



Greater Vancouver Regional District  
LWMP Environmental Management

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FINAL REPORT

PEER REVIEW OF CYCLE 3 OF THE  
IONA DEEP-SEA OUTFALL  
ENVIRONMENTAL MONITORING PROGRAM



Peer Review of Cycle 3 of the  
Iona Deep-Sea Outfall  
Environmental Monitoring Program

FINAL REPORT

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**Prepared for**

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**June 2006**

Correct citation for this publication:

Ellis, D.V., C. Gobeil, K.J. Hall, L.L. Johnson, T.G. Milligan and T.B. Reynoldson. 2006. Peer Review of Cycle 3 of the Iona Deep-Sea Outfall Environmental Monitoring Program. Report prepared for the Greater Vancouver Regional District (GVRD), Burnaby, BC. Project Coordinated by 2WE Associates Consulting Ltd., Victoria, BC. 65 pp. + Appendices.

## PREFACE

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The Greater Vancouver Regional District (GVRD) is committed to the principle of managing liquid waste in a manner that enhances environmental quality. This commitment is detailed in the District's Liquid Waste Management Plan (LWMP). The LWMP process is mandated by the Province of British Columbia and designed to ensure that an integrated, local approach to making good, informed liquid waste management decisions is followed.

A key component of the District's Plan (Commitment C4 of the LWMP) involves monitoring, assessing and forecasting to evaluate the effects of its liquid waste discharges, including wastewater treatment plant effluents, combined sewer overflows and stormwater. This monitoring is vital in providing information to effectively manage liquid waste discharges on a regional basis, and in furnishing a scientific basis for setting priorities and designing system upgrades.

Work in this area is guided and reviewed by an Environmental Monitoring Committee (EMC), an advisory committee to the GVRD under the LWMP. The committee is made up of senior representatives from the provincial and federal governments, the GVRD and its member municipalities, the academic community and a public member.

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## ACKNOWLEDGEMENTS

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This project was administered by Dr. Albert van Roodselaar and Mr. Stanley Bertold respectively of the Policy and Planning Department and Operations and Maintenance Department of the GVRD.

Project management was provided by 2WE Associates, under the management of Mr. Robert C.H. Wilson with the assistance of Dr. John F. Garrett and Dr. J.A. Jeffrey Thompson.

Acknowledgement and gratitude are extended to each of the expert reviewers. The reviewers and their corresponding affiliations and primary theme of responsibilities were as follows:

Dr. Derek V. Ellis, Professor Emeritus, University of Victoria

- Benthic infaunal methodology, data analysis and interpretation (marine benthic biologist)

Dr. Charles Gobeil, Professor, Centre eau, terre et environnement, Université du Québec

- Sediment quality, including chemistry and microbiology

Dr. Kenneth J. Hall, Professor, Institute for Resources, Environment and Sustainability, University of British Columbia

- Integration of results and conclusions

Ms. Lyndal L. Johnson, Zoologist, Northwest Fisheries Science Center, NOAA Fisheries

- Bioaccumulation and fish health

Mr. Timothy G. Milligan, Researcher, Marine Environmental Sciences Division, Bedford Institute of Oceanography, Fisheries & Oceans Canada

- Effluent dispersion and solids deposition modelling

Dr. Trefor B. Reynoldson, Research Associate, Acadia University

- Benthic infaunal methodology, data analysis and interpretation (specialist in multivariate statistical analysis methods)

Summary presentations of program activities pertaining to modelling, fieldwork, taxonomy, histopathology, as well as data analysis, interpretation and reporting were provided to the review panel by the following contractors and subcontractors:

Ms. Cathy A. McPherson and Dr. Peter M. Chapman, Golder Associates Ltd.

- Prime contractor: bioaccumulation; data analysis, interpretation and reporting

Dr. Donald O. Hodgins, Seaconsult Marine Research Ltd.

- Effluent dispersion and solids deposition modelling

Mr. M.L. (Len) Fanning, IRC Integrated Resource Consultants Inc.

- Fieldwork subcontractor

Ms. Valerie I. Macdonald, Biologica Environmental Services Ltd.

- Benthic infaunal processing and taxonomy

Dr. Michael D. Paine, PLA Paine, Ledge and Associates Ltd.

- Sediment chemistry assessment

Dr. Brenda J. Burd, Ecostat Research Ltd.

- Benthic community structure assessment

Ms. Dawna Brand, Independent Consultant

- Biota histopathology assessment

The findings of this report have been presented to the Environmental Monitoring Committee (EMC). The EMC was formed under the District's Liquid Waste Management Plan. The members of the EMC at the time that this report was prepared are listed below:

Doug Pope, P.Eng.	EMC CHAIR, City of North Vancouver
Albert van Roodselaar, Ph.D., P.Eng.	EMC COORDINATOR, GVRD
Les Swain, P.Eng.	BC Ministry of Environment
Brent Moore, R.P.Bio.	BC Ministry of Environment
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Domenic Losito, M.B.A., REHO	Vancouver Coastal Health
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Carrie Baron, P.Eng.	City of Surrey
Don Brynildsen, P.Eng.	City of Vancouver
Ken Hall, Ph.D.	University of British Columbia
Francis Law, Ph.D.	Simon Fraser University
Paul Goud, Ph.D.	Public Representative
Stan Bertold, B.Sc.	Greater Vancouver Regional District

## EXECUTIVE SUMMARY

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Cycle 3 of the Iona Deep-Sea Outfall Environmental Monitoring Program was conducted between 1999 and 2004. The program design was refined following an independent review at the end of Cycle 2. Routine monitoring or special studies have been conducted each year, with consistent methodologies being used for the routine monitoring. Annual monitoring reports are produced. These reports incorporate results from the routine monitoring and special studies and evaluate the environmental conditions at the Iona Island Treatment Plant Deep-Sea Outfall area.

Six independent experts conducted this review of Cycle 3 in the first half of 2005. They found no serious problems with the work undertaken and were generally pleased with the GVRD's approach and attention to detail. The high quality of the data collected is an outstanding feature of the program, placing the GVRD in a position where the environmental data can be used with confidence to support decisions.

The reviewers collectively answered a series of 44 questions that addressed all of the monitoring components carried out in Cycle 3. Following introductory sections with the objectives and methodology for the review, this report contains the reviewers' responses to specific questions outlined in sections corresponding to the major tasks, or themes, of the monitoring program during Cycle 3:

- Plume modelling, wastewater dynamics, and particle settling;
- Sediment quality, comprised of chemical and microbiological analyses;
- Benthic/epibenthic community
- Integration of results and the overall conclusions drawn

The reviewers also provided recommendations for strengthening the monitoring program in Cycle 4. These recommendations are outlined and summarized in Section 5 of the report.

Highlights of the recommendations for Cycle 4 include:

- Creating a hierarchical/relational database to hold all the data from previous cycles
- Determining sediment accumulation rates and contaminant fluxes
- Adding transect lines orthogonal to the 80-m contour
- Reducing the frequency of sampling on the 80-m contour
- Incorporating additional measures of exposure and effect in the fish health study
- Extending the use of additional statistical analysis methods that could extract more value from the benthic invertebrate data
- Surveying the literature to determine if techniques are available to better estimate cumulative effects
- Enhancing water column monitoring

These and other specific improvements to the monitoring and reporting process are described in more detail in the rest of this document.

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Workshop on Peer Review of Cycle 3 of the Iona Deep-Sea Outfall Environmental Monitoring Program, Richmond, BC (4 May 2005)

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## 1. Introduction

The Greater Vancouver Regional District (GVRD) is committed, consistent with its Sustainable Region Initiative, to the principle of managing municipal liquid waste in a manner that enhances environmental quality (GVRD, 2001). The GVRD's environmental management plan is focused on environmental integrity through the application of science-based risk assessments. This plan requires comprehensive monitoring for the purpose of managing the receiving environment and forecasting any effects on the environment by its discharges. The assessments so created help focus management on environmental integrity and ecological health, preventing adverse effects on the receiving environment (GVRD, 2004).

The GVRD owns and operates five major primary and secondary wastewater treatment plants in the Greater Vancouver Region. The Iona Island Wastewater Treatment Plant is the District's largest primary plant, which provides primary treatment to wastewater from approximately 600,000 people in Vancouver, the UBC Endowment Lands, and parts of Richmond and Burnaby. An average of 550 ML/d (2004) of treated effluent is piped through a 7.5-km long conduit to a multi-port diffuser system in the Strait of Georgia at an average depth of 90 m (72-106 m). The diffuser system provides a minimum bulk initial dilution of 150:1 at all effluent flows and all discharge depths, throughout the year.

Before the Iona deep-sea outfall commenced operation, the District undertook environmental monitoring over a two-year period from 1986 to 1987 to provide information on pre-discharge background conditions at and adjacent to the outfall diffuser area. Post-discharge monitoring started in 1988, the year the submarine diffuser system was put into operation, and monitoring has continued on an annual basis. The post-discharge monitoring program has been conducted in regular cycles of approximately 5 years each:

<u>Monitoring Cycle</u>	<u>Review Year</u>
Cycle 1: 1988-1992	–
Cycle 2: 1993-1997	1998
Cycle 3: 1999-2004	2005

Samples for the annual routine monitoring in 2005 were collected using the methodology for Cycle 3. This work was underway at the same time as the review, meaning that 2005 can be thought of as an extension of Cycle 3.

The program comprises regular and cyclical monitoring events as well as special studies and investigations. The work undertaken during Cycle 3 is summarized in Table 1:

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**Table 1.** Cycle 3 of the Iona environmental monitoring program.

Timing for repetitive studies is shown by check marks, while special studies are cross-hatched.

<b>Compartment</b>	<b>1999</b>	<b>2000</b>	<b>2001</b>	<b>2002</b>	<b>2003</b>	<b>2004</b>
Sediment quality		✓	✓	✓	✓	✓
Benthic infauna		✓	✓	✓	✓	✓
Fish health			✓			
Effluent dispersion, solids deposition						

Cycle 3 of the monitoring program addressed six main questions (McPherson *et al.*, 2005):

1. How do sediment and tissue concentrations of contaminants in the wastewater compare to environmental quality guidelines?
2. Are there significant differences in sediment chemistry, the composition of the benthic community, or in the health of resident sentinel species between near- field and far-field stations?
3. Can observed effects on the benthic community or on resident sentinel species be attributed to the Iona outfall?
4. Is 80 m the appropriate depth contour for monitoring receiving environment conditions (sediment chemistry, benthic community)?
5. What are the influences of confounding factors, e.g. other sources of disturbance?
6. Are there differences between years in the results for sediment chemistry and the benthic community?

The last full review of the monitoring program was carried out in 1998, at the end of Cycle 2 (Wilson *et al.*, 1999). Recommendations were used to strengthen the monitoring program for Cycle 3. The purpose of this present review is to assess if further strengthening the fourth cycle of monitoring is required to ensure the optimal benefit of this ongoing program to the environmental assessments required under the District's Liquid Waste Management Plan.

### **1.1. Activities Reviewed**

The District undertakes three broad activities to develop an understanding of environmental effects.

1. *The core monitoring program* consists of repetitive studies and special studies, which, at Iona, have been carried out every year. The core monitoring program is focused on delineating possible effects within the zone of influence of the wastewater discharge. Repetitive studies are carried out on a regular, recurring basis varying from annually to once per cycle. Special studies are conducted to answer process-oriented questions that do not require routine monitoring. Five repetitive monitoring studies and two special studies were reviewed for this report.

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The GVRD also conducts routine monitoring of the bacteriological quality of swimming areas within the Greater Vancouver Region. This activity recently underwent a comprehensive review by the District in consultation with relevant health authorities, so it was not reviewed here.

2. *The ambient program* is being carried out with other levels of government to improve understanding of regional-scale processes and events. For example, the GVRD is exploring contaminant sources and budgets through multi-year sediment investigations in partnership with the Institute of Ocean Sciences.
3. *Research partnerships* are developed to gain understanding on issues that require complex, often multi-year investigation. For example, the District developed research partnerships during Cycle 3 with SFU for risk assessment of pharmaceuticals, and with UBC for the applicability of genomics technology.

Limited information from the ambient studies and research partnerships was available at the time of this review.

