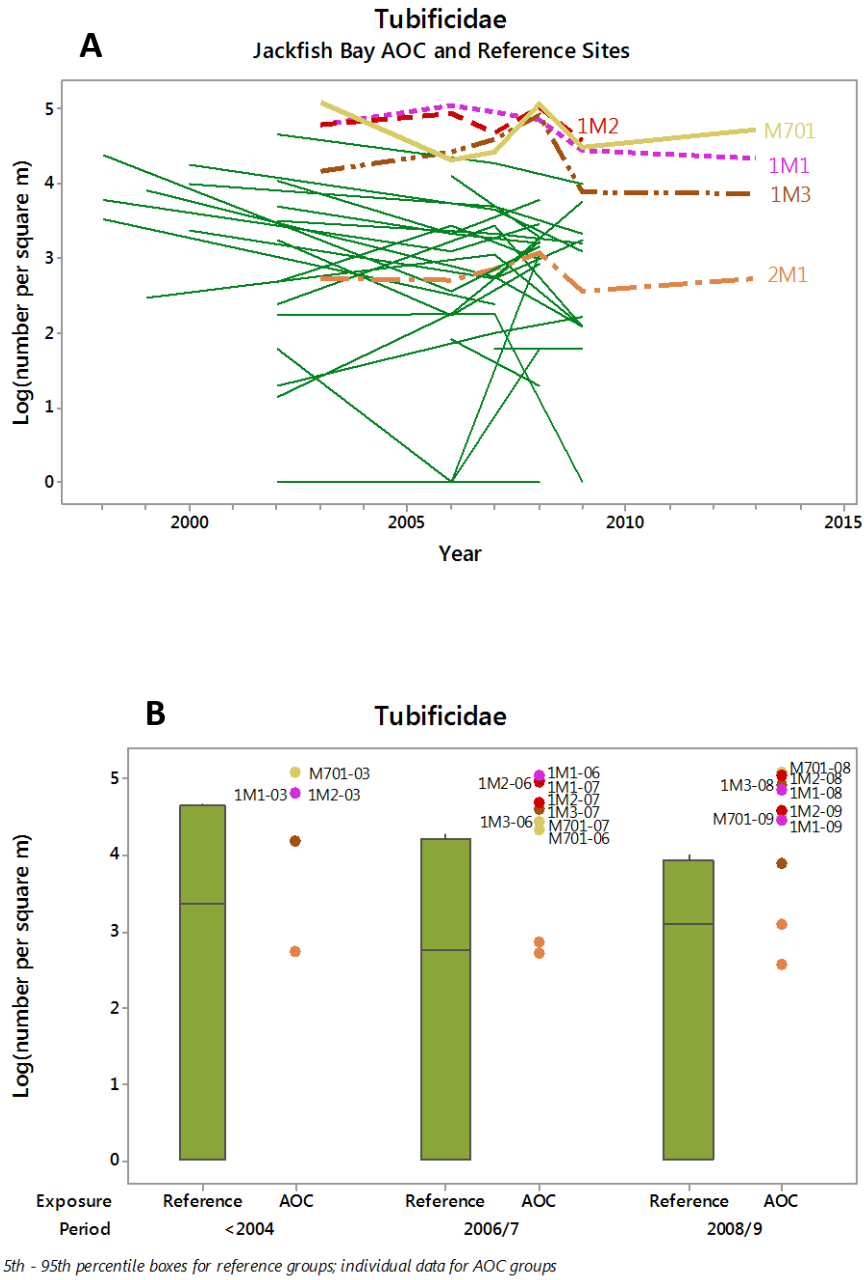


Figure 17. Temporal trends (**A**) and statistical comparisons (**B**) for Tubificidae of Jackfish Bay and reference site benthic communities. See caption for Fig. 13 for explanation.

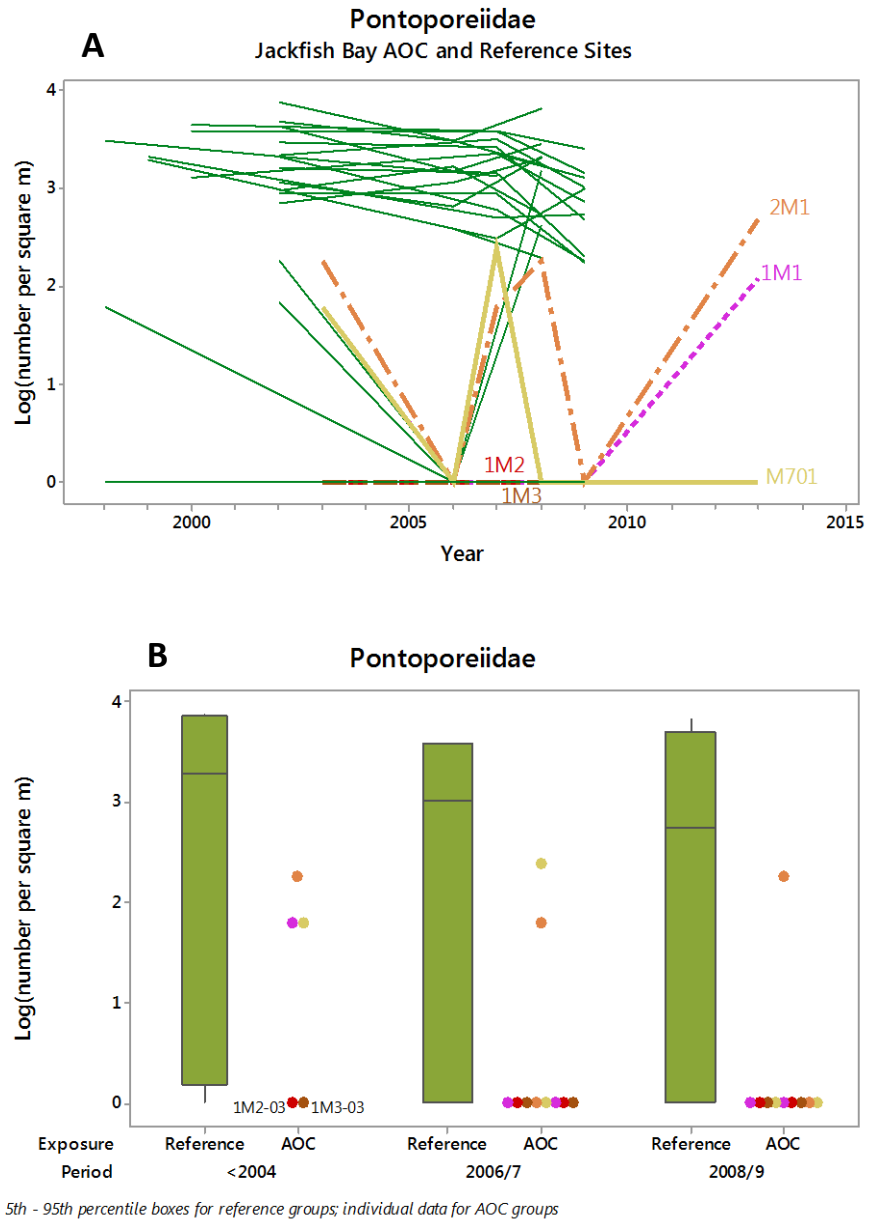


Figure 18. Temporal trends (**A**) and statistical comparisons (**B**) for Pontoporeiidae of Jackfish Bay and reference site benthic communities. See caption for Fig. 13 for explanation.

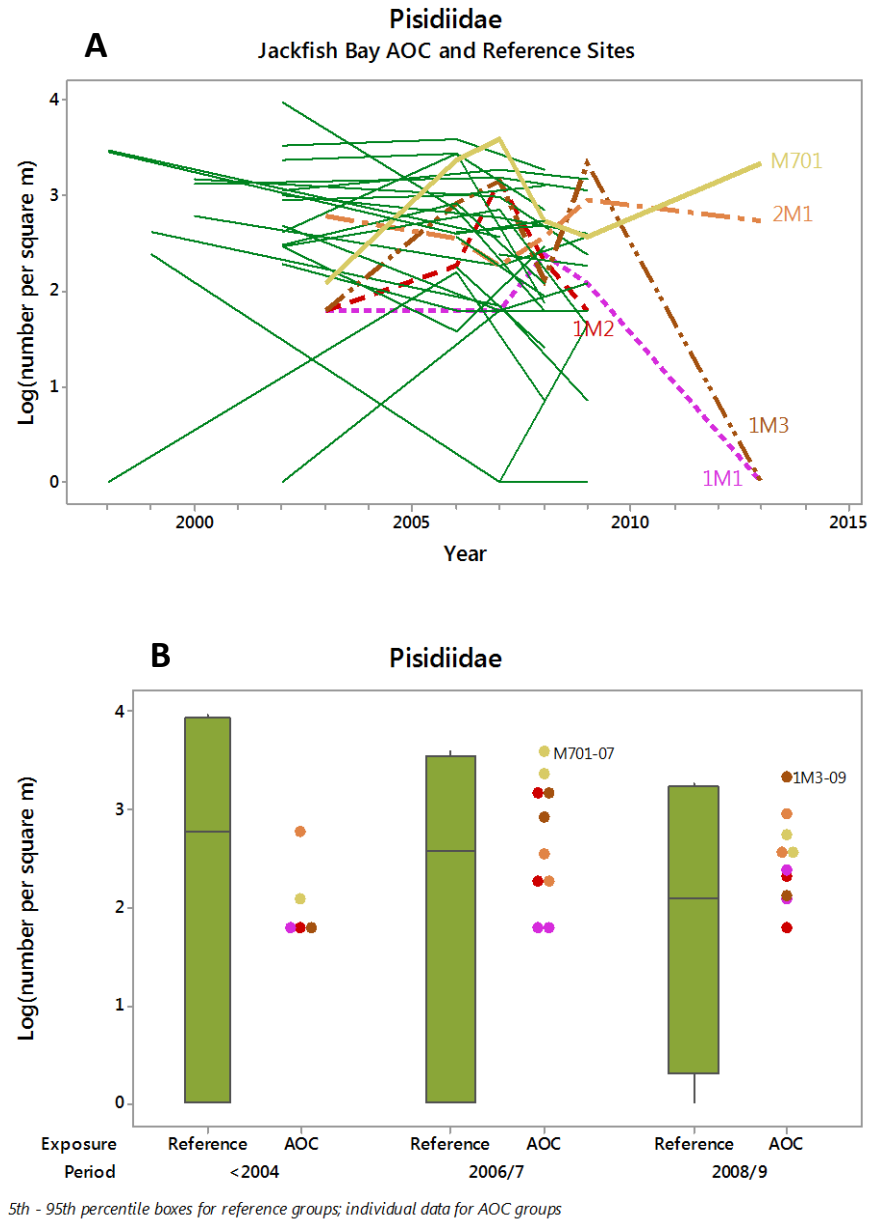


Figure 19. Temporal trends (**A**) and statistical comparisons (**B**) for Pisidiidae of Jackfish Bay and reference site benthic communities. See caption for Fig. 13 for explanation.

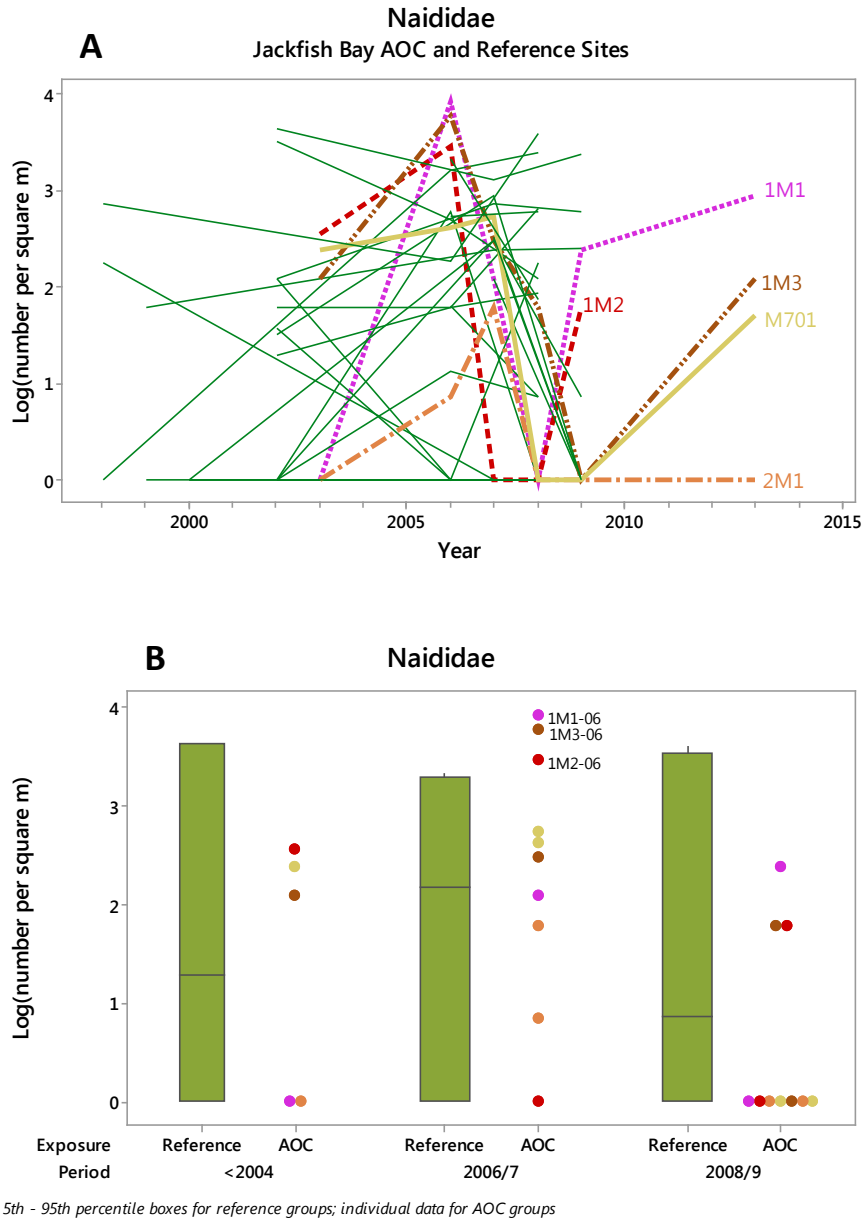


Figure 20. Temporal trends (**A**) and statistical comparisons (**B**) for Naididae of Jackfish Bay and reference site benthic communities. See caption for Fig. 13 for explanation.

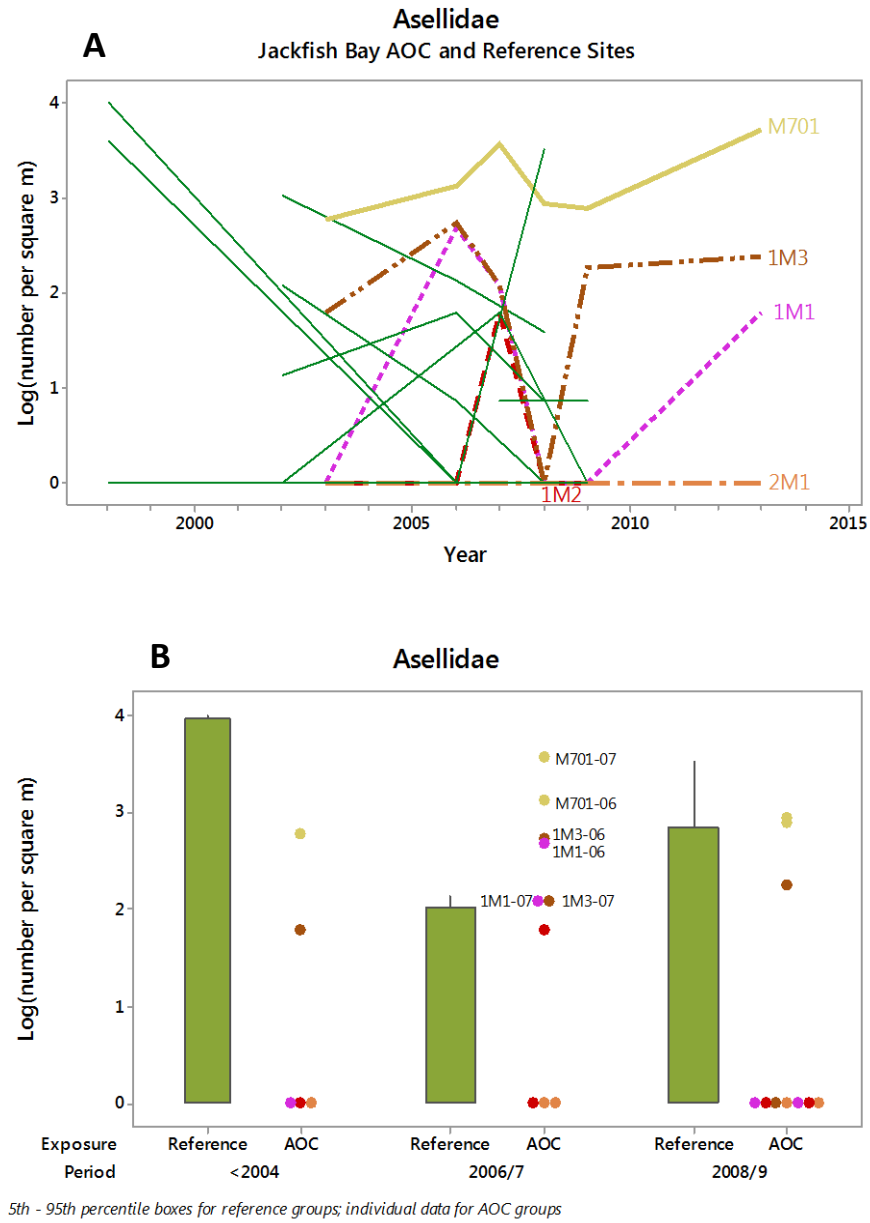


Figure 21. Temporal trends (**A**) and statistical comparisons (**B**) for Asellidae of Jackfish Bay and reference site benthic communities. See caption for Fig. 13 for explanation.

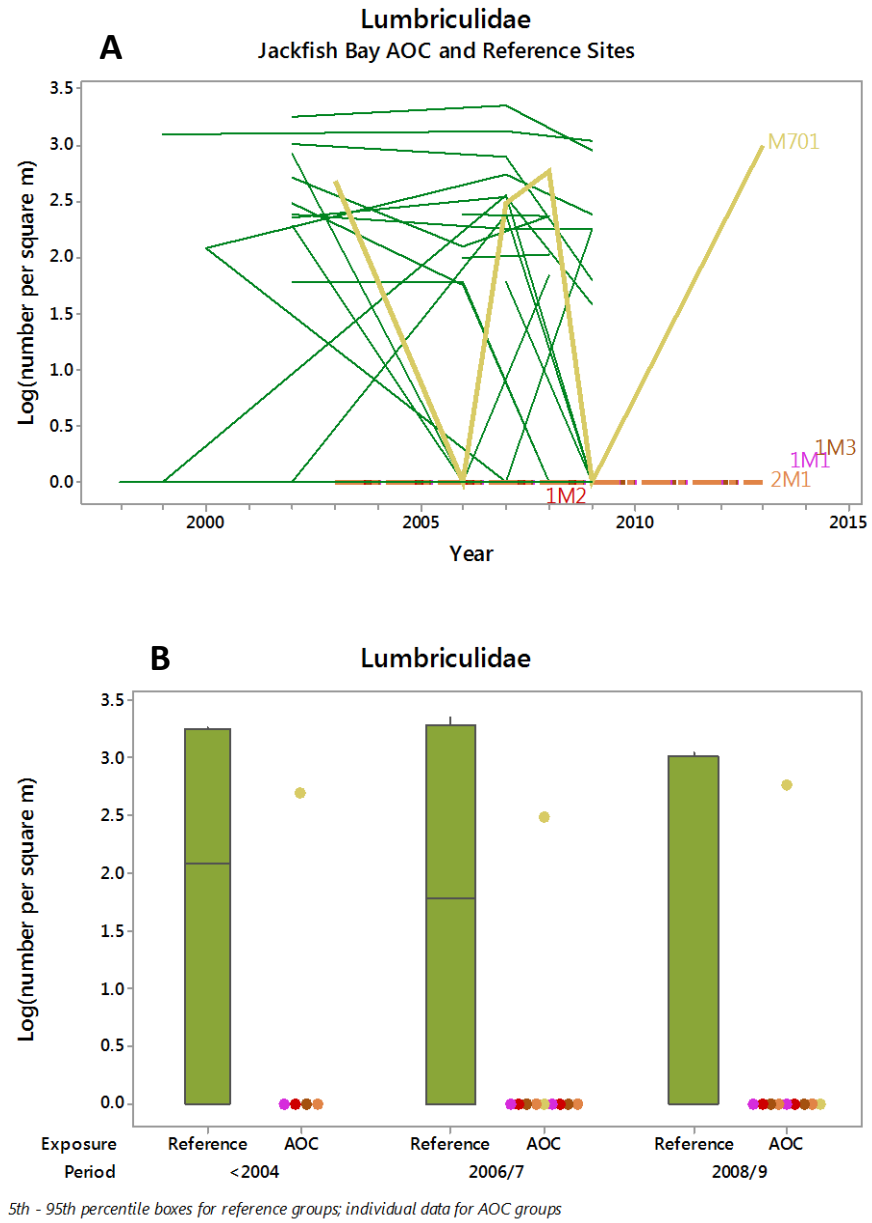


Figure 22. Temporal trends (**A**) and statistical comparisons (**B**) for Lumbriculidae of Jackfish Bay and reference site benthic communities. See caption for Fig. 13 for explanation.

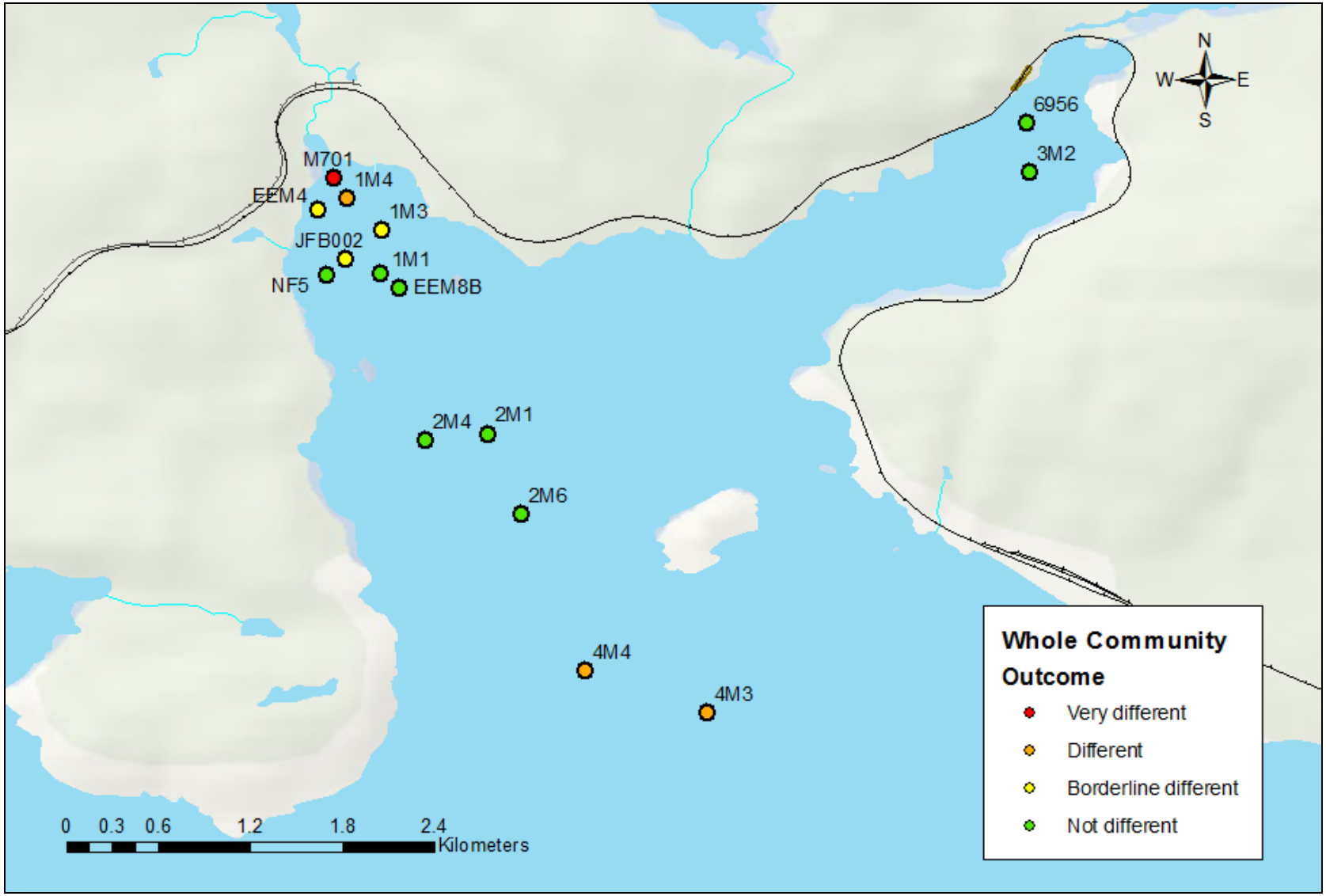
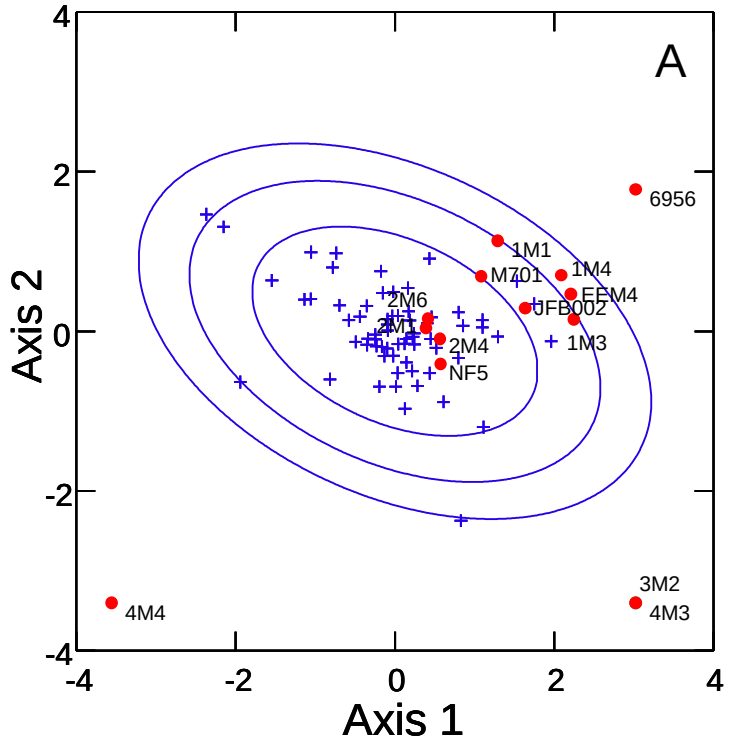


Figure 23. Spatial distribution of 2013 Jackfish Bay sites (n=15) indicating the outcomes of assessments relative to reference conditions.



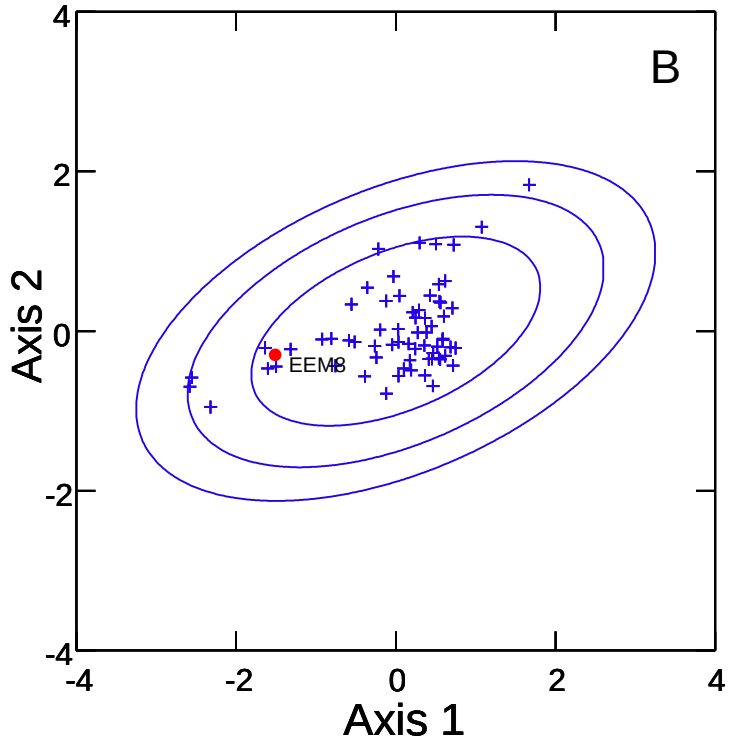


Figure 24. Nonmetric multidimensional scaling of 2013 Jackfish Bay sites (red) fitted into Great Lakes reference site (cross hairs) ordination space. Three confidence ellipses, constructed around the reference sites, define the four assessment bands: Band 1 - non-toxic (within 90%), Band 2 - potentially toxic (between 90% and 99%), Band 3 - toxic and Band 4 - severely toxic (outside the 99.9%). (A) Two-dimensional solution for 14 test sites, mean stress = 12.125, and (B) three-dimensional solution for site EEM8B, summarized on axes 1 and 2, mean stress = 0.

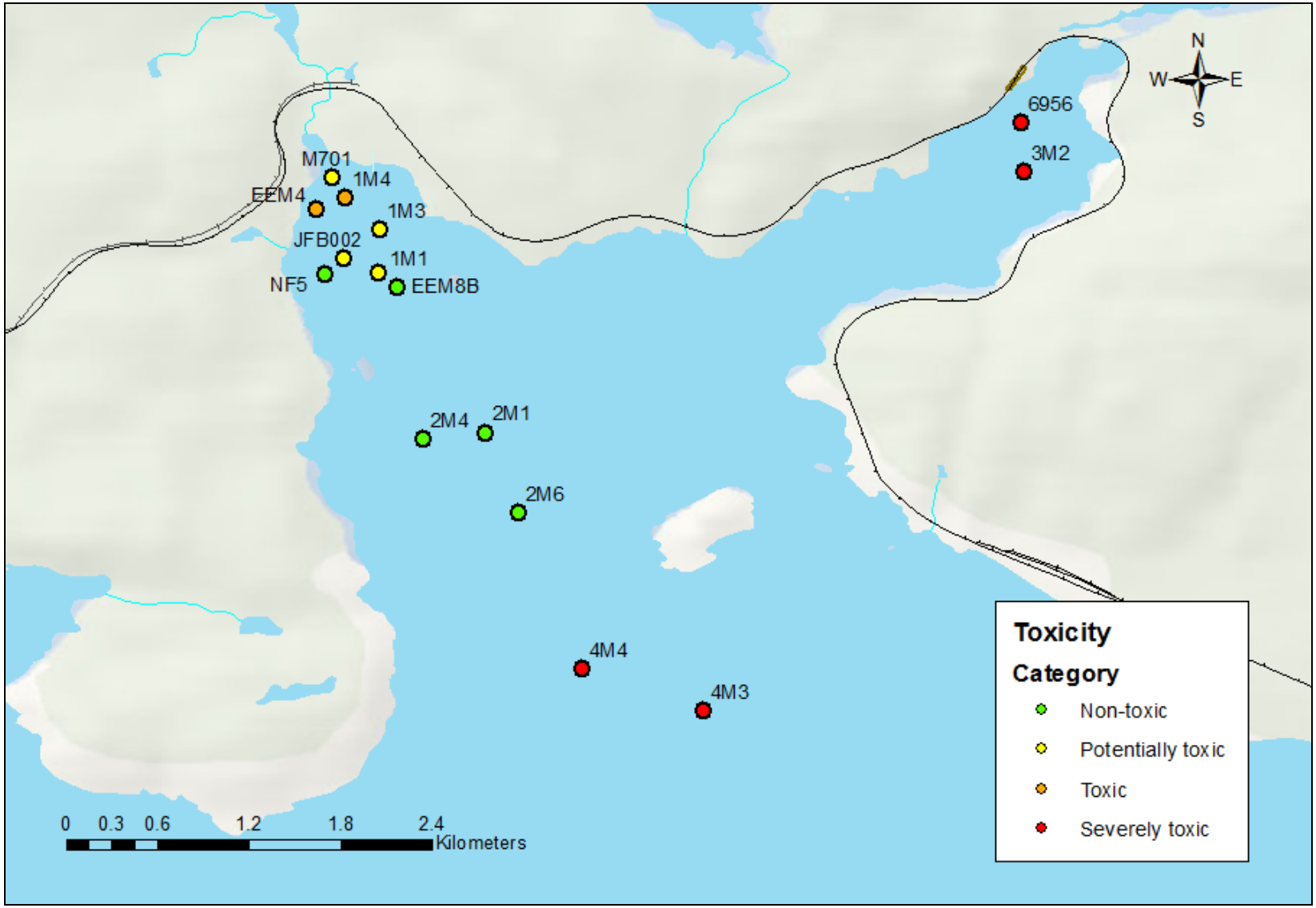


Figure 25. Spatial distribution of 2013 Jackfish Bay sites (n=15) indicating the level of toxicity compared to Great Lakes reference sites.

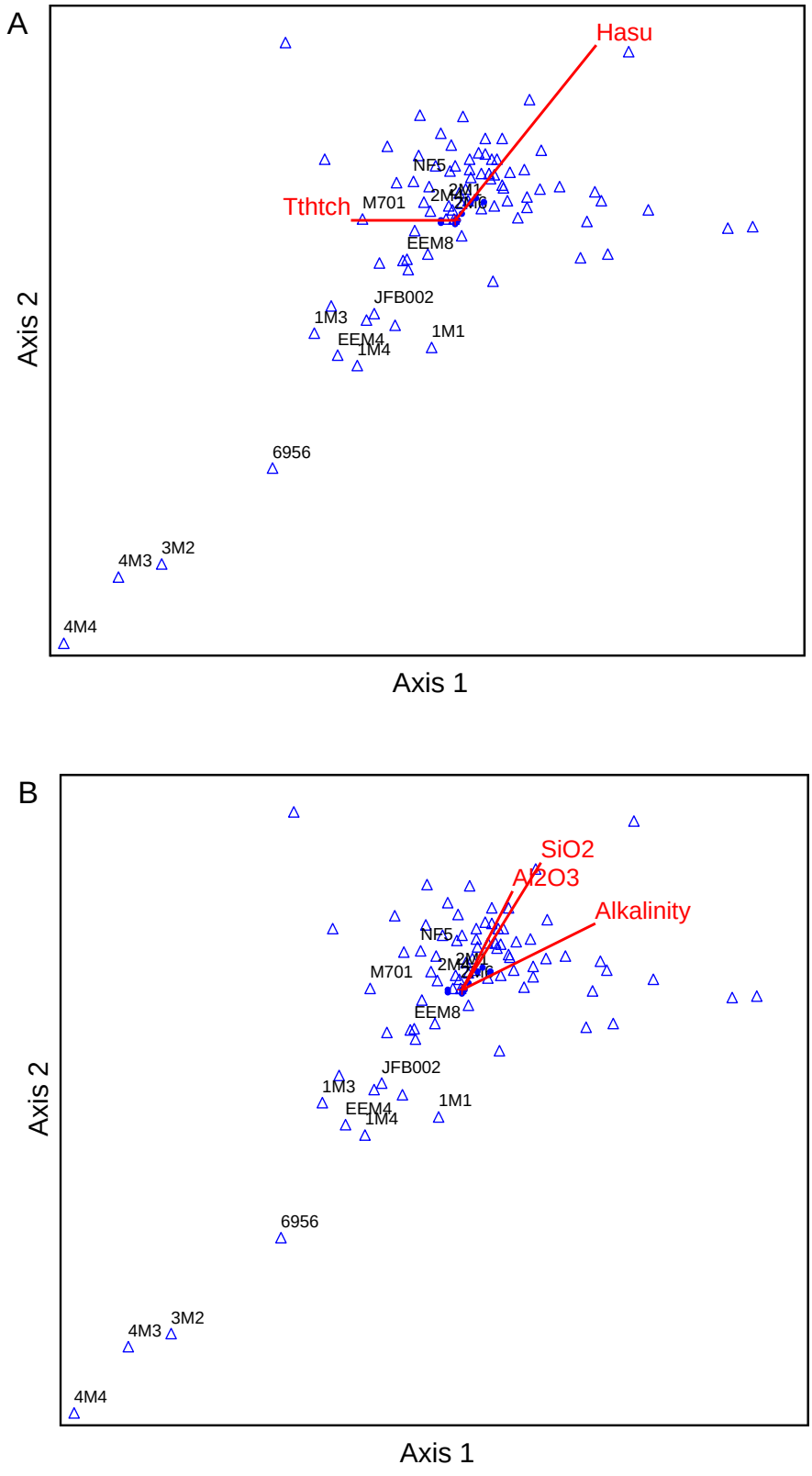


Figure 26. Two-dimensional nonmetric multidimensional scaling of reference and Jackfish Bay (labelled) sites: (A) joint plot showing the relative relationship of toxicity endpoints to the site axes scores, and (B) correlation association between ordination axes scores and explanatory (habitat) variables. Endpoints and habitat variables with $r^2 \geq 0.50$ and $r^2 \geq 0.30$, respectively, are shown. The longer the line the stronger the influence of the variable on the axis (endpoint vectors were scaled down to 60%). Hasu = *Hyalella* survival, Tthtch = Tubifex % hatched cocoons.

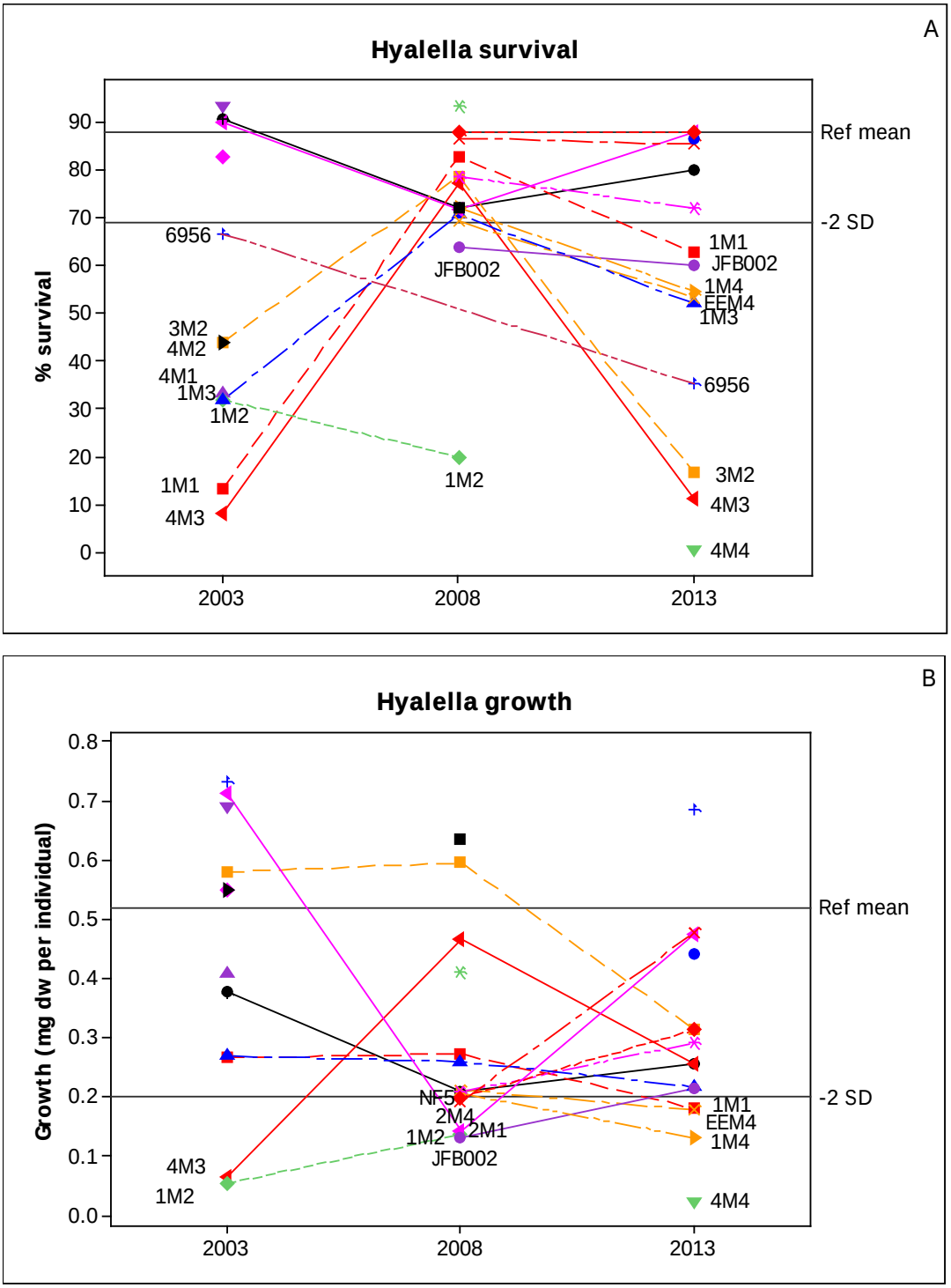


Figure 27. Trends in *H. azteca* (A) survival and (B) growth from 2003-2013 for Jackfish Bay sites. The horizontal lines represent the Great Lakes reference mean (n= 66 sites), and minus 2 standard deviations (SD) from the mean. Sites below -2 SD of the mean are labelled.

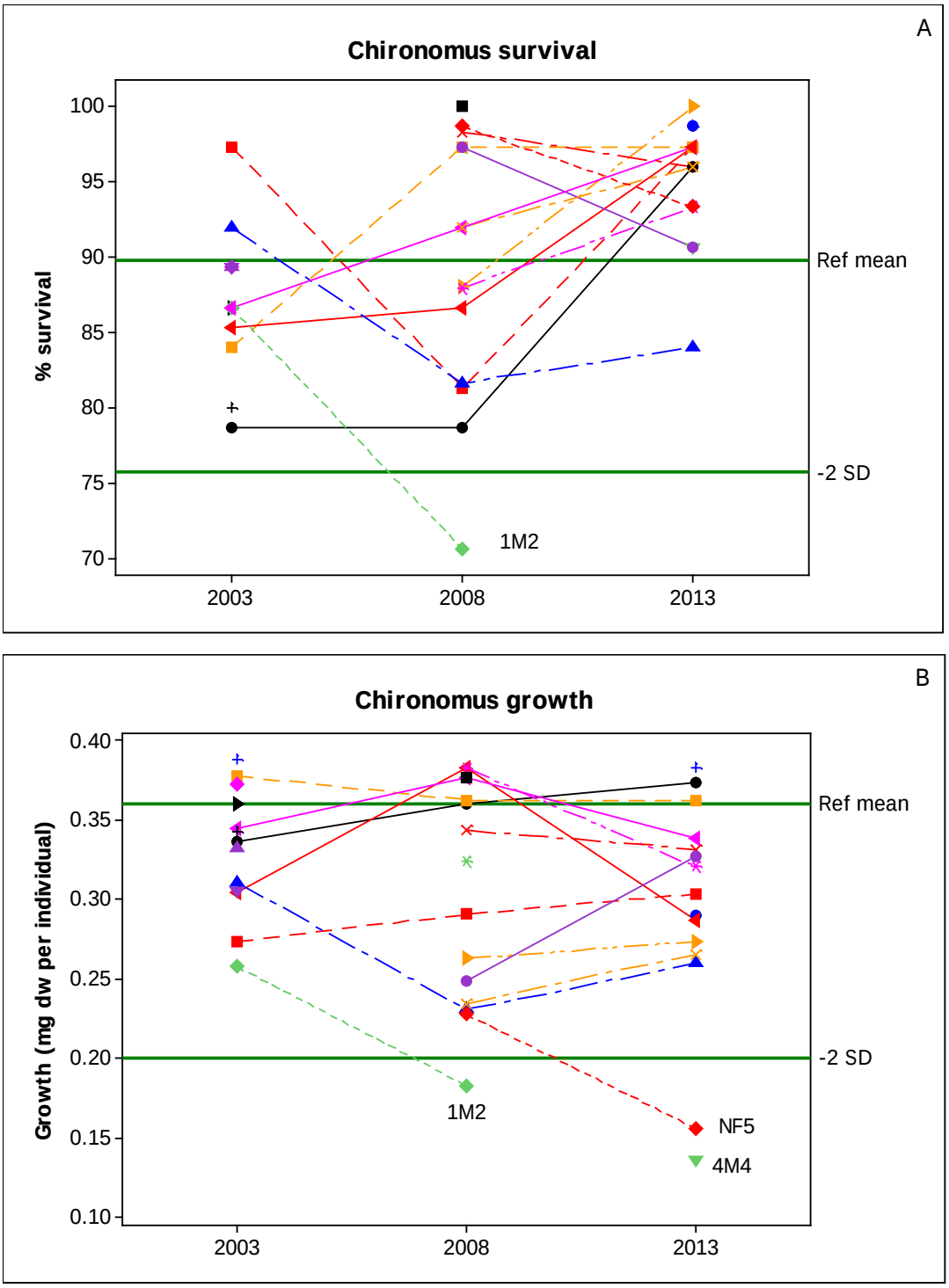


Figure 28. Trends in *C. riparius* (A) survival and (B) growth from 2003-2013 for Jackfish Bay sites. The horizontal lines represent the Great Lakes reference mean (n= 66 sites), and minus 2 standard deviations (SD) from the mean. Sites below -2 SD of the mean are labelled.

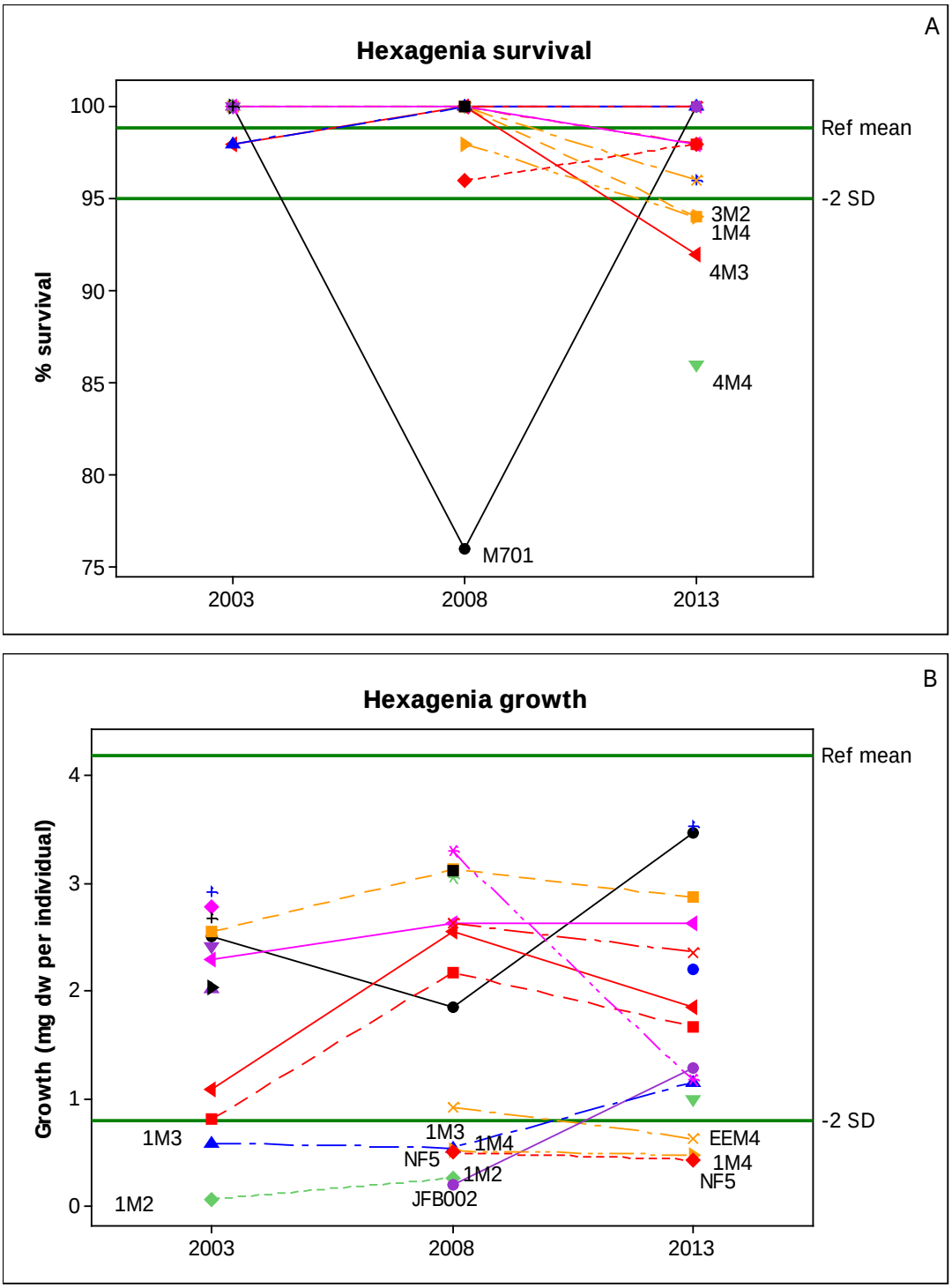


Figure 29. Trends in *Hexagenia* spp. (A) survival and (B) growth from 2003-2013 for Jackfish Bay sites. The horizontal lines represent the Great Lakes reference mean (n= 66 sites), and minus 2 standard deviations (SD) from the mean. Sites below -2 SD of the mean are labelled.

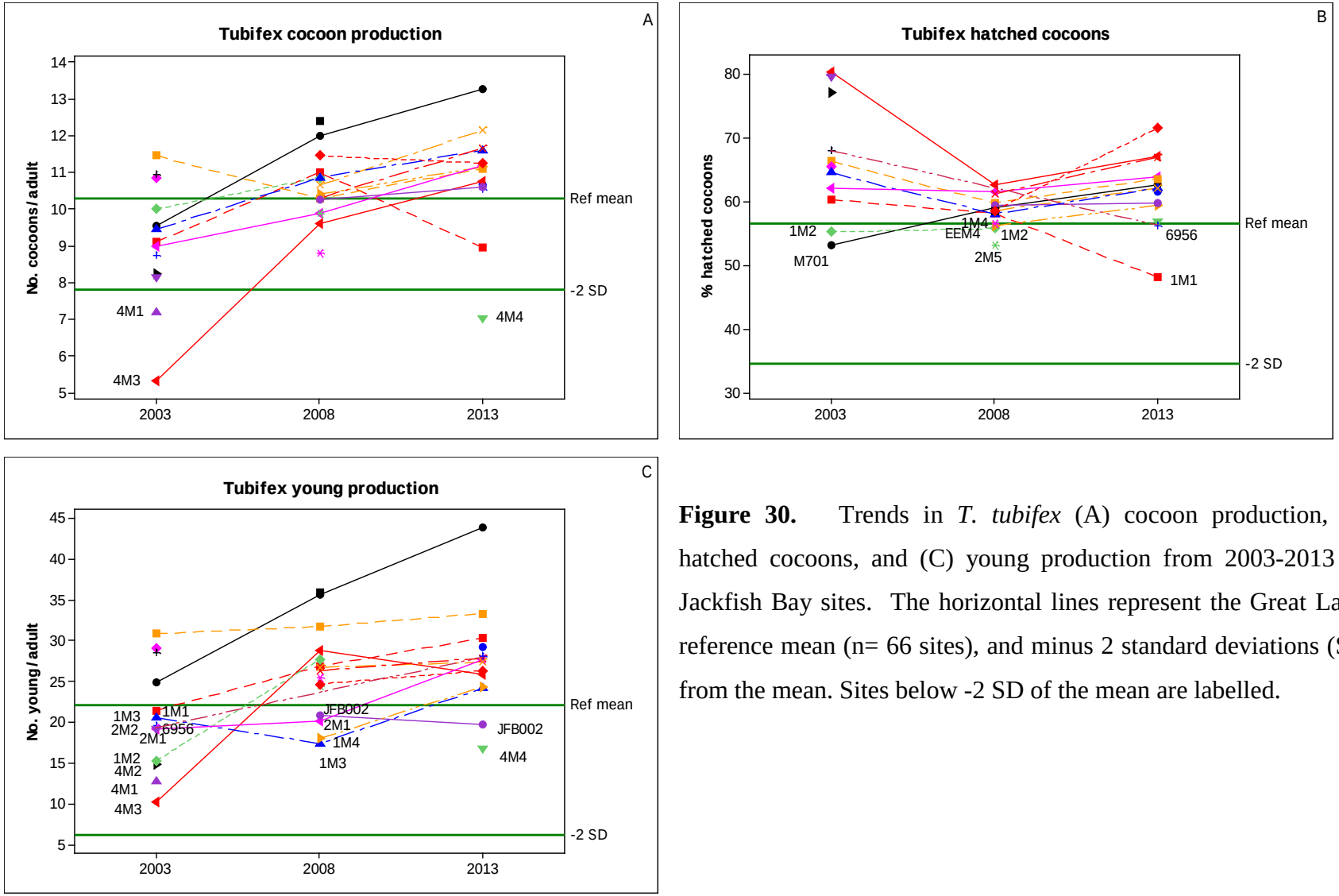


Figure 30. Trends in *T. tubifex* (A) cocoon production, (B) hatched cocoons, and (C) young production from 2003-2013 for Jackfish Bay sites. The horizontal lines represent the Great Lakes reference mean (n= 66 sites), and minus 2 standard deviations (SD) from the mean. Sites below -2 SD of the mean are labelled.

Tables

Table 1. Site coordinates (UTM North, Zone 16) and depth for 2003-2013 studies conducted in Jackfish Bay. The depth and coordinates represent the latest sampling date for the site.

Area	Site	Year(s) Sampled	Depth (m)	Easting	Northing
Moberly Bay	M701	2003, 2006, 2007, 2008, 2009, 2013	11.5	499877.6	5406399.6
Moberly Bay	1M4	2008, 2013	16.2	499935.1	5406271.7
Moberly Bay	EEM4	2008, 2013	15.2	499811.6	5406195.8
Moberly Bay	1M3	2003, 2006, 2007, 2008, 2009, 2013	18.4	500085.7	5406060.5
Moberly Bay	JFB002	2008, 2013	17.2	499931.5	5405869.7
Moberly Bay	1M2	2003, 2006, 2007, 2008, 2009	19.6	500040.8	5405995.1
Moberly Bay	1M1	2003, 2006, 2007, 2008, 2009, 2013	20.0	500078.3	5405777.1
Moberly Bay	NF5	2008, 2013	16.7	499849.5	5405767.8
Moberly Bay	EEM8	2008	15.8	500244.8	5405655.6
Moberly Bay	EEM8B*	2013	18.8	500159.1	5405686.3
Far-field	2M1	2003, 2006, 2007, 2008, 2009, 2013	36.9	500539.8	5404730.3
Far-field	2M2	2003	34.7	500312.0	5404799.0
Far-field	2M3	2003	39.3	500443.0	5404695.0
Far-field	2M4	2008, 2013	37.5	500275.4	5404689.6
Far-field	JFB021	2008	42.9	478295.2	5399830.6
Far-field	2M5	2008	37.7	478646.3	5399779.9
Far-field	2M6	2013	47.0	500686.7	5404202.3
Far far-field	4M1	2003	68.7	501648.0	5403003.0
Far far-field	4M2	2003	62.0	501508.0	5403040.0
Far far-field	4M3	2003, 2008, 2013	61.4	501488.9	5402907.5
Far far-field	4M4	2013	31.7	500959.1	5403185.2
Tunnel Bay	3M2	2003, 2008, 2013	32.0	502871.9	5406439.2
Tunnel Bay	3M3	2003	31.0	502774.0	5406582.0
Tunnel Bay	6956	2003, 2013	29.1	502864.4	5406761.6
L Superior Ref	2600	2013	66.3	658525.9	5310961.1
L Superior Ref	2410	2013	67.0	672025.3	5250289.9
L Superior Ref	2502	2013	14.5	549079.0	5385945.3
L Superior Ref	2616	2013	70.2	559605.5	5355446.6
L Superior Ref	2400	2013	79.7	658943.4	5309556.7
L Superior Ref	2414	2013	39.9	679684.1	5236915.9

* site moved from original location, EEM8, by ~90 m

Table 2. Environmental variables measured at 2013 Jackfish Bay sites.

Field	**Overlying Water** (0.5 m from bottom)	**Sediment** (0 - 10 cm)	**Benthic Invertebrates**
Northing	Alkalinity	Dioxin and Furans	Dioxin and Furans
Easting	Conductivity	Dioxin-like PCBs	Dioxin-like PCBs
Site Depth	Dissolved Oxygen	29 Trace Metals	
	pH	12 Major Oxides	
	Total Kjeldahl N	PAHs (parent)	
	Nitrates+Nitrites-N	Total P	
	Total Ammonia-N	Total Kjeldahl N	
	Total P	Total Organic C	
		Loss on Ignition	
		Clay, Silt , Sand, Gravel	

Table 3. Characteristics of sampling site overlying water for 2013 Jackfish Bay and Lake Superior reference. Values are in mg/L unless otherwise noted.

Location	Site	Temp (deg C)	Alkalinity	Conductivity (µS/cm)	Dissolved O_2	pH	NH_3	NO_3/NO_2	TKN	Total P
Moberly Bay	M701	13.4	56.0	294	11.0	7.3	0.063	0.439	0.478	0.042
	1M4[a]	13.2	52.6	169	9.9	7.3	0.044	0.416	0.352	0.033
	EEM4	13.3	58.0	225	8.4	7.3	0.072	0.455	0.510	0.045
	1M3	7.6	45.6	124	11.0	7.4	0.019	0.369	0.267	0.011
	JFB002	10.4	48.0	150	10.6	7.3	0.018	0.382	0.267	0.020
	1M1	7.0	45.4	117	11.0	7.3	0.019	0.370	1.020	0.015
	NF5[a]	12.4	61.0	233	9.9	7.3	0.102	0.476	0.556	0.056
	EEM8B	7.8	50.5	164	9.9	7.3	0.042	0.412	0.327	0.027
Far-Field	2M4	6.6	43.5	115	11.3	7.4	0.003	0.379	0.111	0.006
	2M1	6.6	43.8	116	11.7	7.4	0.003	0.378	0.111	0.005
	2M6	5.5	43.7	115	12.1	7.3	0.003	0.385	0.164	0.028
Far Far-Field	4M4	13.6	42.7	108	10.3	7.5	0.008	0.334	0.121	0.003
	4M3	5.0	43.0	105	12.3	7.3	0.003	0.388	0.106	0.004
Tunnel Bay	3M2	6.4	43.6	106	6.9	7.3	0.003	0.385	0.104	0.005
	6956	6.8	43.5	108	11.4	7.3	0.003	0.388	0.113	0.005
Lake Superior Reference	2400	5.0	42.9	114	14.0	7.4	0.003	0.390	0.122	0.018
	2410[a]	5.8	42.8	110	13.9	7.4	0.003	0.389	0.124	0.004
	2414	5.6	42.7	118	13.5	7.5	0.005	0.382	0.214	0.004
	2502	13.6	42.9	116	10.6	7.7	0.005	0.335	0.129	0.004
	2600	5.1	42.8	119	14.4	7.6	0.010	0.392	0.198	0.007
	2616	4.3	43.0	108	15.1	7.5	0.003	0.390	0.117	0.005

[a] QA/QC site – values are mean of three field replicates

Table 4. Sediment metal and nutrient concentrations for 2013 Jackfish Bay sites. Values exceeding the Threshold Effect Level (TEL) or Probable Effect Level (PEL) are highlighted in blue and red, respectively.

Parameter	Units	M.D.L.	TEL	PEL	M701	1M4[a]	EEM4	1M3	JFB002	1M1	NF5[a,b]	EEM8B	2M4	2M1	2M6	4M4	4M3	3M2	6956[b]
Aluminum	µg/g	10			5180	6407	6730	9960	8000	8470	9122	6910	9870	10900	12400	14800	9430	12400	10300
Antimony	µg/g	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	< 0.5	< 0.5	< 5
Arsenic	µg/g	0.5	5.9	17	1.6	1.7	1.7	2.5	2.4	2.2	2.2	2.3	4.3	5.0	5.7	2.6	4.1	9.9	7.4
Barium	µg/g	1			31	44	45	67	65	57	63	45	63	74	94	78	50	97	75
Beryllium	µg/g	0.2			< 0.2	0.3	0.2	0.4	0.3	0.3	0.3	0.3	0.4	0.4	0.5	0.5	0.4	0.5	0.4
Bismuth	µg/g	5			< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5
Cadmium	µg/g	0.5	0.6	3.5	0.5	0.9	0.8	1.3	1.4	1.1	1.4	0.9	0.8	0.8	1.2	< 0.5	< 0.5	0.8	0.8
Calcium	µg/g	10			5340	8540	9600	11700	14800	12600	12633	8470	7200	7990	7550	88700	4550	6520	7650
Chromium	µg/g	1	37.3	90	28	36	37	47	50	44	50	37	45	49	53	46	38	46	41
Cobalt	µg/g	1			7	8	8	9	9	9	9	8	10	11	12	12	10	13	11
Copper	µg/g	1	35.7	197	15	19	21	33	33	30	34	26	40	44	54	23	39	51	43
Iron	µg/g	10	20000[c]	40000[c]	12300	14200	15300	19400	15500	17300	17833	15900	21800	23200	25500	32200	20500	28500	22500
Lead	µg/g	5	35	91.3	< 5	6.5	6	9	8	8	9	8	17	20	23	10	20	28	27
Magnesium	µg/g	10			4880	6470	7270	9370	10700	9400	9540	6010	7310	7970	8180	23000	5990	7530	7540
Manganese	µg/g	1	460[c]	1100[c]	170	261	295	336	337	291	326	255	623	919	986	513	836	**1370**	912
Mercury	µg/g	0.005	0.17	0.486	0.038	0.058	0.063	0.081	0.078	0.086	0.07	0.076	0.087	0.108	0.112	0.025	0.067	0.105	0.0945
Molybdenum	µg/g	1			< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
Nickel	µg/g	1	16[c]	75[c]	16	18	19	25	23	21	24	21	25	26	30	25	22	28	25
Phosphorus	µg/g	5			648	773	824	889	833	838	864	917	931	917	956	515	729	1150	943
Potassium	µg/g	30			470	683	740	1300	1180	1080	1177	800	1260	1390	1740	2890	1210	1650	1390
Silicon	µg/g	1			570	575	659	806	673	521	675	637	756	838	894	1100	910	1040	930
Silver	µg/g	0.2			0.3	0.2	< 0.2	0.4	0.5	0.2	0.6	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
Sodium	µg/g	20			220	200	210	300	260	250	280	210	230	260	290	270	170	270	235
Strontium	µg/g	1			14	18	19	22	22	21	22	20	22	23	23	64	17	24	22
Tin	µg/g	10			< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
Titanium	µg/g	1			604	753	791	874	792	810	834	797	1030	1080	1000	1100	937	1050	993
Vanadium	µg/g	1			24	27	29	34	32	32	34	36	40	42	43	47	34	44	39
Yttrium	µg/g	0.5			4.2	5.6	6.1	6.9	6.5	6.6	6.8	6.3	8.2	8.5	9	9.3	8.3	9.7	8.9
Zinc	µg/g	3	123	315	97	117	112	157	162	147	161	118	101	108	123	54	66	98	86
Zirconium	µg/g	0.1			3.7	3.5	3.9	4.7	3.8	3.8	4.1	4.3	5.1	5.5	5.3	16.6	4.3	5.3	4.9
Aluminum (Al2O3)	%	0.04			10.7	10.2	10.3	9.45	9.79	10.2	9.9	10.1	11.4	10.4	11.1	10.3	11.4	9.75	11.5
Barium (BaO)	%	0.002			0.063	0.062	0.064	0.058	0.061	0.064	0.062	0.064	0.074	0.068	0.072	0.056	0.072	0.06	0.074
Calcium (CaO)	%	0.06			2.75	2.93	3.13	2.92	3.49	3.32	3.2	2.83	2.77	2.54	2.48	13.3	2.37	2.86	2.69
Chromium (Cr2O3)	%	0.006			0.01	0.012	0.012	0.013	0.013	0.014	0.014	0.011	0.014	0.014	0.016	0.013	0.012	0.013	0.018
Iron (Fe2O3)	%	0.01			2.96	3.03	3.24	3.33	3.38	3.4	3.39	3.29	4.29	3.97	4.6	5.42	3.69	4.51	4.45
Potasium (K20)	%	0.2			1.9	2.0	2	1.9	2	2	2.0	1.9	2.3	2.1	2.3	2.2	2.3	2	2.4
Magnesium (MgO)	%	0.03			1.56	1.67	1.83	1.98	2.32	2.1	2.11	1.6	1.88	1.83	1.99	4.25	1.55	1.85	1.90
Manganese (MnO)	%	0.003			0.051	0.058	0.065	0.061	0.066	0.06	0.063	0.058	0.107	0.129	0.146	0.096	0.123	0.175	0.145
Sodium (Na2O)	%	0.5			3.7	3.3	3.3	2.6	2.7	3	2.7	3.1	3.2	2.8	2.8	2	3.2	2.6	3.1
Phosphorus (P2O5)	%	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	< 0.5	< 0.5	< 0.5
Silica (SiO2)	%	0.1			65.5	61.4	62.6	53.9	56.5	60.2	57.2	60.2	63.6	57.8	60.1	44.1	66.8	52.1	64.3
Titanium (TiO2)	%	0.02			0.46	0.45	0.46	0.45	0.47	0.48	0.47	0.49	0.54	0.51	0.54	0.55	0.46	0.48	0.53
Whole Rock Total	%				98.2	94.7	97.9	91.2	97	97.7	96.0	96.8	98.5	91.3	97.3	98.2	96.3	85.2	98.6
TC (LOI@1000°C)	%	0.05			8.3	9.6	10.6	14.3	15.9	12.6	14.7	12.9	8.07	8.93	10.8	15.9	4.13	8.49	7.53
Total Organic Carbon	% by wt	0.1	1[c]	10[c]	7.1	6.7	4.8	6.2	6.4	5.5	6.0	**10.1**	3.2	3.5	3.8	0.3	1.2	2.8	2.5
Total Kjeldahl Nitrogen	µg/g	0.05	550[c]	4800[c]	1860	2160	2580	3580	3650	3240	3333	3140	2050	2100	2920	400	933	2290	1960
Phosphorus-Total	µg/g	0.01	600[c]	2000[c]	721	799	945	934	931	981	861	904	1140	1060	1120	627	731	1350	1165

[a] QA/QC site – values are mean of three field replicates [b] average of laboratory duplicates; [c] provincial sediment quality guidelines Lowest/Severe Effect Level; MDL = method detection limit

Table 5. Sediment dioxin and furan concentrations (pg/g dw) and toxic equivalents (TEQ) for 2013 Jackfish Bay sites. TEQs exceeding the Probable Effect Level (21.5 pg TEQ/g) are indicated in red. "<" Indicates that the compound was not detected above the method detection limit or that the target analyte was detected below the Lowest Quantitation Limit (see text).

Location	Moberly Bay								Far-field			Far far-field		Tunnel Bay	
Site	M701[c]	1M4[b]	EEM4[a]	1M3[a]	JFB002	1M1[a]	NF5[b]	EEM8B	2M4	2M1[a]	2M6[a]	4M4	4M3[a]	3M2[a]	6956
Distance (km) from mouth of BBC[d]	0.06	0.19	0.27	0.43	0.59	0.68	0.71	0.82	1.81	1.85	2.4	3.5	3.9	3.0	3.0
2,3,7,8-TCDD	22.1	11.6	12.1	12.5	12.4	12.3	12.8	6.9	8.5	8.6	12.4	0.21	0.44	3.2	2.7
1,2,3,7,8-PeCDD	2.89	1.43	1.58	1.60	<1.1	<1.0	1.21	<0.89	1.18	1.40	1.51	0.19	0.46	1.04	<0.35
1,2,3,4,7,8-HxCDD	<1.5	0.87	<0.49	<0.74	0.67	0.56	0.70	<1.1	<0.45	0.41	1.44	0.13	<0.46	1.06	1.15
1,2,3,6,7,8-HxCDD	3.18	1.70	1.97	1.66	1.74	<1.3	1.66	<1.7	1.70	1.81	2.88	0.40	1.24	1.60	<1.3
1,2,3,7,8,9-HxCDD	<1.3	0.87	1.36	1.10	1.09	0.95	1.20	2.08	<1.1	1.90	2.41	0.28	0.91	1.66	1.71
1,2,3,4,6,7,8-HpCDD	49.8	28.6	44.7	26.3	26.7	26.0	27.3	44.3	22.1	27.0	40.8	2.7	11.1	24.9	28.9
OCDD	218	172	252	154	140	134	159	211	122	131	215	11.4	51.9	130	139
2,3,7,8-TCDF	354	198	206	210	198	164	197	62.2	133	121	174	0.2	3.4	35.0	31.9
1,2,3,7,8-PeCDF	9.35	4.66	<3.7	4.13	5.87	4.27	5.46	<1.6	3.55	3.01	4.73	0.29	0.53	<1.6	1.76
2,3,4,7,8-PeCDF	17.75	9.26	8.96	7.82	11.50	8.13	10.67	2.98	6.30	5.72	8.00	0.14	0.68	2.78	2.43
1,2,3,4,7,8-HxCDF	2.96	1.53	1.76	1.43	2.25	1.49	1.83	<1.6	1.46	1.62	2.65	0.46	0.48	1.52	<1.4
1,2,3,6,7,8-HxCDF	1.43	0.65	0.47	0.96	0.73	0.61	0.89	<0.59	0.83	0.73	1.61	0.30	0.54	0.97	1.11
2,3,4,6,7,8-HxCDF	1.20	<1.3	1.00	<1.0	<0.88	<0.59	<0.98	<0.71	<0.93	0.99	2.61	<0.32	<0.68	<1.3	1.10
1,2,3,7,8,9-HxCDF	1.83	<1.0	0.55	0.44	1.02	0.74	0.56	<1.1	0.58	0.38	0.83	<0.087	0.33	0.46	<0.41
1,2,3,4,6,7,8-HpCDF	18.20	11.98	11.20	8.86	<6.9	10.10	7.14	11.00	5.49	6.70	<12	<2.6	3.23	5.54	6.34
1,2,3,4,7,8,9-HpCDF	<2.2	<1.8	1.54	<1.6	<0.58	1.22	<0.71	<2.9	<0.60	<0.60	1.30	<0.089	<0.39	<1.2	<0.60
OCDF	64.6	48.4	92.8	29.5	25.0	35.9	21.9	31.9	11.1	12.1	16.6	0.48	2.5	6.9	8.5
Toxic Equivalency (WHO 1998)															
Lower Bound PCDD/F TEQ	53.0	27.9	25.9	28.2	29.1	23.2	29.5	11.6	20.0	19.5	27.1	0.65	1.3	6.0	6.5
Mid Point PCDD/F TEQ	53.4	28.2	27.1	28.6	29.8	23.8	29.9	12.6	20.2	19.7	27.9	0.69	1.5	7.1	6.8
Upper Bound PCDD/F TEQ	53.8	28.4	28.3	29.0	30.4	24.4	30.3	13.6	20.3	19.9	28.7	0.72	1.7	8.2	7.0

[a] mean of two sample types (box core and ponar)
[b] QA/QC site – mean of three field replicates
[c] mean of laboratory sample duplicate
[d] BBC = Blackbird Creek

Table 6. Sediment dioxin-like PCB concentrations (pg/g dw) and toxic equivalents (TEQ) for 2013 Jackfish Bay sites. A "<" Indicates that the compound was not detected above the method detection limit or that the target analyte was detected below the Lowest Quantitation Limit (see text).