Cycle 3 began with a special study of effluent dispersion and particle settling. Advances in modelling techniques were applied to improve the understanding developed from previous computer modelling of the outfall in 1983 and 1988. The study had three objectives (Hodgins and Hodgins, 1999):

- 1) "Review and summarize past Iona plume modelling, tracking and supplementary studies from the perspective of understanding effluent characteristics and plume movement and dilution.
- 2) "Update computer simulations of effluent plume dispersion to determine:
  - trapping depths and initial dilution within the provincially-defined initial dilution zone (IDZ), extending  $\pm 100$  m on either side of the diffuser;
  - northern and southern limits of far-field exposure above background concentrations;
  - the depth range of far-field dispersion;
  - seasonal variations in these parameters;
  - likelihood of effluent plume surfacing at times of seasonally weak (winter) stratification;
  - expected seabed exposure zone to settleable solids in the effluent.
- 3) "Present the study findings in a formal report and prepare examples of the model results with data visualization software on CDROM."

The modelling confirmed that wastewater particles would settle in a north-south direction, as two gradients away from the outfall. A linear pattern of sampling stations along the 80-metre depth contour was adopted for 2000 and repeated in subsequent years. The monitoring program follows a gradient design, with stations extending 7 km north and 9 km south of the outfall.

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The objectives for repetitive monitoring were broadly to:

1. compare sediment contaminant concentrations to federal and provincial guidelines,
2. evaluate the health of the infaunal community,
3. test hypotheses about effects of the wastewater discharge, and
4. determine whether any effects seen might be due to the discharge, recognizing that other sources influence sediment quality in the monitoring area.

These objectives were the focus for annual surveys from 2000 through 2004. These five surveys were carried out using similar methodologies. Stations along the transect at 80-m depth were sampled in each of these years. In addition, two cross-transect lines were sampled in 2003, extending from 60 m to 120 m depth near the outfall and at the southern end of the transect.

Bioaccumulation and the health of two indicator species, Dungeness crab and English sole, were monitored in 2001.

The 1999 modelling work and its follow-up study in 2004 were carried out to shed light on the ultimate fate of Iona effluent particles outside the study area and to examine the potential for particle-bound contaminants to accumulate in the food web.

In summary, the subject matter for this review consists of two special monitoring studies on effluent and particle dispersion, five annual monitoring studies of sediment quality and benthic community health, and one study of bioaccumulation and fish health.

## **2. Peer Reviewers**

This is a peer review, with six senior scientists contributing to the overall evaluation.

Criteria for selecting the reviewers were:

- independent of the GVRD;
- work related to environmental science and monitoring and widely recognized in the scientific and environmental communities; and
- represent an overall balance in the areas of work reviewed, and the reviewers' affiliations with universities or government agencies.

Reviewers were confirmed by the GVRD from a list of candidates identified by 2WE Associates. Each reviewer was assigned primary responsibility for one topic, or theme, of the monitoring program (Table 2). 2WE Associates coordinated the review, providing the introductory material and managing the project on behalf of the GVRD.

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**Table 2. Reviewers and the primary topics they evaluated.**

Mr. Tim Milligan	Effluent dispersion, particle settling
Prof. Charles Gobeil	Sediment quality, including chemistry and microbiology
Prof. Derek Ellis	Benthic infaunal methodology, data analysis and interpretation (marine benthic biologist)
Dr. Trefor Reynoldson	Benthic infaunal methodology, data analysis and interpretation (specialist in multivariate statistical analysis methods)
Ms. Lyndal Johnson	Bioaccumulation and fish health
Prof. Ken Hall	Integration of results and conclusions

A paragraph on each individual reviewer follows, with résumés given in Appendix A.

**Derek V. Ellis, Ph.D., R.P.Bio.**, is a marine benthic biologist, with 50+ years experience in field sampling, statistical analyses, and the sociological relevance of the biodiversity assessment of marine sediments and the intertidal zone. His research, and procedural and conceptual developments in the topics, has resulted in 100+ publications spanning 1955 – 2004 in refereed international journals. He was one of the authors of the 1984 Marine Benthos Methods Manual of the International Biological Program. Dr. Ellis was a professor in the Biology Department of the University of Victoria 1964-1996, at which time he retired from full-time teaching. He has continued his research to date, and has acted as marine benthic consultant for a variety of government agencies and industries.

**Charles Gobeil, Ph.D.**, is a full professor at the Centre Eau, Terre et Environnement of the Institut national de la recherche scientifique, Université du Québec. From 1993 to 2002, he was a research scientist at the Maurice Lamontagne Institute of the Department of Fisheries and Oceans. His main research activities focus on sediment diagenesis and on fluxes and pathways of chemical contaminants in lakes, coastal environments and in the Arctic Ocean. His work is based on observations of fine-scale distribution of trace metals, stable and radioactive isotopes and organic contaminants at the sediment-water interface.

**Kenneth J. Hall, Ph.D.**, is a full professor at the University of British Columbia, affiliated with the Department of Civil Engineering and at the Institute for Resource and Environment's Westwater Research Centre. His interests in environmental chemistry, environmental impact, and water resource management span several disciplines. He has worked with graduate students in the Departments of Zoology, Soil Science, Oceanography, Civil Engineering, Forest Science, Bioresource Engineering, Chemical Engineering, in the School of Community and Regional Planning, and at the Institute for Resources and Environment. Prof. Hall has worked extensively on the characteristics and effects of wastewater and is a member of the GVRD's Environmental Monitoring Committee.

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**Lyndal L. Johnson, M.S.**, is a zoologist at the NOAA Fisheries Northwest Fisheries Science Center in Seattle, Washington. She works in the Ecotoxicology and Environmental Fish Health program in the Environmental Conservation Division, as team leader for the program's Reproductive Toxicology Team. This team is one of several research groups within the Ecotoxicology Program, which studies the effects of chemical contaminants and related human activities on the health of marine organisms, and provides technical guidance to resource managers on how to protect marine animals from harmful impacts of toxicants. She works closely with the Washington State Department of Fish and Wildlife to monitor the health of Puget Sound marine fish as part of the Puget Sound Ambient Monitoring Project, and has been taken part in several studies in the Pacific Northwest and Canada to assess damages to marine resources associated with chemical contaminant inputs.

**Timothy G. Milligan, M.Sc.**, is a researcher with the Marine Environmental Sciences Division, Fisheries and Oceans Canada. As head of the Particle Dynamics Lab at the Bedford Institute of Oceanography he leads the group's research into the behaviour of fine particulate material in aquatic environments. He received his BSc in Geology and MSc in Oceanography from Dalhousie University and has been involved with the study of flocculation and its role in sediment transport for over thirty years. Areas of interest include the mechanisms governing the loss of sediment from river plumes, the effect of flocculation on the transport and fate of contaminants, and environmental impacts of offshore oil and gas and aquaculture. Mr. Milligan has led research projects in a wide range of geographical areas, from the Amazon to the Canadian Arctic.

**Trefor B. Reynoldson, Ph.D.**, is a Research Associate at Acadia University's Centre for Estuarine Research. He is also the Coordinator of the North American Benthological Society's (NABS) Taxonomic Certification Program, developed by NABS at the request of the USEPA, USGS, and Environment Canada to provide quality assurance support to bioassessment studies in North America. As a benthic invertebrate ecologist and sediment toxicologist, he spent 18 years at Environment Canada's National Water Research Institute, where he developed improved techniques for using benthic invertebrate assemblages in diagnostic environmental assessment protocols. His expertise lies in the application of multivariate statistical methods to analysis of invertebrate community structure data, and to linking effects at the community level to organism (e.g. survival, growth, reproduction) and sub-organismal (e.g., porphyrin, metallothionein) levels in benthic macroinvertebrates. He has also worked in developing numeric biological criteria for both invertebrate communities and individual invertebrate species.

### **3. Review Process**

#### ***3.1. Objectives for the Review***

Objectives for the review were established in December 2004. The GVRD's overall objectives for this review are:

- 
1. To assess the need to strengthen methodologies for sampling, analysis, and data handling;
  2. To understand what is being done well and where improvements might be made;
  3. To look for ways of making the monitoring more cost-efficient; and
  4. To make other recommendations for a balanced, scientifically sound, environmental monitoring program design that addresses current management needs and critical uncertainties.

More specifically, the review addresses four questions:

5. Can technical merit be improved, and how?
6. Can simplifications be made?
7. Can cost-effectiveness be improved?
8. Are there critical program gaps?

The objectives were expanded into a series of 44 questions. These questions and the five major themes of the review create the structure for the rest of this report.

### **3.1.1. Plume Dispersion Modelling**

Two studies, effluent dispersion and solids deposition modelling, were undertaken during Cycle 3 to improve knowledge about the fate of fine particles discharged with the wastewater. These studies have helped define the geographic boundaries of the monitoring area and established the location of sampling stations.

Specific questions considered were:

1. Did the UM and C3 models provide good estimates for effluent plume trapping, dispersion, and dilution?
2. Do the regular sampling stations likely include the zone most impacted by particles from the wastewater plume and a gradient in each direction?
3. Is the sampling grid large enough to capture the zone significantly affected by the discharge?
4. Are the same sampling locations adequate for Cycle 4?

### **3.1.2. Sediment Chemistry and Microbiology**

The GVRD's purposes in monitoring sediment quality were:

- *To compare sediment contaminant concentrations with relevant sediment quality values (SQVs), as well as background and historical values;*
- *To determine whether, or to what extent, effluents and in particular effluent solids affect the local sediment quality;*
- *To evaluate influences of confounding factors in a multi-source discharge environment.*

Review of the sediment chemistry task focused on the list of chemical variables, the methodologies for sampling and analysis, and on conclusions drawn in reports for the annual surveys from 2000 to 2004.

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Specific questions considered were:

5. Should changes be made to the variable list for sediment chemistry in Cycle 4?
6. Can some variables measured in Cycle 3 be omitted with justification, or measured at reduced frequency?
7. Can sediment DO be measured directly, reliably and for what cost?
8. Should the sampling QA/QC procedures be changed?
9. Should the analytical QA/QC procedures be changed?
10. Were the analytical methodologies good enough for this type of work?
11. Were levels of quantitation low enough to allow comparisons with sediment quality values?
12. Did the sampling design permit sound conclusions to be drawn about the role of the wastewater discharge as it affected the concentrations measured?
13. Were the data handling and other interpretative procedures the most appropriate to achieve objectives?
14. Did the information gained from the one-time study of stations on the extra lateral lines sampled in 2003 justify sampling them again?
15. Should changes be made to the overall monitoring protocol for sediment quality assessment in Cycle 4?

### **3.1.3. Sediment Benthos and Epibenthos**

The benthic community is monitored to provide an early warning of biological effects potentially due to the discharge.

The review focused on methodologies, including taxonomic identification, and data analysis and interpretation. Methodologies were generally consistent throughout the period, but a change in the taxonomic contractor between 2000 and 2001 introduced anomalies discussed in the annual reports.

Specific questions considered were:

16. Do you agree that the gradient sampling design is appropriate for this work?
17. Has the gradient sampling design spanned an appropriate range of potential habitat effects?
18. Should the on-board sampling and screening procedures be changed for Cycle 4?
19. Did the taxonomic procedures, including QA/QC, meet scientific standards for accuracy and consistency?
20. Could the program legitimately save money by doing identifications to the family level? If so, how would the loss of species information affect interpretation of the data?
21. Have data handling and interpretation procedures made best use of the data?
22. Should data handling and interpretation procedures be changed?
23. Would a direct measure of sediment DO enhance data interpretation?
24. Do you agree that the data from Cycle 3 support delineation of the sampling area into five zones?

- 
25. Should monitoring the benthos continue to be done at all stations every year or should the number of stations be abbreviated, as suggested in the previous cycle?
  26. Does the information gained from the one-time study of stations on the extra lateral lines sampled in 2003 justify sampling them again?
  27. Was the monitoring protocol for benthos adequate to assess and measure environmental conditions and the health of the benthic community?
  28. Was the monitoring protocol adequate to observe, record, and predict changes and trends in the benthic community?

### **3.1.4. Adult Fish Survey**

Bioaccumulation, the presence of PAH metabolites in fish, and tissue histopathological effects continued to be the focus of upper trophic level monitoring in Cycle 3. The review looked at methodologies, QA/QC procedures, and data interpretation methodology.

Specific questions addressed were:

29. Should any change be made in the species sampled in Cycle 4?
30. Should other changes be made to the sampling design?
31. Should changes be made to fish handling and sample collection procedures?
32. Were the QA/QC measures taken for sampling and histopathology adequate?
33. Should changes be made in use of the Health Assessment Index or Condition Index?
34. Should an assessment of fish health in Cycle 4 be done in the same manner?
35. Should changes be made to the benchmarks (e.g., tissue quality guideline values) used for comparison of tissue contaminant concentrations?
36. At what frequency should fish health be assessed in Cycle 4?

### **3.1.5. Integration**

The annual monitoring reports have assembled the various lines of evidence into a picture showing a gradient of effects due to the wastewater plume. The reports also discussed other factors and disturbances that might have influenced results. This component of the review addressed the integration of results from the different monitoring themes. Weight-of-evidence approaches to data interpretation have become more established since the last review, and the review paid special attention to this area.

Specific questions to be addressed were:

37. Have data management protocols been adequate to ensure data access, data integrity, data analysis and preservation?
38. Have data handling and statistical procedures to integrate the benthos and sediment chemistry components made best use of the data?
39. Has integration of the data based on sediment chemistry and the benthos produced an accurate picture of the gradient of effects?
40. Would data integration benefit from using a more formal weight-of-evidence approach (e.g., Grapentine *et al.*, 2002)?
41. Are there other ways in which the overall picture of effects could be improved based on the existing monitoring protocol?

- 
42. Was the overall monitoring protocol adequate to assess and measure environmental conditions and the health of ecosystems?
  43. Was the overall monitoring protocol adequate to observe, record, and predict environmental changes and trends?
  44. What newly emerging issues could be considered?

### **3.2. Documentation Reviewed**

The reports produced during Cycle 3 were the main basis of review:

- The special study of effluent dispersion and particle settling undertaken in 1999 by Seaconsult Marine Research Ltd. (Hodgins and Hodgins, 1999).
- The special study into the fate of particles dispersed outside the monitoring area, undertaken in 2004 by Seaconsult Marine Research (Hodgins, 2004).
- The annual monitoring report for 2000, produced by EVS Environment Consultants (McPherson *et al.*, 2001).
- The annual monitoring report for 2001, produced in two volumes (three books) by EVS Environment Consultants (Bailey *et al.*, 2003).
- The annual monitoring report for 2002, produced by EVS Environment Consultants (McPherson *et al.*, 2003).
- The annual monitoring report for 2003, produced in two volumes by EVS Environment Consultants (McPherson *et al.*, 2004).
- The annual monitoring report for 2004, produced in two volumes by EVS Environment Consultants (McPherson *et al.*, 2005). The version reviewed was the February, 2005 draft.

Three additional documents were sent to the reviewers for information purposes only:

- Pre-discharge benthic infaunal information, taken from the feasibility study reported in November, 1983 (S&S Consultants, 1983).
- The review conducted by 2WE Associates at the end of Cycle 2 (Wilson *et al.*, 1999).
- The District's Cautions, Warnings and Triggers report (GVRD, 2004), developed for the Liquid Waste Management Plan. This document has summaries of the state of knowledge obtained from the environmental monitoring program.

The material was given to reviewers in paper copies and as electronic files. A reading guide was also provided to direct reviewers to relevant sections of the documentation. The review material is included on the accompanying CD (Appendix B), which also contains files in Excel format for all the monitoring data collected during Cycle 3.

### **3.3. Workshop**

The reviewers met in Richmond, BC on May 3-4, 2005. A preliminary session on May 3 discussed administrative arrangements and technical questions related to the material. Attendance was limited to the review team, Mr. Stan Bertold of the GVRD, as well as Mr. Bob Wilson and Dr. John Garrett of 2WE Associates. The agenda is shown in Appendix B.

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The main workshop began with two introductory presentations by Dr. Albert van Roodselaar and Mr. Stan Bertold of the GVRD, which were followed by presentations from Ms. Cathy McPherson and Dr. Peter Chapman of EVS Environment Consultants, the prime contractor for Cycle 3, and its key subcontractors. Each major theme of the review was the subject of a presentation. The agenda is shown in Appendix B, and copies of the PowerPoint slides for each presentation are included on the accompanying CD.

Reviewers had side conversations and meetings with the presenters during the workshop and afterwards.

### **3.4. Conference Call**

A two-hour conference call with all the reviewers, Mr. Wilson and Mr. Bertold was held on June 13. Reviewers outlined their preliminary findings, asking questions and discussing the final report.

### **3.5. Report Assembly**

Each reviewer provided a draft set of findings and recommendations, on which Mr. Wilson provided questions and feedback. The final set of findings and recommendations has been integrated below in Section 4 and Section 5, respectively. The GVRD requested that the report be provided in the reviewers' own words to the extent possible, with minor editing for style, uniformity, or synthesis.

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## 4. Responses to Questions

### 4.1. Program Themes

Responsibility for each theme was assigned to individual reviewers (Table 2 above). The comments of individual reviewers on secondary topics are also incorporated in the discussion and recommendations.

### 4.2. Plume Dispersion Modelling

From a sediment perspective, the sampling strategy laid out in the Cycle 3 review of the Iona monitoring program has been successful. The GVRD is to be commended on the quality of the work carried out and their apparent commitment to sound scientific principles. The general trend of particle dispersion has been confirmed by sampling along the 80-m isobath. Discrepancies between the predicted and actual sediment deposition patterns can largely be explained by the failure of the model to include resuspension and floc breakup.

Further refinements to the particle deposition model would be of limited benefit. It would be highly desirable, however, to determine the ultimate fate of the particulate discharge. To investigate the export from the immediate area either down slope or to the north, the amount of material bound in flocs and floc settling velocity will need to be measured *in situ*.

The present monitoring program should be continued in Cycle 4, with the addition of cross-shelf transects to determine the E-W extent of the deposit, and coring to determine accumulation rates. All data, including data from Cycles 1 and 2, should be assembled in a GIS database to facilitate analysis of long-term trends.

- *Did the UM and C3 models provide good estimates for effluent plume trapping, dispersion, and dilution?*

The **UM** model provides sufficiently accurate predictions of the behaviour of the Iona plume. This model is similar to other plume dispersion models and the results are well supported by the dye study. Results from the monitoring program also support the predicted general drift of the plume. However, the model is unable to handle flows parallel to the outfall. Since tidal flow is a major component in the model, it can be expected that flow will be parallel to the outfall for some period of the tidal cycle. The physics of plume dispersion is otherwise well constrained. There would likely be little or no benefit realized from applying other plume dispersion models to the Iona outfall.

The **C3** model misses an important component of the tidal flow (see figures 5.4 and 5.5 in the 1999 modelling report). While the timing between the predicted flow and the measured flow are generally reasonable, there are problems with magnitude and phase in the figures that should be explored in greater detail. One possible explanation is acceleration along the shelf edge shedding eddies. Current meter data in the region of the outfall seems to be limited. Longer and more detailed records using ADCPs could

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resolve this issue and provide better calibration data for the model. The predicted drift pattern of the plume is confirmed by the results of the monitoring program.

The **TDP** model does not appear to be a good predictor of sedimentation. The model places sediment at depths of ~60m, whereas data from the monitoring program and the study of silver by Gordon (1997) suggest that the locus of deposition is between 80 m and 100 m. This discrepancy is likely due to the assumption in the model that there is no resuspension, and the model's inability to parameterize flocculation dynamics. Resuspension of material would be expected to increase with decreasing depth, resulting in dispersion or incorporation into the seabed further offshore. To correctly predict the behaviour of flocculated sediment, increasing bottom shear stress with decreasing depth must be accounted for in the model. Floc break-up has been shown to occur when stresses exceed ~0.1 Pa (Hill *et al.*, 2001). Harris (2004) incorporated a floc break up component into their sediment transport model for the Western Adriatic, successfully recreating sediment deposition patterns in a very complex environment. Estimating bottom stress within the model would help identify regions where floc deposition will be limited by break-up. A more detailed analysis of the bed sediment grain size in the region where predicted and actual accumulation rates differ could also be used to explain the discrepancy. Bottom sediments record within their grain size distributions an integrated record of the processes that formed them (Milligan and Loring 1997). Using grain size, the amount of floc-settled material can be estimated (Milligan and Loring, 1997; Curran *et al.*, 2004). In non-cohesive sediments, bottom stress can also be estimated from maximal grain size (Wiberg and Smith, 1989). Carrying out such an analysis could help explain the discrepancy between predicted and actual sedimentation patterns.

The model makes assumptions about the amount of material bound in flocs or floc fraction ( $f$ ) in the discharge and the settling velocity of the flocs formed ( $w_f$ ) (Fox *et al.*, 2004; Curran *et al.*, 2004). A value of  $1 \text{ mm}\cdot\text{s}^{-1}$  for  $w_f$  is a reasonable approximation (Hill *et al.*, 2001) but  $f$  can vary significantly. A sensitivity analysis of  $f$  and  $w_f$  should be carried out. In predicting the dispersion/dilution of particle-bound contaminants, under or overestimating floc fraction and settling velocity could have a significant impact. Data from the sediment monitoring program, including that collected before the 1999 review, could be used to validate the model results with the different parameter values. Technology also exists now that can measure  $f$  and  $w_f$  *in situ* (Mikkelsen *et al.*, 2004).

While improving the sediment dispersion model would be beneficial, it is not clear if it would alter the present monitoring strategy. For setting station locations, the general drift pattern for the discharged particulate material is sufficient. Monitoring performs a more useful function than modelling at this stage, since it provides data on what is actually occurring. Cross-shelf sampling should be added to the monitoring program on occasion to ensure that material is not accumulating in significant amounts inside the 60m isobath.

The question has been raised as to the ultimate fate of the material discharged from the Iona outfall. To address this, a more sophisticated model that includes floc dynamics is essential. Better parameterization of  $w_f$ ,  $f$ , and the physics of the area will be required.

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- *Do the regular sampling stations likely include the zone most impacted by particles from the wastewater plume and a gradient in each direction?*

Based on data collected in the last cycle, sampling along the 80-m contour appears to be a reasonable way of evaluating the accumulation of material from the Iona outfall. At this time, values appear to fall to background within the sampling domain. Data from the 2003 cross-shelf transects support the use of the 80-m contour for most contaminants, but there is evidence that some components of the waste stream are moving offshore and accumulating near the 100 m isobath. The landward and seaward extent of the impact zone should be established using cross-shelf transects. The northern boundary of the sampling grid is compromised by the effect of sediment from the Fraser River. The sharp increase in grain size indicates that this region receives material from the Fraser plume during some period of the year. Normalization to remove grain size effects could be useful for determining if these stations are receiving material from the outfall. Results from the southern end of the transect suggest that processes there make these stations poor representatives of background conditions. This point is further discussed in later sections.

There is some question as to the source of the coarse material located near the outfall diffusers. One possibility is that this material is from the outfall. Another possible cause is increased bottom stress due to flow over the diffusers. This would mean that the material is from a natural source and is simply a flow feature. The coarse material is only an issue if its source is the outfall, as it would suggest that there are times when the treatment system may not provide a long enough residence time in the settling tanks.

- *Is the sampling grid large enough to capture the zone significantly affected by the discharge?*

With the exception of the most northerly and southerly stations, the zone of impact is well bounded by the stations being occupied. However, cross-shelf transects are required to establish the extent of down-slope movement of material. It is likely that some of this movement occurs after the initial deposition from the plume. Possible causes are current shear along the shelf edge and breaking internal waves. ADCP moorings could be used to resolve this issue.

- *Are the same sampling locations adequate for Cycle 4?*

At this stage it is critical that the sampling strategy established in Cycle 3 continues so a long-term record for the Iona outfall can be established. The changing of station locations in Cycle 3 effectively reset the monitoring clock to zero, placing serious restrictions on future evaluation of long-term changes in the environment. With the possible exception of stations in the “confounded effects” zone towards the southern end of the transect, any changes to the sampling strategy in Cycle 4 should be made by adding to the present sample locations.

While the strategy of sampling along the 80-m isobath successfully captures the general trend of particle dispersion, there is sufficient evidence of cross-shelf transport to warrant a study to determine the full extent of the impact zone. This study should be conducted at least once during the next cycle.