Location	Moberly Bay								Far-field			Far far-field		Tunnel Bay	
Site	**M701[c]**	**1M4[b]**	**EEM4[a]**	**1M3[a]**	**JFB002**	**1M1[a]**	**NF5[b]**	**EEM8B**	**2M4**	**2M1[a]**	**2M6[a]**	**4M4**	**4M3[a]**	**3M2[a]**	**6956**
Target Analytes	pg/g	pg/g	pg/g	pg/g	pg/g	pg/g	pg/g	pg/g	pg/g	pg/g	pg/g	pg/g	pg/g	pg/g	pg/g
PCB 81	<29	<1.8	<1.0	2.93	<2.3	<1.9	1.08	10.1	<1.8	<3.4	2.53	<0.14	0.644	1.19	<0.21
PCB 77	164	24.2	25.2	37.9	30.2	41.4	31	29.5	25.6	24.85	33.7	<1.3	2.64	16.6	15.8
PCB 123	467	135	217	228.5	126	249	158	246	158	177	149	<1.0	8.18	156	61.6
PCB 118	4670	846	1178	1131.5	807	1350	925	1060	728	782	945	<4.2	50.0	264	236
PCB 114	254	33.1	43.1	<46	25.1	<33	27.1	<18	<17	27.3	<25	<0.26	<2.6	10.8	<5.6
PCB 105	2790	360	403	419	306	445	343	390	259	251	295	<1.9	26.9	109	106
PCB 126	19.2	<11	<46	<4.4	4.27	3.09	<8.1	<14	<4.1	<1.4	<9.4	0.367	<2.1	4.85	4.28
PCB 167	115	56.4	76.0	144	38.9	105	53.1	110	52.9	70.2	90.1	<0.11	2.47	34.8	37.4
PCB 156	555.5	145	382	274.5	107	272	131	280	167	183	310	<0.61	19.5	67.8	54.7
PCB 157	138	30.4	53.4	63	<15	41.1	35.2	<36	34.4	31.3	47.6	<0.39	4.55	14.6	<7.5
PCB 169	<7.0	<3.6	<15	<15	<8.1	<3.8	<14	<42	<2.7	<3.8	<6.2	<0.13	<1.4	<12	<2.9
PCB 189	41.25	23.2	44.6	54.5	19.2	53.3	18.5	68.4	31	38.7	52.1	0.287	3.07	14.45	<13
Total	9213	1653	2421	2355	1464	2560	1722	2194	1456	1585	1924	0.65	118	693	516
Toxic Equivalency (WHO 1998)															
Lower Bound PCDD/F TEQ	0.158	0.010	0.012	0.016	0.032	0.024	0.011	0.019	0.010	0.010	0.012	0.002	0.001	0.017	0.025
Mid Point PCDD/F TEQ	0.165	0.025	0.075	0.025	0.032	0.030	0.022	0.055	0.021	0.014	0.032	0.002	0.004	0.026	0.026
Upper Bound PCDD/F TEQ	0.172	0.040	0.138	0.035	0.033	0.036	0.033	0.091	0.031	0.018	0.053	0.002	0.008	0.034	0.026

[a] mean of two sample types (box core and ponar); [b] QA/QC site – mean of three field replicates; [c] mean of laboratory sample duplicate

Table 7. Sediment petroleum hydrocarbon (µg/g), PAH (µg/g) and oil and grease (mg/kg) concentrations for 2013 Jackfish Bay sites. Values below method detection limits are indicated by "<". Values exceeding Sediment Quality Guideline Threshold Effect Level (TEL) or Probable Effect Level (PEL) are highlighted in blue and red, respectively.

Analyte	TEL	PEL	M701	1M1	1M3	1M4[a]	EEM4	EEM8B	JFB002	NF5[a]	2M1	2M4	2M6	4M4	4M3	3M2	6956
Aggregate Organics																	
Oil and grease			19900	19400	13200	13733	10700	74500	16000	15500	5600	6200	7900	<500	<750	3300	2000
Hydrocarbons																	
F1 (C6-C10)			32	7.5	7.5	5	5	10	7.5	7.5	7.5	5	7.5	2.5	3.75	5	5
F1-BTEX			30	7.5	7.5	5	5	10	7.5	7.5	7.5	5	7.5	2.5	3.75	5	5
F2 (C10-C16)			138	120	74	146	62	791	131	99.0	39	32	35	5	7.5	10	10
F2-Naphth			138	120	74	146	62	791	131	99.0	39	32	35	5	7.5	10	10
F3 (C16-C34)			6360	4600	3570	3907	2130	8770	4230	3387	1590	1450	1810	25	37.5	380	250
F3-PAH			6360	4600	3570	3907	2130	8770	4230	3387	1590	1450	1810	25	37.5	380	250
F4 (C34-C50)			860	1000	720	850	500	3710	790	623	470	410	490	25	37.5	110	50
F4G-SG (GHH-Silica)			3690	4470	3760	3590	1800	14900	3250	2300	1620	1950	1850	125	190	800	250
Total PHCs			10220	9198	7412	7647	3997	24471	7619	5793	3257	3437	3703	157.5	238.75	1195	515
Chrom. to baseline at nC50			YES	YES	YES	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	YES
PAHs																	
Acenaphthene	0.007	0.089	<0.10	<0.15	<0.15	<0.15	<0.10	<0.25	<0.15	<0.15	<0.10	<0.10	<0.10	<0.050	<0.075	<0.10	<0.10
Acenaphthylene	0.006	0.128	<0.10	<0.15	<0.15	<0.15	<0.10	<0.25	<0.15	<0.15	<0.10	<0.10	<0.10	<0.050	<0.075	<0.10	<0.10
Acridine			<1.6	<2.4	<2.4	<2.4	<1.6	<4.0	<2.4	<2.4	<1.6	<1.6	<1.6	<0.80	<1.2	<1.6	<1.6
Anthracene	0.047	0.245	<0.10	0.22	0.22	0.185	<0.10	<0.25	0.18	0.12	<0.10	<0.10	<0.10	<0.050	<0.075	<0.10	<0.10
Benzo(a)anthracene	0.032	0.385	0.16	<0.15	<0.15	0.15	<0.10	0.37	<0.15	<0.15	<0.10	<0.10	<0.10	<0.050	<0.075	<0.10	<0.10
Benzo(a)pyrene	0.032	0.782	0.072	<0.060	<0.060	0.087	0.053	0.16	<0.060	0.043	<0.040	0.047	<0.040	<0.020	<0.030	0.047	<0.040
Benzo(b)fluoranthene			0.11	<0.15	<0.15	0.165	0.11	<0.25	<0.15	0.12	<0.10	<0.10	<0.10	<0.050	<0.075	<0.10	<0.10
Benzo(g,h,i)perylene	0.17[b]		<0.10	<0.050	<0.15	<0.15	<0.10	<0.25	<0.15	<0.15	<0.10	<0.10	<0.10	<0.050	<0.075	<0.10	<0.10
Benzo(k)fluoranthene	0.24[b]		<0.040	<0.060	<0.060	<0.060	<0.040	<0.10	<0.060	<0.060	<0.040	<0.040	<0.040	<0.020	<0.030	<0.040	<0.040
Chrysene	0.057	0.862	0.24	<0.15	<0.15	0.265	0.12	0.46	<0.15	0.11	<0.10	<0.10	<0.10	<0.050	<0.075	<0.10	<0.10
Dibenzo(ah)anthracene	0.006	0.135	<0.10	<0.15	<0.15	<0.15	<0.10	<0.25	<0.15	0.19	<0.10	<0.10	<0.10	<0.050	<0.075	<0.10	<0.10
Fluoranthene	0.111	2.355	0.44	0.23	<0.15	0.36	0.21	0.35	0.29	0.18	<0.10	0.11	<0.10	<0.050	<0.075	0.11	<0.10
Fluorene	0.021	0.144	<0.10	<0.15	<0.15	<0.15	<0.10	<0.25	<0.15	<0.15	<0.10	<0.10	<0.10	<0.050	<0.075	<0.10	<0.10
Indeno(1,2,3-cd)pyrene	0.20[b]		<0.10	<0.15	<0.15	<0.15	<0.10	<0.25	<0.15	<0.15	<0.10	<0.10	<0.10	<0.050	<0.075	<0.10	<0.10
1-Methylnaphthalene			<0.10	<0.15	<0.15	<0.15	<0.10	0.33	<0.15	<0.15	<0.10	<0.10	<0.10	<0.050	<0.075	<0.10	<0.10
2-Methylnaphthalene	0.020	0.201	<0.10	<0.15	<0.15	<0.15	<0.10	<0.25	<0.15	<0.15	<0.10	<0.10	<0.10	<0.050	<0.075	<0.10	<0.10
Naphthalene	0.035	0.391	0.047	<0.030	<0.030	0.036	<0.020	<0.050	<0.030	<0.030	<0.020	<0.020	<0.020	<0.010	<0.015	<0.020	<0.020
Phenanthrene	0.042	0.515	0.59	0.17	0.10	0.29	0.12	1.19	0.19	0.11	<0.060	0.06	0.06	<0.030	<0.045	<0.060	<0.060
Pyrene	0.053	0.875	0.35	0.19	<0.15	0.29	0.19	0.60	0.24	0.15	<0.10	0.11	<0.10	<0.050	<0.075	<0.10	<0.10
Quinoline			<0.10	<0.15	<0.15	<0.15	<0.10	<0.25	<0.15	<0.15	<0.10	<0.10	<0.10	<0.050	<0.075	<0.10	<0.10
Sum PAHs	4[b]		2.01	0.81	0.32	1.83	0.80	3.46	0.90	1.02	<	0.33	0.06	<	<	0.16	<

[a] QA/QC site – values are mean of three field replicates' [b] provincial sediment quality guidelines Lowest/Severe Effect Level

Table 8. Benthic invertebrate dioxin and furan concentrations, expressed in dry weight (pg/g) and toxic equivalents (ng TEQ/kg ww), for 2013 Jackfish Bay sites. A "<"indicates that a target analyte was either not detected above the provided estimated detection limit (EDL) or that the value was below the calibrated range but above the EDL. Detected congeners are highlighted blue. TEQs that are above the modified tissue residue guideline (7.4 ng TEQ/kg ww) and the TEQ for reference sites (10.4 ng/kg) are highlighted red.

Site-Taxon	EEM4 - CHIR	EEM4 - OLIG	1M3 - AMP	1M3 - CHIR	1M3 - OLIG	1M1 - AMP	1M1 - CHIR	1M1 - OLIG	2M1 - AMP	2M1 - CHIR	2M1 - OLIG	2M6 - AMP	2M6 - CHIR	2M6 - OLIG	4M3 - AMP	4M3 - CHIR	3M2 - AMP	3M2 - CHIR	3M2 - OLIG
2,3,7,8-TCDD	<30	<19	<22	4.51	<4.2	<7.8	<8.2	<14	<7.3	<210	<8.2	8.56	<71	<39	<5.5	<130	<4.5	<8.4	<26
1,2,3,7,8-PeCDD	<17	<9.0	<12	<2.0	<1.8	<3.4	<4.9	<8.5	<3.0	<100	<3.4	<2.5	<28	<15	<2.3	<46	<2.3	<4.9	<16
1,2,3,4,7,8-HxCDD	<15	<8.0	<6.9	<1.2	<1.5	<3.2	<2.8	<7.6	<2.0	<76	<2.3	<1.9	<22	<9.1	<2.5	<46	<2.2	<2.8	<11
1,2,3,6,7,8-HxCDD	<13	<7.3	<6.5	1.17	<1.4	<3.0	<2.5	<6.1	<2.2	<71	<2.7	2.78	<21	<8.6	<2.3	<43	<2.0	<2.7	<9.8
1,2,3,7,8,9-HxCDD	<12	<6.8	<5.9	<1.0	<1.3	<2.8	<2.4	<5.8	<1.7	<65	<2.0	<1.6	<19	<7.9	<2.1	<39	<1.8	<2.4	<9.2
1,2,3,4,6,7,8-HpCDD	<22	<8.4	19.1	<5.9	2.66	8.8	8.3	<9.9	7.16	94.5	28.1	6.19	31.6	<11	<4.5	<43	<5.5	14.7	99.3
OCDD	33.3	9.17	42	<13	6.82	38.8	14.3	8.33	18.6	198	69	12.8	71.1	26.6	8.44	84.6	<7.0	42.8	300
2,3,7,8-TCDF	64.9	60.1	168	58.5	44.4	128	49.6	36.6	170	<190	32.4	143	<53	<33	<4.8	<110	40.8	13.8	<23
1,2,3,7,8-PeCDF	<16	<6.9	<11	2.8	<1.9	<5.6	<4.5	<9.6	7.76	<82	<3.4	5.87	<29	<11	<2.8	<57	<3.7	<4.2	<12
2,3,4,7,8-PeCDF	<13	<6.3	<14	2.32	<2.1	7.17	<4.0	<8.1	14.7	<68	<2.8	<11	<23	<9.4	<2.5	<48	<5.6	<3.6	<9.8
1,2,3,4,7,8-HxCDF	<14	<6.2	<6.9	<1.3	<1.5	2.93	<2.7	<5.7	<3.1	<55	<3.8	<2.5	<20	<9.8	<2.2	<26	<2.1	<3.1	<13
1,2,3,6,7,8-HxCDF	<12	<5.5	<6.0	<1.2	<1.3	<2.0	<2.5	<4.5	<2.4	<51	<2.1	<1.3	<18	<8.6	<1.8	<22	<2.0	<2.7	<12
2,3,4,6,7,8-HxCDF	<13	<5.9	<6.3	<1.2	<1.3	<2.6	<2.6	<5.4	3.06	<52	<2.2	<3.6	<19	<8.8	<1.9	<26	2.55	2.84	<12
1,2,3,7,8,9-HxCDF	<19	<8.3	14.5	<1.6	2.32	<5.7	<3.2	<9.4	<3.1	<66	7.25	<2.9	<25	<12	<2.5	<50	<2.7	<4.1	<16
1,2,3,4,6,7,8-HpCDF	<15	<7.4	<8.0	1.31	<1.3	<3.5	<3.3	<6.1	<1.7	<60	6.64	<2.8	<18	<8.4	<1.1	<31	<3.2	<4.4	<19
1,2,3,4,7,8,9-HpCDF	<21	<10	<10	<1.4	<1.6	<4.4	<4.4	<10	<2.2	<80	<2.1	<1.7	<23	<11	<1.5	<39	<2.3	<5.0	<19
OCDF	<21	<9.0	<9.3	1.74	<1.8	<3.5	<3.7	<13	3.91	<91	7.15	<2.4	<33	<17	<2.4	<46	<2.3	<4.6	30.8
Homologue Group Totals																			
Total-TCDD	<30	<19	<22	4.51	<4.2	<7.8	<8.2	<14	<6.3	<210	<8.2	11.8	<71	<39	9.81	<130	9.53	<8.4	<26
Total-PeCDD	<17	<9.0	<12	2.24	<1.8	5.08	<4.9	<8.5	24.6	<100	<3.4	14.1	<28	<15	3.47	<46	7.48	<4.9	<16
Total-HxCDD	<15	<8.0	<6.9	1.82	<1.5	9.18	4.45	<7.6	4.5	<76	<2.3	23.8	<22	<9.1	4.04	<46	7.85	12.7	<11
Total-HpCDD	<22	<8.4	19.1	6.8	5.98	16.8	8.3	<9.9	12	94.5	68.8	12.6	31.6	<11	<2.0	<43	5.32	14.7	233
Total-TCDF	100	72.6	275	127	86.5	289	62.1	36.6	470	<190	47.9	416	<53	<33	<4.8	<110	128	30	37.3
Total-PeCDF	<16	<6.9	12.1	5.12	<1.7	7.17	<4.5	<9.6	44.1	<82	<3.4	57.1	<29	<11	7.98	<57	12.4	<4.2	<12
Total-HxCDF	<19	<8.3	54.4	5	2.32	18.3	<3.2	<9.4	9.05	148	25.6	18.4	<25	<12	11.2	126	14.2	6.55	<16
Total-HpCDF	<21	<10	<10	3.3	<1.6	<4.4	<4.4	<10	<2.2	<80	6.64	<1.7	<23	<11	<1.5	<39	<2.3	<5.0	34.5
SUM Homologue Groups	133	82	403	158	102	384	89	45	587	441	225	567	103	27	45	211	185	107	636
Toxic Equivalency																			
Lower Bound PCDD/F TEQ	10.4	10.6	29.6	10.5	7.9	23.7	7.9	6.5	32.5	0.02	5.9	26.6	0.006	0.0005	0.0001	0.001	7.2	2.3	0.02
Mid Point PCDD/F TEQ	16.0	14.1	34.2	10.7	8.7	24.9	9.5	9.6	33.5	48.9	7.3	27.9	15.2	9.1	1.5	28.8	8.4	3.8	7.4
Upper Bound PCDD/F TEQ	21.6	17.5	38.8	10.9	9.5	26.0	11.0	12.7	34.5	97.8	8.6	29.2	30.4	18.2	2.9	57.5	9.6	5.3	14.8

Table 9. Benthic invertebrate dioxin-like PCB concentrations, expressed in dry weight (pg/g) and toxic equivalents (ng TEQ/kg ww), for 2013 Jackfish Bay sites. A "<"indicates that a target analyte was either not detected above the provided estimated detection limit (EDL) or that the value was below the calibrated range but above the EDL. Detected congeners are highlighted blue. TEQs that were above the modified tissue residue guideline (3.8 ng TEQ/kg ww) are highlighted red.

Site-Taxon	EEM4 - CHIR	EEM4 - OLIG	1M3 - AMP	1M3 - CHIR	1M3 - OLIG	1M1 - AMP	1M1 - CHIR	1M1 - OLIG	2M1 - AMP	2M1 - CHIR	2M1 - OLIG	2M6 - AMP	2M6 - CHIR	2M6 - OLIG	4M3 - AMP	4M3 - CHIR	3M2 - AMP	3M2 - CHIR	3M2 - OLIG
PCB-081	<53	<26	<66	<9.0	<11	<73	<36	<21	<63	<89	<58	<50	<17	<140	<36	<420	<39	<25	<100
PCB-077	<64	36.6	<99	35.8	25.8	<77	<35	<21	<63	307	<66	<53	<18	<150	<51	<450	<40	<25	711
PCB-123	<23	<13	<75	23.3	<11	<98	<45	<32	<67	<93	<32	<96	<22	<70	<34	<320	<46	<73	<77
PCB-118	1060	661	3680	1220	788	2650	1010	816	4560	3030	1290	4090	212	682	2140	2020	2100	1220	4200
PCB-114	<42	<13	<110	33.1	24.4	<94	43.2	<29	90.7	<82	<28	108	<18	<70	<31	<290	<54	<66	198
PCB-105	388	240	1480	408	317	936	394	298	1450	1310	544	1370	103	299	818	<650	792	570	1870
PCB-126	<23	<13	<55	<11	<6.5	<97	<50	<30	<93	<79	44.5	120	<25	<78	<53	370	105	138	<240
PCB-167	84.8	48.4	363	90.9	64.5	234	82.3	<53	619	332	141	560	<32	<76	200	<350	441	246	376
PCB-156/157	176	112	746	228	133	587	258	152	1360	747	387	1200	79.5	<140	441	884	784	497	898
PCB-169	<21	<11	<43	<11	13.7	<35	<22	<12	<58	<47	<27	<48	<17	<86	<38	<240	<60	<41	<56
PCB-189	<27	17.1	123	31.3	24.7	103	57.4	<27	272	210	97.4	218	<12	80.4	98.4	<270	188	143	196
SUM DL-PCBs	1709	1115	6392	2070	1391	4510	1845	1266	8352	5936	2504	7666	395	1061	3697	3274	4410	2814	8449
Toxic Equivalency																			
Lower Bound TEQ	0.01	0.3	0.05	0.3	0.2	0.03	0.01	0.01	0.1	2.5	0.8	2.2	0.003	0.01	0.03	5.9	1.9	2.2	6.4
Mid Point TEQ	0.9	0.7	1.5	0.5	0.4	1.9	0.9	0.6	1.7	3.8	1.6	2.8	0.4	2.6	1.0	11.1	2.4	2.5	9.4
Upper Bound TEQ	1.7	1.0	3.0	0.6	0.6	3.7	1.7	1.1	3.3	5.2	2.4	3.5	0.8	5.2	2.0	16.3	2.9	2.8	12.4

Table 10. Macroinvertebrate abundance (per m^2) and taxon richness for 2013 Jackfish Bay sites.

Area	Moberly Bay								Far-field			Far Far-field		Tunnel Bay	
Site	M701	1M4[a]	EEM4	1M3	JFB002	1M1	NF5[a]	EEM8B	2M4	2M1	2M6	4M4	4M3	3M2	6956
No. Taxa	12	9	6	4	7	5	5	10	6	5	4	6	4	4	4
Tubificidae	54303	11922	12606	7539	12907	22557	11399	19542	905	543	422	0	0	1448	1327
Chironomidae	5547	804	1267	1025	905	1387	965	844	663	241	181	181	241	1448	663
Naididae	49	6594	2352	121	2051	905	1005	1930	0	0	0	0	0	0	0
Asellidae	5232	2171	1206	241	2051	60	1106	241	0	0	0	0	0	0	0
Pisidiidae	2189	1327	784	0	121	0	261	241	663	543	241	60	60	483	181
Pontoporeiidae	0	40	0	0	0	121	0	121	181	483	784	663	1870	784	422
Lumbriculidae	989	60	0	0	0	0	0	121	60	0	0	422	0	0	0
Enchytraeidae	80	0	0	0	0	0	0	0	0	0	0	181	362	0	0
Ceratopogonidae	37	0	0	0	121	0	0	60	60	0	0	0	0	0	0
Gammaridae	204	0	0	0	0	0	0	0	0	60	0	0	0	0	0
Valvatidae	0	0	0	0	0	0	0	0	0	0	0	181	0	0	0
Halacaridae	6	40	0	0	60	0	0	60	0	0	0	0	0	0	0
Hydrozetidae	0	20	60	0	0	0	0	0	0	0	0	0	0	0	0
Tetrastemmatidae	0	0	0	0	0	0	0	60	0	0	0	0	0	0	0
Planorbidae	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glossiphoniidae	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Abundance	68656	22979	18275	8926	18215	25030	14737	23221	2533	1870	1628	1689	2533	4162	2593

[a] QA/QC site – value represent mean of three box-core drops

Table 11a. The outcomes of assessments* of Jackfish Bay site status in 2013 relative to reference conditions.

Site	Whole community (NMDS axes)	Total benthos	Taxon richness	Evenness	Tubificidae	Chironomidae	Pontoporeiidae	Pisidiidae	Naididae	Asellidae	Lumbriculidae
M701											
1M4											
EEM4	**										
1M3	**										
JFB002	**										
1M1											
NF5											
EEM8B											
2M4											
2M1											
2M6											
4M4											
4M3											
3M2											
6956											

* not different from reference ($p > 0.10$)
different from reference ($0.10 \geq p > 0.01$)
very different from reference ($p \leq 0.01$)

** borderline different

Table 11b. The outcomes of whole community assessments of site status in 2006 to 2009.

Site	Year sampled			
	2006	2007	2008	2009
M701				
1M3				
1M2				
1M1				
2M1				

Table 12. Mean percent survival, growth (mg dry weight) and reproduction per individual in 2013 sediment toxicity tests.. Numerical guidelines for each endpoint based on 66 Great Lakes reference sites are provided; test site potential toxicity and toxicity are indicated in blue and red, respectively.

Site	*C. riparius*		*H. azteca*		*Hexagenia* spp.		*T. tubifex*				TOXICITY BAND
	Growth	% Survival	Growth	% Survival	Growth	% Survival	No. cocoons/ Adult	% cocoons hatched	% Survival	No. young/ Adult	
GL REF mean[a]	0.36	89.8	0.52	87.9	4.18	98.9	10.3	56.5	99.9	22.1	
M701	0.37	96.0	0.26	80.0	3.46	100	13.3	62.7	100	43.8	2
1M4	0.27	100.0	0.13	54.7	0.48	94	11.2	59.4	100	24.4	3
EEM4	0.27	96.0	0.18	53.3	0.63	96	12.2	62.1	100	27.4	3
1M3	0.26	84.0	0.22	52.0	1.15	100	11.6	62.1	100	24.2	2
JFB002	0.33	90.7	0.21	60.0	1.29	100	10.6	59.8	100	19.7	2
1M1	0.30	97.3	0.18	62.7	1.67	98	9.0	48.1	100	30.4	2
NF5	0.16	93.3	0.31	88.0	0.44	98	11.3	71.5	100	26.4	1
EEM8B	0.32	93.3	0.29	72.0	1.18	100	--[b]	--[b]	--[b]	--[b]	1
2M4	0.33	96.0	0.48	85.3	2.36	100	11.7	66.9	100	27.9	1
2M1	0.34	97.3	0.47	88.0	2.63	98	11.2	63.9	100	27.7	1
2M6	0.29	98.7	0.44	86.7	2.20	100	10.7	61.5	100	29.3	1
4M4	0.14	90.7	0.03	0.7	0.99	86	7.1	57.0	100	16.8	4
4M3	0.29	97.3	0.26	11.3	1.85	92	10.8	67.0	100	25.9	4
3M2	0.36	97.3	0.31	16.7	2.87	94	11.1	63.6	100	33.3	4
6956	0.38	98.7	0.69	35.3	3.53	96	10.6	56.3	100	28.1	4
Non-toxic[c]	0.53 - .21	≥75.8	0.83 - 0.21	≥69.2	7.87 - 0.50	≥95.1	12.8 – 7.9	78.4 – 34.7	≥98.4	38.0 - 6.4	-
Pot. toxic	0.20 - 0.12	75.7- 68.6	0.20 - 0.05	69.1 - 59.7	0.49 - 0.00	95.0 - 93.0	7.8 - 6.6	34.6 – 23.7	98.3 - 97.5	6.3- 0.1	-
Toxic	<0.12	<68.6	<0.05	<59.7	neg.	<93.0	<6.6	<23.7	<97.5	0.0	-

[a] Mean of 66 Great Lakes reference sites; Environment Canada, unpublished data
[b] Toxicity test not run with *Tubifex* due to excessive worms present in sample
[c] The upper limit for non-toxic category is set using 2 × standard deviation of the mean and indicates excessive growth or reproduction

Table 13. Summary of status and trends for sediment contamination, benthic communities and toxicity of Jackfish Bay.

	Status of Jackfish Bay sites in 2013	
Indicator	Relative to reference sites	Trend from 2003 to 2013
Contaminants Levels		
Arsenic	similar	stable
Cadmium	similar or higher	stable
Chromium	similar	stable/some slight decrease from 2003
Copper	similar	stable
Iron	similar	stable
Lead	similar	stable
Manganese	similar	stable
Mercury	similar	stable
Nickel	similar	stable
Zinc	similar or higher	stable
PCDD/Fs as TEQ (sediment)	similar/higher in Moberly Bay and far-field	stable-slightly decreases; variable
PCDD/Fs as TEQ (benthos)		stable to lower
Benthic Community		
Total benthos	mostly similar	mostly stable
Taxon richness	similar	stable
Evenness	mostly similar	mostly variable
Tubificidae	mostly higher	mostly stable
Chironomidae	similar	mostly stable
Pontoporeiidae	mostly lower *	mostly absent
Pisidiidae	similar	mostly stable
Naididae	mostly lower *	highly variable
Asellidae	mostly absent	increase
Lumbriculidae	mostly lower *	mostly stable
Toxicity		
H. azteca survival	mostly lower	variable
T. tubifex young reproduction	similar	mostly increase
C. riparius survival	similar or lower	increase
Hexagenia spp. survival	similar or lower	stable

* not statistically different due to truncation at zero of reference distribution

APPENDIX A

Selection of test site-specific reference sites for assessment of benthic communities in Jackfish Bay, 2013 and site assessment ordination results

BENTHIC COMMUNITY ASSESSMENT METHODS AND RESULTS

Selection of test site-specific reference sites for assessment of benthic communities in Jackfish Bay, 2013

Background

Assessments of benthic communities in Area of Concern sites for studies funded by the Great Lakes Action Plan (e.g., Milani and Grapentine 2007) have mostly used the BEAST methodology of Reynoldson et al. (2000). While this approach has worked well for assessments in the past, changes in reference site conditions in the Great Lakes together with recent developments in statistical procedures have led to a modification of the BEAST methodology.

The modified methodology addresses an important issue with the BEAST. One of the steps in the BEAST procedure divides the reference sites into 5-6 groups based on a cluster analysis of the benthic community data. One or more of these groups is then matched to each test site based on similarity in habitat conditions using discriminant functions analysis (DFA). For each test site, a probability of membership in each reference group is determined. The group with the highest probability is then selected as the group of reference sites for the test site. If, however, the group membership probabilities do not clearly assign the test site to one group, but are rather split among several groups in their assignment, the site assessment is complicated and the reference sites may not be appropriate for the test site. This situation can arise if the clustering of reference sites (based on benthos data) does not result in clearly defined groups. In fact, recent (post 2005) reference site benthic community data suggest only 2 clear groups, associated with the upper and lower Great Lakes.

In the modified methodology, only upper Great Lake reference sites are used for the assessment of Jackfish Bay sites. The cluster analysis and DFA of the BEAST are replaced with multiple linear regressions (MLRs) for determining relationships between benthic community descriptors and environmental (habitat) variables. The MLR models are then used to select a subset of reference sites for each test site based on its habitat conditions. As with the BEAST procedure, the purpose of the modified methodology is to drop from the list of candidate reference sites those that are too different from the test site in habitat conditions to be appropriate reference sites. A diagram of the procedure is shown in Fig. A1 and the steps are described below.

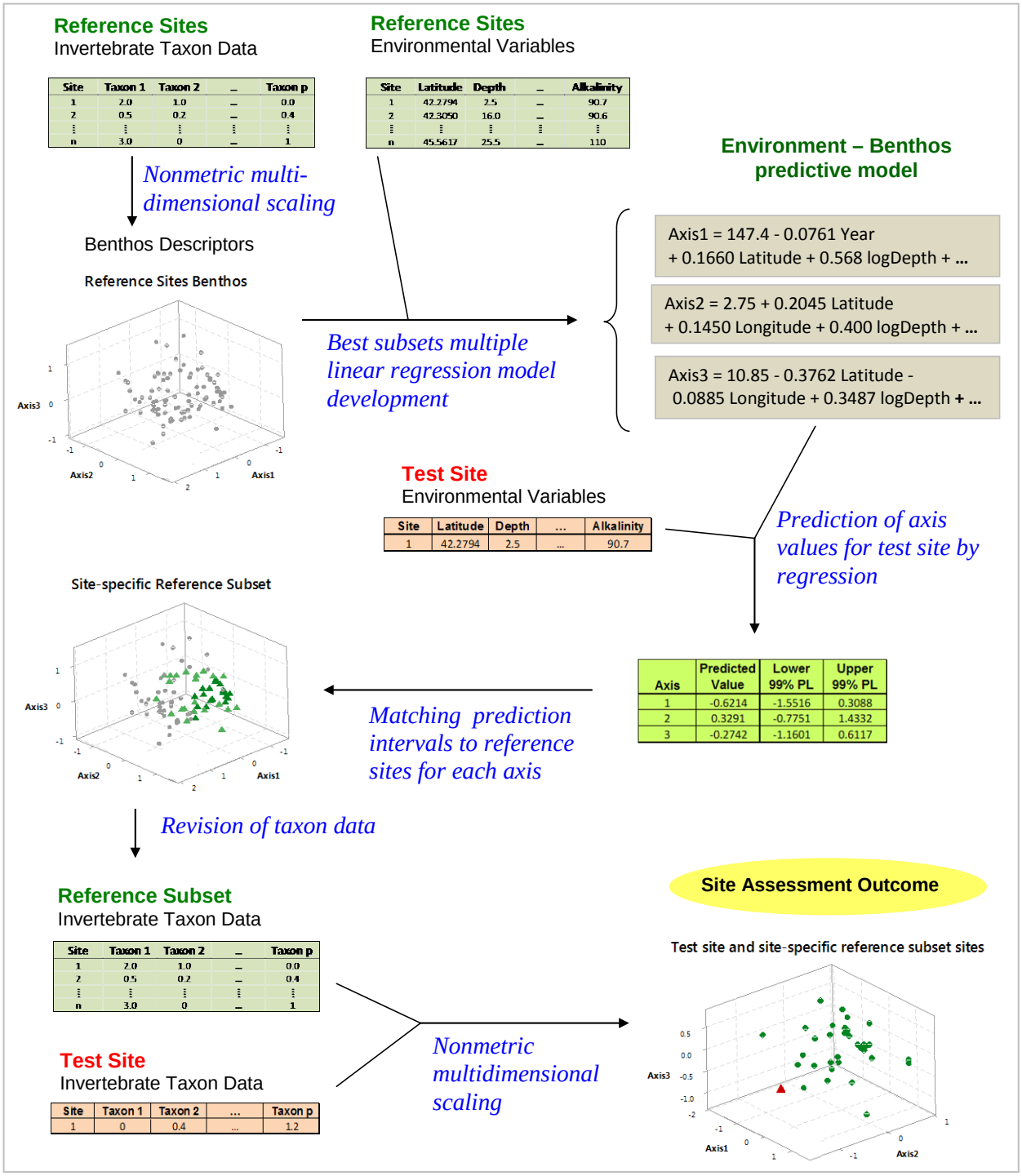


Figure A1. Steps for selecting reference site subsets for a test site and testing for difference.

Upper Great Lakes reference sites data

Benthic communities in test sites were compared to a subset of reference site communities selected from 91 reference sites in Lakes Superior and Huron (Table A1). Habitat and benthos data for these sites were exported from Environment Canada's CABIN database (http://ec.gc.ca/rcba-cabin/default.asp?lang=En&n=4A1D6389-1) and have the following attributes:

- Years: 2006-2013
- Areas: L. Superior, N. Channel, Georgian B., L. Huron proper
- n = 91; 1 sample (most recent) per site
- 70 habitat + 57 family taxon variables
- benthos data units = mean number per m^2
- benthos data log(x+1)-transformed

Due to changes in analytical methods for some variables, only data from 2006 and later were used. To avoid potential problems with sample nonindependence, only 1 sample per site was used. For the upper Great Lake AOC assessments, sites from L. Erie and L. Ontario were excluded due to large differences in benthic fauna and habitat between the lower and upper lakes. All data were checked for outliers and errors.

Relationships between benthic community descriptors and habitat variables

Benthic communities were described by the axes from a nonmetric multidimensional scaling (NMDS) analysis of the benthos data (36 taxa after dropping taxa present at < 3 sites) conducted with PC-ORD. A stress test was applied to determine the appropriate number of dimensions based on the following criteria: (1) a final stress value < 20, (2) randomization test $p < 0.05$, and (3) a ≥ 5 point stress reduction between dimensions (Peck 2010). Figure A2 shows the general pattern of the site and taxon scores.

Of the 70 habitat variables measured, 27 were tested for relationships with the benthos data (Table A2). These were selected based on being potentially able to affect reference benthic communities and whose methods of measurement are compatible among years. Habitat variables were log(x)-transformed if normality of the distribution was improved.

Table A1. Location and sampling year of candidate reference sites.

Site	Year	Latitude	Longitude	Site	Year	Latitude	Longitude
0503	2010	43.3666667	-82.0005556	1507	2012	46.0334444	-82.0834722
0504	2010	43.3700000	-81.7666667	1508	2013	46.0002778	-82.1830556
0507	2010	43.9061111	-81.8738889	1509	2012	46.0011944	-82.2391944
0601	2012	44.8550833	-81.3366389	1510	2009	45.9922222	-82.3336111
0602	2011	44.9933333	-81.3800000	1511	2009	46.1388889	-82.3369444
0604	2013	45.0827778	-81.5944444	1512	2009	46.0666667	-82.3083333
0610	2010	44.9694444	-81.2038889	1513	2007	46.0866667	-82.2333333
0611	2013	45.0000000	-81.2494444	1514	2012	46.1112778	-82.2863333
0612	2010	44.9352778	-81.1222222	1515	2012	46.1215000	-82.2097222
0613	2011	44.9002778	-81.0830556	1600	2010	44.7666667	-79.7177778
0615	2013	44.9655556	-81.0044444	1602	2011	44.8416667	-79.8447222
0616	2011	44.7825000	-81.0997222	1603	2010	44.8800000	-79.8836111
0700	2012	44.7747222	-80.8850278	1605	2011	44.9977778	-79.9787500
0701	2011	44.6011111	-80.9313889	1606	2010	45.0502778	-80.0202778
0702	2011	44.6394444	-80.8916667	1607	2012	44.9973056	-80.1696111
0703	2010	44.6669444	-80.8808333	1609	2011	45.3050000	-80.2619444
0704	2010	44.7111111	-80.8419444	1614	2012	45.8905833	-80.7597222
0705	2013	44.7161111	-80.8819444	1615	2012	45.8433611	-80.7416667
0706	2012	44.7500833	-80.7985278	2200	2008	46.1369444	-82.6130556
0707	2010	44.8172222	-80.7488889	2202	2008	46.1138889	-82.5727778
0708	2013	44.7580556	-80.7077778	2205	2012	46.1167222	-82.4663333
0712	2010	44.6819444	-80.4147222	2400	2013	47.9197222	-84.8725000
0714	2011	44.6166667	-80.1658333	2410	2013	47.3833333	-84.7208333
0716	2010	44.5488889	-80.1672222	2414	2013	47.2605556	-84.6250000
1201	2013	44.7005556	-80.0655556	2500	2009	48.5325000	-86.2755556
1203	2011	44.8144444	-80.0658333	2501	2009	48.5919444	-86.3275000
1206	2013	44.9491667	-80.0052778	2502	2013	48.6247222	-86.3338889
1207	2010	44.7833333	-79.9388889	2504	2009	48.7269444	-86.6158333
1210	2010	44.8133333	-79.9000000	2506	2009	48.7572222	-86.6605556
1211	2010	44.7669444	-79.8658333	2507	2009	48.7877778	-86.6969444
1213	2010	44.7947222	-79.8233333	2512	2008	48.8500000	-87.6080556
1214	2011	44.7727778	-79.8377778	2600	2013	47.9322222	-84.8777778
1215	2010	44.7666667	-79.7913889	2616	2013	48.3493833	-86.1955000
1403	2006	46.2791667	-83.6097222	5100	2008	48.7413889	-87.9397222
1405	2006	46.2469444	-83.8241667	5101	2008	48.8355556	-87.7501389
1406	2012	46.2299722	-83.8055556	5102	2008	48.7744444	-87.7269444
1407	2006	46.1605556	-83.8050000	5103	2008	48.8047222	-87.7494444
1408	2012	46.1466389	-83.8664722	5104	2008	48.7202778	-87.9244444
1410	2012	45.9387222	-82.9843611	5105	2008	48.6069444	-88.1869444

1412	2012	45.8590833	-82.7343056	5106	2008	48.5036111	-88.4300000
1414	2012	45.8386389	-82.5701667	5108	2009	48.3950000	-88.5955556
1415	2012	45.9336111	-82.2667222	5109	2009	48.4677778	-88.5955556
1501	2012	46.0216944	-81.6166944	5110	2009	48.5963889	-88.5138889
1502	2012	45.9838611	-81.6337222	5112	2009	48.4244444	-88.6716667
1503	2012	46.0250556	-81.7003056	5113	2009	48.3602778	-88.6600000
1505	2012	46.0818889	-82.0491111				

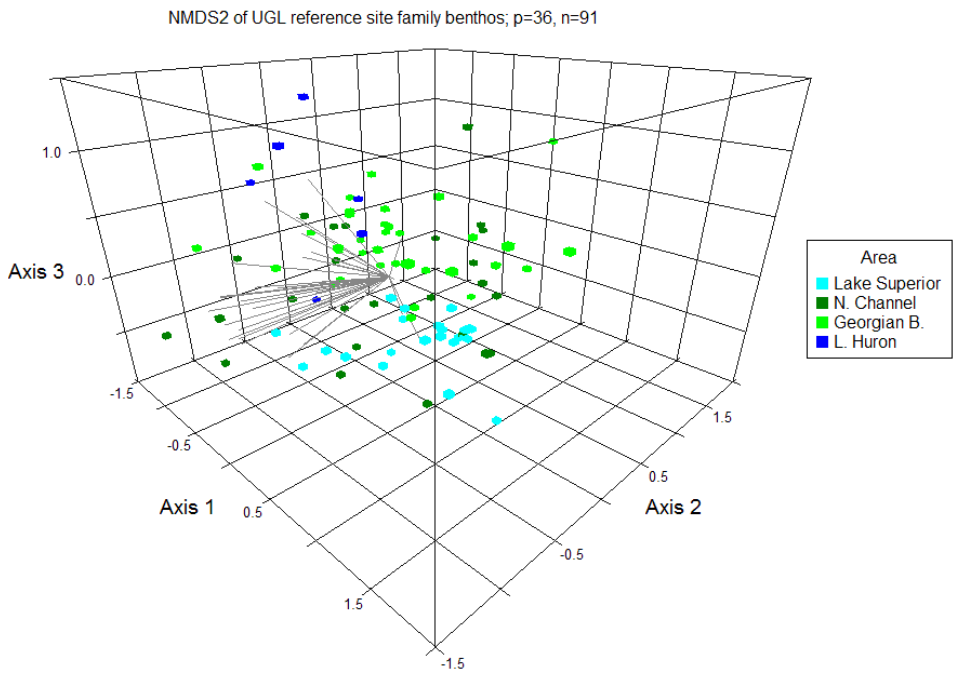


Figure A2. Sample (points) and taxon (outer ends of line segments) scores for NMDS of upper Great Lakes reference site benthic communities. Stress = 12.5.

Multiple linear regressions were calculated and optimized using the candidate habitat predictors and a stepwise procedure ("best subsets regression"; Minitab 2011) for each of the 3 axis scores from the NMDS of the benthos data. Overall best models (among models with 1-27 predictors) were determined based on lowest AIC followed by evaluation of additional model statistics (predicted R^2 [R^2_{pred}], P-values for predictors, P-value for regression) and goodness-of-fit measures (distribution of residuals, number of large residuals, variance inflation factors [VIFs] for predictors, residual vs fitted value pattern). All final models had adjusted R^2 (R^2_{adj}) = 43.2-77.6%, P for regression <0.001, P for predictors <0.15, predictor VIF<10, residuals that were normally distributed and homoscedastic, and <7 large (<-2 or >2) standardized residuals.

The overall best models were:

Axis1 = 147.4 - 0.0761 Year + 0.1660 Latitude + 0.568 logDepth + 0.176 logSand+1 + 0.000009 Fe2O3 + 0.000015 K2O - 0.000014 Na2O - 0.245 logTKN(Sed) + 0.00461 Cond + 0.0909 DO - 0.613 pH + 1.530 NO2+NO3 (Wat)

Axis2 = 2.75 + 0.2045 Latitude + 0.1450 Longitude + 0.400 logDepth + 0.000007 Fe2O3 - 0.000007 Na2O - 0.403 logTKN(Sed) + 0.444 logTOC + 0.0290 Temp

Axis3 = 10.85 - 0.3762 Latitude - 0.0885 Longitude + 0.3487 logDepth + 0.000004 Al2O3 - 0.490 logMnO - 0.01403 Temp

Table A2. Variables tested for habitat-benthos models.

Candidate habitat predictors	*Code*	*Transform*	*Comment*
Year	*Year*	*n*	
Latitude	*Latitude*	*n*	
Longitude	*Longitude*	*n*	*-log(|x|) not suff. better ~N*
*Cum Stress quintile**	*CumStress*	*n*	*ordinal data*
Depth (m)	*Depth*	*y*	*log(x) better*
Sand (%)	*Sand*	*y*	*log(x+1) better*
Al2O3 (ppm)	*Al2O3*	*n*	
CaO (ppm)	*CaO*	*y*	*log(x) better*
Fe2O3 (ppm)	*Fe2O3*	*n*	
K2O (ppm)	*K2O*	*n*	
LOI (%)	*LOI (%)*	*y*	*log(x) better*
MgO (ppm)	*MgO*	*y*	*log(x) better*
MnO (ppm)	*MnO*	*y*	*log(x) better; omitted initial value for 1502-12*
Na2O (ppm)	*Na2O*	*n*	*log(x) not better; outlier*
TKN (Sed, ppm)	*TKN (Sed)*	*y*	*log(x) better*
SiO2 (ppm)	*SiO2*	*n*	*log(x) slightly less ~N*
TOC (%)	*TOC*	*y*	*log(x) better*
TP (Sed, ppm)	*TP (Sed)*	*n*	
Alkalinity (mg/L)	*Alkal*	*n*	*log(x) not better*
Conductivity (uS/cm)	*Cond*	*n*	*log(x) not better*
DO (mg/L)	*DO*	*n*	
pH	*pH*	*n*	
Temp-lake bottom (Deg)	*Temp*	*n*	
N-NH3 (mg/L)	*NH3 (Wat)*	*y*	*log(x) better*
N-NO2+NO3 (mg/L)	*NO2+NO3 (Wat)*	*n*	
N-TKN (mg/L)	*TKN (Wat)*	*y*	*log(x) better*
TP (Wat, mg/L)	*TP (Wat)*	*y*	*log(x) better*

* From Allan et al. (2013)

Prediction of benthic community descriptor values for Jackfish Bay sites

For each NMDS axis, habitat data from the test sites were entered into the axis model to calculate the 99% prediction intervals (PIs) for the sites (Table A3). These PIs are the ranges of benthic conditions (described by the NMDS axes) expected at the tests sites based on the habitat-benthos models.

Table A3. Upper and lower prediction limits (PLs) for benthic community descriptors of Jackfish Bay 2013 sites from habitat-benthos models.

	Axis1		Axis2		Axis3	
Site	Lower 99% PL	Upper 99% PL	Lower 99% PL	Upper 99% PL	Lower 99% PL	Upper 99% PL
6956	-0.47829	1.43562	-1.29126	0.94313	-1.42485	0.37282
691M1	-0.79621	1.17470	-1.37824	0.90492	-1.34095	0.46672
691M3	-0.86519	1.11496	-1.35041	0.94060	-1.39661	0.41586
691M4	-0.74431	1.36950	-1.24274	1.05082	-1.44542	0.35424
692M1	-0.46439	1.43312	-1.22708	1.02483	-1.39268	0.41111
692M4	-0.48593	1.41568	-1.24374	1.00114	-1.30665	0.48729
692M6	-0.29390	1.61451	-1.21629	1.03467	-1.33774	0.46389
693M2	-0.96466	1.09492	-1.25091	0.98859	-1.51960	0.30490
694M3	-0.15466	1.71165	-1.29254	0.94452	-1.23851	0.56241
694M4	-0.42626	1.45027	-1.07089	1.16332	-1.45046	0.35570
69M701	-0.38112	2.31638	-1.24865	1.08235	-1.45981	0.34272
EEM4	-0.70271	1.74814	-1.26308	1.02064	-1.48138	0.31864
EEM8B	-0.69239	1.43725	-1.27976	1.04463	-1.35663	0.44959
JFB002	-0.74601	1.30652	-1.27920	1.00732	-1.44435	0.35797
NF5	-0.48730	2.02003	-1.23325	1.05141	-1.45701	0.34293

Selection of reference subsets for each Jackfish Bay site

Reference sites were then matched to the PIs for each test site. Using the full set of 91 reference sites, described by the NMDS Axes 1-3, reference sites whose axis scores were within the PI were identified for each axis. Sites whose axis scores were within the PIs for all 3 axes were selected as reference sites for the test site. Table A4 shows the reference sites selected for each Jackfish Bay site.

Table A4. Subsets of reference sites (highlighted) selected for individual Jackfish Bay sites.

6956	691M1	691M3	691M4	692M1	692M4	692M6	693M2	694M3	694M4	69M701	EEM4	EEM8B	JFB002	NF5
r0503	r0503	r0503	r0503	r0503	r0503	r0503	r0503	r0503	r0503	r0503	r0503	r0503	r0503	r0503
r0504	r0504	r0504	r0504	r0504	r0504	r0504	r0504	r0504	r0504	r0504	r0504	r0504	r0504	r0504
r0507	r0507	r0507	r0507	r0507	r0507	r0507	r0507	r0507	r0507	r0507	r0507	r0507	r0507	r0507
r0601	r0601	r0601	r0601	r0601	r0601	r0601	r0601	r0601	r0601	r0601	r0601	r0601	r0601	r0601
r0602	r0602	r0602	r0602	r0602	r0602	r0602	r0602	r0602	r0602	r0602	r0602	r0602	r0602	r0602
r0604	r0604	r0604	r0604	r0604	r0604	r0604	r0604	r0604	r0604	r0604	r0604	r0604	r0604	r0604
r0610	r0610	r0610	r0610	r0610	r0610	r0610	r0610	r0610	r0610	r0610	r0610	r0610	r0610	r0610
r0611	r0611	r0611	r0611	r0611	r0611	r0611	r0611	r0611	r0611	r0611	r0611	r0611	r0611	r0611
r0612	r0612	r0612	r0612	r0612	r0612	r0612	r0612	r0612	r0612	r0612	r0612	r0612	r0612	r0612
r0613	r0613	r0613	r0613	r0613	r0613	r0613	r0613	r0613	r0613	r0613	r0613	r0613	r0613	r0613
r0615	r0615	r0615	r0615	r0615	r0615	r0615	r0615	r0615	r0615	r0615	r0615	r0615	r0615	r0615
r0616	r0616	r0616	r0616	r0616	r0616	r0616	r0616	r0616	r0616	r0616	r0616	r0616	r0616	r0616
r0700	r0700	r0700	r0700	r0700	r0700	r0700	r0700	r0700	r0700	r0700	r0700	r0700	r0700	r0700
r0701	r0701	r0701	r0701	r0701	r0701	r0701	r0701	r0701	r0701	r0701	r0701	r0701	r0701	r0701
r0702	r0702	r0702	r0702	r0702	r0702	r0702	r0702	r0702	r0702	r0702	r0702	r0702	r0702	r0702
r0703	r0703	r0703	r0703	r0703	r0703	r0703	r0703	r0703	r0703	r0703	r0703	r0703	r0703	r0703
r0704	r0704	r0704	r0704	r0704	r0704	r0704	r0704	r0704	r0704	r0704	r0704	r0704	r0704	r0704
r0705	r0705	r0705	r0705	r0705	r0705	r0705	r0705	r0705	r0705	r0705	r0705	r0705	r0705	r0705
r0706	r0706	r0706	r0706	r0706	r0706	r0706	r0706	r0706	r0706	r0706	r0706	r0706	r0706	r0706
r0707	r0707	r0707	r0707	r0707	r0707	r0707	r0707	r0707	r0707	r0707	r0707	r0707	r0707	r0707
r0708	r0708	r0708	r0708	r0708	r0708	r0708	r0708	r0708	r0708	r0708	r0708	r0708	r0708	r0708
r0712	r0712	r0712	r0712	r0712	r0712	r0712	r0712	r0712	r0712	r0712	r0712	r0712	r0712	r0712
r0714	r0714	r0714	r0714	r0714	r0714	r0714	r0714	r0714	r0714	r0714	r0714	r0714	r0714	r0714
r0716	r0716	r0716	r0716	r0716	r0716	r0716	r0716	r0716	r0716	r0716	r0716	r0716	r0716	r0716
r1201	r1201	r1201	r1201	r1201	r1201	r1201	r1201	r1201	r1201	r1201	r1201	r1201	r1201	r1201
r1203	r1203	r1203	r1203	r1203	r1203	r1203	r1203	r1203	r1203	r1203	r1203	r1203	r1203	r1203
r1206	r1206	r1206	r1206	r1206	r1206	r1206	r1206	r1206	r1206	r1206	r1206	r1206	r1206	r1206
r1207	r1207	r1207	r1207	r1207	r1207	r1207	r1207	r1207	r1207	r1207	r1207	r1207	r1207	r1207
r1210	r1210	r1210	r1210	r1210	r1210	r1210	r1210	r1210	r1210	r1210	r1210	r1210	r1210	r1210
r1211	r1211	r1211	r1211	r1211	r1211	r1211	r1211	r1211	r1211	r1211	r1211	r1211	r1211	r1211
r1213	r1213	r1213	r1213	r1213	r1213	r1213	r1213	r1213	r1213	r1213	r1213	r1213	r1213	r1213
r1214	r1214	r1214	r1214	r1214	r1214	r1214	r1214	r1214	r1214	r1214	r1214	r1214	r1214	r1214
r1215	r1215	r1215	r1215	r1215	r1215	r1215	r1215	r1215	r1215	r1215	r1215	r1215	r1215	r1215
r1403	r1403	r1403	r1403	r1403	r1403	r1403	r1403	r1403	r1403	r1403	r1403	r1403	r1403	r1403
r1405	r1405	r1405	r1405	r1405	r1405	r1405	r1405	r1405	r1405	r1405	r1405	r1405	r1405	r1405
r1406	r1406	r1406	r1406	r1406	r1406	r1406	r1406	r1406	r1406	r1406	r1406	r1406	r1406	r1406
r1407	r1407	r1407	r1407	r1407	r1407	r1407	r1407	r1407	r1407	r1407	r1407	r1407	r1407	r1407
r1408	r1408	r1408	r1408	r1408	r1408	r1408	r1408	r1408	r1408	r1408	r1408	r1408	r1408	r1408
r1410	r1410	r1410	r1410	r1410	r1410	r1410	r1410	r1410	r1410	r1410	r1410	r1410	r1410	r1410
r1412	r1412	r1412	r1412	r1412	r1412	r1412	r1412	r1412	r1412	r1412	r1412	r1412	r1412	r1412
r1414	r1414	r1414	r1414	r1414	r1414	r1414	r1414	r1414	r1414	r1414	r1414	r1414	r1414	r1414
r1415	r1415	r1415	r1415	r1415	r1415	r1415	r1415	r1415	r1415	r1415	r1415	r1415	r1415	r1415
r1501	r1501	r1501	r1501	r1501	r1501	r1501	r1501	r1501	r1501	r1501	r1501	r1501	r1501	r1501
r1502	r1502	r1502	r1502	r1502	r1502	r1502	r1502	r1502	r1502	r1502	r1502	r1502	r1502	r1502
r1503	r1503	r1503	r1503	r1503	r1503	r1503	r1503	r1503	r1503	r1503	r1503	r1503	r1503	r1503
r1505	r1505	r1505	r1505	r1505	r1505	r1505	r1505	r1505	r1505	r1505	r1505	r1505	r1505	r1505
r1507	r1507	r1507	r1507	r1507	r1507	r1507	r1507	r1507	r1507	r1507	r1507	r1507	r1507	r1507
r1508	r1508	r1508	r1508	r1508	r1508	r1508	r1508	r1508	r1508	r1508	r1508	r1508	r1508	r1508
r1509	r1509	r1509	r1509	r1509	r1509	r1509	r1509	r1509	r1509	r1509	r1509	r1509	r1509	r1509
r1510	r1510	r1510	r1510	r1510	r1510	r1510	r1510	r1510	r1510	r1510	r1510	r1510	r1510	r1510
r1511	r1511	r1511	r1511	r1511	r1511	r1511	r1511	r1511	r1511	r1511	r1511	r1511	r1511	r1511
r1512	r1512	r1512	r1512	r1512	r1512	r1512	r1512	r1512	r1512	r1512	r1512	r1512	r1512	r1512
r1513	r1513	r1513	r1513	r1513	r1513	r1513	r1513	r1513	r1513	r1513	r1513	r1513	r1513	r1513
r1514	r1514	r1514	r1514	r1514	r1514	r1514	r1514	r1514	r1514	r1514	r1514	r1514	r1514	r1514
r1515	r1515	r1515	r1515	r1515	r1515	r1515	r1515	r1515	r1515	r1515	r1515	r1515	r1515	r1515
r1600	r1600	r1600	r1600	r1600	r1600	r1600	r1600	r1600	r1600	r1600	r1600	r1600	r1600	r1600
r1602	r1602	r1602	r1602	r1602	r1602	r1602	r1602	r1602	r1602	r1602	r1602	r1602	r1602	r1602
r1603	r1603	r1603	r1603	r1603	r1603	r1603	r1603	r1603	r1603	r1603	r1603	r1603	r1603	r1603
r1605	r1605	r1605	r1605	r1605	r1605	r1605	r1605	r1605	r1605	r1605	r1605	r1605	r1605	r1605
r1606	r1606	r1606	r1606	r1606	r1606	r1606	r1606	r1606	r1606	r1606	r1606	r1606	r1606	r1606
r1607	r1607	r1607	r1607	r1607	r1607	r1607	r1607	r1607	r1607	r1607	r1607	r1607	r1607	r1607
r1609	r1609	r1609	r1609	r1609	r1609	r1609	r1609	r1609	r1609	r1609	r1609	r1609	r1609	r1609
r1614	r1614	r1614	r1614	r1614	r1614	r1614	r1614	r1614	r1614	r1614	r1614	r1614	r1614	r1614
r1615	r1615	r1615	r1615	r1615	r1615	r1615	r1615	r1615	r1615	r1615	r1615	r1615	r1615	r1615
r2200	r2200	r2200	r2200	r2200	r2200	r2200	r2200	r2200	r2200	r2200	r2200	r2200	r2200	r2200
r2202	r2202	r2202	r2202	r2202	r2202	r2202	r2202	r2202	r2202	r2202	r2202	r2202	r2202	r2202
r2205	r2205	r2205	r2205	r2205	r2205	r2205	r2205	r2205	r2205	r2205	r2205	r2205	r2205	r2205
r2400	r2400	r2400	r2400	r2400	r2400	r2400	r2400	r2400	r2400	r2400	r2400	r2400	r2400	r2400
r2410	r2410	r2410	r2410	r2410	r2410	r2410	r2410	r2410	r2410	r2410	r2410	r2410	r2410	r2410
r2414	r2414	r2414	r2414	r2414	r2414	r2414	r2414	r2414	r2414	r2414	r2414	r2414	r2414	r2414
r2500	r2500	r2500	r2500	r2500	r2500	r2500	r2500	r2500	r2500	r2500	r2500	r2500	r2500	r2500
r2501	r2501	r2501	r2501	r2501	r2501	r2501	r2501	r2501	r2501	r2501	r2501	r2501	r2501	r2501
r2502	r2502	r2502	r2502	r2502	r2502	r2502	r2502	r2502	r2502	r2502	r2502	r2502	r2502	r2502
r2504	r2504	r2504	r2504	r2504	r2504	r2504	r2504	r2504	r2504	r2504	r2504	r2504	r2504	r2504
r2506	r2506	r2506	r2506	r2506	r2506	r2506	r2506	r2506	r2506	r2506	r2506	r2506	r2506	r2506
r2507	r2507	r2507	r2507	r2507	r2507	r2507	r2507	r2507	r2507	r2507	r2507	r2507	r2507	r2507
r2512	r2512	r2512	r2512	r2512	r2512	r2512	r2512	r2512	r2512	r2512	r2512	r2512	r2512	r2512
r2600	r2600	r2600	r2600	r2600	r2600	r2600	r2600	r2600	r2600	r2600	r2600	r2600	r2600	r2600
r2616	r2616	r2616	r2616	r2616	r2616	r2616	r2616	r2616	r2616	r2616	r2616	r2616	r2616	r2616
r5100	r5100	r5100	r5100	r5100	r5100	r5100	r5100	r5100	r5100	r5100	r5100	r5100	r5100	r5100
r5101	r5101	r5101	r5101	r5101	r5101	r5101	r5101	r5101	r5101	r5101	r5101	r5101	r5101	r5101
r5102	r5102	r5102	r5102	r5102	r5102	r5102	r5102	r5102	r5102	r5102	r5102	r5102	r5102	r5102
r5103	r5103	r5103	r5103	r5103	r5103	r5103	r5103	r5103	r5103	r5103	r5103	r5103	r5103	r5103
r5104	r5104	r5104	r5104	r5104	r5104	r5104	r5104	r5104	r5104	r5104	r5104	r5104	r5104	r5104
r5105	r5105	r5105	r5105	r5105	r5105	r5105	r5105	r5105	r5105	r5105	r5105	r5105	r5105	r5105
r5106	r5106	r5106	r5106	r5106	r5106	r5106	r5106	r5106	r5106	r5106	r5106	r5106	r5106	r5106
r5108	r5108	r5108	r5108	r5108	r5108	r5108	r5108	r5108	r5108	r5108	r5108	r5108	r5108	r5108
r5109	r5109	r5109	r5109	r5109	r5109	r5109	r5109	r5109	r5109	r5109	r5109	r5109	r5109	r5109
r5110	r5110	r5110	r5110	r5110	r5110	r5110	r5110	r5110	r5110	r5110	r5110	r5110	r5110	r5110
r5112	r5112	r5112	r5112	r5112	r5112	r5112	r5112	r5112	r5112	r5112	r5112	r5112	r5112	r5112
r5113	r5113	r5113	r5113	r5113	r5113	r5113	r5113	r5113	r5113	r5113	r5113	r5113	r5113	r5113

Assessment of benthic communities in Jackfish Bay, 2013

Multivariate comparisons of test and reference site whole communities

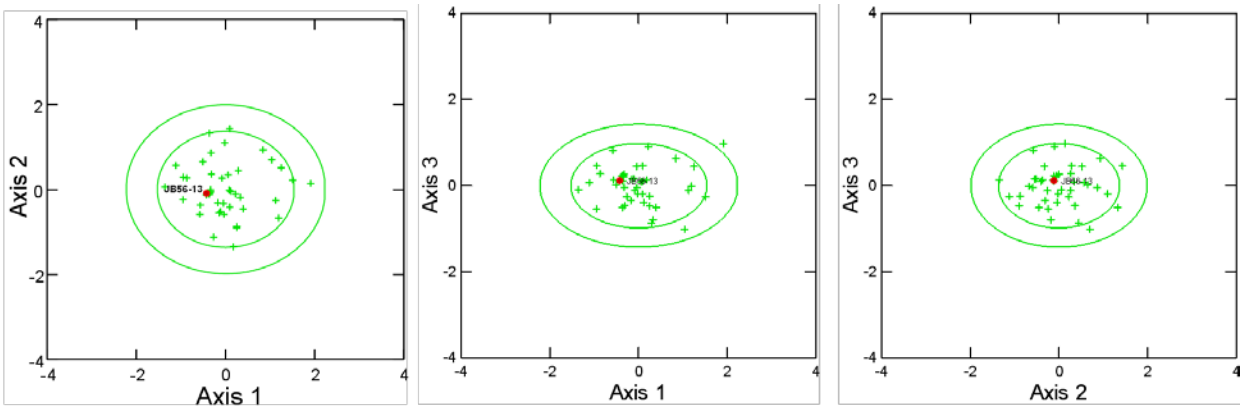
Benthic communities at Jackfish Bay sites were compared to communities in their corresponding reference subset sites by NMDS of the merged test and reference site invertebrate family count data. The status of the test site was determined by its NMDS site score relative to 90 and 99% probability ellipses for the reference site scores, shown in Fig. A3a-e.

These ellipses demark three categories of difference from reference:

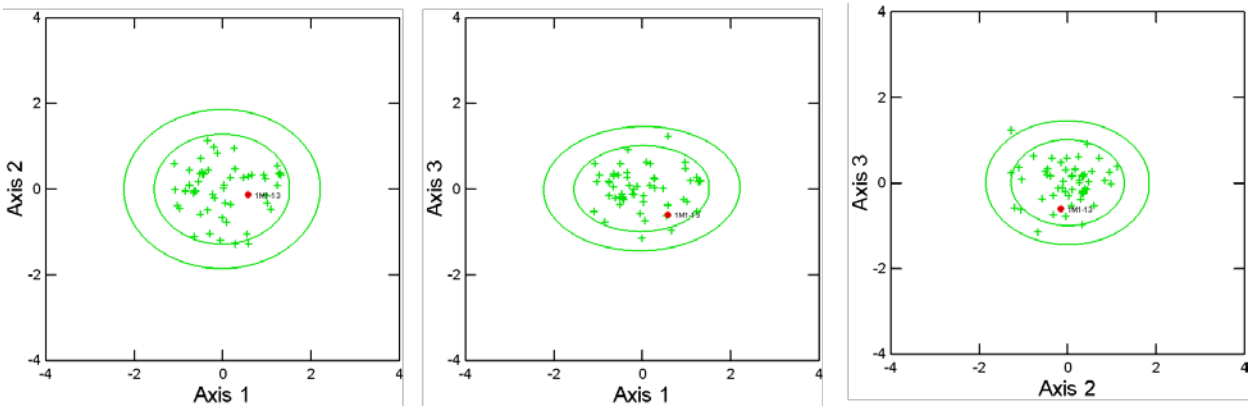
- within the inner ellipse – not different from reference ($p > 0.10$),
- between the inner and outer ellipses – different from reference ($0.10 \geq p > 0.01$) and
- beyond the outer ellipse – very different from reference ($p \leq 0.01$).

NMDS was performed using PC-ORD (McCune and Mefford 2011). Probability ellipses were constructed using Systat (Systat Software Inc. 2007).

Site 6956



Site 691M1



Site 691M3

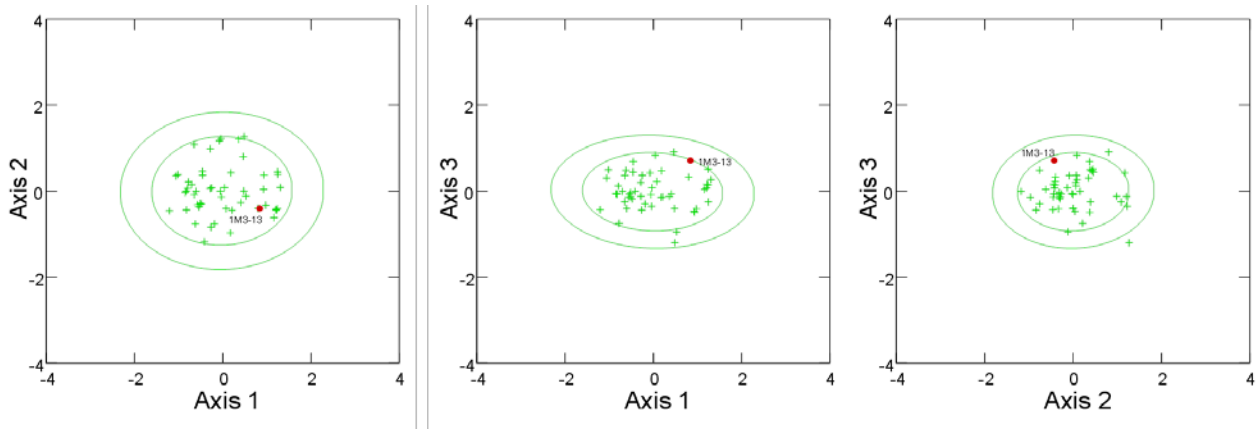
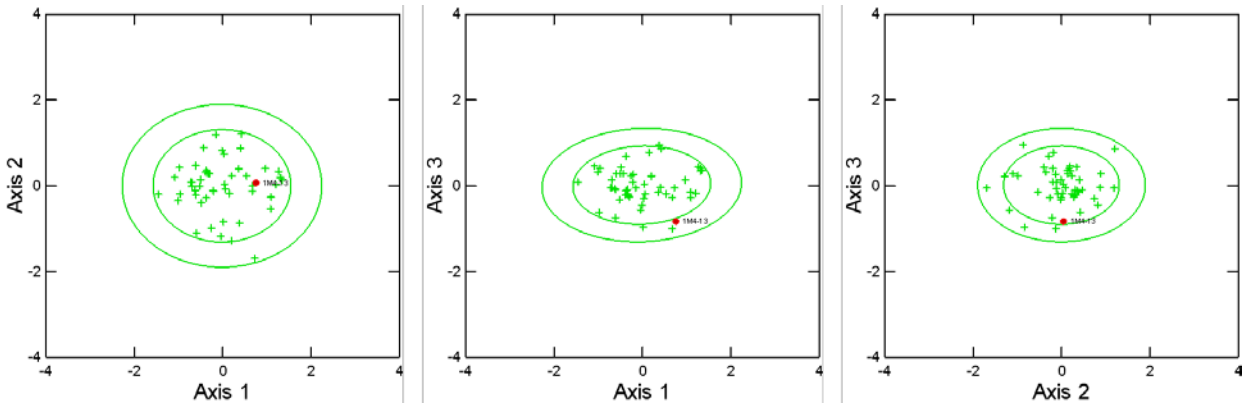
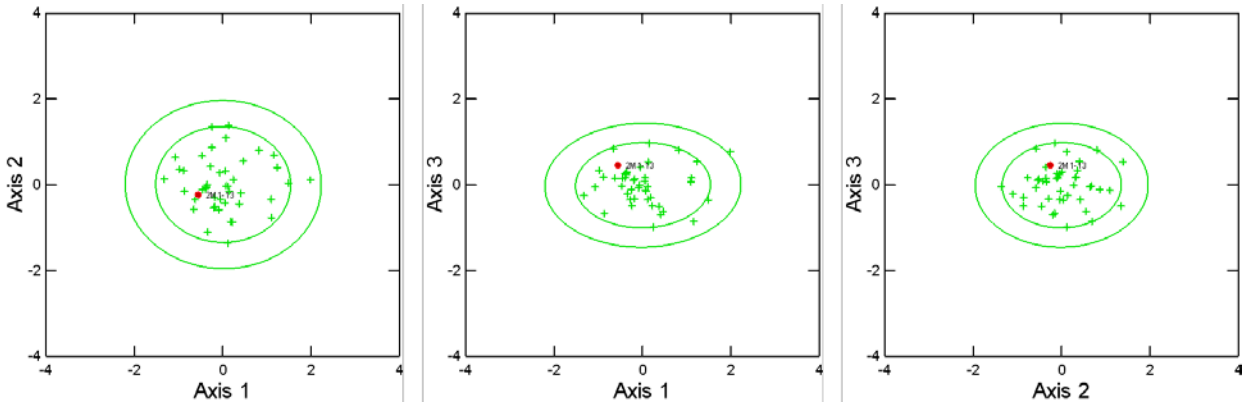


Figure A3a. Scores for Jackfish Bay test (●) and matched reference sites (+) from NMDSs, with 90 and 99% probability ellipses for the reference site scores.

Site 691M4



Site 692M1



Site 692M4

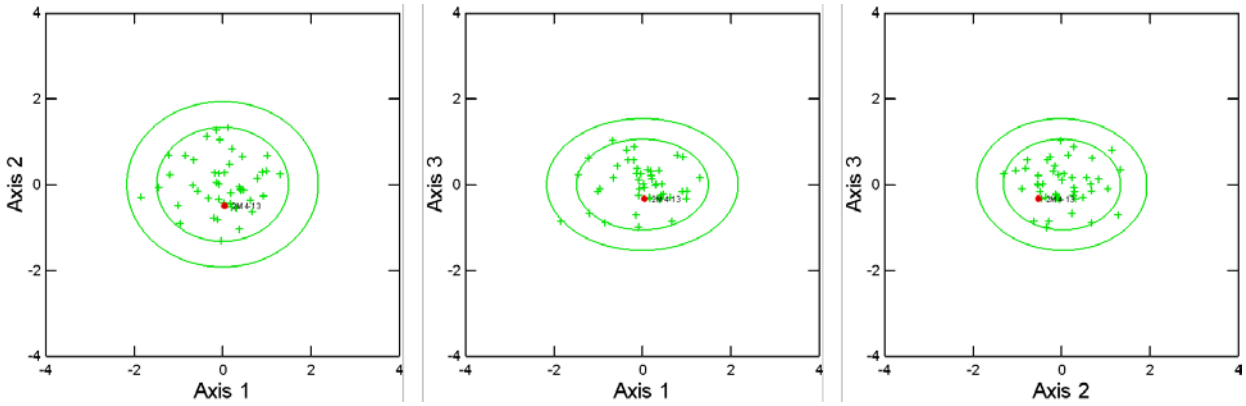
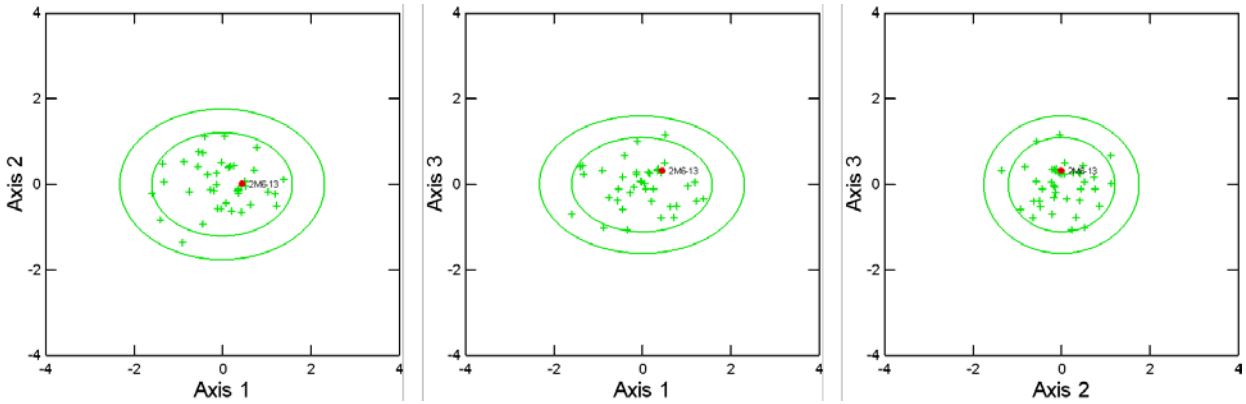
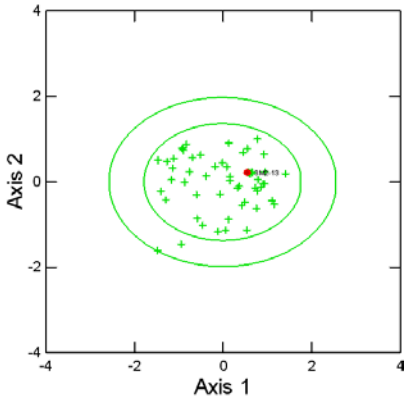


Figure A3b. Scores for Jackfish Bay test (●) and matched reference sites (+) from NMDSs, with 90 and 99% probability ellipses for the reference site scores.