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Data provided in the reports show that the pattern and rate of deposition from the plume has remained relatively constant over the last cycle. The consistency in the values suggests that less frequent sampling could be considered. Decreasing the frequency of N-S sampling could be offset by the additional cost of carrying out an E-W sampling investigation.

The homogeneity of the bottom should be evaluated. It appears that considerable time and effort are expended to take samples exactly at the station locations. On the one hand, returning to the same place is the essence of good time-series monitoring. However, the data suggest that the tolerance for sample site acceptance, 5 m, is too restrictive considering the scale of real spatial variability and the questions being asked. While a wonderful tool, DGPS has forced field operators to concentrate too much on being in exactly the right place rather than knowing where the sample was taken.

### **4.3. Sediment Chemistry and Microbiology**

Other than for the body burden analysis of demersal biota, the chemical and microbiological component of Cycle 3 was based primarily on sediment analyses. Surface sediments were collected annually at 16 stations along a north-south transect on the 80-m depth contour. In 2003, sediment samples were also collected on two short east-west transects crossing the main transect near the outfall and at the southernmost station. All samples were collected with a Van Veen grab, with three replicate samples per station being composited for analysis. The chemicals routinely measured include heavy metals and one metalloid (Cd, Cr, Cu, Pb, Hg, Ni, Ag, Zn; As), organic contaminants (chlorobenzenes, PCBs, organochlorine pesticides, PAHs, nonylphenol, phthalate esters and selected estradiols and sterols), acid volatile sulfide (AVS), and organic carbon and nitrogen. The analytical protocols and QA/QC procedure are generally adequate – although they could somewhat be improved and described better. The bacteria counted were fecal coliforms.

The results for the last five years have been very consistent. They show that counts of fecal coliforms and concentrations of many chemicals (e.g., Ag, coprostanol, Cd and nonylphenol) are higher in sediments collected within a distance of 5 km from the outfall (on the North side), suggesting that the outfall is a point source of contaminants. It should be noted that Ag is generally recognized to be a tracer of municipal effluents (e.g. Sanudo-Wilhelmy and Flegal, 1992). However, the concentrations of many other chemicals, including PAHs and PCBs, are not significantly higher in these same sediments. As reported in the annual reports, the sedimentary concentrations of chemicals do not generally exceed the sediment quality guidelines for probable biological effects, except for As, Ni, and Cu (the measured concentrations of which are, however, probably close to natural levels). PAHs also exceed the guidelines in some cases, probably due to the Fraser River and not the Iona outfall.

Overall, the chemical and microbiological component has been very well done. This evaluation recognises that the program's leaders have realised some limitations related

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to routine monitoring with grab samples and decided to initiate complementary activities for sediment cores and persistent organics in collaboration with experts in the field.

- *Should changes be made to the variable list for sediment chemistry in Cycle 4?*

The current list includes the most important contaminant metals (Hg, Cd, Pb, Zn, Ag), classical persistent organic pollutants (PCBs, organochlorine pesticides, PAHs), and less frequently measured compounds such as nonylphenol, which can act as an endocrine disruptor. Such monitoring should be maintained. Although the Iona outfall is unlikely to be the only source of these contaminants, supporting data are needed. The consultants have suggested that some trace elements (e.g. As, Ni, Cr) could be excluded from the list. Removing some of the metals would not be a problem, but why those and not others? Is it because concentrations of these metals exceed sediment quality guidelines at a few stations? This would not be a good reason to stop measuring these elements. It would be better to make the case that the present guidelines may be inadequate for the area and should be improved.

The inclusion of non-classical organic contaminants, such as pharmaceutical compounds, which potentially affect the reproductive function of aquatic organisms, would be warranted. While their inclusion would be proactive, there are serious questions as to which compounds should be monitored (they number in the thousands) and by which analytical method and QA/QC procedure. These methods and procedures are not yet standardized. These non-classical organic compounds, especially pharmaceutical products, might represent a real threat to the environment but further research is needed before they can be routinely determined in a monitoring program, as recommended below.

- *Can some variables measured in Cycle 3 be omitted with justifications, or measured at reduced frequency?*

There is little point in Cycle 4 repeating every year exactly the same analyses at exactly the same sites because the results do not vary significantly. The GVRD's money would be better invested in extending the study area somewhat. One potential benefit would be to improve understanding of dispersion outside the 80-m depth contour. Another very interesting addition to the current program would be to analyze sediment cores from stations where most of the deposition occurs, as recommended below.

- 7) *Can sediment DO be measured directly, reliably and at about what cost?*

There is no reason to measure dissolved oxygen in sediment pore water, especially when collected with a Van Veen grab. The depth of oxygen penetration in coastal sediments is usually less than 1 cm. This is likely the case along the 80-m transect because AVS has been detected at all stations (AVS being the product of sulfate reduction, which occurs only in anoxic conditions).

- 8) *Should the sampling QA-QC procedures be changed?*

The Iona dataset is very extensive, so it is important to have detailed protocols for data management. Excellent details are collected on sampling site (boat log and GPS

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location), with excellent collection details (field conditions, sample characteristics). As well, chain-of-custody information is documented so that any sampling or analytical irregularities can be checked out.

A Van Veen grab is an efficient sampling device. However, it usually disturbs the sediment surface, so that one can never be sure that the sub-samples used for analysis (i.e. the first 2 cm) are actually surface sediments. This could be demonstrated by occasionally comparing the analytical results of a few grab samples with the upper 2 cm of cores.

It would be useful to know the time needed for a 2-cm layer of sediments to accumulate. Published estimates in the range of 0.85 to 2.6 cm per year (Johannessen *et al.*, 2005) suggest perhaps one to two years. However, the mixing rate in the upper sediment exceeds the deposition rate, further raising the question of why the same stations should be sampled every year.

The emphasis of the present program is on particulate contaminants, but the wastewater treatment plant also releases dissolved contaminants. Although many contaminants are particle reactive, the dissolved forms, especially for metals, most likely are the most bioavailable fraction (e.g., Sanudo-Wilhelmy *et al.*, 2004). The water column should occasionally be monitored for dissolved forms.

Techniques and their detection limits do change over time. For the trace metal determinations, there are different values reported when two techniques are used to determine the same element. This is evident when comparing total metal analyses such as copper and zinc that were analyzed by both flame atomic absorption and by full scan ICP where the two sets of values can vary by more than 50% for these elements in the same sample. Which value is considered to be more accurate and which is the value that one compares to the relevant criteria in terms of the sediment quality values. Or do they use the average of the two values? This is not clear in the reports.

9) *Should the analytical QA-QC procedures be changed?*

The analytical laboratories have understood the importance of evaluating their performance. Precision has been determined through replicate analyses, and accuracy through analysis of standard reference materials when available. This level of rigour must be maintained in the future.

Metals can now be routinely determined in sediments with precision and accuracy of about 5-10%. The acceptance criteria for metals (65% for precision and 30-120% for accuracy) are pretty loose, and it would be better for the laboratory to report the actual precision and accuracy than to say that these criteria were met. The wide range for accuracy is a function of the method used to digest the sediments (see Question 10).

*Comment provided by Ken Hall, integrator:* The analytical laboratories have very good records of performance and lots of experience analyzing environmental samples for trace contaminants. Quality assurance/quality control (QA/QC) protocols are generally extensive and adequate information is provided in the annual reports on the reproducibility of the analyses and accuracy of the methods. Generally, enough

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analytical details on the methodology are provided so that any future changes in the methodology can be traced and impacts on the analytical data evaluated.

10) *Were the analytical methodologies good enough for this type of work?*

Metal analyses have been performed by flame AAS and ICP-OES. Detection of elements by ICP-OES is not as specific as AAS, with ICP-OES usually being less sensitive than AAS with a graphite furnace. Cd and Ag, which are at very low concentrations in sediments, were measured by AAS using a flame rather than a graphite furnace.

Digestion of sediments for metal analysis was not total since it was not done with hydrofluoric acid. A complete digestion, however, would improve the analytical accuracy, since concentrations in the standard reference sediments are given for total metals. This is especially true for metals such as Al, Zn, and Cr, an important fraction of which is contained in the aluminosilicate lattice; complete dissolution of aluminosilicate requires hydrofluoric acid. This point is made just for consideration of improving the precision and accuracy of metal results for standard reference sediments, because moving to a total digestion with HF would introduce a major discontinuity into the overall data set.

The problem with using a standard soil or sediment to determine accuracy is that the reported metal values are total. Most environmental projects are uninterested in metals bound to the silicate structure of the minerals so, as with the Iona program, they use nitric acid or *aqua regia* digestion. With these acids, the measurable concentrations are lower. What we really need is for the standard sediment trace metal values to be developed using a variety of digestion methods, so that data from the proper acid combination are available for comparison. Though such an activity is beyond the GVRD's mandate, an occasion could be sought to make this point to the NRC, who are responsible for the standards.

Analytical results for metals determined on the same sample by flame atomic absorption and by ICP-OES can vary by more than 50%. The GVRD should consider doing away with the ICP-OES analyses, focusing instead on a few more important trace metals and using the more sensitive AA techniques.

*Comment provided by Ken Hall, integrator:* Good analytical details and easy-to-follow flow charts have been provided for the trace organic methods. However, a few concerns related to data reporting should be cleared up for Cycle 4. The analytical methods incorporate surrogate determination to evaluate method recovery. For some groups of compounds (e.g., chlorinated hydrocarbons in 2004) it was stated that concentrations were not corrected for recovery. Since some surrogate recoveries are in the range of 30-50%, how has the decision been made whether to correct for recovery or not? Correction can make a considerable difference in the values reported. For example, nonylphenol recovery varies from 30-55%. The organic lab also provides sample-specific detection limits for each sediment sample. These values can be quite different even when the sediment characteristics are quite similar. Is this just analytical variability at these very low levels?

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11) *Were levels of quantification low enough to allow comparisons with sediment quality values?*

The levels of quantification reported annually appear to be good enough. However, as just said, a graphite furnace should have been used rather than a flame to measure Cd and Ag by atomic absorption spectroscopy. It would have lowered the detection limit and increased the analytical precision.

12) *Did the sampling design permit sound conclusions to be drawn about the role of the wastewater discharge as it affected the concentrations measured?*

The idea behind annual sampling is to determine the recent deposition of contaminants from the Iona outfall in the study area and, from that, to determine changes. Sediment sampling with the Van Veen grab unfortunately limits the capacity to do so, since this technique tends to disturb the sediment structure and to homogenize the samples. Biological mixing also tends to smear concentrations in the biologically active zone, perhaps the upper 10 cm. One could hypothesize that this is why the results are more or less constant over the years.

13) *Were the data handling and other interpretative procedures the most appropriate to achieve objectives?*

It would be useful to normalize the trace element concentrations with total Al (Windom *et al.*, 1989) or total Li (Loring, 1990) to take into account the effect of grain size. The natural concentration of metals is usually higher in fine-grained sediments. Geochemical normalization of sediment concentrations for grain size is superior to granulometric normalization because the geochemical normalization can also compensate for mineralogical changes (Loring, 1991). Various elements have been used for geochemical normalization of heavy metal variability, but for high latitude areas dominated by glaciation or other physical weathering, lithium normalization is preferred (Loring, 1991). In the reports, background values of Zn and Cu are said to be naturally high. Normalization with Li could be used to determine if concentrations in the Iona sediments are at natural background levels or if they are enriched beyond CCME levels (Yeats *et al.*, 2005).

The statistical treatment of the results needs not have been so sophisticated, especially in view of the way the samples have been collected (Van Veen grab) and the relatively low and variable recovery of many organic analytes (though it should be noted that analytical recovery is within generally accepted limits). These limitations affect the capacity to draw solid conclusions on temporal variations, especially over a period as short as 5 years.

14) *Did the information gained from the one-time study of stations on the extra lateral lines sampled in 2003 justify sampling them again?*

Yes, it is important to extend the study area outside the 80-m depth contour. Extra lateral lines might be added occasionally.

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15) *Should changes be made to the overall monitoring protocols for sediment quality assessment in Cycle 4?*

As already pointed out, sampling surface sediments with the Van Veen grab is imprecise. Collecting sediment cores would provide more representative samples of the sediment surface and add a completely new dimension to the program. Determining <sup>210</sup>Pb and <sup>137</sup>Cs in sediment cores (these measurements are not expensive relative to most others) would permit determining the sedimentation rate, the thickness of the bioturbated layer, and the intensity of biomixing. The sedimentation rate and dated, undisturbed samples are critical to estimating contaminant fluxes and the fraction of the Iona outfall contaminants deposited in the study area.

#### **4.4. Benthic Community**

The benthos monitoring theme has developed extraordinarily well over the years, as requirements for information and knowledge of how to obtain it have grown. The program has been well designed and implemented. As a result, the quality of the benthic data obtained from the past 5-year cycle of monitoring is outstanding. Methods are generally sound, quality control is good, and data analysis and interpretation generally are sound. GVRD now knows the basics of the benthic effects and their distribution along the coast and offshore. The annual surveys show repeated patterns, suggesting that the results obtained and conclusions reached are valid. However, some refinement of details is needed, as outlined in this section.

16) *Do you agree that the gradient sampling design is appropriate for this work?*

A qualified yes; it would be highly desirable to have at least one extensive survey to define lateral movement of the plume, and data on very, very far field reference sites. In fact once the plume delineation was complete, and if distinct zones can be identified, routine monitoring could potentially be cut back to one or two sites within a zone, with less frequent extensive sampling (perhaps once per cycle). However, such a decision to change the structure of the program would require extensive discussion.

17) *Has the gradient sampling design spanned an appropriate range of potential habitat effects?*

Yes, other than determining the extent of lateral dispersion.

18) *Should the on-board sampling and screening procedures be changed for Cycle 4?*

Absolutely no. One of the excellent components of this program is the consistency of methods.

19) *Did the taxonomic procedures, including QA/QC, meet scientific standards for accuracy and consistency?*

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Yes, and these procedures are a great strength of the program. The report describes the procedures in detail, which is important in assuring technical readers, and hence the general public, that the work has been undertaken to the latest professional standards. Both the procedures used and the reported descriptions set standards of best practice for others to follow.

As with the fieldwork, the sample processing, taxa identifications and enumeration meet current best practice for obtaining accurate quantitative data, and for in-house and independent quality control of the procedures. In particular, while samples are being processed they are identified by a laboratory code rather than a field number. This ensures that sorters do not know the location of each sample, hence cannot be biased to produce expected results. This is important for statistical comparisons between samples and between surveys, and to provide assurance that the data and conclusions are valid.

The current practice of enumerating juvenile, intermediate, and adult specimens can provide additional information about the health of the organisms e.g. growth and an indicator of breeding success. In the last four years, the benthic data sorting has differentiated these three size classes. However, the data analysis currently makes very little use of the size distributions and how they might relate to reproductive success or recruitment into a possibly changing habitat. These data may become increasingly useful in the future.

*Comment provided by Ken Hall, integrator:* The benthic invertebrate data are backed up by excellent field notes, debris description, excellent sorting efficiency, and by a large body of taxonomic reference literature. The data sheets provide complete information on family and species, biomass, and individual numbers. Code identification numbers are used to track the organisms. For future data collation and comparison it might be useful to code all the previous benthic data, since doing so would make computer retrieval and statistical comparisons of temporal and spatial data easier.

*20) Could the program legitimately save money by doing identifications to the family level? If so, how would the loss of species information affect interpretation of the data?*

There are currently opposing viewpoints on this, both based on appropriate research and publications. Also, GVRD's objectives are different from those at the localities previously exposed to this research. Finally this issue cannot be considered on its own, since there have been suggestions to reduce sampling frequency and replication also (See Questions 25, 26, and Section 5). Changing the lowest level of identification to the family level might save money but risk losing considerable biological information that would have been obtained if the current procedures were maintained. However, this is a postulation only and needs further examination. (A very preliminary analysis was conducted which suggested that family level was equal or better at detecting difference between exposed and reference conditions – see Recommendation 18 in Section 5, Pages 44-48).

Analysis should be conducted to establish if the ability to detect change is affected by taxonomic level. If there is little difference in cost, identification to species level should continue to be done regardless, although data analysis may be more appropriately

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conducted at the higher taxonomic level. There may be little cost saving and in this case the recommendation would be to continue to identify to the lowest level. Data analysis, however, may still be conducted at the higher level as often there is a lower signal to noise ratio at that level and thus difference between the exposed and reference conditions is easier to detect, particularly with multivariate methods.

Alternatively, conducting identification to the family level only could be pursued if there is a major cost savings which would allow the savings to be applied to other components of the study (e.g., more sites, or special studies).

*21) Have data handling and interpretation procedures made best use of the data?*

Generally yes. However one of the two reviewers for the benthic component indicated a preference for using multivariate analysis of community data because the data appear to be more suited to multivariate analysis. There is potential for loss of information if data analysis is based on reducing data to metrics. Hence, a greater reliance should be put on multivariate analyses. Use of methods such as ordination and principle axis correlation, cluster analysis and ANOSIM or correspondence analysis could help identify patterns and relationships between the community and the habitat. For example, temporal trends can be observed from the trajectory in ordination space of exposed station relative to reference sites.

*22) Should data handling and interpretation procedures be changed?*

During the next 5-year cycle it is to be expected that there will be continuing advances in appropriate statistical analyses of biodiversity data. GVRD's benthic ecologist should be given the option of adding to the analyses when appropriate.

*23) Would a direct measure of sediment DO enhance data interpretation?*

No. Sediment dissolved oxygen (DO) levels are not good indicators of biological activity. Some species are adapted to living in an anoxic zone below a thin oxygenated zone at the interface by means of tubes kept oxygenated by fanning actions of one sort or another. They feed at the interface (suspension feeders), but can withdraw into their tubes (and keep them oxygenated) when predators pass by.

*24) Do you agree that the data from Cycle 3 support delineation of the sampling area into five zones?*

Yes, along the 80-m depth contour.

*25) Should monitoring the benthos continue to be done at all stations every year, or should the number of stations be abbreviated as suggested in the previous cycle?*

Initial review does indicate that a reduced pattern and/or frequency may be considered (see program recommendations in Section 5).

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26) *Does the information gained from the one-time study of stations on the extra lateral lines sampled in 2003 justify sampling them again?*

Yes. A one time effort should be employed to define the lateral extent of community response, and then reduced sampling effort may be considered.

27) *Was the monitoring protocol for benthos adequate to assess and measure environmental conditions and the health of the benthic community?*

Yes, even more than adequate. In fact, there are possibly sufficient data to construct a RIVPACS-type predictive model of community response that would provide a probabilistic determination of taxonomic composition (see the examples in Section 5).

28) *Was the monitoring protocol adequate to observe, record, and predict changes and trends in the benthic community?*

Yes. However some changes in survey design and analysis would improve understanding. Such changes should not be implemented without cautious review of not just the benefits but also the potential information losses.

#### **4.5. Adult Fish Survey**

29) *Should any change be made in the species sampled in Cycle 4?*

The current sentinel species for the demersal biota/adult fish monitoring are English sole and Dungeness crab. These species were chosen originally because they met a number of criteria for good target species (i.e. in close contact with sediments or near the top of the food chain, easily collected, distributed throughout the sampling area, have limited migration patterns, appropriate tissues available for monitoring bioaccumulation, or potential risks associated with human consumption). Both species are also used as sentinels in other regional monitoring programs in Puget Sound and Georgia Basin (e.g., PSAMP). Continuing with the same species will add to the database for trend monitoring. For these reasons, the two sentinel species used in Cycle 3 should be retained for Cycle 4.

However, additional species might be useful for two reasons:

- To collect data on contaminant concentrations in species targeted by active sports or commercial fisheries, to evaluate their safety for human consumption. This would be particularly important if some of these fish were higher in body fat content than English sole, as they would be likely to accumulate higher concentrations of contaminants.
- To get more information on the extent of exposure through pathways other than sediments and benthos. For example, there appears to be some concern about exposure from suspended material in the water column, or through the planktonic food chain. A pelagic species could be added to monitor exposure through this pathway. Pelagic species occurring in the Puget Sound/Georgia Basin include

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Pacific herring, walleye pollock, smelt, shiner perch and others. The Puget Sound Ambient Monitoring Program (PSAMP) uses Pacific herring as a representative fish for this habitat and trophic level, but it would be less appropriate for monitoring a defined site such as the Iona outfall.

The importance of adding additional species would depend on whether they were already being examined in other ambient monitoring programs. If so, it wouldn't be necessary to add them to the core program.

Herring might be appropriate, as they are used in Puget Sound. In the PSAMP studies, herring sampling is restricted to a select group of sites where they congregate for spawning, and the data show regional differences between populations from Central Puget Sound and those from other areas further from urban development. Herring would have to be sampled in the spring, just before the spawning period, which is different from the sampling time for crab and sole.

It would be good to add a pelagic, planktivorous fish species as part of the core program if an appropriate one could be identified. If no suitable species could be identified (i.e., one that was abundant and large enough to provide tissue samples, and showed reasonable site fidelity) GVRD could consider monitoring water column contaminants with semi-permeable membrane devices.

*30) Should other changes be made to the sampling design?*

In Cycle 3, the fish health assessment was performed in November at a near-field site encompassing stations 7-9, near the outfall, and a reference area to the south encompassing stations 15 and 16. There is little reason to alter this schedule in Cycle 4. The November sampling is advantageous, not only because larger fish appear to be more abundant at this time, but also because sole are becoming reproductively active so reproductive problems can more easily be monitored. However, the program should be expanded to include additional samples and measurements:

- The number of composite samples is fairly low (2 per sex per site), making statistical comparisons more difficult. Increasing the number of composites from two to three would be an improvement.
- Data should be normalised to a lipid-weight basis to make comparisons with other work easier.
- Consider measuring contaminant concentrations in fish stomach contents to obtain more data on what they are accumulating from local prey, and how well this correlates with contaminant body burdens and/or concentrations of contaminants in bodily fluids (e.g., bile). This would help address concerns about whether effects on the target species are really representative of contaminant concentrations around the outfall, or if there is substantial exposure from other sources. An alternative would be to conduct chemical analyses on a subset of benthic samples obtained from invertebrate community studies. These data would also be useful for analysis of benthic community data to better assess whether or not there were correlations between contaminant concentrations in benthos and changes in their abundance or distribution.

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31) *Should changes be made to fish handling and sample collection procedures?*

Fish handling and sample collection procedures are similar to standard procedures (Chapman, 1990; O'Neill *et al.*, 1995; Stehr *et al.*, 1993) for sampling English sole and other benthic fish. Sample quality might be improved by using shorter trawls (~10 minutes) and a shorter holding period for fish before they are processed. This might reduce the prevalence of lesions such as epithelial lifting in the gills that was common in English sole from all sampling sites.

32) *Were the QA/QC measures taken for sampling and histopathology adequate?*

The QA/QC measures for histopathology (blind slide reading, reading of a proportion of slides by an additional reader) are standard procedures for this type of study and should be adequate.

The QA/QC procedures for the bile and tissue chemistry analyses also look fine, with adequate replication, use of internal standards and reference materials. It would be interesting to determine if the bile metabolite analyses conducted by the GVRD match up with those conducted by other laboratories (e.g., the method of Krahn *et al.*, 1984). If this information were available, it would facilitate comparison of PAH exposure levels in the Iona outfall fish with those at other sites in the Georgia Basin and Puget Sound. Protein correction was not performed on bile samples. This isn't critical, but can be useful to adjust for variability in PAH metabolite levels associated with the feeding status of the sampled fish. If possible, it would be good to add this correction in the next round of sampling.

33) *Should changes be made in use of the Health Assessment Index or Condition Index?*

The Health Assessment Index (HAI) has been widely used in monitoring programs and environmental assessments around the country. It is inexpensive once the samples have been collected, and a valuable aspect of the Iona program. It is, however, fairly non-specific and relies heavily on gross pathology, so combining it with histopathological examination has been a good idea.