Site 692M6



Site 693M2 (2-D solution calculated)



Site 69M3

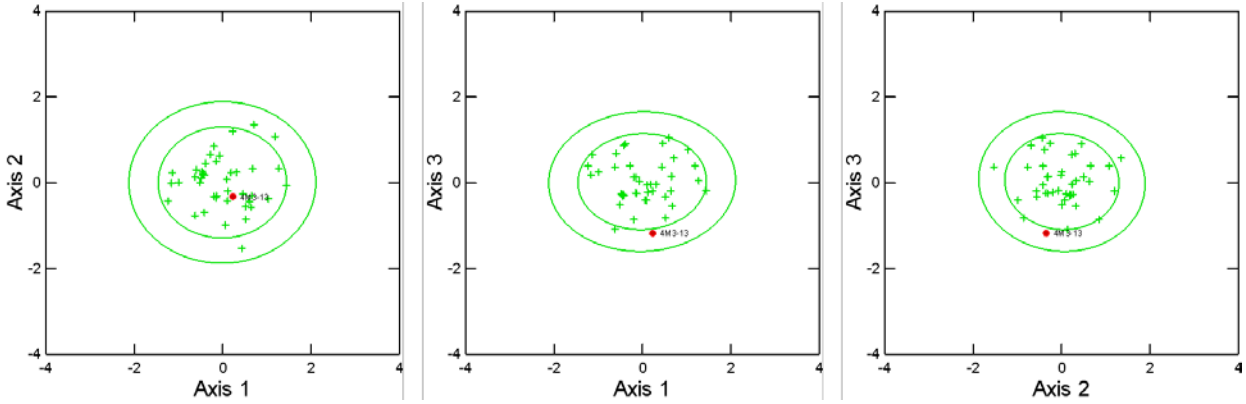
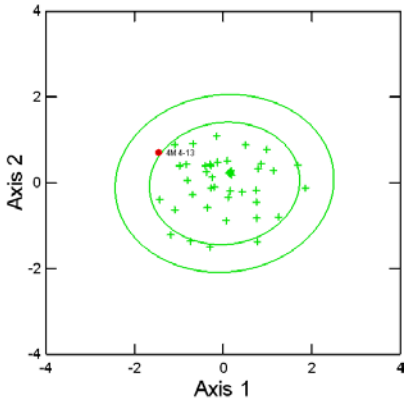
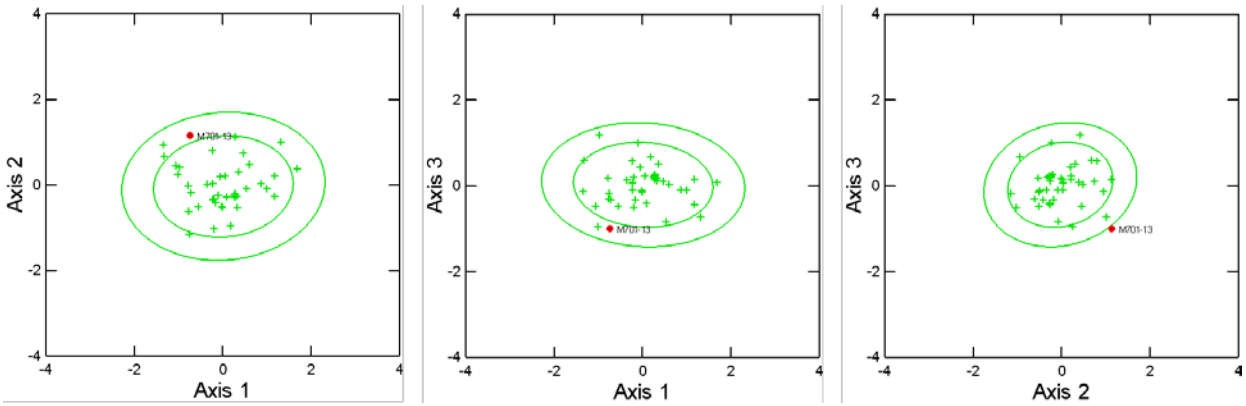


Figure A3c. Scores for Jackfish Bay test (●) and matched reference sites (+) from NMDSs, with 90 and 99% probability ellipses for the reference site scores.

Site 694M4 (2-D solution calculated)



Site 69M701



Site EEM4

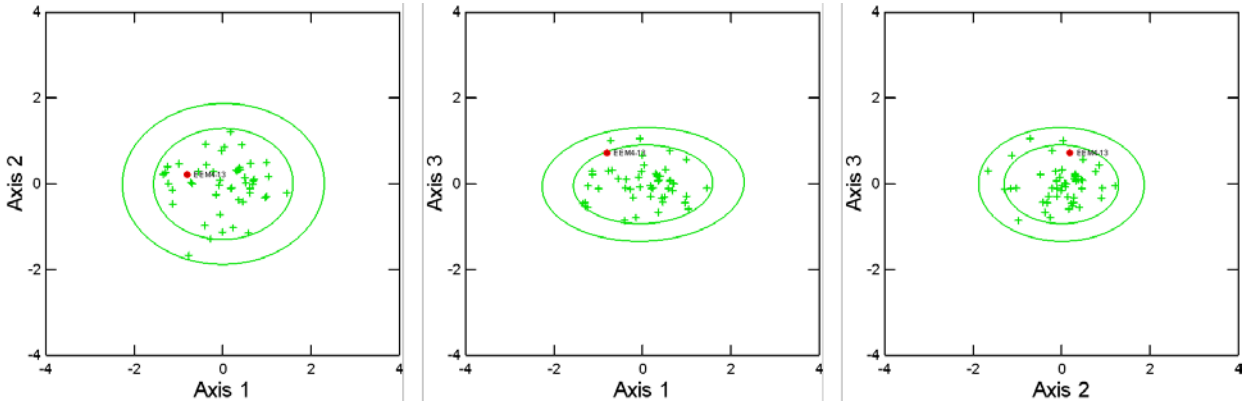
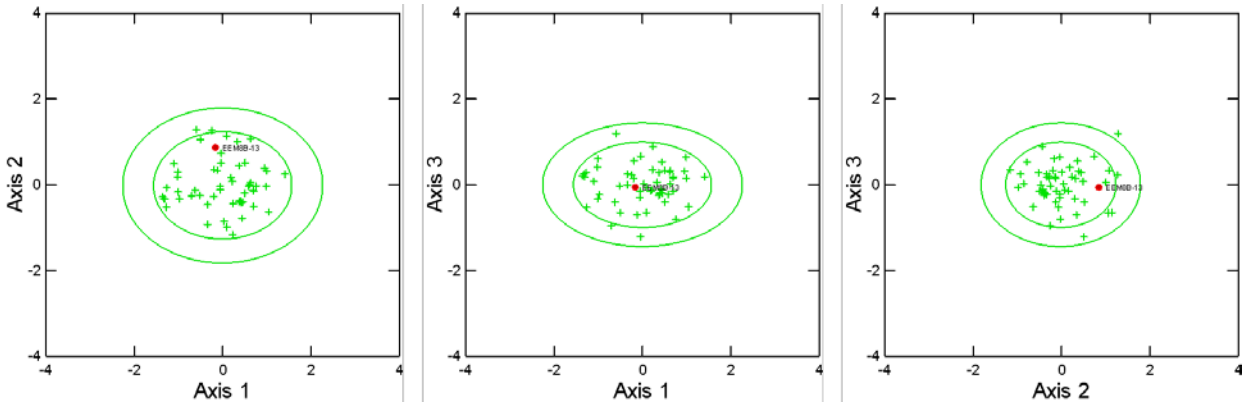
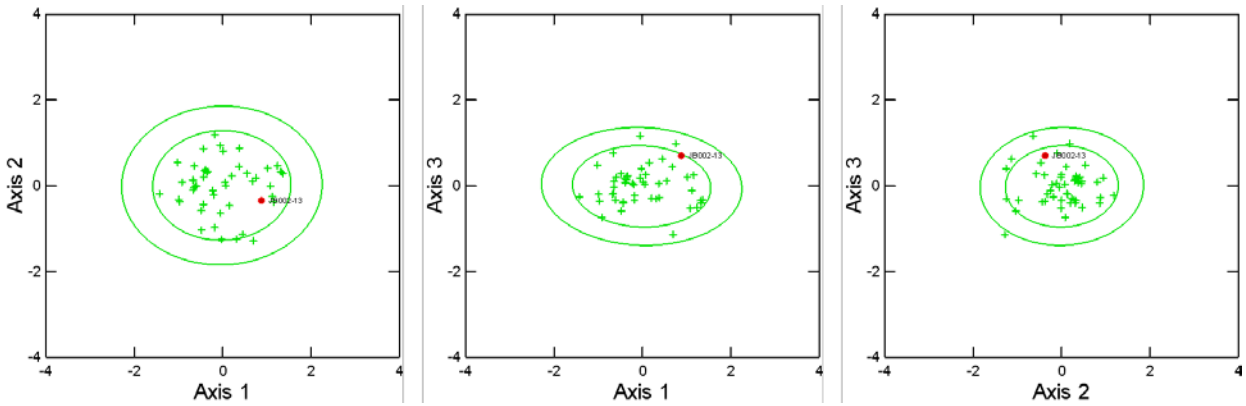


Figure A3d. Scores for Jackfish Bay test (●) and matched reference sites (+) from NMDSs, with 90 and 99% probability ellipses for the reference site scores.

Site EEM8B



Site JFB002



Site NF5

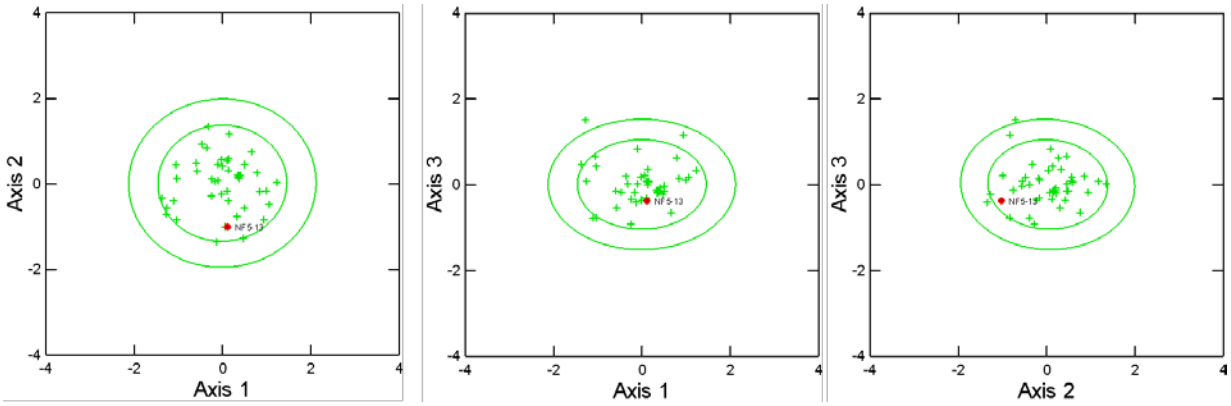


Figure A3e. Scores for Jackfish Bay test (●) and matched reference sites (+) from NMDSs, with 90 and 99% probability ellipses for the reference site scores.

Additional benthic community descriptors of Jackfish Bay relative to reference sites

Jackfish Bay benthic communities were also compared to reference conditions in a series of univariate analyses of:

- total benthos (total number of individuals per m^2),
- taxon richness (number of families),
- Pielou's evenness (= Shannon diversity/ln(taxon richness); Legendre and Legendre 1998),
- Tubificidae density,
- Chironomidae density,
- Pontoporeiidae density,
- Pisidiidae density,
- Naididae density,
- Asellidae density, and
- Lumbriculidae density.

For each descriptor, the value for each Jackfish Bay community in 2013 was compared to the 5th and 95th percentile interval and the range (i.e., minimum to maximum) for the site-specific reference data (Fig. A4a-o). Three categories of difference from reference were defined:

- not different from reference ($p > 0.10$) for within the 5th – 95th percentile interval
- different from reference ($0.10 \geq p > \sim 0.02$) for outside the 5th – 95th percentile interval, and
- very different from reference ($p < \sim 0.02$) for outside the range.

The estimated p-value for being outside the reference range depends on the number of reference sites in the subset, which ranged from 42 to 57. The data sets used to analyze the additional community descriptors were the same as those used for the whole community (multivariate) assessments.

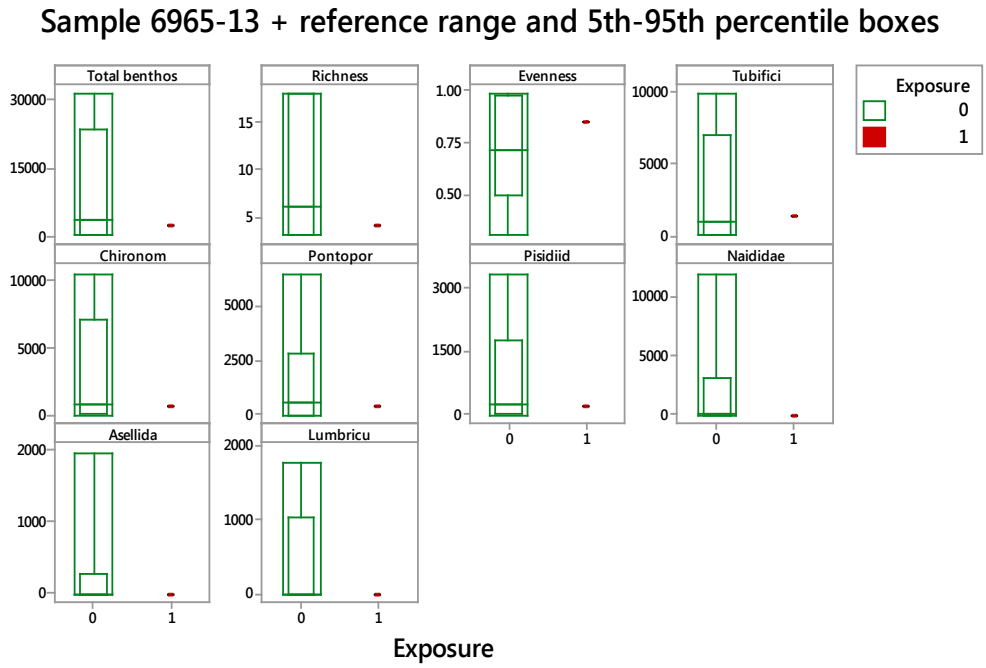


Fig. A4a. Comparisons of benthic descriptors for site 6965 in 2013 (red line) to reference conditions (green boxes).

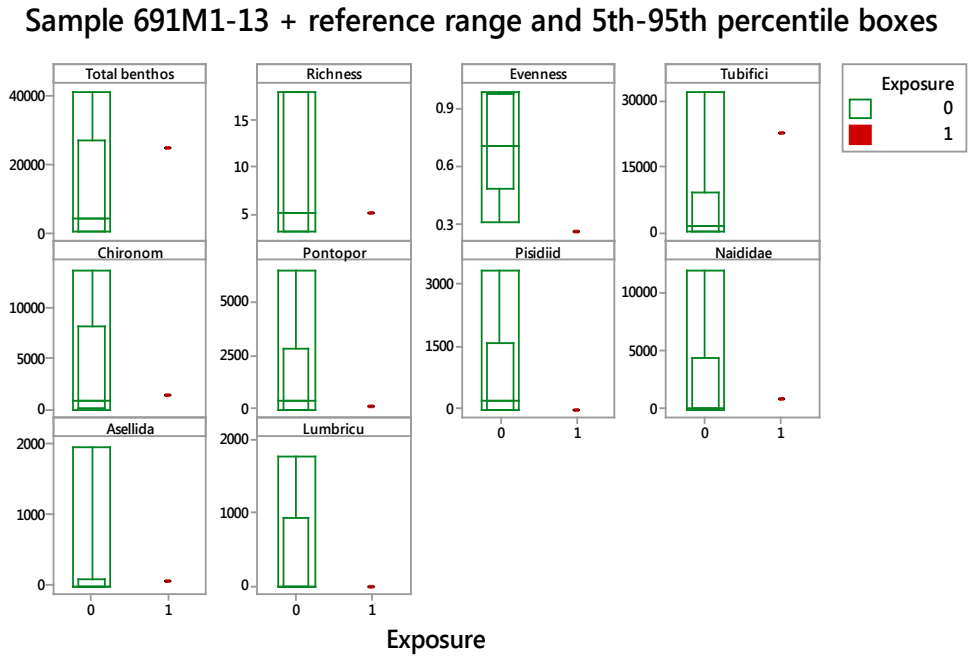


Fig. A4b. Comparisons of benthic descriptors for site 691M1 in 2013 (red line) to reference conditions (green boxes).

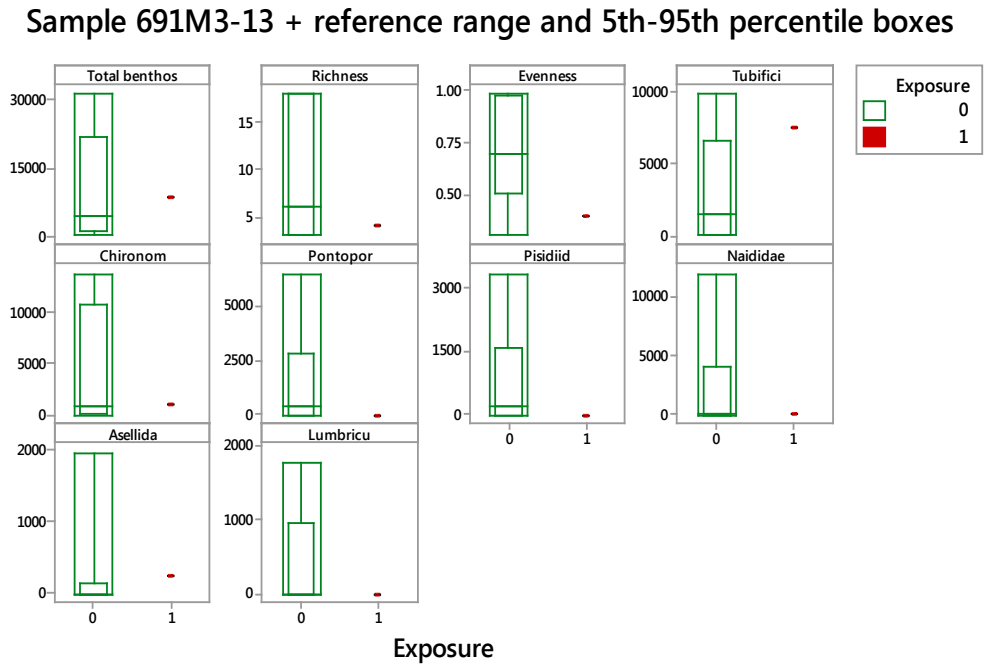


Fig. A4c. Comparisons of benthic descriptors for site 691M3 in 2013 (red line) to reference conditions (green boxes).

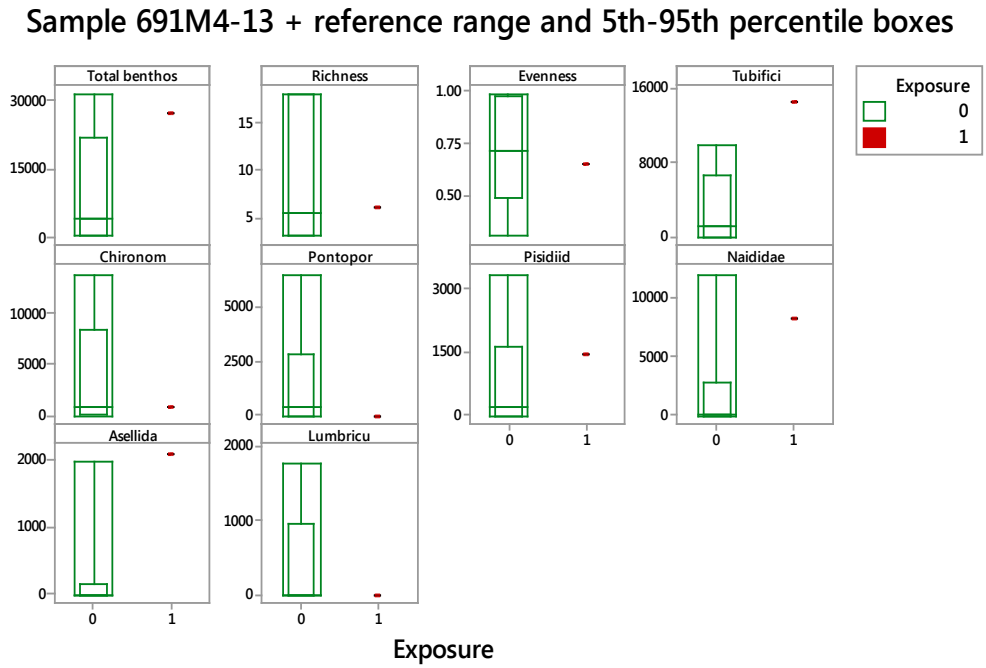


Fig. A4d. Comparisons of benthic descriptors for site 691M4 in 2013 (red line) to reference conditions (green boxes).

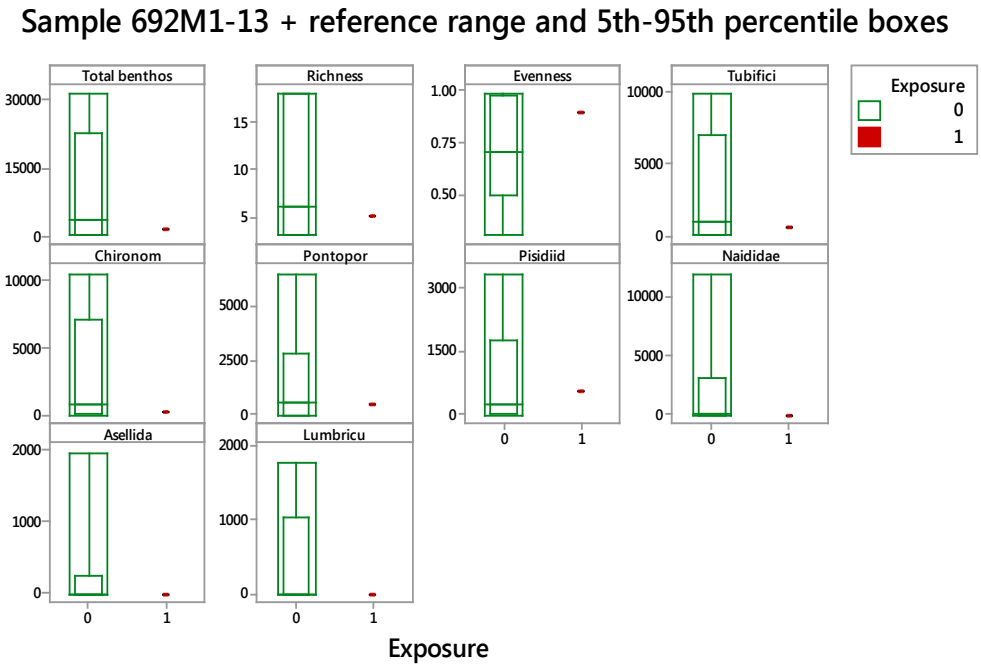


Fig. A4e. Comparisons of benthic descriptors for site 692M1 in 2013 (red line) to reference conditions (green boxes).

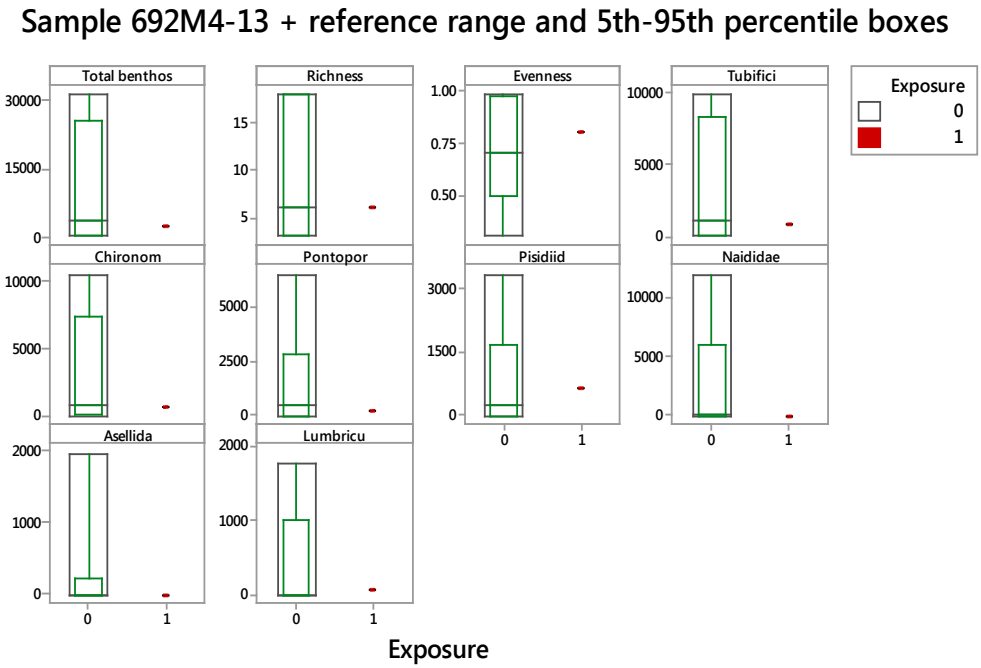


Fig. A4f. Comparisons of benthic descriptors for site 692M4 in 2013 (red line) to reference conditions (green boxes).

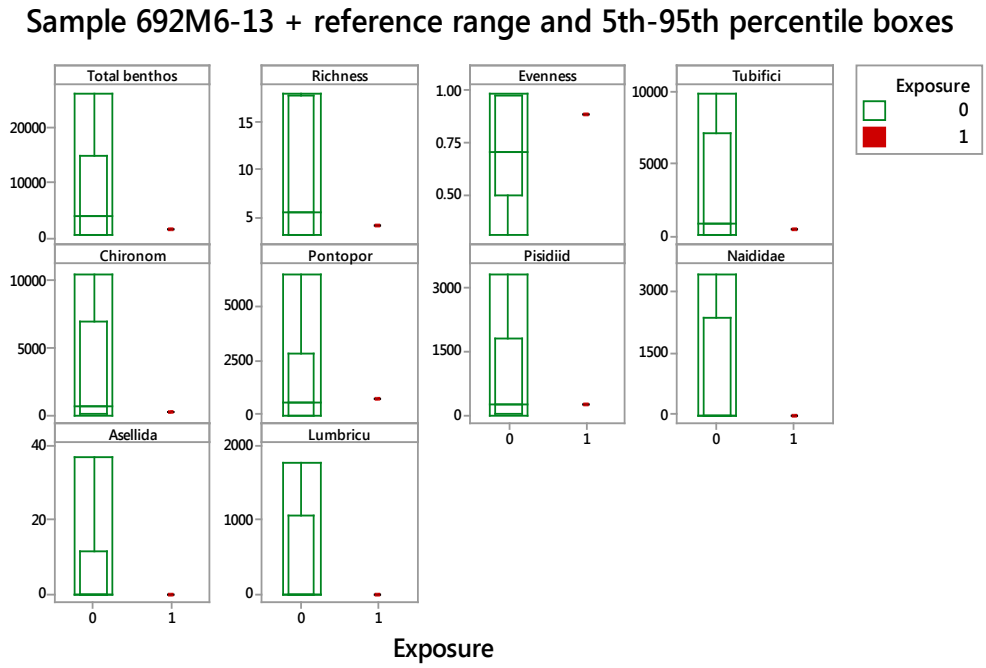


Fig. A4g. Comparisons of benthic descriptors for site 692M6 in 2013 (red line) to reference conditions (green boxes).

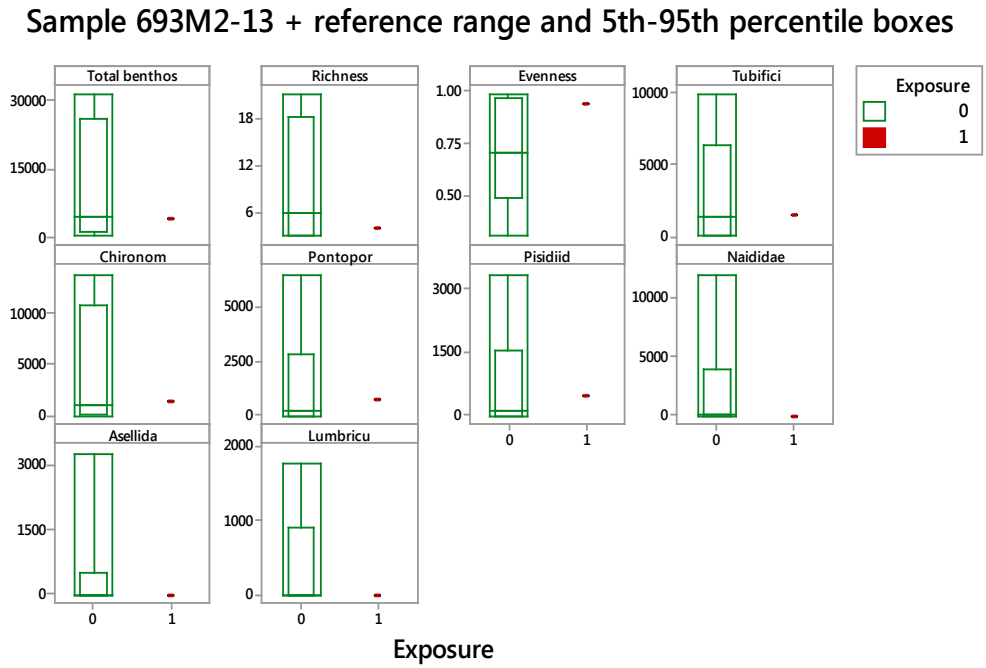


Fig. A4h. Comparisons of benthic descriptors for site 693M2 in 2013 (red line) to reference conditions (green boxes).

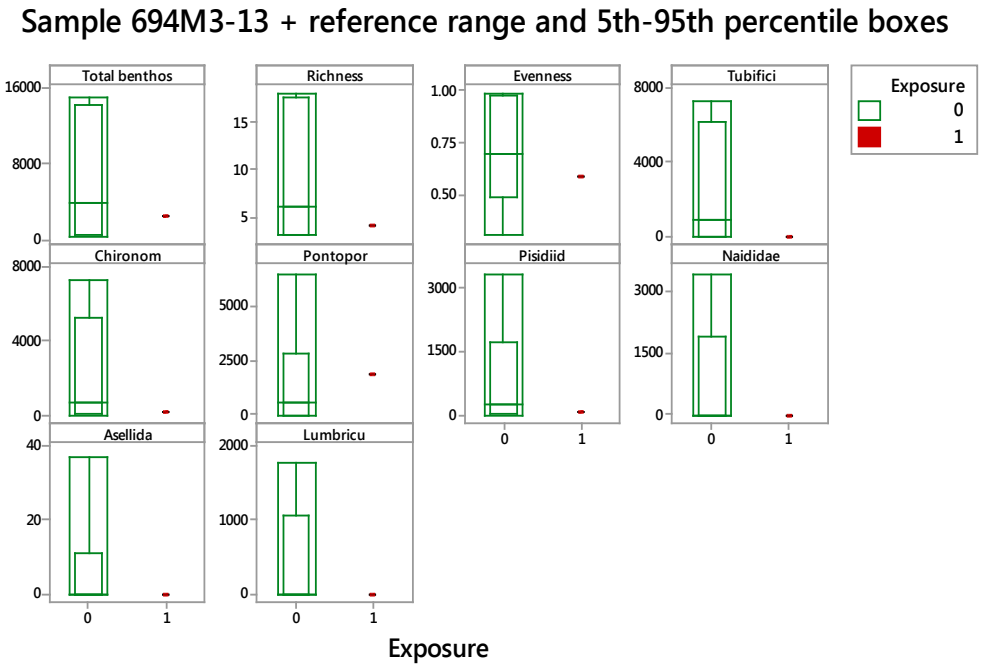


Fig. A4i. Comparisons of benthic descriptors for site 694M3 in 2013 (red line) to reference conditions (green boxes).

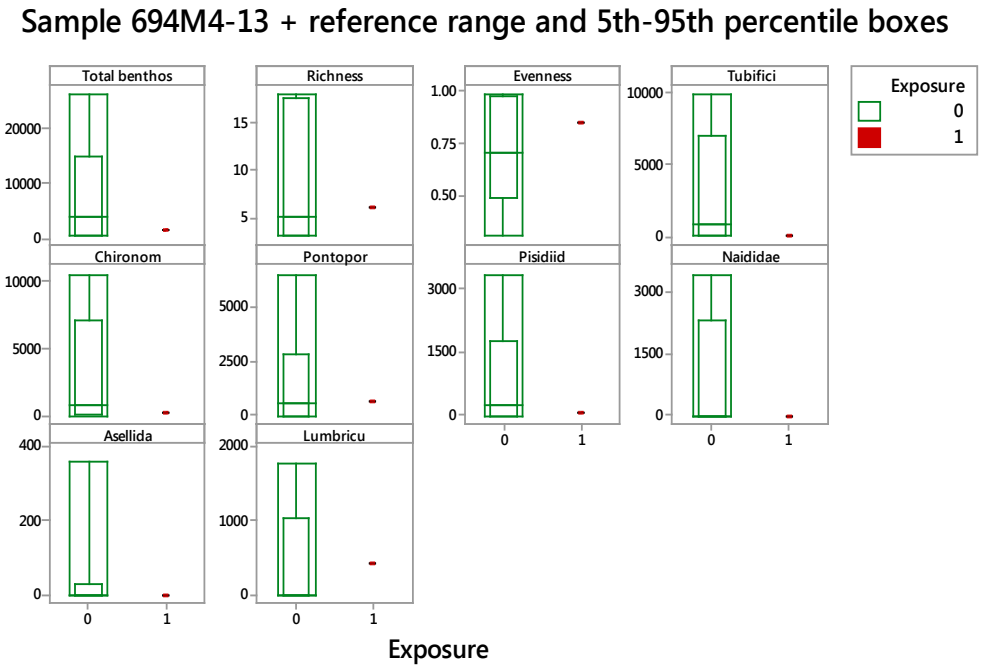


Fig. A4j. Comparisons of benthic descriptors for site 694M4 in 2013 (red line) to reference conditions (green boxes).