The condition indices are easy to calculate and can be quite valuable, so should be retained. Currently the condition indices are calculated using total weight. It may be preferable to use a gutted weight (i.e., weight with internal organs, stomach contents, and gonads removed). Using a gutted weight would minimize variability associated with recent feeding or stage of reproductive maturity. It would be useful to calculate liver somatic index, gonadosomatic index, and possibly spleen somatic index as well. These could be obtained as part of the current sampling protocol with very little additional effort. Hepatosomatic, or liver somatic, index is widely used as an indicator of toxicant exposure, as liver hypertrophy is a common response to toxic compounds, while changes in spleen weight have been associated with immunotoxicity. Gonadosomatic indices would be useful for comparing effects on reproductive development of fish.

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34) Should an assessment of fish health in Cycle 4 be done in the same manner?

While earlier monitoring focused primarily on preneoplastic and neoplastic lesions in liver and hepatopancreas, the Cycle 3 fish health assessment was much more comprehensive. It included histopathological examination of several organs (liver, kidney, spleen, gonads, other), as well as the gross pathological conditions and parasite occurrences monitored as part of the HAI. These additional analyses increase the likelihood of identifying effects other than neoplasia, and should be retained in Cycle 4. However, histopathological techniques alone may not be adequate to detect all potential effects on important physiological processes such as reproduction, immune function, or growth and metabolism.

For this reason, it would be useful to add additional biochemical measurements that address other potential problems at the outfall, such as exposure to xenoestrogens or other endocrine disrupting substances. This seems especially appropriate because the signature compounds found in sediments near the outfall included nonylphenol and various sterols, which are known to have estrogenic or endocrine modulating activity (Tyler *et al.*, 1998). GVRD should consider adding the following measurements to Cycle 4:

- Assess exposure to estrogenic compounds through monitoring of vitellogenin induction in male English sole. This would require collecting plasma samples from a representative number of male sole from the sampling sites (the 20 fish per site that are already being collected under the current protocol would probably be adequate). Vitellogenin could be measured using an enzyme-linked immunoassay (ELISA). An assay has been developed for English sole for application in Puget Sound (Lomax *et al.*, 2003), and antibodies and standards for this type of assay are also available commercially for some flatfish species (e.g., see [www.biosense.com](http://www.biosense.com)). It might also be possible to measure vitellin in Dungeness crab hemolymph, since assays have been developed for blue crab and some other crustaceans (Oberdoerster *et al.*, 2000; Lee and Watson, 1994), but this is more of a research activity and might only be considered if induction was found in sole.
- For sole only, consider adding other measurements of biological or biochemical effects of exposure to xenoestrogens or other endocrine disruptors. These would include concentrations of plasma reproductive steroids (17 $\beta$ -estradiol, testosterone, and 11-ketotestosterone), gonadotropins, and possibly StAR protein, an enzyme that is involved in steroid biogenesis and is quite sensitive to estrogen exposure (Stocco, 2001; Christenson and Strauss, 2001). Exposure to exogenous estrogens typically suppresses testosterone in male fish, as well as gonadotropin levels and StAR protein activity in both sexes (Harris *et al.*, 2001; Yadetie and Male, 2002; Swanson *et al.*, 2004). Plasma sex steroids could be measured easily in sole as part of the core monitoring program; especially if blood were already being collected for vitellogenin screening, but other measures would be better suited to a special study.
- Investigate the possibility of measuring alkylphenols and synthetic and natural estrogens in sole bile. Some methods have recently been developed (Gibson *et*

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*al.*, 2005; Smith and Hill, 2004), and might be applied in a pilot study or special study, for possible inclusion in future monitoring efforts.

Include a more comprehensive assessment of reproductive development in English sole, perhaps beginning with the gonad histology data that were collected in Cycle 3. In Puget Sound, at sites in Elliott Bay where vitellogenin induction has been observed in male sole, alterations in reproductive timing have also been seen in both sexes, but especially the females. These include female fish beginning to mature at earlier ages or sizes; maturation earlier in the reproductive season, including a higher proportion of vitellogenic females in the summer, when fish are typically not reproductively active; and a delay in spawning time (Lomax *et al.*, 2003). Several of these endpoints (i.e., age or size at sexual maturation, proportions of adults at different stages of gonadal development) could be easily determined in samples collected as part of routine monitoring, as well as prevalences of intersex fish, ovarian atresia, and degenerative lesions in the testes.

All of these endpoints could be measured in November, except for delay in spawning time and the early seasonal maturation seen in Elliott Bay sole, where some fish are already entering vitellogenesis in summer. However the program could evaluate differences in the proportion of sole in vitellogenesis in November, or differences in the level of gonad development. Age or size at maturation could be measured, but this would require collection of some additional female fish of younger age to be done effectively. More detailed reporting of ovarian and testicular lesions (e.g., atresia prevalences) would be applicable for November sampling as well.

A more comprehensive assessment of immune function might also be useful, as this potentially important health effect is quite sensitive to impacts of contaminants and other stressors associated with environmental degradation. A variety of industrial contaminants may cause immunosuppression (e.g., PCBs, PAH, DDTs). Studies also show that reproductive steroids have an important role in regulating immune response (Da Silva, 1999), so exposure to endocrine disrupting compounds, environmental estrogens, or other substances that alter hormone balance can affect the immune system (Law *et al.*, 2001; Burnam *et al.*, 2003).

An evaluation of immune function would best be done as a special study rather than as part of the monitoring program, as it typically requires special laboratory assays or disease challenge studies (Arkoosh *et al.*, 2005). However, some simple indicators could be incorporated into the current monitoring program to provide more assessment of immunotoxicity, e.g.:

- Evaluation of macrophage aggregate (MA) density. This technique has been used successfully in some field studies (Agius and Roberts, 2003; Fournie *et al.*, 2001) but is complicated by effects of parasites and fish age. This could be performed in conjunction with histopathological analyses now part of the monitoring program. MAs were noted in Cycle 3 but were not monitored as quantitatively as in the studies cited.

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- Leukocrit measurement. Various studies have shown declines in plasma leucocytes with exposure to immunotoxic substances (e.g., Arunkumar *et al.*, 2000), and this measurement was included as part of the original HAI (Adams *et al.*, 1993). Hematocrit could also be measured, as another indicator of health.
  - Spleen weight (splenosomatic index) has also been used as an indicator of immunotoxicity (Fatima *et al.*, 2001, Arunkumar *et al.*, 2000), and would be easily measured.

35) *Should changes be made to the benchmarks (e.g., tissue quality guideline values) used for comparison of tissue contaminant concentrations?*

Tissue guidelines for human health are probably adequate for protection of the general public from any adverse health effects associated with eating sole or crab from near the outfall. One caveat would be that English sole are a very lean fish, so concentrations of bioaccumulative contaminants in their muscle tissue may not be representative of what would be found in fish with a higher fat content. This would be better addressed by adding a second target species with higher fat content though, not by changing species. This could be partially addressed by extrapolating from lipid-adjusted contaminant concentrations in English sole to what might be found in a fish with a similar diet but higher fat content.

There might be a need to alter benchmarks for protection of specific populations that consume a larger amount of fish than the general population, if any are known.

In addition to the human health benchmarks, it would be a good idea to include benchmarks for effects on wildlife in the comparisons, as well as tissue residue guidelines for the protection of the fish themselves, when these are available. Unfortunately such guidelines have been developed for relatively few contaminants. An effort to develop more comprehensive guidelines and apply them would be a good subject for a broader national or provincial initiative, but is outside the scope of GVRD's mission.

36) *At what frequency should fish health be assessed in Cycle 4?*

With fish health assessments being conducted only every 5 years, it will be difficult to collect enough data to easily detect temporal changes. If sampling could be increased to every 3 years, or supplemented with additional data from other ambient monitoring surveys, that would be desirable, although surveys so far suggest that concentrations of most tissue contaminants, as well as lesion prevalences, are fairly low and show little temporal change.

One option would be to do an abbreviated survey focusing on exposure measurements (e.g., bile metabolites and tissue chemistry) every three years, and full histopathological workup every five years. First, however Cycle 4 should be modified to include measurement of vitellogenin induction or similar endpoints that are more specifically related to contaminants associated with the outfall (e.g., xenoestrogens, alkylphenols). If there appears to be an impact from these compounds, then frequency should be increased.

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## 4.6. Integration of Results

37) *Have data management protocols been adequate to ensure data access, data integrity, data analysis and preservation?*

The data base for monitoring the potential impacts of the Iona outfall are very extensive so it is important to have detailed protocols for data management. Excellent details are collected on sampling site (boat log and GPS location), with excellent collection details (field conditions, sample characteristics). As well, chain-of-custody information is documented so that any sampling or analytical irregularities can be checked out.

The analytical laboratories used for the analyses have very good records of performance and have lots of experience analyzing environmental samples for trace contaminants. Quality assurance/quality control (QA/QC) protocols by the laboratories are very extensive and adequate information is provided in the annual reports on the reproducibility of the analysis and accuracy of the methods. Generally, sufficient analytical details on the methodology are provided so that any future changes in the methodology can be traced and impacts on the analytical data evaluated.

Generally the precision and accuracy of trace organic analyses is better than for the trace metals. The problem with using a standard soil or sediment for accuracy determination is that the reported total metal values are usually done with HF/HCl/HNO<sub>3</sub> digestion and one has to use Teflon beakers or microwave digestion tubes for the digestion step. Very few environmental projects are interested in the metals that are bound to the silicate structure of the minerals so they either use a HNO<sub>3</sub> or an aqua regia digestion. Therefore with these acids you are bound to get lower values. What we really need is for the standard sediment trace metal values to be reported using a variety of digestion reagents so that you can pick the proper acid combination to compare your data to and come up with a relevant accuracy number.

For the trace organic analyses, good analytical details along with a flow chart are provided which is easy to follow. However, there are also a few concerns related to data reporting that need to be cleared up. The analytical methods incorporate surrogate analysis to evaluate the recovery of the techniques. For a certain group of compounds it was stated that the compounds that were quantitated (e.g., chlorinated hydrocarbons in the 2004 data) were not corrected for recovery. How is the decision made on whether to correct for recovery or not since this can make considerable difference in the values that are reported when some surrogate recoveries are in the 30-50% level? For example, nonylphenol recovery varies from 30-55%. The organic analyses also provide sample specific detection limits for each sediment sample. These values can be quite different even when the sediment characteristics are quite similar. Is this just analytical variability at these very low trace levels?

The benthic invertebrate data are backed up by excellent field notes, debris description, excellent sorting efficiency and a large body of reference literature for identification. The data sheets provide complete information on family and species biomass and individual numbers. The more recent analyses are also tracking the different life stages of organisms which are providing important recruitment information. Code identification

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numbers are now provided to track the organisms. For future data collation and comparison it might be useful to code all of the previous benthic data since it would make computer retrieval and statistical comparisons of temporal and spatial data easier.

38) *Have data handling and statistical procedures to integrate the benthos and sediment chemistry components made best use of the data?*

In some of the earlier reports, several statistical techniques were used to compare sediment chemistry to the benthic invertebrate information, including both univariate (e.g., species abundance, richness) and multivariate (e.g., cluster and principle component) tools. Some of the multivariate ordinations, such as PC1 and PC2 for both the metal group and the organic contaminant group, were plotted against non-metric multidimensional scoring (NMDS) of the invertebrates to determine trends and relationships. For the last three years (2002, 2003, and 2004), the comparison of the benthic infauna to sediment chemistry has relied on correlation tables to identify linear relationships between exposure indicators, physical sediment factors, and the benthic invertebrates. This is supplemented with figures plotting spatial changes in sediment chemistry (nonylphenol, coprostanol, and AVS) against changes in some of the taxonomic groups (*Axinopsida*, *Amphiodia*, *Capitella* and *Heterophoxus*).

These techniques appear to be up to date and utilize the data in a variety of ways to determine spatial and any temporal trends and delineate relationships. It is amazing how consistent the 80-m transect data have been, when several years' data are plotted together, which tends to demonstrate that a rather stable community has been established along this transect. The data presentation could be improved. Some data are plotted showing distances (in km with + for N and – for S of the outfall), while other figures just show the data plotted against the station numbers. Although this practice may be suitable for someone very familiar with the station locations, it made data comparison difficult for the reviewers. It would be better to include the station numbers on the x-axis together with the distance from the outfall, to make these data easier to understand and compare.

39) *Has integration of the data based on sediment chemistry and the benthos produced an accurate picture of the gradient of effects?*

Yes, the gradient effects are adequately depicted in the many figures plotting exposure indicators and the different taxonomic groups along the 80-m contour. Again, the uniformity of the data along this transect from the last few years is striking and will be very important in following any future trends or changes. However, although several years' data are available along this N-S transect only two transects (Stations 8 and 16, 2003) were made during Cycle 3 in an E-W direction, at different depths. More E-W transect data on exposure indicators and the benthos are needed to delineate the footprint of the Iona outfall.

40) *Would data integration benefit from using a more formal weight-of-evidence approach (e.g., Grapentine et al., 2002)?*

A recent journal issue (Human and Ecological Risk Assessment Vol. 8, No. 7, 2002) provides a series of papers that review the methodologies and framework for a weight-

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of-evidence approach to assess sediment quality and ecological effects. A more recent paper (Chapman and Anderson, 2005) sets up a process and decision-making framework for investigations of sediment contamination. This framework has evolved out of the sediment triad concept, which relied on three indicators: sediment chemistry, sediment bioassays, and sediment benthic community structure. It provides a nine-step process, with decision points after each step, as various measurements are evaluated in the decision matrix. These steps include:

- 1) examine available data,
- 2) develop and implement a sampling and analysis plan for the contaminants of potential concern (COPC),
- 3) compare COPC to reference conditions,
- 4) model biomagnification potential,
- 5) assess sediment toxicity,
- 6) assess benthic community structure,
- 7) construct a decision matrix,
- 8) conduct further assessments, and
- 9) assess deeper sediments.

However, even with this rather complex framework, the decisions are based primarily on biology and not chemistry. Scoring levels can be set up at each step to help make a decision on whether to move to the next step or to decide on a management strategy. The earlier papers also mention in their weight-of-evidence process the possible inclusion of site stability and the spatial extent of effects (Grapentine *et al.*, 2002, Chapman *et al.*, 2002).

The process above can be compared to the approach incorporated into the Cautions, Warnings, Triggers (CWT) process, which the GVRD has set up to guide their decisions in dealing with discharges and their potential impacts (GVRD, 2004). Although the CWT process is basically a three-step process, some of the elements included as steps in the weight-of-evidence approach in the Management Decision Framework are implicit. Tables 25 and 26 in Chapter 4 of the CWT set up the indicators and the amount of change needed to move to different levels in the process. As with the weight-of-evidence approach, changes in the sediment biota (nine indicators for Iona) are the main driver for making decisions, with sediment quality (4-nonylphenol, fecal coliforms) and geochemistry (AVS) providing supporting information. The CWT process does not, however, formally incorporate the areal extent of effects or the stability of sediment on the slope, and does not model contaminant biomagnification or use sediment bioassays. The last review (Wilson *et al.*, 1999) recommended that sediment bioassays be dropped since the data were so inconsistent.

Since the CWT process is already in place, with benchmarks established for decisions, this process should be allowed to proceed to see if it provides the decisions that are needed in a timely context to protect the environment near the outfall. To try to bring in a new framework before the present system has been properly evaluated would be unnecessary.

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*41) Are there other ways in which the overall picture of effects could be improved based on the existing monitoring protocol?*

Within the existing monitoring protocol, the data have been interpreted very logically and it is unlikely that there can be significant improvements in using any other analysis. Some of the existing data could be used to help model the potential for bioaccumulation of persistent contaminants in top predators that is one of the processes suggested by Chapman and Anderson (2005). Most of the contaminants are evaluated in the context of individual criteria such as sediment quality values, while the community associated with the sediment responds to the cumulative effects of all of the contaminants in their living environment. It would be worthwhile taking a closer look at the literature to determine if there are any techniques to determine the cumulative impact of sediment associated contaminants on biota.

*42) Was the overall monitoring protocol adequate to assess and measure environmental conditions and the health of ecosystems?*

A very good data base is emerging on the presences of sediment contaminants along the 80-m contour (x-axis) and its effect on the benthic invertebrates during this monitoring period (2000 to 2004). However, with only two transects measured during one sampling year, the data along the y-axis of the surface sediment, where there is a variation in depth, needs more monitoring. There is a need to determine the spatial footprint of the exposure indicators as well as the benthic community response.

Contaminants have only been measured in two groups of organisms (sole and crabs) during one year of study. Contaminant levels need to be measured more frequently in these keystone species. Two more sets of tissue contaminant data at three-year intervals would be very useful in confirming any contaminant bioaccumulation.

Since both of these selected organisms are bottom feeders, it would be useful to determine if any of their prey are accumulating contaminants. Contaminant levels in some of the more numerous benthic invertebrates such as mussels and polychaetes could be measured.

*43) Was the overall monitoring protocol adequate to observe, record, and predict environmental changes and trends?*

The monitoring protocol is adequate to evaluate environmental trends and changes along the 80-m north-south contour with several years of both indicator and benthic invertebrate data. There is concern about what is an adequate reference station for comparison since all of the stations along this transect could be impacted by some human activities. There probably are no ideal reference stations in the Fraser estuary area. Are there potentially any other estuaries such as the Courtenay, Campbell, Bella Coola, or Cowichan which are less impacted by humans that would provide better reference stations at this 80-m depth? There is a need to get more spatial coverage of the areal footprint of the Iona outfall impacts which will involve several transects in the east-west direction. Also, some selected sediment core profiles are needed within this zone. Since there is approximately 2 cm of sediment deposited annually in this area, a core of a meter should easily delineate the vertical profiles of some of the indicator

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contaminants such as 4-nonylphenol and coprostanol that should be only distributed down to the 30-50 cm depth.

With this information one can start to calculate the loading of contaminants that have been deposited in the area of the outfall and compare it to the total loading of contaminants discharged. This will help provide a rough estimate of the proportion of the outfall contaminants that have a wider dispersal pattern in the Strait of Georgia. Some core data have been collected in the area of the outfall (Johannessen *et al.*, 2005), but it is difficult to determine exactly where their cores are from without some more accurate location information.

It would be useful to also try and deploy some sediment traps to collect particulate materials settling out from the outfall plume area for chemical characterization.

One factor in relation to the impact of contaminants on sediment dwelling organisms is the availability of the contaminants. Some research has been conducted to determine the sulphide association of the trace metals that affects availability. The emerging literature needs to be surveyed to evaluate recent techniques and assess their application to the Iona outfall situation. Some techniques such as semi-permeable membrane devices (SPMDs) have been used to estimate the availability of organic contaminants. However, it would be difficult to deploy such systems in 80 m of water.

Perhaps laboratory experiments (Macrae and Hall, 1998) could be conducted with sediments retrieved from the site to help answer some of the availability questions. Also, more frequent monitoring of contaminants in selected tissue will better document if there is a problem of contaminant availability that needs to be considered.

#### *44) What newly emerging issues could be considered?*

The group of contaminants that are receiving lots of attention these days are the flame retardants (polybrominated diphenylethers). The GVRD is aware of this issue and is looking at monitoring these contaminants although there has not been a monitoring program put before the Environmental Monitoring Committee (EMC). The whole area of personal care products including hormones, hormone mimics and antibiotics is also receiving lots of attention as contaminants with significant environmental impact that can be discharged by sewage treatment plants. The GVRD has participated in some nationwide screening studies and has some special projects that are trying to evaluate this problem in their discharges. One compound used extensively is the antimicrobial agent, triclosan, which is present in toothpastes, hand soaps and other personal care products in the range from 0.1 to 1.0% (Rule et al. 2005). The GVRD needs to look closer at this contaminant. Finally the Iona sewage treatment plant is a combined system which receives a lot of stormwater during the rainy season. There is a program of sewer separation in progress but it will take 50-60 years to complete it. The GVRD needs to be certain that they can accurately document the stormwater contribution of contaminants to their sewage discharge and determine that a program of best management practices (BMPs) is in place to help with removal of the predominant stormwater contaminants before they reach the treatment plant where removal is relatively inefficient.

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## 5. Program Recommendations

Cycle 3 of the Iona Deep-Sea Outfall Environmental Monitoring Program was reviewed by a group of six senior scientists. The reviewers came from a variety of academic backgrounds covering the study themes and were at arm's length from the GVRD. They were drawn from government agencies and the academic community.

In addition to their review of assigned components of the monitoring program for Cycle 3, the reviewers provided recommendations to further strengthen the monitoring program for the next cycle of monitoring. The recommendations are outlined below by program theme.

### 5.1. *Plume and Sediment Dynamics*

#### 1) *Evaluate bottom shear stress over the model domain*

The region of maximum sedimentation in the present plume dispersion model does not agree with the data. Maximum disposition is found along the 80-m isobath whereas the model predicts deposition will be greatest along the 60m isobath. To provide an explanation for this discrepancy and to help define the inner limit of possible accumulation of particulate wastes, it is recommended that the modeling results be reinterpreted during Cycle 4 to provide estimates of bottom stress. The difference between the predicted and the actual region of maximum deposition is likely due to the inability of the model to re-suspend sediment. In its present form, the model assumes that once the sediment is deposited it no longer moves. Since the model also assumes that the bulk of the material flocculates, it uses a floc settling velocity on the order of 1 mm.s<sup>-1</sup>. Hill *et al.*, (2001) have shown that flocs break up at stresses in excess of ~0.1 Pa. Maximal floc deposition has been shown to occur in regions where bottom stress falls below the 0.1Pa threshold for floc break-up (Harris, 2004). Mapping predicted bottom stress should provide a relatively simple way to identify areas where floc deposition will be minimal. While estimating bottom stress could provide a reason for the discrepancy between predicted and actual depth of deposition, it does not address the fate of material that becomes re-suspended.

#### 2) *Determine sediment accumulation rates and contaminant profile*

A continuous record of surficial sediment contaminant loading since the start of discharge from the new Iona outfall has been lost due to changes in sampling strategy. To examine the levels of contaminant input to the bed over the life of the present outfall, a coring program should be carried out along the drift line to determine both the sediment accumulation rate and the levels of contaminants.

One of the outstanding questions is how much of the particulate discharge from the Iona outfall makes its way into the Strait of Georgia? Data gathered from the cores could provide the basis for estimating how much of the total particulate discharge remains

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within the immediate deposit and how much is lost. Calculating a mass balance based on input, accumulation rate, and area of deposition could give a reasonable estimate of the trapping efficiency of the present deposit.

If a coring program is carried out consideration should be given to using a hydraulically damped corer such as that used by Bothner *et al.*, (1998) to study the recovery of contaminated sediments in Boston Harbour after sewage treatment facilities were upgraded. This type of corer preserves the sediment water interface and significantly reduces compaction. In considering impacts of effluent on benthic organisms it is important that the loose floc found at the sediment water interface is not lost during sampling.

Consideration should be given to mapping the entire deposit using Multibeam and/or sidescan sonar. The area of deposition could be determined from backscatter intensity which is highly influenced by porosity and organic deposition. Prior to conducting a survey, areas that might have previously been surveyed using Multibeam should be identified. This would determine if Multibeam mapping would be effective and provide temporal coverage. A Multibeam or sidescan survey might also help determine if the source of the anomalous results from the southern control station are due to fishing activity.

### 3) *Integrate previous data with Cycle-3 results*

As a result of the second review panel recommendations, the sampling plan and methodology for the Iona outfall monitoring program were changed. In the documents provided, only 5 years of data from the stations on the newly established 80-m transect were presented. In that data there is a suggestion that values of some contaminants have decreased over the last 5 years. While it is recognised that significant improvements were made to the monitoring program after the 1999 review, it is unfortunate that earlier data appears to have been ignored. Stations from the previous sampling grid will in some cases be very close to stations on the present grid. The sediment in the region of the outfall shows sufficient homogeneity that the data from previous studies could be used to assess changes over the entire life of the monitoring program. Much of this long term assessment could be carried out if a GIS database was created for all the data that has been gathered.

### 4) *Normalize metals results for grain size effects*

Normalization for grain size effects using lithium should be carried out. Geochemical normalization of sediment concentrations for grain size has been found to be superior to granulometric normalization because the geochemical normalization can also compensate for mineralogical changes (Loring, 1991). Various elements have been used for geochemical normalization of heavy metal variability, but for high latitude areas dominated by glaciation or other physical weathering, lithium normalization is preferred (Loring, 1991). In the reports, background values of Zn and Cu are said to be naturally high. Normalization with Li could be used to determine if concentrations in the Iona sediments are at natural background levels or if they are enriched beyond CCME and PEL levels (Yeats *et al.*, in press).