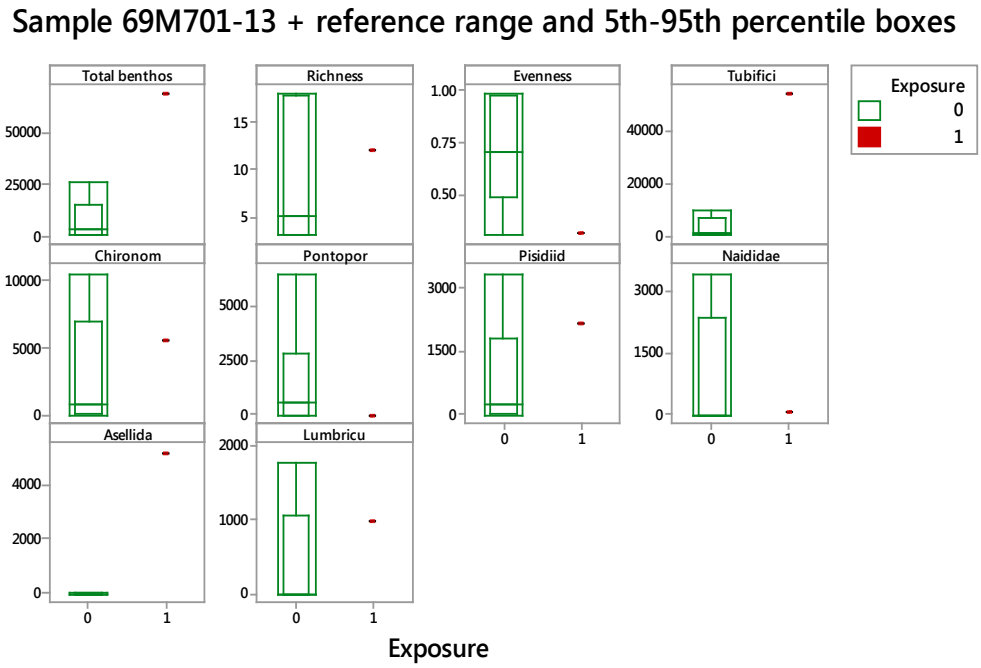


Fig. A4k. Comparisons of benthic descriptors for site 69M701 in 2013 (red line) to reference conditions (green boxes).

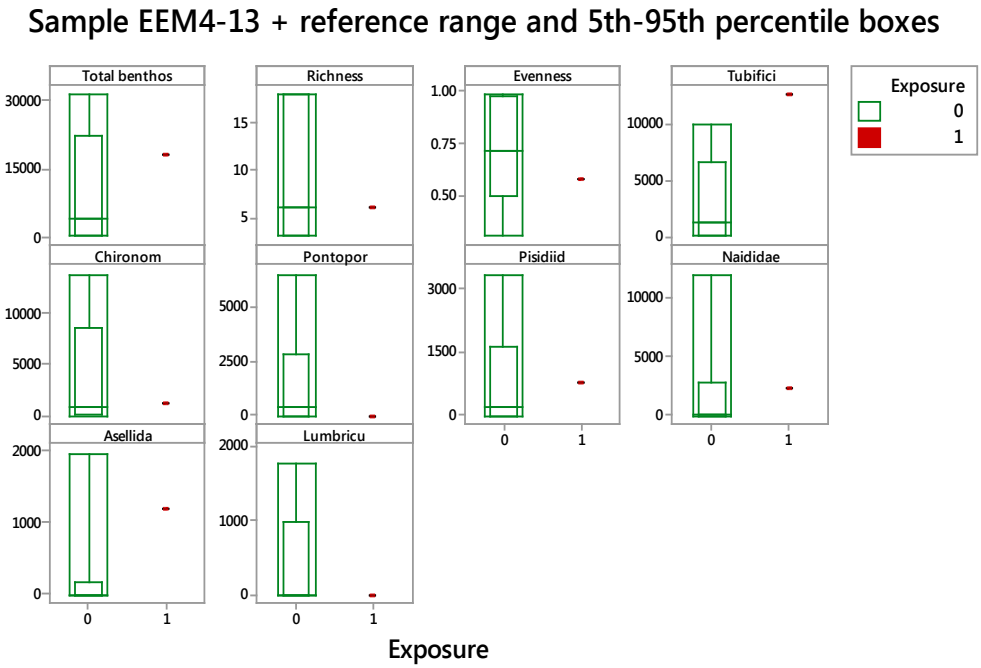


Fig. A4l. Comparisons of benthic descriptors for site EEM4 in 2013 (red line) to reference conditions (green boxes).

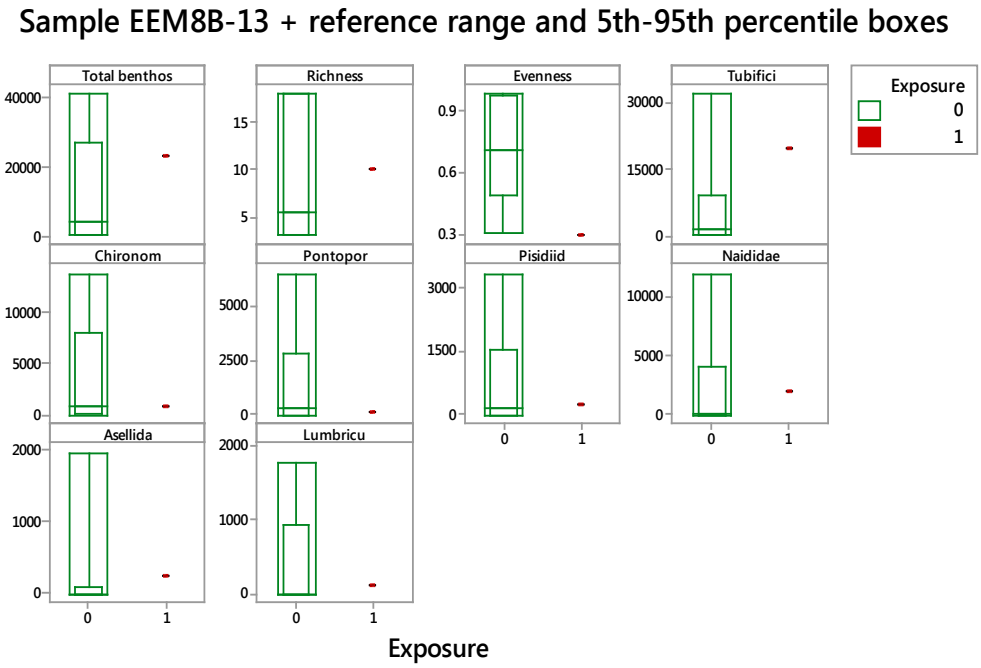


Fig. A4m. Comparisons of benthic descriptors for site EEM8B in 2013 (red line) to reference conditions (green boxes).

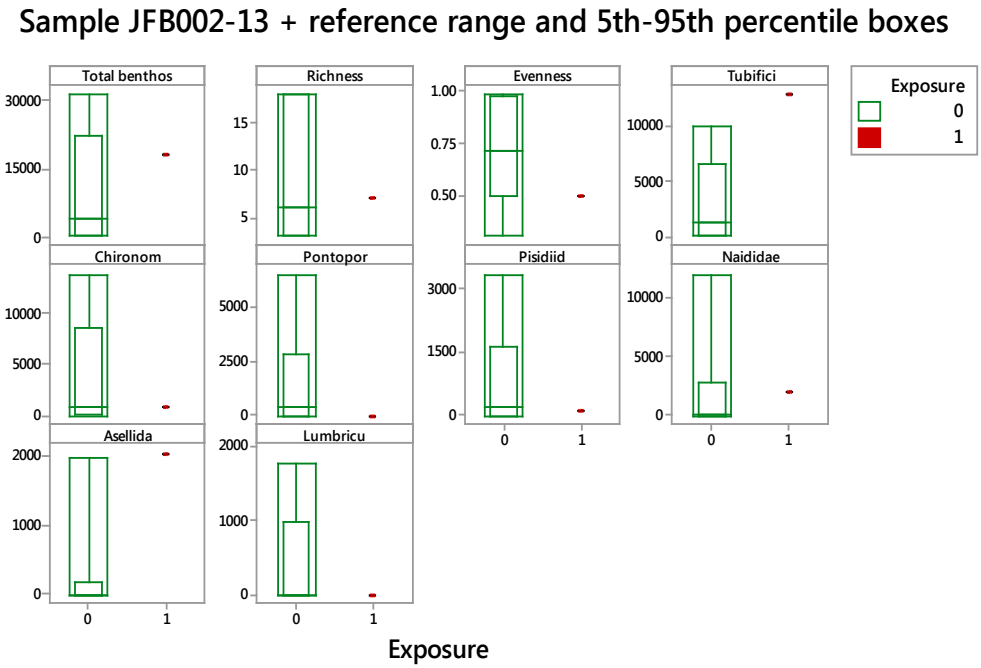


Fig. A4n. Comparisons of benthic descriptors for site JFB002 in 2013 (red line) to reference conditions (green boxes).

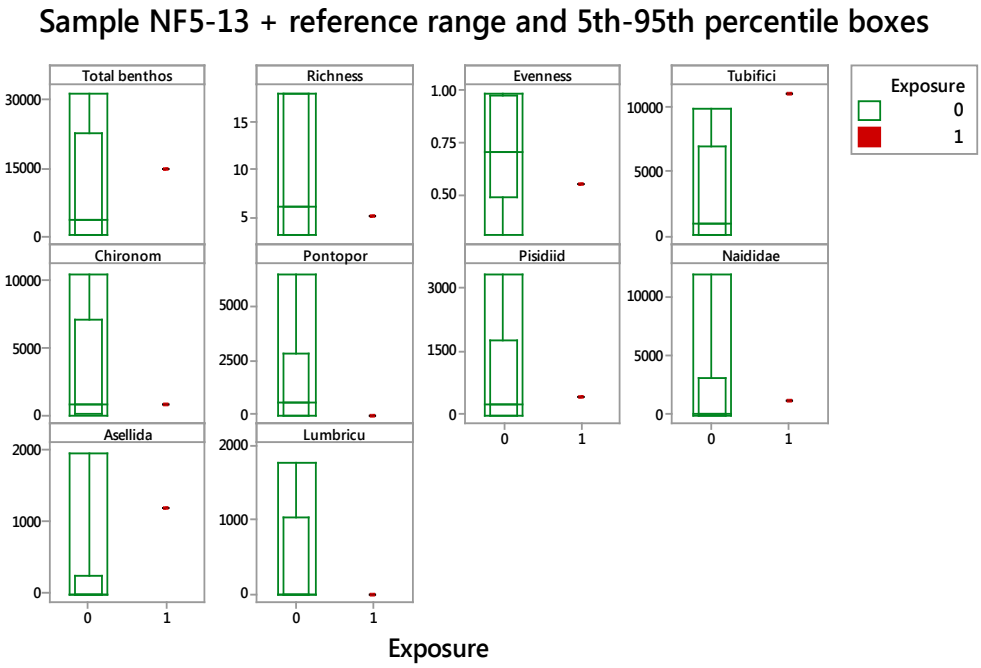


Fig. A4o. Comparisons of benthic descriptors for site NF5 in 2013 (red line) to reference conditions (green boxes).

APPENDIX B

Quality Assurance/Quality Control Results

Table B1. Variation (coefficient of variation, CV) in trace metal, metal oxides and nutrient analysis for 2013 Jackfish Bay and Lake Superior reference field-replicated samples.

Parameter	Units	M.D.L.	1M400	1M401	1M402	CV	NF500	NF501	NF502	CV	241000	241001	241002	CV
Aluminum	µg/g	10	6490	5340	7390	16.0	9060	9250	9055	1.2	7300	7130	7840	5.0
Antimony	µg/g	0.5	< 0.5	< 0.5	< 0.5	-	< 0.5	< 0.5	< 0.5	-	< 0.5	< 0.5	< 0.5	-
Arsenic	µg/g	0.5	1.8	1.4	2	17.6	2.2	2.1	2.4	6.8	8.8	9.9	9.8	6.4
Barium	µg/g	1	44	37	52	16.9	62	65	62.5	2.5	45	50	49	5.5
Beryllium	µg/g	0.2	0.2	< 0.2	0.3	28.3	0.3	0.3	0.3	0.0	0.3	0.3	0.3	0.0
Bismuth	µg/g	5	< 5	< 5	< 5	-	< 5	< 5	< 0.5	-	< 5	< 5	< 5	-
Cadmium	µg/g	0.5	0.8	< 0.5	1	15.7	1.3	1.5	1.3	8.4	0.5	0.7	0.6	16.7
Calcium	µg/g	10	9590	5930	10100	26.6	12100	13600	12200	6.6	3360	3670	3580	4.5
Chromium	µg/g	1	37	31	40	12.7	50	51	50	1.1	22	24	23	4.3
Cobalt	µg/g	1	7	8	8	7.5	9	9	9	0.0	8	9	8	6.9
Copper	µg/g	1	20	13	25	31.2	33	35	33.5	3.1	44	54	50	10.2
Iron	µg/g	10	14300	12600	15700	10.9	17900	17900	17700	0.6	16900	15700	17600	5.7
Lead	µg/g	5	6	< 5	7	10.9	9	9	9.5	3.1	23	31	29	15.0
Magnesium	µg/g	10	6980	4890	7540	21.6	9260	10100	9260	5.1	3750	4090	4030	4.6
Manganese	µg/g	1	248	229	307	15.6	325	321	331.5	1.6	397	380	400	2.7
Mercury	µg/g	0.005	0.057	0.046	0.07	20.8	0.071	0.073	0.07	2.1	0.035	0.045	0.037	13.6
Molybdenum	µg/g	1	< 1	< 1	< 1	-	< 1	< 1	< 1	-	< 1	< 1	< 1	-
Nickel	µg/g	1	18	17	20	8.3	23	24	23.5	2.1	16	18	17	5.9
Phosphorus	µg/g	5	780	743	795	3.5	862	865	865	0.2	686	677	700	1.7
Potassium	µg/g	30	700	490	860	27.2	1160	1220	1150	3.2	720	820	810	7.0
Silicon	µg/g	1	565	513	646	11.7	631	650	744.5	9.0	665	705	753	6.2
Silver	µg/g	0.2	< 0.2	< 0.2	0.2	-	0.4	0.4	1	57.7	< 0.2	< 0.2	< 0.2	-
Sodium	µg/g	20	200	170	230	15.0	280	290	270	3.6	210	220	210	2.7
Strontium	µg/g	1	18	17	19	5.6	22	23	22	2.6	12	14	14	8.7
Tin	µg/g	10	< 10	< 10	< 10	-	< 10	< 10	< 10	-	< 10	< 10	< 10	-
Titanium	µg/g	1	734	740	785	3.7	830	820	852.5	2.0	496	549	548	5.7
Vanadium	µg/g	1	27	25	30	9.2	33	34	33.5	1.5	29	33	31	6.5
Yttrium	µg/g	0.5	5.6	5.1	6	8.1	6.8	6.7	6.85	1.1	6.5	7.1	7	4.7
Zinc	µg/g	3	116	109	125	6.9	157	171	155	5.4	62	73	70	8.3
Zirconium	µg/g	0.1	3.7	3	3.7	11.7	3.9	4	4.4	6.5	1.7	1.9	1.9	6.3
Aluminum (Al2O3)	%	0.04	10.4	9.92	10.2	2.4	10.1	9.32	10.28	5.2	10	10.9	10.1	4.8
Barium (BaO)	%	0.002	0.064	0.059	0.064	4.6	0.063	0.058	0.064	5.2	0.052	0.058	0.052	6.4
Calcium (CaO)	%	0.06	3.13	2.56	3.09	10.9	3.2	3.09	3.26	2.7	2.21	2.39	2.19	4.9
Chromium (Cr2O3)	%	0.006	0.013	0.009	0.013	19.8	0.015	0.013	0.0145	7.3	0.008	0.01	0.008	13.3
Iron (Fe2O3)	%	0.01	3.17	2.69	3.22	9.7	3.47	3.22	3.475	4.3	3.19	3.65	3.19	7.9
Potasium (K20)	%	0.2	2.1	1.8	2	7.8	2	1.9	2.05	3.9	1.7	1.9	1.7	6.5
Magnesium (MgO)	%	0.03	1.82	1.35	1.84	16.6	2.09	2.08	2.16	2.1	1.17	1.35	1.15	9.0
Manganese (MnO)	%	0.003	0.059	0.052	0.062	8.9	0.064	0.059	0.066	5.7	0.069	0.075	0.068	5.4
Sodium (Na2O)	%	0.5	3.4	3.2	3.3	3.0	2.8	2.5	2.85	7.0	3	3.1	3	1.9
Phosphorus (P2O5)	%	0.5	< 0.5	< 0.5	< 0.5	-	< 0.5	< 0.5	< 0.5	-	< 0.5	< 0.5	< 0.5	-
Silica (SiO2)	%	0.1	62.7	60.3	61.2	2.0	58.5	53.4	59.75	5.9	62.5	68	62.5	4.9
Titanium (TiO2)	%	0.02	0.47	0.4	0.48	9.7	0.49	0.44	0.485	5.8	0.36	0.41	0.36	7.7
Whole Rock Total	%		96.9	90.4	96.9	4.0	96.8	91.7	99.4	4.1	90.4	98.7	90	5.3
TC (LOI@1000°C)	%	0.05	9.46	8	11.2	16.8	13.9	15.5	14.55	5.5	6.06	6.65	5.51	9.4
Total Organic Carbon	% by wt	0.1	5.5	8.8	5.7	27.8	6	6.2	5.9	2.5	2.8	2.1	2.2	16.0
Total Kjeldahl Nitrogen	µg/g	0.05	2520	1530	2430	25.3	3520	3370	3110	6.2	1890	1740	1490	11.8
Phosphorus-Total	µg/g	0.01	856	709	831	9.8	915	828	839	5.5	765	711	637	9.1
						10.9				3.7				6.3
						2-31.2				0-57.7				0-16.7

Table B2. Variation (coefficient of variation, CV) in dioxin and furan analysis for 2013 field-replicated sediment samples.

Site	1M400	1M401	1M402	CV	NF500	NF501	NF502	CV
Matrix	sediment	sediment	sediment		sediment	sediment	sediment	
Target Analytes	**pg/g**	**pg/g**	**pg/g**		**pg/g**	**pg/g**	**pg/g**	
2,3,7,8-TCDD	8.44	16.30	9.92	36.2	12.80	11.00	14.50	13.7
1,2,3,7,8-PeCDD	<0.67	1.93	0.92	50.1	1.28	1.14	<1.3	8.2
1,2,3,4,7,8-HxCDD	<0.35	1.00	0.74	21.6	<0.44	0.70	<0.50	
1,2,3,6,7,8-HxCDD	<0.93	1.70	<1.3		1.90	1.48	1.61	12.9
1,2,3,7,8,9-HxCDD	0.49	1.16	0.96	39.5	<1.0	0.75	1.64	52.3
1,2,3,4,6,7,8-HpCDD	24.1	35.1	26.6	20.2	28.0	<21	26.5	3.9
OCDD	144	216	156	22.4	204	131	143	24.6
2,3,7,8-TCDF	128	306	160	47.9	204	171	215	11.6
1,2,3,7,8-PeCDF	4.14	6.36	3.49	32.3	5.33	5.12	5.94	7.8
2,3,4,7,8-PeCDF	7.70	13.00	7.09	35.1	10.60	10.10	11.30	5.7
1,2,3,4,7,8-HxCDF	1.94	1.25	1.41	23.6	1.77	1.44	2.28	23.1
1,2,3,6,7,8-HxCDF	0.68	<0.64	0.61	7.1	0.88	<0.76	0.89	0.6
2,3,4,6,7,8-HxCDF	<0.37	<1.0	<1.3		<0.71	<0.98	<0.76	
1,2,3,7,8,9-HxCDF	<0.41	<1.0	<0.37		<0.73	0.56	<0.40	
1,2,3,4,6,7,8-HpCDF	9.54	13.80	12.60	18.3	7.28	7.24	6.90	2.9
1,2,3,4,7,8,9-HpCDF	<0.57	<1.8	<1.1		<0.71	<0.48	<0.68	
OCDF	34.2	62.7	48.4	29.4	<20	23.5	20.3	10.3
			Median	29.4				10.3
			Range	7.1-50.1				0.6-52.3

Table B3. Variation (coefficient of variation, CV) in dioxin-like PCB analysis for 2013 field-replicated sediment samples.

Site	1M400	1M401	1M402	CV	NF500	NF501	NF502	CV
Matrix	Sediment	Sediment	Sediment		Sediment	Sediment	Sediment	
Target Analytes	**pg/g**	**pg/g**	**pg/g**		**pg/g**	**pg/g**	**pg/g**	
PCB 81	<0.79	<1.1	<1.8	-	1.08	<0.57	<0.98	-
PCB 77	19.7	<30	28.7	26.3	36.9	25.1	<26	26.9
PCB 123	85.6	195	125	41.0	189	122	162	21.4
PCB 118	528	1210	800	40.6	1150	701	925	24.3
PCB 114	13.6	55.5	30.3	63.7	33.5	27.5	20.4	24.2
PCB 105	191	586	302	56.6	436	272	320	24.6
PCB 126	<2.7	<3.4	<11	-	<8.1	<0.50	<3.8	-
PCB 167	35.7	79.3	54.2	38.8	56.3	39.1	63.9	23.9
PCB 156	97.5	218	118	44.6	152	108	132	16.9
PCB 157	18.4	45.1	27.8	44.5	35.2	<16	<17	-
PCB 169	<3.6	<2.6	<2.7	-	<10	<1.7	<14	-
PCB 189	15.5	35.4	18.6	46.2	18.9	14.7	21.8	19.3
			Median	44.5				24.0
			Range	26.3-63.7				16.9-26.9

Table B4. Variation (coefficient of variation, CV) in petroleum hydrocarbon analysis for 2013 field-replicated samples.

Site	Units	NF5-00	NF5-01	NF5-02	CV	1M4-00	1M4-01	1M4-02	CV
Oil and Grease, Total	mg/kg	16200	13700	16600	10.1	9900	18000	13300	29.6
Hydrocarbons									
F1 (C6-C10)	ug/g	<15	<15	<15	-	<10	<10	<10	-
F1-BTEX	ug/g	<15	<15	<15	-	<10	<10	<10	-
F2 (C10-C16)	ug/g	93	87	117	16.0	106	226	105	47.8
F2-Naphth	ug/g	93	87	117	16.0	106	226	105	47.8
F3 (C16-C34)	ug/g	3320	3230	3610	5.9	2900	5750	3070	40.9
F3-PAH	ug/g	3320	3230	3610	5.9	2900	5750	3070	40.9
F4 (C34-C50)	ug/g	600	590	680	7.9	600	1300	650	45.9
F4G-SG (GHH-Silica)	ug/g	2240	2170	2490	7.3	2610	5330	2830	42.1
PAHs									
Acenaphthene	ug/g	<0.15	<0.10	<0.10	-	<0.10	<0.15	<0.15	-
Acenaphthylene	ug/g	<0.15	<0.10	<0.10	-	<0.10	<0.15	<0.15	-
Acridine	ug/g	<2.4	<1.6	<1.6	-	<1.6	<2.4	<2.4	-
Anthracene	ug/g	<0.15	0.12	<0.10	-	0.14	0.23	<0.15	34.4
Benzo(a)anthracene	ug/g	<0.15	<0.10	<0.10	-	0.12	0.18	<0.15	28.3
Benzo(a)pyrene	ug/g	<0.060	<0.040	0.043	-	0.072	0.102	<0.060	24.4
Benzo(b)fluoranthene	ug/g	<0.15	<0.10	0.12	-	0.16	0.17	<0.15	4.3
Benzo(g,h,i)perylene	ug/g	<0.15	<0.10	<0.10	-	<0.10	<0.15	<0.15	-
Benzo(k)fluoranthene	ug/g	<0.060	<0.040	<0.040	-	<0.040	<0.060	<0.060	-
Chrysene	ug/g	<0.15	<0.10	0.11	-	0.18	0.35	<0.15	45.4
Dibenzo(ah)anthracene	ug/g	<0.15	<0.10	<0.10	-	<0.10	<0.15	<0.15	-
Fluoranthene	ug/g	0.19	0.16	0.18	8.6	0.37	0.49	0.21	39.4
Fluorene	ug/g	<0.15	<0.10	<0.10	-	<0.10	<0.15	<0.15	-
Indeno(1,2,3-cd)pyrene	ug/g	<0.15	<0.10	<0.10	-	<0.10	<0.15	<0.15	-
1-Methylnaphthalene	ug/g	<0.15	<0.10	<0.10	-	<0.10	<0.15	<0.15	-
2-Methylnaphthalene	ug/g	<0.15	<0.10	<0.10	-	<0.10	<0.15	<0.15	-
Naphthalene	ug/g	<0.030	<0.020	<0.020	-	0.030	0.041	<0.030	21.9
Phenanthrene	ug/g	0.106	0.104	0.106	1.1	0.242	0.502	0.140	63.3
Pyrene	ug/g	0.17	0.14	0.15	10.0	0.30	0.40	0.18	37.6
Quinoline	ug/g	<0.15	<0.10	<0.10	-	<0.10	<0.15	<0.15	-
				Median	8.3				40.2
				Range	1.1-16				4.3-63.3

Table B5. Relative percent difference (RPD) for 2013 Jackfish Bay sample duplicates (Caducean Laboratories).

Parameter	Units	M.D.L.	6956	6956 - Dup	R.P.D.	NF502	NF502- Dup	R.P.D.
Aluminum	µg/g	10	10600	10000	**5.8**	8980	9130	**1.7**
Antimony	µg/g	0.5	< 5	< 0.5	**-**	< 0.5	< 0.5	**-**
Arsenic	µg/g	0.5	7.4	7.4	**0**	2.2	2.6	**16.7**
Barium	µg/g	1	75	75	**0**	62	63	**1.6**
Beryllium	µg/g	0.2	0.4	0.4	**0**	0.3	0.3	**0**
Bismuth	µg/g	5	< 5	< 5	**-**	< 0.5	< 5	**-**
Cadmium	µg/g	0.5	0.8	0.8	**0**	1.3	1.3	**0**
Calcium	µg/g	10	7580	7720	**1.8**	12000	12400	**3.3**
Chromium	µg/g	1	41	41	**0**	49	51	**4.0**
Cobalt	µg/g	1	11	11	**0**	9	9	**0**
Copper	µg/g	1	42	43	**2.4**	32	35	**9.0**
Iron	µg/g	10	23200	21800	**6.2**	17600	17800	**1.1**
Lead	µg/g	5	26	27	**3.8**	9	10	**10.5**
Magnesium	µg/g	10	7470	7610	**1.9**	9100	9420	**3.5**
Manganese	µg/g	1	903	921	**2.0**	326	337	**3.3**
Mercury	µg/g	0.005	0.096	0.093	**3.2**	0.068	0.072	**5.7**
Molybdenum	µg/g	1	< 1	< 1	**-**	< 1	< 1	**-**
Nickel	µg/g	1	25	25	**0**	23	24	**4.3**
Phosphorus	µg/g	5	928	957	**3.1**	860	870	**1.2**
Potassium	µg/g	30	1390	1390	**0**	1130	1170	**3.5**
Silicon	µg/g	1	906	953	**5.1**	681	808	**17.1**
Silver	µg/g	0.2	< 0.2	< 0.2	**-**	0.3	1.7	**140**
Sodium	µg/g	20	230	240	**4.3**	260	280	**7.4**
Strontium	µg/g	1	22	22	**0**	22	22	**0**
Tin	µg/g	10	< 10	< 10	**-**	< 10	< 10	**-**
Titanium	µg/g	1	993	992	**0.1**	833	872	**4.6**
Vanadium	µg/g	1	39	39	**0**	33	34	**3.0**
Yttrium	µg/g	0.5	8.9	8.9	**0**	6.8	6.9	**1.5**
Zinc	µg/g	3	85	87	**2.3**	151	159	**5.2**
Zirconium	µg/g	0.1	4.9	4.9	**0**	4.1	4.7	**13.6**
Aluminum (Al2O3)	%	0.04	11.3	11.7	**3.5**	9.96	10.6	**6.2**
Barium (BaO)	%	0.002	0.072	0.076	**5.4**	0.062	0.066	**6.3**
Calcium (CaO)	%	0.06	2.63	2.74	**4.1**	3.13	3.39	**8.0**
Chromium (Cr2O3)	%	0.006	0.013	0.023	**55.6**	0.014	0.015	**6.9**
Iron (Fe2O3)	%	0.01	4.37	4.53	**3.6**	3.34	3.61	**7.8**
Potasium (K20)	%	0.2	2.3	2.4	**4.3**	2	2.1	**4.9**
Magnesium (MgO)	%	0.03	1.85	1.95	**5.3**	2.07	2.25	**8.3**
Manganese (MnO)	%	0.003	0.142	0.147	**3.5**	0.063	0.069	**9.1**
Sodium (Na2O)	%	0.5	3	3.1	**3.3**	2.8	2.9	**3.5**
Phosphorus (P2O5)	%	0.5	< 0.5	< 0.5	**-**	< 0.5	< 0.5	**-**
Silica (SiO2)	%	0.1	62.9	65.6	**4.2**	57.6	61.9	**7.2**
Titanium (TiO2)	%	0.02	0.52	0.53	**1.9**	0.47	0.5	**6.2**
Whole Rock Total	%		97.1	100	**2.9**	95.8	103	**7.2**
TC (LOI@1000°C)	%	0.05	7.7	7.36	**4.5**	14.1	15	**6.2**
Total Organic Carbon	% by wt	0.1	2.4	2.5	**4.1**	5.9	5.9	**0**
Total Kjeldahl Nitrogen	µg/g	0.05	1940	1980	**2.0**	2920	3300	**12.2**
Phosphorus-Total	µg/g	0.01	1160	1170	**0.9**	816	862	**5.5**
				median	2.4			5.3
				range	0-55.6			0-140

Table B6. Relative percent difference (RPD) for 2013 Jackfish Bay sediment sample duplicates, PCDD/F and dl-PCBs (ALS environmental Group).

Site	M701	Duplicate of M701	RPD
Dioxins and Furans	**pg/g**	**pg/g**	
2,3,7,8-TCDD	23.6	20.5	14.1
1,2,3,7,8-PeCDD	2.61	3.17	19.4
1,2,3,4,7,8-HxCDD	<1.5	<1.1	-
1,2,3,6,7,8-HxCDD	3.18	<2.4	-
1,2,3,7,8,9-HxCDD	<0.50	<1.3	-
1,2,3,4,6,7,8-HpCDD	51.9	47.6	8.6
OCDD	224	211	6.0
2,3,7,8-TCDF	365	343	6.2
1,2,3,7,8-PeCDF	9.35	<6.5	-
2,3,4,7,8-PeCDF	19.9	15.6	24.2
1,2,3,4,7,8-HxCDF	2.96	<1.7	-
1,2,3,6,7,8-HxCDF	1.43	<0.66	-
2,3,4,6,7,8-HxCDF	<1.5	1.2	-
1,2,3,7,8,9-HxCDF	<1.0	1.83	-
1,2,3,4,6,7,8-HpCDF	18.3	18.1	1.1
1,2,3,4,7,8,9-HpCDF	<2.2	<1.1	-
OCDF	68.4	60.7	11.9
		Median	10.3
		Range	1.1-24.2
Dioxin-like PCBs	**pg/g**	**pg/g**	
PCB 81	<29	<24	-
PCB 77	178	149	17.7
PCB 123	480	454	5.6
PCB 118	5120	4220	19.3
PCB 114	265	243	8.7
PCB 105	3020	2560	16.5
PCB 126	<25	19.2	-
PCB 167	123	107	13.9
PCB 156	594	517	13.9
PCB 157	163	113	36.2
PCB 169	<7.0	<1.6	-
PCB 189	47	35.5	27.9
		Median	16.5
		Range	5.6-36.2

Table B7. Relative percent difference (RPD) for 2013 Jackfish Bay sample duplicates – F2-F4 petroleum hydrocarbons, PAHs and PCBs (ALS environmental Group).

Analyte	Replicate 1	Replicate 2	Units	RPD	RPD Limit	Qualifier
F4G-SG (GHH-Silica)	66	65.6	%	0.7	50	-
F4G-SG (GHH-Silica)	84	86.6	%	3.0	50	-
Oil and Grease, Total	<500	<500	mg/kg	-	40	RPD-NA
F2 (C10-C16)	104.5	99.3	%	5.1	50	-
F2 (C10-C16)	101.1	104.7	%	3.5	50	-
F3 (C16-C34)	110.2	107.3	%	2.6	50	-
F3 (C16-C34)	102	105.9	%	3.8	50	-
F4 (C34-C50)	107.9	105.3	%	2.4	50	-
F4 (C34-C50)	100.6	106.5	%	5.7	50	-
Acenaphthene	<0.15	<0.15	ug/g	-	40	RPD-NA
Acenaphthene	107.1	110	%	2.7	50	-
Acenaphthene	97.5	108.3	%	10.0	50	-
Acenaphthylene	<0.15	<0.15	ug/g	-	40	RPD-NA
Acenaphthylene	110.6	111.9	%	1.1	50	-
Acenaphthylene	99.8	110	%	9.7	50	-
Acridine	<2.4	<2.4	ug/g	-	50	RPD-NA
Acridine	103.3	108	%	4.5	50	-
Acridine	98.4	108.6	%	9.8	50	-
Anthracene	0.18	0.16	ug/g	11.0	40	-
Anthracene	110.4	114.6	%	3.7	50	-
Anthracene	95.4	106	%	11.0	50	-
Benzo(a)anthracene	<0.15	<0.15	ug/g	-	40	RPD-NA
Benzo(a)anthracene	106.6	108.7	%	1.9	50	-
Benzo(a)anthracene	94.1	103.6	%	9.7	50	-
Benzo(a)pyrene	<0.060	<0.060	ug/g	-	40	RPD-NA
Benzo(a)pyrene	102	104	%	2.0	50	-
Benzo(a)pyrene	90.7	100.8	%	11.0	50	-
Benzo(b)fluoranthene	<0.15	<0.15	ug/g	-	50	RPD-NA
Benzo(b)fluoranthene	98.4	99.9	%	1.5	50	-
Benzo(b)fluoranthene	89.4	100.5	%	12.0	50	-
Benzo(g,h,i)perylene	<0.15	<0.15	ug/g	-	40	RPD-NA
Benzo(g,h,i)perylene	88.6	91.3	%	2.9	50	-
Benzo(g,h,i)perylene	92.1	103.3	%	11.0	50	-
Benzo(k)fluoranthene	<0.060	<0.060	ug/g	-	40	RPD-NA
Benzo(k)fluoranthene	107.4	111.2	%	3.4	50	-
Benzo(k)fluoranthene	82.6	93.3	%	12.0	50	-
Chrysene	<0.15	<0.15	ug/g	-	40	RPD-NA
Chrysene	115.7	119.8	%	3.5	50	-
Chrysene	96	108.6	%	12.0	50	-
Dibenzo(ah)anthracene	<0.15	<0.15	ug/g	-	40	RPD-NA
Dibenzo(ah)anthracene	96.3	98.1	%	1.9	50	-
Dibenzo(ah)anthracene	94	104.8	%	11.0	50	-
Fluoranthene	0.29	0.24	ug/g	19.0	40	-
Fluoranthene	107.2	110.4	%	3.0	50	-
Fluoranthene	93.2	103.8	%	11.0	50	-
Fluorene	<0.15	<0.15	ug/g	-	40	RPD-NA
Fluorene	109.6	111.6	%	1.8	50	-
Fluorene	99.8	110.9	%	11.0	50	-
Indeno(1,2,3-cd)pyrene	<0.15	<0.15	ug/g	-	40	RPD-NA
Indeno(1,2,3-cd)pyrene	90.1	89.1	%	1.1	50	-
Indeno(1,2,3-cd)pyrene	89.4	100.1	%	11.0	50	-
1-Methylnaphthalene	<0.15	<0.15	ug/g	-	40	RPD-NA
1-Methylnaphthalene	107.7	110.5	%	2.6	50	-
1-Methylnaphthalene	95	106.9	%	12.0	50	-
2-Methylnaphthalene	<0.15	<0.15	ug/g	-	40	RPD-NA
2-Methylnaphthalene	109.1	112	%	2.7	50	-
2-Methylnaphthalene	98.9	109.7	%	10.0	50	-
Naphthalene	<0.030	<0.030	ug/g	-	40	RPD-NA
Naphthalene	109.6	112.1	%	2.3	50	-
Naphthalene	99.7	111	%	11.0	50	-
Phenanthrene	0.188	0.166	ug/g	12.0	40	-
Phenanthrene	104.6	108	%	3.2	50	-
Phenanthrene	91.6	101.7	%	10.0	50	-
Pyrene	0.24	0.2	ug/g	19.0	40	-
Pyrene	108.3	111.4	%	2.9	50	-
Pyrene	101.2	112.6	%	11.0	50	-
Quinoline	<0.15	<0.15	ug/g	-	50	RPD-NA
Quinoline	104.7	107.7	%	2.8	50	-
Quinoline	92.1	102.2	%	10.0	50	-
Aroclor 1242	<0.030	<0.030	mg/kg	-	50	RPD-NA
Aroclor 1242	91.8	94.2	%	2.6	50	-
Aroclor 1242	96.4	103.7	%	7.3	50	-
Aroclor 1248	<0.030	<0.030	mg/kg	-	50	RPD-NA
Aroclor 1248	93.1	93.1	%	0.0	50	-
Aroclor 1248	106.5	106.5	%	0.0	50	-
Aroclor 1254	<0.030	<0.030	mg/kg	-	50	RPD-NA
Aroclor 1254	91.8	92.2	%	0.4	50	-
Aroclor 1254	100.5	105	%	4.4	50	-
Aroclor 1260	<0.030	<0.030	mg/kg	-	50	RPD-NA
Aroclor 1260	88.8	91.4	%	2.9	50	-
Aroclor 1260	106.1	110.2	%	3.8	50	-
			Median	3.8		
			Range	0-19.0		

Table B8. Recovery (%) of 2013 laboratory control samples (LCS), matrix spikes (MS), certified reference material (CRM), and method blanks (MB) – oil and grease and F2-F4 petroleum hydrocarbon analysis (ALS Laboratory Group).

QC Type	Analyte	Reference	Result	Target	Units	%	Limits
Aggregate Organics							
LCS	Oil and Grease, Total		9320	10000	mg/kg	93.0	70-130
MB	Oil and Grease, Total		<500	<500	mg/kg	-	500
Hydrocarbons							
CRM	F2 (C10-C16)	ALS PHC2 IRM	2060	1680	mg/kg	122.2	70-130
CRM	F3 (C16-C34)	ALS PHC2 IRM	3810	3100	mg/kg	123.0	70-130
CRM	F4 (C34-C50)	ALS PHC2 IRM	2240	1900	mg/kg	117.8	70-130
CRM	F2 (C10-C16)	ALS PHC2 IRM	1750	1680	mg/kg	103.7	70-130
CRM	F3 (C16-C34)	ALS PHC2 IRM	3060	3100	mg/kg	98.6	70-130
CRM	F4 (C34-C50)	ALS PHC2 IRM	1750	1900	mg/kg	91.9	70-130
LCS	F2 (C10-C16)		300	287	mg/kg	104.5	80-120
LCS	F3 (C16-C34)		760	690	mg/kg	110.2	80-120
LCS	F4 (C34-C50)		87.2	81	mg/kg	107.9	80-120
LCS	F2 (C10-C16)		290	287	mg/kg	101.1	80-120
LCS	F3 (C16-C34)		704	690	mg/kg	102.0	80-120
LCS	F4 (C34-C50)		81.3	81	mg/kg	100.6	80-120
MB	F2 (C10-C16)		<10	<10	mg/kg	-	10
MB	F3 (C16-C34)		<50	<50	mg/kg	-	50
MB	F4 (C34-C50)		<50	<50	mg/kg	-	50
MB	F2 (C10-C16)		<10	<10	mg/kg	-	10
MB	F3 (C16-C34)		<50	<50	mg/kg	-	50
MB	F4 (C34-C50)		<50	<50	mg/kg	-	50
MS	F2 (C10-C16)	Anonymous	717	704	mg/kg	101.8	50-150
MS	F3 (C16-C34)	Anonymous	1860	1780	mg/kg	104.6	50-150
MS	F4 (C34-C50)	Anonymous	286	198	mg/kg	144.0	50-150
MS	F2 (C10-C16)	Anonymous	324	314	mg/kg	103.0	50-150
MS	F3 (C16-C34)	Anonymous	793	755	mg/kg	105.0	50-150
MS	F4 (C34-C50)	Anonymous	93.3	89	mg/kg	105.4	50-150

Table B9. Recovery (%) of 2013 laboratory control samples (LCS) - PAHs (ALS Laboratory Group).

QC Type	Analyte	Reference	Result	Target	Units	%	Limits	Qualifier
Polycyclic Aromatic Hydrocarbons								
LCS	Acenaphthene		0.857	0.800	ug/g	107.1	60-130	
LCS	Acenaphthylene		0.885	0.800	ug/g	110.6	60-130	
LCS	Acridine		0.827	0.80	ug/g	103.3	50-140	
LCS	Anthracene		0.883	0.800	ug/g	110.4	60-130	
LCS	Benzo(a)anthracene		0.853	0.800	ug/g	106.6	60-130	
LCS	Benzo(a)pyrene		0.816	0.800	ug/g	102.0	60-140	
LCS	Benzo(b)fluoranthene		0.787	0.800	ug/g	98.4	50-140	
LCS	Benzo(g,h,i)perylene		0.709	0.800	ug/g	88.6	60-130	
LCS	Benzo(k)fluoranthene		0.859	0.800	ug/g	107.4	60-130	
LCS	Chrysene		0.925	0.800	ug/g	115.7	60-130	
LCS	Dibenzo(ah)anthracene		0.770	0.800	ug/g	96.3	60-130	
LCS	Fluoranthene		0.858	0.800	ug/g	107.2	60-130	
LCS	Fluorene		0.877	0.800	ug/g	109.6	60-130	
LCS	Indeno(1,2,3-cd)pyrene		0.721	0.800	ug/g	90.1	60-130	
LCS	1-Methylnaphthalene		0.861	0.800	ug/g	107.7	50-140	
LCS	2-Methylnaphthalene		0.872	0.800	ug/g	109.1	50-140	
LCS	Naphthalene		0.876	0.800	ug/g	109.6	50-130	
LCS	Phenanthrene		0.837	0.800	ug/g	104.6	60-130	
LCS	Pyrene		0.866	0.800	ug/g	108.3	60-130	
LCS	Quinoline		0.837	0.800	ug/g	104.7	50-140	
LCS	Acenaphthene		0.780	0.800	ug/g	97.5	60-130	
LCS	Acenaphthylene		0.799	0.800	ug/g	99.8	60-130	
LCS	Acridine		0.788	0.80	ug/g	98.4	50-140	
LCS	Anthracene		0.763	0.800	ug/g	95.4	60-130	
LCS	Benzo(a)anthracene		0.752	0.800	ug/g	94.1	60-130	
LCS	Benzo(a)pyrene		0.726	0.800	ug/g	90.7	60-140	
LCS	Benzo(b)fluoranthene		0.715	0.800	ug/g	89.4	50-140	
LCS	Benzo(g,h,i)perylene		0.737	0.800	ug/g	92.1	60-130	
LCS	Benzo(k)fluoranthene		0.661	0.800	ug/g	82.6	60-130	
LCS	Chrysene		0.768	0.800	ug/g	96.0	60-130	
LCS	Dibenzo(ah)anthracene		0.752	0.800	ug/g	94.0	60-130	
LCS	Fluoranthene		0.745	0.800	ug/g	93.2	60-130	
LCS	Fluorene		0.799	0.800	ug/g	99.8	60-130	
LCS	Indeno(1,2,3-cd)pyrene		0.715	0.800	ug/g	89.4	60-130	
LCS	1-Methylnaphthalene		0.760	0.800	ug/g	95.0	50-140	
LCS	2-Methylnaphthalene		0.791	0.800	ug/g	98.9	50-140	
LCS	Naphthalene		0.798	0.800	ug/g	99.7	50-130	
LCS	Phenanthrene		0.733	0.800	ug/g	91.6	60-130	
LCS	Pyrene		0.810	0.800	ug/g	101.2	60-130	
LCS	Quinoline		0.737	0.800	ug/g	92.1	50-140	

Table B10. Recovery (%) of 2013 laboratory control samples (LCS), matrix spikes (MS), and method blanks (MB) - PAHs and PCB aroclors (ALS Laboratory Group).

QC Type	Analyte	Reference	Result	Target	Units	%	Limits	Qualifier
Polycyclic Aromatic Hydrocarbons								
MS	Acenaphthene	Anonymous	0.896	0.847	ug/g	105.7	50-140	
MS	Acenaphthylene	Anonymous	0.913	0.847	ug/g	107.8	50-140	
MS	Acridine	Anonymous	0.853	0.85	ug/g	100.7	50-150	
MS	Anthracene	Anonymous	0.93	0.847	ug/g	109.8	50-140	
MS	Benzo(a)anthracene	Anonymous	0.878	0.847	ug/g	103.7	50-140	
MS	Benzo(a)pyrene	Anonymous	0.829	0.847	ug/g	97.8	50-140	
MS	Benzo(b)fluoranthene	Anonymous	0.817	0.847	ug/g	96.5	50-140	
MS	Benzo(g,h,i)perylene	Anonymous	0.725	0.847	ug/g	85.6	50-140	
MS	Benzo(k)fluoranthene	Anonymous	0.885	0.847	ug/g	104.5	50-140	
MS	Chrysene	Anonymous	0.924	0.847	ug/g	109.1	50-140	
MS	Dibenzo(ah)anthracene	Anonymous	0.778	0.847	ug/g	91.9	50-140	
MS	Fluoranthene	Anonymous	0.895	0.847	ug/g	105.6	50-140	
MS	Fluorene	Anonymous	0.913	0.847	ug/g	107.8	50-140	
MS	Indeno(1,2,3-cd)pyrene	Anonymous	0.772	0.847	ug/g	91.1	50-140	
MS	1-Methylnaphthalene	Anonymous	0.895	0.847	ug/g	105.7	50-140	
MS	2-Methylnaphthalene	Anonymous	0.908	0.847	ug/g	107.2	50-140	
MS	Naphthalene	Anonymous	0.922	0.847	ug/g	108.8	50-140	
MS	Phenanthrene	Anonymous	0.878	0.847	ug/g	103.7	50-140	
MS	Pyrene	Anonymous	0.905	0.847	ug/g	106.8	50-140	
MS	Quinoline	Anonymous	0.856	0.847	ug/g	101	50-150	
Polychlorinated Biphenyls								
LCS	Aroclor 1242		0.184	0.2	mg/kg	91.8	65-130	
LCS	Aroclor 1248		0.186	0.2	mg/kg	93.1	65-130	
LCS	Aroclor 1254		0.184	0.2	mg/kg	91.8	65-130	
LCS	Aroclor 1260		0.178	0.2	mg/kg	88.8	65-130	
LCS	Aroclor 1242		0.193	0.2	mg/kg	96.4	65-130	
LCS	Aroclor 1248		0.213	0.2	mg/kg	106.5	65-130	
LCS	Aroclor 1254		0.201	0.2	mg/kg	100.5	65-130	
LCS	Aroclor 1260		0.212	0.2	mg/kg	106.1	65-130	
MB	Aroclor 1242		<0.010	<0.01	mg/kg	-	0.01	
MB	Aroclor 1248		<0.010	<0.01	mg/kg	-	0.01	
MB	Aroclor 1254		<0.010	<0.01	mg/kg	-	0.01	
MB	Aroclor 1260		<0.010	<0.01	mg/kg	-	0.01	
MB	Aroclor 1242		<0.010	<0.01	mg/kg	-	0.01	
MB	Aroclor 1248		<0.010	<0.01	mg/kg	-	0.01	
MB	Aroclor 1254		<0.010	<0.01	mg/kg	-	0.01	
MB	Aroclor 1260		<0.010	<0.01	mg/kg	-	0.01	
MS	Aroclor 1242	Anonymous	0.199	0.212	mg/kg	93.8	50-150	
MS	Aroclor 1254	Anonymous	0.202	0.212	mg/kg	95.2	50-150	
MS	Aroclor 1260	Anonymous	0.192	0.212	mg/kg	90.8	50-150	
MS	Aroclor 1242	L1391925-6	0.713	0.746	mg/kg	95.6	50-150	
MS	Aroclor 1254	L1391925-6	0.746	0.746	mg/kg	100	50-150	
MS	Aroclor 1260	L1391925-6	0.823	0.746	mg/kg	110.3	50-150	

Table B11. Concentration of dioxins and furans (pg/g) in method blanks, and recovery (%) of target analytes and extraction standards in method blanks and laboratory control samples (LCS) – run concurrently with sediment samples (ALS Laboratory Group).

Sample Name	Method Blank	LCS	Method Blank	LCS
Target Analytes	**pg/g**	**% Rec**	**pg/g**	**% Rec**
2,3,7,8-TCDD	<0.36	100	<0.40	101
1,2,3,7,8-PeCDD	<0.17	104	<0.28	105
1,2,3,4,7,8-HxCDD	<0.19	110	<0.25	111
1,2,3,6,7,8-HxCDD	<0.16	100	<0.24	104
1,2,3,7,8,9-HxCDD	<0.15	107	<0.22	103
1,2,3,4,6,7,8-HpCDD	<0.25	109	<0.26	109
OCDD	<0.15	103	0.580	103
2,3,7,8-TCDF	<0.32	96	<0.36	97
1,2,3,7,8-PeCDF	<0.16	108	<0.18	107
2,3,4,7,8-PeCDF	<0.13	107	<0.16	108
1,2,3,4,7,8-HxCDF	<0.14	108	<0.20	108
1,2,3,6,7,8-HxCDF	<0.12	101	<0.17	104
2,3,4,6,7,8-HxCDF	<0.83	99	<0.58	95
1,2,3,7,8,9-HxCDF	<0.20	109	<0.26	108
1,2,3,4,6,7,8-HpCDF	<1.5	102	<0.69	99
1,2,3,4,7,8,9-HpCDF	<0.26	104	<0.31	111
OCDF	<0.37	107	<0.43	103
Median		104		104
Range		96-110		97-111
Extraction Standards	**% Rec**	**% Rec**	**% Rec**	**% Rec**
13C12-2,3,7,8-TCDD	87	93	72	61
13C12-1,2,3,7,8-PeCDD	107	118	71	76
13C12-1,2,3,4,7,8-HxCDD	74	90	74	68
13C12-1,2,3,6,7,8-HxCDD	85	94	69	62
13C12-1,2,3,4,6,7,8-HpCDD	94	107	90	81
13C12-OCDD	107	123	110	97
13C12-2,3,7,8-TCDF	95	102	75	66
13C12-1,2,3,7,8-PeCDF	110	118	78	76
13C12-2,3,4,7,8-PeCDF	116	126	75	80
13C12-1,2,3,4,7,8-HxCDF	84	88	78	68
13C12-1,2,3,6,7,8-HxCDF	90	100	70	59
13C12-2,3,4,6,7,8-HxCDF	110	79	64	61
13C12-1,2,3,7,8,9-HxCDF	99	104	83	77
13C12-1,2,3,4,6,7,8-HpCDF	89	77	62	65
13C12-1,2,3,4,7,8,9-HpCDF	102	118	103	89
Median	86			
Range	59-126			

Table B12. Concentration of dioxin-like PCBs (pg/g) in method blanks, and recovery (%) of target analytes and extraction standards in method blanks and laboratory control samples (LCS)– run concurrently with sediment samples (ALS Laboratory Group).

Sample Name	Method Blank	LCS	Method Blank	LCS
Target Analytes	**pg/g**	**% Rec**	**pg/g**	**% Rec**
PCB 81	<0.12	106	<0.55	107
PCB 77	<0.24	118	1.39	111
PCB 123	<0.27	113	<0.50	109
PCB 118	<0.23	95	<0.44	104
PCB 114	<0.23	109	<0.46	102
PCB 105	<0.24	105	<0.46	100
PCB 126	<0.26	111	<0.52	117
PCB 167	<0.096	107	<0.59	102
PCB 156	<0.17	99	<0.61	109
PCB 157	<0.11	118	<0.60	105
PCB 169	<0.12	113	<0.67	118
PCB 189	<0.060	105	<0.18	105
Median		108		106
Range		95-118		100-118
Extraction Standards	**% Rec**	**% Rec**	**% Rec**	**% Rec**
13C12 PCB 81	83	83	61	60
13C12 PCB 77	84	87	63	64
13C12 PCB 123	80	82	58	63
13C12 PCB 118	77	80	60	56
13C12 PCB 114	83	83	62	63
13C12 PCB 105	78	83	62	61
13C12 PCB 126	84	89	64	61
13C12 PCB 167	85	87	65	66
13C12 PCB 156	81	92	63	68
13C12 PCB 157	83	86	66	67
13C12 PCB 169	84	91	66	67
13C12 PCB 189	87	93	67	70
Median	73.5			
Range	56-93			

Table B13. Concentration of dioxins and furans (pg/g) in method blanks, and recovery (%) of target analytes and extraction standards in method blanks and laboratory control samples (LCS) – run concurrently with tissue samples (ALS Laboratory Group).

Sample Name	Method Blank	LCS	Method Blank	LCS
Target Analytes	**pg/g**	**% Rec**	**pg/g**	**% Rec**
2,3,7,8-TCDD	<15	98	<22	101
1,2,3,7,8-PeCDD	<7.2	99	<14	102
1,2,3,4,7,8-HxCDD	<5.9	104	<12	107
1,2,3,6,7,8-HxCDD	<5.5	94	<10	97
1,2,3,7,8,9-HxCDD	<5.1	96	<9.8	99
1,2,3,4,6,7,8-HpCDD	<8.3	99	<14	104
OCDD	<16	95	<11	100
2,3,7,8-TCDF	<16	87	<23	91
1,2,3,7,8-PeCDF	<5.3	93	<11	99
2,3,4,7,8-PeCDF	<4.6	92	<9.3	97
1,2,3,4,7,8-HxCDF	<5.2	98	<8.0	101
1,2,3,6,7,8-HxCDF	<4.8	92	<7.3	96
2,3,4,6,7,8-HxCDF	<5.2	98	<8.0	101
1,2,3,7,8,9-HxCDF	<6.9	98	<10	99
1,2,3,4,6,7,8-HpCDF	<3.4	100	<12	106
1,2,3,4,7,8,9-HpCDF	<4.7	100	<16	103
OCDF	<12	90	<16	94
Median		98		100
Range		87-104		91-107
Extraction Standards	**% Rec**	**% Rec**	**% Rec**	**% Rec**
13C12-2,3,7,8-TCDD	40	64	85	90
13C12-1,2,3,7,8-PeCDD	51	84	113	116
13C12-1,2,3,4,7,8-HxCDD	47	74	100	105
13C12-1,2,3,6,7,8-HxCDD	45	69	91	93
13C12-1,2,3,4,6,7,8-HpCDD	53	82	110	115
13C12-OCDD	59	97	137	98
13C12-2,3,7,8-TCDF	43	70	100	97
13C12-1,2,3,7,8-PeCDF	49	83	112	112
13C12-2,3,4,7,8-PeCDF	52	85	114	116
13C12-1,2,3,4,7,8-HxCDF	43	69	87	89
13C12-1,2,3,6,7,8-HxCDF	45	70	94	92
13C12-2,3,4,6,7,8-HxCDF	45	70	95	94
13C12-1,2,3,7,8,9-HxCDF	49	76	108	105
13C12-1,2,3,4,6,7,8-HpCDF	46	71	96	100
13C12-1,2,3,4,7,8,9-HpCDF	53	86	116	120
Median	86.5			
Range	40-137			

Table B14. Concentration of dioxin-like PCBs (pg/g) in method blanks, and recovery (%) of target analytes and extraction standards in method blanks and laboratory control samples (LCS)-run concurrently with tissue samples (ALS Laboratory Group).

Sample Name	Method Blank	LCS
Target Analytes	**pg/g**	**% Rec**
PCB-081	<32	106.6
PCB-077	<33	104.7
PCB-123	<17	116.2
PCB-118	<32	104.6
PCB-114	<15	102.7
PCB-105	<17	107.3
PCB-126	<38	111.1
PCB-167	<24	108
PCB-156/157	<33	110.1
PCB-169	<32	107.4
PCB-189	<28	119.1
Median		107.4
Range		102.7-119.1
Extraction Standards	**% Rec**	**% Rec**
13C12-PCB-081	39.4	64.3
13C12-PCB-077	39.6	64.9
13C12-PCB-123	45.7	74.9
13C12-PCB-118	44.7	72.1
13C12-PCB-114	43.6	71.8
13C12-PCB-105	43.1	71.5
13C12-PCB-126	42.8	72.1
13C12-PCB-167	44.7	64
13C12-PCB-156/157	38.8	58.2
13C12-PCB-169	41.9	62.8
13C12-PCB-189	45.6	68
Median	52.0	
Range	38.8-74.9	

Table B15. Recovery (%) of 2013 method blanks (MB) - PAHs (ALS Laboratory Group).

QC Type	Analyte	Reference	Result	Target	Units	%	Limits	Qualifier
Polycyclic Aromatic Hydrocarbons								
MB	Acenaphthene		<0.050	<0.05	ug/g	-	0.05	
MB	Acenaphthylene		<0.050	<0.05	ug/g	-	0.05	
MB	Acridine		<0.80	<0.8	ug/g	-	0.8	
MB	Anthracene		<0.050	<0.05	ug/g	-	0.05	
MB	Benzo(a)anthracene		<0.050	<0.05	ug/g	-	0.05	
MB	Benzo(a)pyrene		<0.020	<0.02	ug/g	-	0.02	
MB	Benzo(b)fluoranthene		<0.050	<0.05	ug/g	-	0.05	
MB	Benzo(g,h,i)perylene		<0.050	<0.05	ug/g	-	0.05	
MB	Benzo(k)fluoranthene		<0.020	<0.02	ug/g	-	0.02	
MB	Chrysene		<0.050	<0.05	ug/g	-	0.05	
MB	Dibenzo(ah)anthracene		<0.050	<0.05	ug/g	-	0.05	
MB	Fluoranthene		<0.050	<0.05	ug/g	-	0.05	
MB	Fluorene		<0.050	<0.05	ug/g	-	0.05	
MB	Indeno(1,2,3-cd)pyrene		<0.050	<0.05	ug/g	-	0.05	
MB	1-Methylnaphthalene		<0.050	<0.05	ug/g	-	0.05	
MB	2-Methylnaphthalene		<0.050	<0.05	ug/g	-	0.05	
MB	Naphthalene		<0.010	<0.01	ug/g	-	0.01	
MB	Phenanthrene		<0.030	<0.03	ug/g	-	0.03	
MB	Pyrene		<0.050	<0.05	ug/g	-	0.05	
MB	Quinoline		<0.050	<0.05	ug/g	-	0.05	
MB	Acenaphthene		<0.050	<0.05	ug/g	-	0.05	
MB	Acenaphthylene		<0.050	<0.05	ug/g	-	0.05	
MB	Acridine		<0.80	<0.8	ug/g	-	0.8	
MB	Anthracene		<0.050	<0.05	ug/g	-	0.05	
MB	Benzo(a)anthracene		<0.050	<0.05	ug/g	-	0.05	
MB	Benzo(a)pyrene		<0.020	<0.02	ug/g	-	0.02	
MB	Benzo(b)fluoranthene		<0.050	<0.05	ug/g	-	0.05	
MB	Benzo(g,h,i)perylene		<0.050	<0.05	ug/g	-	0.05	
MB	Benzo(k)fluoranthene		<0.020	<0.02	ug/g	-	0.02	
MB	Chrysene		<0.050	<0.05	ug/g	-	0.05	
MB	Dibenzo(ah)anthracene		<0.050	<0.05	ug/g	-	0.05	
MB	Fluoranthene		<0.050	<0.05	ug/g	-	0.05	
MB	Fluorene		<0.050	<0.05	ug/g	-	0.05	
MB	Indeno(1,2,3-cd)pyrene		<0.050	<0.05	ug/g	-	0.05	
MB	1-Methylnaphthalene		<0.050	<0.05	ug/g	-	0.05	
MB	2-Methylnaphthalene		<0.050	<0.05	ug/g	-	0.05	
MB	Naphthalene		<0.010	<0.01	ug/g	-	0.01	
MB	Phenanthrene		<0.030	<0.03	ug/g	-	0.03	
MB	Pyrene		<0.050	<0.05	ug/g	-	0.05	
MB	Quinoline		<0.050	<0.05	ug/g	-	0.05	

Table B16. Quality control sample percent recoveries for 2013 reference materials/standards (Caducean Laboratories).

PARAMETERS	QC Sample Recovery Calculation				
	Raw Data (µg/g)			QC Sample Recovery	
LKSD-3 (18,19-Nov-13)	**QC Result**	**Reference Value**	**Lab Mean**	**%Recovery**	**Control Limits**
Aluminum *(SC0063618)*	**10300**	12200		**84**	70 - 130
Antimony	**0.9**	1.0	0.9	**103**	70 - 130
Arsenic	**28.7**	23	23.0	**125**	70 - 130
Barium	**161**	N/A	160	**101**	70 - 130
Beryllium	**0.6**	N/A	0.6	**106**	70 - 130
Cadmium *(SC0063618)*	**2.7**	3.17	3.17	**85**	70 - 130
Cobalt	**31**	30	28	**110**	70 - 130
Chromium	**50**	51	47	**98**	70 - 130
Copper	**33**	34	32	**103**	70 - 130
Manganese	**1390**	1220	1169	**114**	70 - 130
Molybdenum *(SC0063618)*	**5**	6.8	5.7	**94**	70 - 130
Nickel	**43**	44.0	41.7	**98**	70 - 130
Lead	**25**	26	24.2	**103**	70 - 130
Silver	**2.2**	2.4	2.5	**92**	70 - 130
Strontium	**27**	N/A	23.5	**115**	70 - 130
Titanium	**1090**	N/A	963	**113**	70 - 130
Vanadium	**48**	55	46.3	**104**	70 - 130
Zinc	**138**	139	127	**109**	70 - 130
LKSD-2 (15-Nov-13)					
Mercury	**0.145**	0.160	0.144	**91**	70 - 130

LKSD-2 (21-Nov-13)					
Aluminum (Al2O3)	**10.50**	12.3		**85**	75 - 125
Calcium (CaO)	**2.13**	2.2		**97**	75 - 125
Iron (Fe2O3)	**5.70**	6.2		**92**	75 - 125
Magnesium (MgO)	**1.60**	1.7		**94**	75 - 125
Manganese (MnO)	**0.247**	0.3		**82**	60 - 140
Potasium (K20)	**2.4**	2.6		**92**	70 - 130
Silica (SiO2)	**54.0**	58.9		**92**	75 - 125
Titanium (TiO2)	**0.5**	0.6		**80**	75 - 125
LOI @1000°C	**13.0**	13.6		**95**	75 - 125
D053-542 (28-Nov-13)					
Total Kjeldahl Nitrogen	1427	1300	1493	**96**	50 - 150
Phosphorus-Total	1059	811	1012	**105**	44 - 156

Table B17. Recovery (%) of surrogate spikes for volatile organic compounds (VOC), hydrocarbons, and PAHs (ALS Laboratory Group).

Compound	VOC- BTEX	VOC - F1	hydrocarbons (F2-F4)	PAHs	PAHs
Surrogate	2-Bromobenzotrifluoride	2-Fluorobiphenyl	3,4-Dichlorotoluene	p-Terphenyl d14	d14-Terphenyl
M701	97.9	100.3	71.3	109.2	100.2
1M400	94.2	99.6	84.5	104.1	101.6
1M401	94.8	103.1	71.8	108.8	106.5
1M402	92.7	103.1	84.1	106.4	103.7
EEM4	92.9	100.8	88.4	105.8	102.7
JFB002	93.6	99.3	85	99.8	103.4
1M3	93.7	102.7	85.3	103.7	107.7
1M1	96.8	94.7	83.1	97.1	99.7
3M2	91.2	107.9	85.6	110.6	115.4
6956	90.3	97.6	80	100.2	107.9
2M4	88.4	109.2	84.3	113	115.7
2M1	92.1	99	96.7	103.1	106.9
2M6	84.7	107.3	84	111.2	116
4M4	85.7	104	99	107.2	112.8
4M3	85.3	111.2	95.2	111.4	116.9
EEM8B	95.6	97.5	77.8	101.1	100.1
NF500	92.3	98.6	81.3	100.3	104.1
NF501	94.3	98.5	73.1	99.8	102.9
NF502	97.8	99.3	81.9	99.9	103.9
median	92.9	100.3	84.1	104.1	104.1
range	84.7-97.9	94.7-111	71.3-99	97.1-113	99.7-117

Table B18. Sorting efficiencies (SE) (%) for 2013 Jackfish Bay benthic invertebrate samples.

Sample No.	Original Count	QC Audit Count	Organisms missed	% SE
1M3-iv	45	44	0	100%
1M402-iii	116	116	0	100%
2M1-iii	4	4	0	100%
2M6-ii	8	8	0	100%
4M3-iv	10	11	0	100%
4M4-i	4	4	0	100%
EEM4-i	54	53	0	100%
EEM8B-i	61	60	0	100%
JFB002-v	38	37	1	1 – (1/38)*100 = 97.4%
NF502-i	58	58	0	100%
			Average % SE	**99.7%** **PASS**

Table B19. Taxonomy identification errors (IE) (%) and corrective action taken for 2013 Jackfish Bay samples.

Sample No.	Family	Mis-identification	% IE	Comment and Corrective action
1M3-iv		0	0.00	None
1M402-iii	Immature tubificid without chaetal hairs	1	0.86	One of 15 immature Tubificinae was identified as *Limnodrilus profundicola* by auditor. After discussing the characteristics and rechecking the slides, original taxonomist agreed with auditor. All other slides re-checked.
2M1-iii		0	0.00	None
2M6-ii		0	0.00	None
4M3-iv		0	0.00	None
4M4-i		0	0.00	None
EEM4-i		0	0.00	None
EEM8B-i		0	0.00	None
JFB002-v	Immature tubificid with chaetal hairs	1	2.63	One of 12 immature Tubificinae was identified as *Aulodrilus pluriseta*. This was a case of incorrectly recording the identification on bench sheet. All bench sheets were rechecked to ensure data entries matched bench sheet.
NF502-i		0	0.00	None
Identification Error			**0.35**	**PASS**

Table B20. Toxicological response in laboratory control sediment (Long Point, Lake Erie) run concurrently with 2013 Jackfish Bay test sites.

		H. azteca		*C. riparius*		*Hexagenia* spp.		*T. tubifex*				
Test Set No.	Sites	% survival	growth	% survival	growth	% survival	growth	% survival	No. cocoons/ adult	% cocoons hatched	No. young/ adult	Meets quality objectives?
1	3M2, 6956, 4M3, 4M4	85.3	0.29	97.3	0.39	88	5.55	100	11.9	58.6	38.7	yes - however, unusual results observed for *H. azteca* in some replicates throughout test - test rerun for verification
Rerun 1	3M2, 6956, 4M3, 4M4	94.6	0.33	-	-	-	-	-	-	-	-	yes - results similar to original test; mean of 2 test taken as final results
2	2M1, 2M4, 2M6	92.0	0.41	94.6	0.38	96	5.22	100	12.4	62.1	38.4	yes
3	M701, NF5	90.6	0.31	92	0.40	98	5.74	100	12.3	62.4	43.6	yes
4	1M1, 1M3, 1M4, EEM4	92.0	0.42	97.3	0.41	100	5.09	100	12.1	54.2	42.1	yes
5	EEM8, JFB002	97.3	0.48	93.3	0.46	100	5.30	100	12.1	58.3	39.1	yes

APPENDIX C

Supplementary physicochemical data

Table C1. Sediment metal and nutrient concentrations at Lake Superior reference sites, sampled concurrently with Jackfish Bay sites in 2013. Values exceeding the Threshold Effect Level (TEL) or Probable Effect Level (PEL) are highlighted in red and blue, respectively.

Parameter	Units	M.D.L.	TEL	PEL	2600	2410[a]	2502	2616	2400	2414
Aluminum	µg/g	10			5940	7423	4250	5150	8460	10800
Antimony	µg/g	0.5			< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
Arsenic	µg/g	0.5	5.9	17	9.5	9.5	1.1	1.8	**19.9**	3.2
Barium	µg/g	1			39	48	21	26	60	33
Beryllium	µg/g	0.2			< 0.2	0.3	< 0.2	0.2	0.3	0.2
Bismuth	µg/g	5			< 5	< 5	< 5	< 5	< 5	< 5
Cadmium	µg/g	0.5	0.6	3.5	< 0.5	0.6	< 0.5	< 0.5	1.0	< 0.5
Calcium	µg/g	10			11000	3537	30100	2460	4490	3060
Chromium	µg/g	1	37.3	90	24	23	17	17	31	46
Cobalt	µg/g	1			8	8	4	5	11	12
Copper	µg/g	1	35.7	197	26	49	8	14	54	33
Iron	µg/g	10	20000[b]	40000[b]	16900	16733	9490	11600	26700	25300
Lead	µg/g	5	35	91.3	8	28	< 5	6	27	12
Magnesium	µg/g	10			6830	3957	16800	3040	5780	8080
Manganese	µg/g	1	460[c]	1100[c]	723	392	160	225	**1280**	348
Mercury	µg/g	0.005	0.17	0.486	0.022	0.039	0.014	0.008	0.05	0.011
Molybdenum	µg/g	1			< 1	< 1	< 1	< 1	< 1	< 1
Nickel	µg/g	1	16[b]	75[b]	15	17	9	10	22	25
Phosphorus	µg/g	5			584	688	405	486	793	422
Potassium	µg/g	30			580	783	560	540	790	790
Silicon	µg/g	1			583	708	482	588	776	744
Silver	µg/g	0.2			0.4	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
Sodium	µg/g	20			130	213	90	110	170	140
Strontium	µg/g	1			17	13	16	10	16	10
Tin	µg/g	10			< 10	< 10	< 10	< 10	< 10	< 10
Titanium	µg/g	1			545	531	493	466	608	1040
Vanadium	µg/g	1			23	31	14	20	32	47
Yttrium	µg/g	0.5			5	6.9	4.5	5	7.2	4.5
Zinc	µg/g	3	123	315	42	68	26	29	80	76
Zirconium	µg/g	0.1			1.8	1.8	3.8	1.4	2.3	2.2
Aluminum (Al2O3)	%	0.04			11.1	10.3	9.24	11.1	11.1	12.1
Barium (BaO)	%	0.002			0.06	0.054	0.06	0.063	0.061	0.054
Calcium (CaO)	%	0.06			3.83	2.26	5.44	2.15	2.59	2.45
Chromium (Cr2O3)	%	0.006			0.009	0.009	0.007	0.007	0.01	0.011
Iron (Fe2O3)	%	0.01			3.46	3.34	1.88	2.37	4.92	4.49
Potasium (K20)	%	0.2			1.9	1.8	2.1	2.2	2	1.9
Magnesium (MgO)	%	0.03			1.8	1.22	3.06	0.98	1.64	1.85
Manganese (MnO)	%	0.003			0.116	0.071	0.035	0.049	0.188	0.071
Sodium (Na2O)	%	0.5			3.5	3.0	2.9	3.6	3.2	3.9
Phosphorus (P2O5)	%	0.5			< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
Silica (SiO2)	%	0.1			68.6	64.3	65.2	71.9	66.4	65.1
Titanium (TiO2)	%	0.02			0.37	0.38	0.27	0.3	0.43	0.43
Whole Rock Total	%				99.1	93.0	94.9	97	98	95.1
TC (LOI@1000°C)	%	0.05			4.23	6.07	4.63	2.12	5.26	2.68
Total Organic Carbon	% by wt	0.1	1[b]	10[b]	0.9	2.4	0.7	0.3	1.8	0.6
Total Kjeldahl Nitrogen	µg/g	0.05	550[b]	4800[b]	682	1707	570	384	1340	343
Phosphorus-Total	µg/g	0.01	600[b]	2000[b]	664	704	583	535	830	405

[a] QA/QC site – values are mean of three field replicates
[b] provincial sediment quality guidelines Lowest/Severe Effect Level
MDL = method detection limit

Table C2. Physical characteristics of sediment at Jackfish Bay and Lake Superior reference sites sampled in 2013.

Area	Site	Sampling Device	% Clay	% Silt	% Sand	% Gravel
Moberly Bay	M701	Ponar	5.8	33.8	60.4	0.0
	1M4[a]	Box Core	7.7	54.7	37.6	0.0
	EEM4	Box Core	8.5	59.8	31.7	0.0
	1M3	Box Core	16	71.7	12.3	0.0
	JFB002	Box Core	14.2	72.9	12.9	0.0
	1M1	Box Core	13.2	68.3	18.5	0.0
	NF5[a]	Box Core	13.9	71.0	15.1	0.0
	EEM8B	Box Core	6.7	57	36.3	0.0
Far-field	2M4	Box Core	14.6	63.1	22.3	0.0
	2M1	Box Core	14.6	65.9	19.5	0.0
	2M6	Box Core	20	68.7	11.3	0.0
Far Far-field	4M4	Box Core	52.3	37.5	7.4	2.8
	4M3	Box Core	10.6	49.7	39.4	0.3
Tunnel Bay	3M2	Box Core	19.2	66.9	13.9	0.0
	6956	Box Core	15.4	67.8	16.8	0.0
Lake Superior	2600	Box Core	4.5	48.6	46.9	0.0
Reference	2410[a]	Box Core	11.2	53.8	35.1	0.0
	2502	Ponar	5.3	51.2	43.5	0.0
	2616	Ponar	4.8	28.7	66.1	0.4
	2400	Box Core	9.2	66.1	24.7	0.0
	2414	Ponar	0.4	26.5	73	0.1

[b] QA/QC site; value represents mean of three field replicates

Table C3. Contribution (%) of congeners 2,3,7,8-TCDD, 2,3,7,8-TCDF and 1,2,3,7,8-PeCDD on total dioxin and furan TEQ; colour coded by area.

site	PCDD/F TEQ	2378 TCDD	2378 TCDF	12378PeCDD
M701	53.4	41.3	33.1	5.4
1M4avg	28.2	41.5	34.5	3.4
EEM4	17.6	46.9	39.0	1.6
1M3	19.0	42.1	34.5	2.0
JFB002	29.8	41.6	33.2	1.8
NF5avg	29.9	42.6	32.9	3.5
1M1	26.7	46.0	33.3	1.9
EEM8B	12.6	54.2	24.6	3.5
2M1	24.3	43.2	30.9	6.5
2M4	20.2	41.9	33.0	5.8
2M6	24.7	41.7	30.6	6.1
4M4	0.69	30.8	1.6	28.2
4M3	2.2	19.8	7.5	29.4
3M2	8.2	39.5	23.5	5.7
6956	6.8	39.4	23.6	2.6

Table C4. BTEX and total PCB concentrations (mg/kg) in Jackfish Bay sediments collected in 2013.

Analyte	M701	1M1	1M3	1M4[a]	EEM4	EEM8	JFB002	NF5[a]	2M1	2M4	2M6	4M4	4M3	3M2	6956
Volatile Organic Compounds															
Benzene	<0.10	<0.15	<0.15	<0.10	<0.10	<0.20	<0.15	<0.15	<0.15	<0.10	<0.15	<0.050	<0.075	<0.10	<0.10
Ethyl Benzene	<0.10	<0.15	<0.15	<0.10	<0.10	<0.20	<0.15	<0.15	<0.15	<0.10	<0.15	<0.050	<0.075	<0.10	<0.10
Toluene	1.92	<0.15	<0.15	<0.10	<0.10	<0.20	<0.15	<0.15	<0.15	<0.10	<0.15	<0.050	<0.075	<0.10	<0.10
o-Xylene	<0.10	<0.15	<0.15	<0.10	<0.10	<0.20	<0.15	<0.15	<0.15	<0.10	<0.15	<0.050	<0.075	<0.10	<0.10
m+p-Xylenes	<0.20	<0.30	<0.30	<0.20	<0.20	<0.40	<0.30	<0.30	<0.30	<0.20	<0.30	<0.10	<0.15	<0.20	<0.20
Xylenes (Total)	<0.22	<0.34	<0.34	<0.22	<0.22	<0.45	<0.34	<0.34	<0.34	<0.22	<0.34	<0.11	<0.17	<0.22	<0.22
PCBs															
Aroclor 1242	<0.020	<0.030	<0.030	<0.030	<0.020	<0.050	<0.030	<0.030	<0.020	<0.020	<0.020	<0.010	<0.015	<0.020	<0.020
Aroclor 1248	<0.020	<0.030	<0.030	<0.030	<0.020	<0.050	<0.030	<0.030	<0.020	<0.020	<0.020	<0.010	<0.015	<0.020	<0.020
Aroclor 1254	<0.020	<0.030	<0.030	<0.030	<0.020	<0.050	<0.030	<0.030	<0.020	<0.020	<0.020	<0.010	<0.015	<0.020	<0.020
Aroclor 1260	<0.020	<0.030	<0.030	<0.030	<0.020	<0.050	<0.030	<0.030	<0.020	<0.020	<0.020	<0.010	<0.015	<0.020	<0.020
Total PCBs	<0.040	<0.060	<0.060	<0.060	<0.040	<0.10	<0.060	<0.060	<0.040	<0.040	<0.040	<0.020	<0.030	<0.040	<0.040

Table C5. Biota-sediment accumulation factors (BSAFs) for PCDD/F – 2008 and 2013 samples. Values exceeding 1 are highlighted red. Values highlighted are co-located sites.

Site-Yr	Amph	2,3,7,8-TCDD	1,2,3,7,8-PeCDD	1,2,3,4,7,8-HxCDD	1,2,3,6,7,8-HxCDD	1,2,3,7,8,9-HxCDD	1,2,3,4,6,7,8-HpCDD	OCDD	2,3,7,8-TCDF	1,2,3,7,8-PeCDF	2,3,4,7,8-PeCDF	1,2,3,4,7,8-HxCDF	1,2,3,6,7,8-HxCDF	2,3,4,6,7,8-HxCDF	1,2,3,7,8,9-HxCDF	1,2,3,4,6,7,8-HpCDF	1,2,3,4,7,8,9-HpCDF	OCDF
1M1 - 2008																		
1M3 - 2008																		
2M1 - 2008								0.48	1.33	3.16	4.94							
4M3 - 2008							0.52	0.33										7.27
3M2 - 2008							0.23	0.39	0.87		1.36	0.81	1.76					2.48
M701 - 2008																		

Site-Yr	Amph	2,3,7,8-TCDD	1,2,3,7,8-PeCDD	1,2,3,4,7,8-HxCDD	1,2,3,6,7,8-HxCDD	1,2,3,7,8,9-HxCDD	1,2,3,4,6,7,8-HpCDD	OCDD	2,3,7,8-TCDF	1,2,3,7,8-PeCDF	2,3,4,7,8-PeCDF	1,2,3,4,7,8-HxCDF	1,2,3,6,7,8-HxCDF	2,3,4,6,7,8-HxCDF	1,2,3,7,8,9-HxCDF	1,2,3,4,6,7,8-HpCDF	1,2,3,4,7,8,9-HpCDF	OCDF
1M1 - 2013							0.32	0.28	0.75		0.85	1.88						
1M3 - 2013							0.78	0.30	0.87						35.60			
2M1 - 2013							0.16	0.09	0.86	1.57	1.57			1.88				0.20
4M3 - 2013								0.03										
3M2 - 2013									0.57									
EEM4 - 2013																		
2M6 - 2013		0.46			0.64		0.10	0.04	0.54	0.82								

Site-Yr	Chir	2,3,7,8-TCDD	1,2,3,7,8-PeCDD	1,2,3,4,7,8-HxCDD	1,2,3,6,7,8-HxCDD	1,2,3,7,8,9-HxCDD	1,2,3,4,6,7,8-HpCDD	OCDD	2,3,7,8-TCDF	1,2,3,7,8-PeCDF	2,3,4,7,8-PeCDF	1,2,3,4,7,8-HxCDF	1,2,3,6,7,8-HxCDF	2,3,4,6,7,8-HxCDF	1,2,3,7,8,9-HxCDF	1,2,3,4,6,7,8-HpCDF	1,2,3,4,7,8,9-HpCDF	OCDF
1M1 - 2008		1.34					1.24	0.45	1.46		1.46							0.63
1M3 - 2008		1.36					1.46	0.82	1.26									
2M1 - 2008																		
4M3 - 2008																		
3M2 - 2008							0.25		0.19			0.29						0.95
M701 - 2008									1.82	1.26								

Site-Yr	Chir	2,3,7,8-TCDD	1,2,3,7,8-PeCDD	1,2,3,4,7,8-HxCDD	1,2,3,6,7,8-HxCDD	1,2,3,7,8,9-HxCDD	1,2,3,4,6,7,8-HpCDD	OCDD	2,3,7,8-TCDF	1,2,3,7,8-PeCDF	2,3,4,7,8-PeCDF	1,2,3,4,7,8-HxCDF	1,2,3,6,7,8-HxCDF	2,3,4,6,7,8-HxCDF	1,2,3,7,8,9-HxCDF	1,2,3,4,6,7,8-HpCDF	1,2,3,4,7,8,9-HpCDF	OCDF
1M1 - 2013							0.20	0.07	0.19									
1M3 - 2013		0.26			0.51				0.20	0.49	0.21					0.11		0.04
2M1 - 2013							1.43	0.62										
4M3 - 2013								0.23										
3M2 - 2013							0.19	0.11	0.13									
EEM4 - 2013								0.07	0.18									
2M6 - 2013							0.34	0.15										

Table C5. Continued.

Site-Yr	Olig	2,3,7,8-TCDD	1,2,3,7,8-PeCDD	1,2,3,4,7,8-HxCDD	1,2,3,6,7,8-HxCDD	1,2,3,7,8,9-HxCDD	1,2,3,4,6,7,8-HpCDD	OCDD		2,3,7,8-TCDF	1,2,3,7,8-PeCDF	2,3,4,7,8-PeCDF	1,2,3,4,7,8-HxCDF	1,2,3,6,7,8-HxCDF	2,3,4,6,7,8-HxCDF	1,2,3,7,8,9-HxCDF	1,2,3,4,6,7,8-HpCDF	1,2,3,4,7,8,9-HpCDF	OCDF
1M1 - 2008		0.26					0.15	0.12		0.27		0.29							
1M3 - 2008		0.40					0.41	0.37		0.45		0.18							
2M1 - 2008								0.02		0.27	0.16		0.12	0.53					0.10
4M3 - 2008																			1.94
3M2 - 2008							0.08			0.12		0.29		0.59					0.40
M701 - 2008								0.59		1.06									
Site-Yr	Olig	2,3,7,8-TCDD	1,2,3,7,8-PeCDD	1,2,3,4,7,8-HxCDD	1,2,3,6,7,8-HxCDD	1,2,3,7,8,9-HxCDD	1,2,3,4,6,7,8-HpCDD	OCDD		2,3,7,8-TCDF	1,2,3,7,8-PeCDF	2,3,4,7,8-PeCDF	1,2,3,4,7,8-HxCDF	1,2,3,6,7,8-HxCDF	2,3,4,6,7,8-HxCDF	1,2,3,7,8,9-HxCDF	1,2,3,4,6,7,8-HpCDF	1,2,3,4,7,8,9-HpCDF	OCDF
1M1 - 2013								0.02		0.08									
1M3 - 2013							0.04	0.02		0.08						2.06			
2M1 - 2013							0.23	0.12		0.06						4.17	0.22		0.13
4M3 - 2013																			
3M2 - 2013							0.70	0.41											0.79
EEM4 - 2013								0.01		0.09									
2M6 - 2013								0.03											

Table C6. Biota-sediment accumulation factors (BSAFs) for dioxin-like PCBs - 2013 samples.

BSAFs	AMPHIPOD	PCB-081	PCB-077	PCB-123	PCB-118	PCB-114	PCB-105	PCB-126	PCB-167	PCB-156/157	PCB-169	PCB-189
1M1					0.103		0.111		0.118	0.099		0.102
1M3					0.218		0.237		0.169	0.148		0.151
EEM4					0.137					0.129		
2M1					0.124	0.071	0.123		0.188	0.135		0.150
2M6					0.109		0.117		0.156	0.084		0.105
4M3					0.107		0.076		0.203	0.046		0.081
3M2					0.109		0.100	0.296	0.173	0.130		0.178
BSAFs	CHIRONOMID	PCB-081	PCB-077	PCB-123	PCB-118	PCB-114	PCB-105	PCB-126	PCB-167	PCB-156/157	PCB-169	PCB-189
1M1					0.0263		0.0312		0.0277	0.0290		0.0379
1M3			0.0423	0.0046	0.0482		0.0436		0.0282	0.0302		0.0257
EEM4					0.0241		0.0259		0.0299	0.0108		
2M1			0.1762		0.0553		0.0744		0.0675	0.0497		0.0774
2M6					0.0038		0.0059			0.0037		
4M3					0.0678					0.0616		
3M2					0.0423		0.0479	0.2597	0.0645	0.0550		0.0903
BSAFs	OLIGOCHAETE	PCB-081	PCB-077	PCB-123	PCB-118	PCB-114	PCB-105	PCB-126	PCB-167	PCB-156/157	PCB-169	PCB-189
1M1					0.012		0.013			0.009		
1M3			0.016		0.017		0.018		0.011	0.010		0.011
EEM4			0.021		0.008		0.009		0.009	0.004		0.006
2M1					0.013		0.017		0.016	0.014		0.019
2M6					0.007		0.009					0.014
4M3					0.056					0.030		
3M2			0.212		0.079	0.091	0.085		0.053	0.054		0.067

APPENDIX D

Benthic invertebrate counts for 2013

Table D1. Macroinvertebrate abundance counts (per 33.16 cm^2 – area of core tube) for 2013 Jackfish Bay sites.

Site	Phylum	Class	Order	Family	Genus	Species	Count
1M1	Annelida	Oligochaeta	Haplotaxida	Naididae	Arcteonais	Arcteonais lomondi	1
					Nais	Nais communis	1.6
					Vejdovskyella	Vejdovskyella comata	0.4
				Tubificidae	Aulodrilus	Aulodrilus pluriseta	0.2
					Immatures with cheatal hairs		63.2
					Immatures without cheatal hairs		10.2
					Peloscolex	Peloscolex ferox	1.2
	Arthropoda	Insecta	Diptera	Chironomidae	Chironomus	Chironomus salinarius	0.2
					Cladotanytarsus		0.2
					Dicrotendipes	Dicrotendipes modestus	0.2
					Heterotrissocladius	Heterotrissocladius changi	0.4
					Heterotrissocladius	Heterotrissocladius marcidus	0.2
					Microtendipes	Microtendipes pedellus	0.2
					Polypedilum	Polypedilum scalaenum	0.4
					Procladius		1.8
					Protanypus	Protanypus ramosus	0.4
					Tanytarsus		0.6
		Malacostraca	Amphipoda	Pontoporeiidae	Diporeia	Diporeia hoyi	0.4
			Isopoda	Asellidae	Caecidotea	Caecidotea racovitzai	0.2
1M3	Annelida	Oligochaeta	Haplotaxida	Naididae	Vejdovskyella	Vejdovskyella intermedia	0.4
				Tubificidae	Aulodrilus	Aulodrilus pluriseta	0.6
					Immatures with cheatal hairs		17.4
					Immatures without cheatal hairs		6.2
					Peloscolex	Peloscolex ferox	0.8
	Arthropoda	Insecta	Diptera	Chironomidae	Chironomus	Chironomus salinarius	0.2
					Heterotrissocladius	Heterotrissocladius changi	0.2
					Polypedilum	Polypedilum scalaenum	0.2
					Procladius		2.8
		Malacostraca	Isopoda	Asellidae	Caecidotea	Caecidotea racovitzai	0.8
1M400	Annelida	Oligochaeta	Haplotaxida	Naididae	Vejdovskyella	Vejdovskyella intermedia	27.2
				Tubificidae	Aulodrilus	Aulodrilus pluriseta	9.4
					Immatures with cheatal hairs		22.6
					Immatures without cheatal hairs		15.2
					Limnodrilus	Limnodrilus hoffmeisteri	0.4
					Peloscolex	Peloscolex ferox	0.2
	Arthropoda	Arachnida	Trombidiformes	Halacaridae			0.2
		Insecta	Diptera	Chironomidae	Chironomus		0.2
					Procladius		2.4
		Malacostraca	Isopoda	Asellidae	Caecidotea	Caecidotea racovitzai	7
	Mollusca	Bivalvia	Veneroida	Pisidiidae	Pisidium		1.2
					Pisidium	Pisidium casertanum	0.4
					Pisidium	Pisidium ferrugineum	0.8
					Pisidium	Pisidium nitidum	1.8
					Pisidium	Pisidium supinum	0.6
1M401	Annelida	Oligochaeta	Haplotaxida	Tubificidae	Aulodrilus	Aulodrilus pluriseta	0.8
					Immatures with cheatal hairs		14.2
					Immatures without cheatal hairs		11.8
					Limnodrilus	Limnodrilus hoffmeisteri	0.2
			Lumbriculida	Lumbriculidae	Stylodrilus	Stylodrilus heringianus	0.6
	Arthropoda	Insecta	Diptera	Chironomidae	Polypedilum	Polypedilum scalaenum	0.2
					Procladius		1
		Malacostraca	Isopoda	Asellidae	Caecidotea	Caecidotea racovitzai	8.8
	Mollusca	Bivalvia	Veneroida	Pisidiidae	Pisidium		0.4
					Pisidium	Pisidium casertanum	0.2
					Pisidium	Pisidium supinum	2
					Pisidium	Pisidium variabile	0.4
1M402	Annelida	Oligochaeta	Haplotaxida	Naididae	Vejdovskyella	Vejdovskyella intermedia	38.4
				Tubificidae	Aulodrilus	Aulodrilus pluriseta	6.2
					Immatures with cheatal hairs		21.8
					Immatures without cheatal hairs		15.2
					Limnodrilus	Limnodrilus hoffmeisteri	0.4
					Peloscolex	Peloscolex ferox	0.2
	Arthropoda	Arachnida	Sarcoptiformes	Hydrozetidae	Hydrozetes		0.2
			Trombidiformes	Halacaridae			0.2
		Insecta	Diptera	Chironomidae	Limnophyes		0.2
					Polypedilum	Polypedilum scalaenum	0.2
					Procladius		3.4
					Tanytarsus		0.4
		Malacostraca	Amphipoda	Pontoporeiidae	Diporeia	Diporeia hoyi	0.4
			Isopoda	Asellidae	Caecidotea	Caecidotea racovitzai	5.8
	Mollusca	Bivalvia	Veneroida	Pisidiidae	Pisidium		0.4
					Pisidium	Pisidium casertanum	0.8
					Pisidium	Pisidium ferrugineum	1
					Pisidium	Pisidium nitidum	2.2
					Pisidium	Pisidium supinum	1

Table D1. Continued.

Site	Phylum	Class	Order	Family	Genus	Species	Count
2M1	Annelida	Oligochaeta	Haplotaxida	Tubificidae	Ilyodrilus	Ilyodrilus templetoni	0.2
					Immatures with cheatal hairs		0.2
					Rhyacodrilus	Rhyacodrilus montanus	1.4
	Arthropoda	Insecta	Diptera	Chironomidae	Heterotrissocladius	Heterotrissocladius changi	0.4
					Parakiefferiella		0.2
					Protanypus	Protanypus ramosus	0.2
		Malacostraca	Amphipoda	Gammaridae			0.2
				Pontoporeiidae	Diporeia	Diporeia hoyi	1.6
	Mollusca	Bivalvia	Veneroida	Pisidiidae	Pisidium		0.2
					Pisidium	Pisidium casertanum	0.6
					Pisidium	Pisidium nitidum	1.0
2M4	Annelida	Oligochaeta	Haplotaxida	Tubificidae	Immatures with cheatal hairs		0.4
					Rhyacodrilus	Rhyacodrilus montanus	2.6
			Lumbriculida	Lumbriculidae	Stylodrilus	Stylodrilus heringianus	0.2
	Arthropoda	Insecta	Diptera	Ceratopogonidae	Probezzia		0.2
				Chironomidae	Heterotrissocladius	Heterotrissocladius changi	1.2
					Parakiefferiella		0.2
					Procladius		0.2
					Protanypus	Protanypus ramosus	0.6
		Malacostraca	Amphipoda	Pontoporeiidae	Diporeia	Diporeia hoyi	0.6
	Mollusca	Bivalvia	Veneroida	Pisidiidae	Pisidium		0.6
					Pisidium	Pisidium casertanum	0.8
					Pisidium	Pisidium nitidum	0.8
2M6	Annelida	Oligochaeta	Haplotaxida	Tubificidae	Immatures with cheatal hairs		0.4
					Immatures without cheatal hairs		0.2
					Rhyacodrilus	Rhyacodrilus montanus	0.8
	Arthropoda	Insecta	Diptera	Chironomidae	Cladotanytarsus		0.2
					Paratendipes	Paratendipes subaequalis	0.2
					Tanytarsus		0.2
		Malacostraca	Amphipoda	Pontoporeiidae	Diporeia	Diporeia hoyi	2.6
	Mollusca	Bivalvia	Veneroida	Pisidiidae	Pisidium		0.2
					Pisidium	Pisidium nitidum	0.6
3M2	Annelida	Oligochaeta	Haplotaxida	Tubificidae	Immatures with cheatal hairs		2.6
					Immatures without cheatal hairs		0.4
					Rhyacodrilus	Rhyacodrilus montanus	1.6
					Tubifex	Tubifex tubifex	0.2
	Arthropoda	Insecta	Diptera	Chironomidae	Chironomus	Chironomus salinarius	0.4
					Heterotrissocladius	Heterotrissocladius changi	3.2
					Protanypus	Protanypus ramosus	1.2
		Malacostraca	Amphipoda	Pontoporeiidae	Diporeia	Diporeia hoyi	2.6
	Mollusca	Bivalvia	Veneroida	Pisidiidae	Pisidium	Pisidium casertanum	0.2
					Pisidium	Pisidium nitidum	1.4
4M3	Annelida	Oligochaeta	Haplotaxida	Enchytraeidae	Mesenchytraeus		1.2
	Arthropoda	Insecta	Diptera	Chironomidae	Heterotrissocladius	Heterotrissocladius changi	0.8
		Malacostraca	Amphipoda	Pontoporeiidae	Diporeia	Diporeia hoyi	6.2
	Mollusca	Bivalvia	Veneroida	Pisidiidae	Pisidium	Pisidium nitidum	0.2
4M4	Annelida	Oligochaeta	Haplotaxida	Enchytraeidae	Mesenchytraeus		0.6
			Lumbriculida	Lumbriculidae			1.0
					Stylodrilus	Stylodrilus heringianus	0.4
	Arthropoda	Insecta	Diptera	Chironomidae	Chironomus		0.2
					Heterotrissocladius	Heterotrissocladius changi	0.4
		Malacostraca	Amphipoda	Pontoporeiidae	Diporeia	Diporeia hoyi	2.2
	Mollusca	Bivalvia	Veneroida	Pisidiidae	Pisidium	Pisidium casertanum	0.2
		Gastropoda	Heterostropha	Valvatidae	Valvata	Valvata lewisi	0.4
					Valvata	Valvata perdepressa	0.2
6956	Annelida	Oligochaeta	Haplotaxida	Tubificidae	Immatures with cheatal hairs		2.8
					Immatures without cheatal hairs		0.8
					Limnodrilus	Limnodrilus hoffmeisteri	0.2
					Rhyacodrilus	Rhyacodrilus montanus	0.6
	Arthropoda	Insecta	Diptera	Chironomidae	Chironomus	Chironomus salinarius	0.6
					Cladotanytarsus		0.2
					Heterotrissocladius	Heterotrissocladius changi	0.8
					Protanypus	Protanypus ramosus	0.6
		Malacostraca	Amphipoda	Pontoporeiidae	Diporeia	Diporeia hoyi	1.4
	Mollusca	Bivalvia	Veneroida	Pisidiidae	Pisidium	Pisidium casertanum	0.2
					Pisidium	Pisidium nitidum	0.4

Table D1. Continued.

Site	Phylum	Class	Order	Family	Genus	Species	Count
M701	Annelida	Hirudinea	Rhynchobdellida	Glossiphoniidae	Helobdella	Helobdella stagnalis	0.02
		Oligochaeta	Haplotaxida	Enchytraeidae	Enchytraeus		0.27
				Naididae	Nais	Nais communis	0.02
					Vejdovskyella	Vejdovskyella intermedia	0.14
				Tubificidae	Aulodrilus	Aulodrilus pluriseta	3.53
					Immatures with cheatal hairs		49.67
					Immatures without cheatal hairs		104.87
					Limnodrilus	Limnodrilus hoffmeisteri	3.65
					Limnodrilus	Limnodrilus profundicola	0.68
					Peloscolex	Peloscolex ferox	2.15
					Potamothrix	Potamothrix hammoniensis	0.27
					Rhyacodrilus	Rhyacodrilus montanus	0.06
					Trasserkidrilus	Trasserkidrilus superiorensis	0.14
					Tubifex	Tubifex ignotus	15.05
			Lumbriculida	Lumbriculidae	Stylodrilus	Stylodrilus heringianus	3.28
	Arthropoda	Arachnida	Trombidiformes	Halacaridae			0.02
		Insecta	Diptera	Ceratopogonida	Probezzia		0.12
				Chironomidae	Chironomus		3.24
					Chironomus	Chironomus decorus	9.80
					Cricotopus		0.02
					Procladius		5.29
					Psectrotanypus		0.02
					Tanytarsus		0.02
		Malacostraca	Amphipoda	Gammaridae	Gammarus	Gammarus pseudolimnaeus	0.68
			Isopoda	Asellidae	Caecidotea	Caecidotea racovitzai	17.35
	Mollusca	Bivalvia	Veneroida	Pisidiidae	Musculium	Musculium partumeium	0.02
					Pisidium		5.78
					Pisidium	Pisidium casertanum	0.02
					Pisidium	Pisidium compressum	0.29
					Pisidium	Pisidium ferrugineum	0.47
					Pisidium	Pisidium nitidum	0.25
					Pisidium	Pisidium supinum	0.16
					Pisidium	Pisidium variabile	0.27
		Gastropoda	Basommatophor	Planorbidae			0.02
					Gyraulus		0.02
EEM4	Annelida	Oligochaeta	Haplotaxida	Naididae	Vejdovskyella	Vejdovskyella intermedia	7.8
				Tubificidae	Aulodrilus	Aulodrilus pluriseta	4.8
					Immatures with cheatal hairs		5
					Immatures without cheatal hairs		27
					Limnodrilus	Limnodrilus hoffmeisteri	1.4
					Peloscolex	Peloscolex ferox	3.6
	Arthropoda	Arachnida	Sarcoptiformes	Hydrozetidae	Hydrozetes		0.2
		Insecta	Diptera	Chironomidae	Chironomus		0.4
					Heterotrissocladius	Heterotrissocladius subpilosus	0.2
					Procladius		3.4
					Tanytarsus		0.2
		Malacostraca	Isopoda	Asellidae	Caecidotea	Caecidotea racovitzai	4
	Mollusca	Bivalvia	Veneroida	Pisidiidae	Pisidium		0.4
					Pisidium	Pisidium casertanum	0.6
					Pisidium	Pisidium nitidum	0.8
					Pisidium	Pisidium punctatum	0.4
					Pisidium	Pisidium supinum	0.4
EEM8	Annelida	Oligochaeta	Haplotaxida	Naididae	Nais	Nais communis	6.4
				Tubificidae	Aulodrilus	Aulodrilus pluriseta	0.2
					Immatures with cheatal hairs		44
					Immatures without cheatal hairs		12.8
					Limnodrilus	Limnodrilus hoffmeisteri	0.2
					Peloscolex	Peloscolex ferox	6.6
					Rhyacodrilus	Rhyacodrilus montanus	1
			Lumbriculida	Lumbriculidae	Stylodrilus	Stylodrilus heringianus	0.4
	Arthropoda	Arachnida	Trombidiformes	Halacaridae			0.2
		Insecta	Diptera	Ceratopogonida	Probezzia		0.2
				Chironomidae	Chironomus		0.4
					Chironomus	Chironomus salinarius	0.2
					Heterotrissocladius	Heterotrissocladius marcidus	0.2
					Parakiefferiella		0.2
					Polypedilum	Polypedilum scalaenum	0.2
					Procladius		1.2
					Protanypus	Protanypus ramosus	0.4
		Malacostraca	Amphipoda	Pontoporeiidae	Diporeia	Diporeia hoyi	0.4
			Isopoda	Asellidae	Caecidotea	Caecidotea racovitzai	0.8
	Mollusca	Bivalvia	Veneroida	Pisidiidae	Pisidium		0.2
					Pisidium	Pisidium casertanum	0.2
					Pisidium	Pisidium nitidum	0.4
	Nemertea	Enopla	Hoplonemertea	Tetrastemmatid	Prostoma		0.2

Table D1. Continued.

Site	Phylum	Class	Order	Family	Genus	Species	Count
JFB002	Annelida	Oligochaeta	Haplotaxida	Naididae	Arcteonais	Arcteonais lomondi	0.2
					Dero	Dero nivea	0.2
					Vejdovskyella	Vejdovskyella intermedia	6.4
				Tubificidae	Aulodrilus	Aulodrilus pluriseta	7
					Immatures with cheatal hairs		20.8
					Immatures without cheatal hairs		14.8
					Limnodrilus	Limnodrilus hoffmeisteri	0.2
	Arthropoda	Arachnida	Trombidiformes	Halacaridae			0.2
		Insecta	Diptera	Ceratopogonida	Probezzia		0.4
				Chironomidae	Parakiefferiella		0.6
					Polypedilum		0.2
					Polypedilum	Polypedilum scalaenum	0.2
					Procladius		1.8
					Protanypus	Protanypus ramosus	0.2
		Malacostraca	Isopoda	Asellidae	Caecidotea	Caecidotea racovitzai	6.8
	Mollusca	Bivalvia	Veneroida	Pisidiidae	Pisidium	Pisidium nitidum	0.4
	Platyhelminthe	Turbellaria	Neorhabdocoela				0.2
NF500	Annelida	Oligochaeta	Haplotaxida	Naididae	Vejdovskyella	Vejdovskyella intermedia	4
				Tubificidae	Aulodrilus	Aulodrilus pluriseta	2.6
					Immatures with cheatal hairs		21
					Immatures without cheatal hairs		12.6
					Limnodrilus	Limnodrilus hoffmeisteri	0.2
					Peloscolex	Peloscolex ferox	0.4
	Arthropoda	Insecta	Diptera	Chironomidae	Polypedilum	Polypedilum scalaenum	0.2
					Procladius		2.6
		Malacostraca	Isopoda	Asellidae	Caecidotea	Caecidotea racovitzai	4
	Mollusca	Bivalvia	Veneroida	Pisidiidae	Pisidium	Pisidium nitidum	1.4
NF501	Annelida	Oligochaeta	Haplotaxida	Naididae	Arcteonais	Arcteonais lomondi	0.4
					Vejdovskyella	Vejdovskyella intermedia	3
				Tubificidae	Aulodrilus	Aulodrilus pluriseta	3.6
					Immatures with cheatal hairs		17.8
					Immatures without cheatal hairs		7.8
					Limnodrilus	Limnodrilus hoffmeisteri	0.2
					Peloscolex	Peloscolex ferox	0.4
	Arthropoda	Insecta	Diptera	Chironomidae	Chironomus		0.2
					Polypedilum	Polypedilum scalaenum	0.6
					Procladius		2.2
					Protanypus	Protanypus ramosus	0.2
					Tanytarsus		0.2
		Malacostraca	Isopoda	Asellidae	Caecidotea	Caecidotea racovitzai	1.6
	Mollusca	Bivalvia	Veneroida	Pisidiidae	Pisidium	Pisidium nitidum	0.2
					Pisidium	Pisidium variabile	0.2
NF502	Annelida	Oligochaeta	Haplotaxida	Naididae	Arcteonais	Arcteonais lomondi	0.2
					Vejdovskyella	Vejdovskyella intermedia	2.4
				Tubificidae	Aulodrilus	Aulodrilus pluriseta	4.6
					Immatures with cheatal hairs		25.2
					Immatures without cheatal hairs		15.6
					Limnodrilus	Limnodrilus hoffmeisteri	0.6
					Peloscolex	Peloscolex ferox	0.8
	Arthropoda	Insecta	Diptera	Chironomidae	Polypedilum	Polypedilum scalaenum	0.4
					Procladius		2.8
					Tanytarsus		0.2
		Malacostraca	Isopoda	Asellidae	Caecidotea	Caecidotea racovitzai	5.4
	Mollusca	Bivalvia	Veneroida	Pisidiidae	Pisidium		0.2
					Pisidium	Pisidium casertanum	0.6

APPENDIX E

Non-metric multidimensional scaling of toxicity data

Table E1. Pearson and Kendall Endpoint Correlations with Ordination Axes, N= 81. Endpoints with $r^2 \geq 0.50$ are highlighted.

```
PC-ORD 6.19
9 Jul 2015, 14:19:03

Correlation endpoint with main matrix

Pearson and Kendall Correlations with Ordination Axes   N= 81 (66 Ref + 15
test)
```

Axis:	1			2		
	r	r-sq	tau	r	r-sq	tau
Crgw	.276	.076	.098	.297	.089	.190
Crsu	-.043	.002	-.019	-.473	.224	-.402
Hagw	.382	.146	.237	.479	.230	.290
Hasu	.826	.683	.633	.923	**.851**	.536
Hlgw	.508	.258	.379	.347	.120	.194
Hlsu	.509	.259	.196	.455	.207	.058
Ttcc	.192	.037	-.020	.029	.001	-.027
Tthtch	-.712	**.506**	-.592	.011	.000	.031
Ttsu	-.043	.002	-.053	-.091	.008	-.123
Ttyg	-.399	.159	-.233	-.081	.007	-.020

Table E2. Pearson and Kendall Habitat Correlations with Ordination Axes, N= 81. Variables with $r^2 \geq 0.30$ are highlighted.

```
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Correlation coefficients between ordination axes scores and each habitat
(explanatory) variable

Pearson and Kendall Correlations with Ordination Axes   N= 81
```

Axis:	1			2		
	r	r-sq	tau	r	r-sq	tau
Sand	.098	.010	.008	.114	.013	-.010
Alkalini	.626	**.392**	.455	.441	.194	.232
NO2NO3	-.445	.198	-.327	-.382	.146	-.260
TKNw	.136	.019	.110	.066	.004	.001
NH3	-.122	.015	-.161	.096	.009	.111
TPw	-.117	.014	-.158	.006	.000	.030
Al2O3	.382	.146	.083	.535	.286	.253
As	-.122	.015	-.066	-.114	.013	-.084
BaO	.389	.151	.159	.495	.245	.237
CaO	.360	.130	.392	.236	.056	.193
Cd	-.189	.036	-.231	-.171	.029	-.215
Co	-.201	.041	-.192	-.167	.028	-.174
Cr	-.356	.127	-.288	-.241	.058	-.203
Cu	-.288	.083	-.248	-.216	.046	-.185
Depth	-.385	.148	-.260	-.403	.163	-.273
Fe2O3	.245	.060	.062	.369	.136	.150
Hg	-.020	.000	-.147	-.086	.007	-.151
K2O	.343	.118	.171	.478	.228	.258
LOI	.219	.048	.137	-.001	.000	-.082
MgO	.367	.135	.267	.366	.134	.151
MnO	.143	.020	.122	.216	.047	.158
Na	.048	.002	.025	.175	.031	.040
Ni	-.120	.014	-.156	.043	.002	-.004
Pb	-.056	.003	-.045	.010	.000	-.003
SiO2	.481	.231	.215	.608	.369	.349
TiO2	.349	.122	.178	.417	.174	.231
TKNs	.125	.016	.040	.072	.005	-.076
TOC	-.093	.009	-.134	-.108	.012	-.188
TPs	.009	.000	-.012	-.120	.014	-.103
V	-.370	.137	-.326	-.223	.050	-.182
Zn	-.176	.031	-.194	-.156	.024	-.197

```
****************************** Operation completed
******************************
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```

APPENDIX F

Regression Analysis

Table F1. Regression Analysis: log *Hyalella* growth versus log F3 fraction.

Regression Analysis: log Hy growth versus log F3

```
The regression equation is
log Hyalella growth = 0.419 - 0.286 log F3


Predictor      Coef  SE Coef      T      P    VIF
Constant     0.4189   0.3666   1.14  0.277
log F3      -0.2855   0.1083  -2.64  0.023  1.000


S = 0.168805   R-Sq = 38.7%   R-Sq(adj) = 33.1%

PRESS = 0.453097   R-Sq(pred) = 11.42%


Analysis of Variance

Source          DF       SS       MS     F      P
Regression       1  0.19806  0.19806  6.95  0.023
Residual Error  11  0.31345  0.02850
Total           12  0.51150


Durbin-Watson statistic = 1.68699

No evidence of lack of fit (P >= 0.1).
```