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5) *Determine floc fraction and floc settling velocity*

The present model assumes a value for the amount of material incorporated into flocs and a floc settling velocity. To improve prediction of the dispersion of the particulate fraction from the Iona effluent, data on floc fraction and floc settling velocity are required. Values for floc fraction used in the model were determined in the laboratory. The size and settling velocity of flocs can vary considerably *in situ* therefore direct measurements should be made. While not critical for the monitoring program, correct values for floc fraction and settling velocity would be required to determine the net export of particulate material from the immediate area of the outfall.

6) *Determine suspension threshold for deposited sediments*

The reworking of sewage derived sediments during stress events can redistribute the mass and can release contaminants (Wiberg *et al.*, 2002a, b). To determine the long-term fate of material deposited at the Iona outfall, estimates of resuspension threshold should be made. Data could then be used to model the removal rate of sediment and release of contaminants over the longer term. Integration with a well-constrained physical model that could predict combined stress from current and waves will be required.

## **5.2. Sediment Chemistry and Microbiology**

7) *Frequency of sampling*

Sampling at the original stations on the 80-m depth contour could be carried out only every other year, which would leave the alternate years free for collecting and analyzing about the same number of samples from a sediment core or from extra lateral lines.

8) *Sediment cores and contaminant profiles*

As previously mentioned, sampling surface sediments with a Van Veen grab can be imprecise. Collecting sediment cores would provide more representative samples of the sediment surface and add a completely new dimension to the program. Analyzing 210-Pb and 137-Cs in sediment cores (these measurements are not expensive relative to most others) would permit to determine the sedimentation rate, the thickness of the bioturbated layer, and the intensity of the biomixing. The sedimentation rate is critical to estimate contaminant fluxes and the fraction of the Iona outfall contaminants deposited in the study area.

9) *Analytical procedure*

Consider carrying out total digestion of the sediments for the metal analysis and determining Cd and Ag by AAS with a graphite furnace rather than a flame.

10) *Scientific collaborations*

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The GVRD should pursue its collaboration with various experts for collecting and interpreting sediment core and sediment trap data. It should also consider developing other collaborations on the critical issue of pharmaceuticals compounds and dissolved contaminants.

*11) Data interpretation*

Geochemical normalization with Al or Li for trace elements is recommended to correct for the grain size effect. Normalization will also help demonstrate whether certain elements are naturally enriched in the sediment.

Complex statistical treatment of the results to determine temporal trends should be dispensed with, considering the sampling technique and biomixing of the sediment.

Although comparing contaminant concentrations with sediment quality guidelines is important, there is a general feeling in the scientific community that such guidelines are less than ideal. A surer path to adequately determine the impact of the Iona outfall may in time prove to be the quantitative assessment of the contaminant fluxes and biological effects.

### **5.3. Benthic Community**

*12) Reduction in the 80-m contour sampling*

The confounded sites to the south should probably be discarded in future. While there is no evidence that the effects observed at stations 13 and 14 are related to the discharge it would probably be prudent for the GVRD to determine potential causes.

If trend analysis shows that no trends are discernable in the data since 2001 then reduce the 80-m contour sampling to every two years, i.e. 2007 and 2009 for the next 5-year cycle.

*13) Shoreward and offshore spread of benthic effects*

- (i) Information is needed on the shoreward and offshore spread of benthic effects, using grab sampling methods currently applied to the 80-m contour sampling. The biostatistician responsible for analyzing the data should be responsible for designing the sampling. The hypothesis to be tested would be something like “Benthic effects spread laterally northwards between the 40 and 120 m depth contours”. However, the criteria for defining an effect needs to be agreed upon *a priori* (e.g. a change of more than 50% in a key or several key species, or a change in community structure detected at the 0.95 level based on ordination, etc.) otherwise endless argument may take place on what is “significant”. The depth contours (40 – 120 m) are suggested from the plume, coring and trapping depth data. This lateral station sampling could be implemented in the alternate years dropped from the 80-m contour sampling, i.e. 2006 and 2008.

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- (ii) Gradient designs are widely used and are an accepted design by the Environment Canada EEM program. The premise behind the gradient design is that it encompasses the range of exposure observed by the receiving system. The reported data show a consistent pattern in year to year response that indicate exposure is largely to the north and that there are differing degrees of response in the benthic community. However, because the sampling program is restricted to the 80-m contour the delineation of effect is only one-dimensional. It is incumbent upon the program to identify the lateral extent of any effects associated with the discharge. This is most easily accomplished by sampling cross sectional transects at each of stations 1 – 9. The previous lateral transects were at station 8 (likely too close to the outfall for lateral dispersion to have occurred and at station 16 (outside area of effect). The plume dispersion study may provide a guide as to the required extent of the transects, however, it should extend sufficiently far to be beyond the likely extension of the plume.

Therefore, it is recommended that sampling extend beyond the 80-m contour, to delineate any lateral trend in plume dispersion – there are two alternatives to not increasing the sampling effort, but that would require discussion:

- Reduce survey frequency to biannual as there is not a strong directional (as opposed to normal annual variation) temporal signal,
- Reduce within site replication (it is also the smallest source of variation – see the analysis done on Pages 50-53), as this data/variation is not used in determining response, to a single grab and increase number of locations.

To assure that samples are representative, grabs could be composited and sub-sampled – however this would include a change in methodology, and should be done in parallel (i.e. both methods should be done to verify effects). In fact this can be done with no greater effort by pseudo-compositing (i.e. doing analysis with replicates and sum of replicates) at 2-3 sites.

#### *14) Reduction of effort in benthos sampling*

- (i) Reduction of species identifications to taxonomic Families: If a lumping analysis for 2004 shows that Family level identifications and quantifications demonstrate the now-known effects zones with sufficient power, then consider reducing the identifications to Families only. However, this should only be implemented if there is general consensus after a review by a group of benthic biologists, and there is a substantial cost saving.
- (ii) Reduction of sampling sites within each effects zone: Only consider this if analysis shows that the effects zones can be demonstrated with sufficient power by such reductions. Again the option should be first considered by a review group.
- (iii) Reduction in the number of replicates at each site within the effects zones: Also, only consider this if analysis shows that the effects zones can be demonstrated with sufficient power by such reductions. This option should also be first considered by a review group.

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- (iv) Overall recommendation about reductions in the benthic program: Any proposed reduction in the benthic program, whether under items i, ii or iii above should only be implemented after review of all three sets of statistical analyses together. This review should be by a group with the appropriate biological and biostatistical expertise. The reason for the extra review (additional to this review, and after the extra statistical analyses) is that it would be counter-productive to introduce cost-saving measures, only to end up a few years later regretting the losses of species biological information which could have explained any developing benthic population or health effects.

*15) Interactions between benthos and other aspects of the monitoring program*

- (i) There should be some integration between benthic community and species health/bioaccumulation effects. The latter may act as Triggers for the former.

Since the shrimp fishery is of some importance, it would seem appropriate to include the dominant shrimp in the fishery among the species health/bioaccumulation monitoring.

It may also be possible to include a pelagic species, but only if there is evidence that the species stays feeding on the delta front for a prolonged time period. For example if there is a herring spawning run into delta shallows, and the herring aggregate and feed nearshore for several months beforehand, they may be exposed to contaminants, hence could be good monitors of contaminant uptake. However since herring spawn in the spring, and fish sampling is in the fall, this presents timing problems. Herring would have to be sampled in the spring just before the spawning period.

Another fish species to include could be juvenile salmon (especially coho) or sea-run trout (steelhead or cutthroat). These may stay feeding in shallow water along the delta front for some months in late spring and early summer. Again, there is a timing problem for sampling.

- (ii) In view of the complexity of the benthic monitoring, and interactions between benthos and other disciplines, and the other GVRD programs, there is advantage to GVRD organizing an annual meeting of the consultants and researchers involved. This should encompass the Ambient Monitoring Program supported by GVRD, and specific research projects also supported by GVRD.

*16) Adequacy of reference stations*

There was a difference of opinion expressed by the two reviewers for benthic community on the feasibility of identifying true reference stations and acquiring that data. The following section is the view of reviewer 1.

- (i) There has been some discussion on identifying Reference Stations for sampling. In principle and in theory this is highly desirable. In practice, this has been almost a holy grail in marine sediment studies for the past 100 years.

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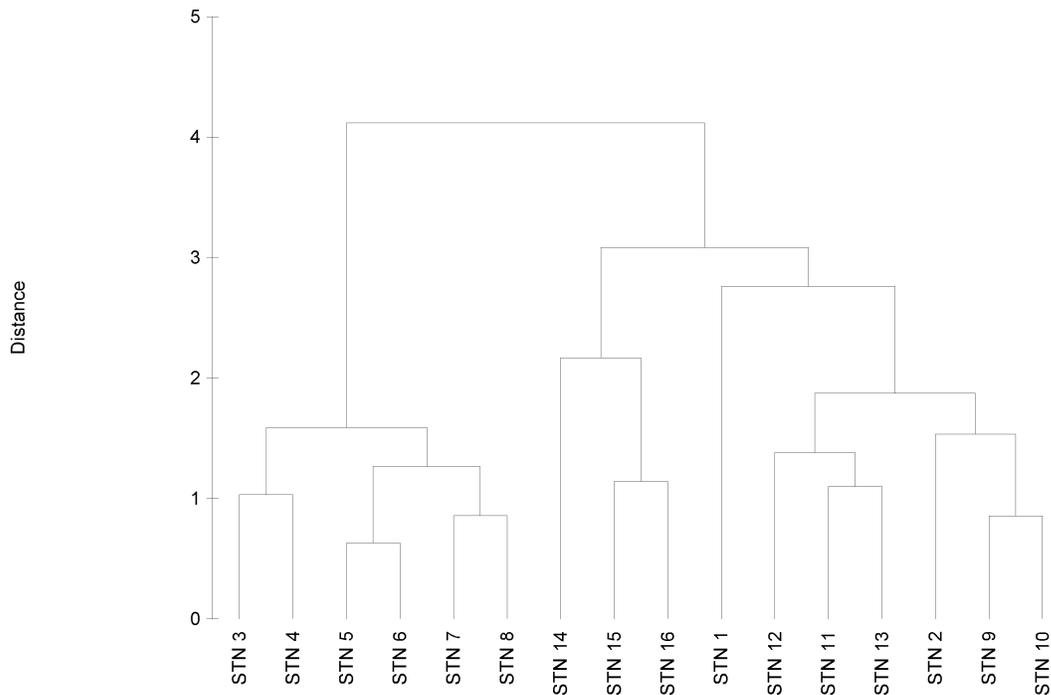
The problem is the variability of the infaunal benthos. This includes the number of species as well as the abundance of any one species. The variation is both from time to time, and from place to place. This happens both on dynamic sediments, and on uniform stable substrates. The causes are biological and possibly, in part, it also relates to patchiness of habitat. Infaunal benthos are almost invariably clustered, for many different reasons, hence a replicate grab samples can be from a dense cluster, at the edges of a cluster or between clusters. Populations vary randomly from year to year due to the success (or failure) of the annual larval breeding season.

However, if current biostatistical techniques can identify one or more reference stations, then there is no question that the program will be the stronger for it. The search for such stations and the data analysis will likely require so much effort, over several years, in sampling, sample processing and data analysis, with the possibility of not being successful, that the present reliance on end-of-gradient sampling stations will have to be accepted.

- (ii) Gradient designs assume that the extent of the gradient furthest from the source represents, reference or background conditions, because there is no *a priori* or independent definition of either the reference or disturbed community. Furthermore, all assessment determine disturbance by comparison to the reference community and this programme is no exception. Finally, the reference sites are used to define the criteria (triggers) for action. It is therefore absolutely critical that there is complete confidence that these stations do represent appropriate reference conditions. There is a considerable literature on selecting and defining reference conditions for freshwater systems (e.g., Hughes 1995, Davis and Simon 1995, Hawkins et al. 2000, Bailey et al. 2004) and there is no reason why the basic principles would not apply to the marine environment. First, among these is that you do not need to restrict selection to the immediate locale. For example in western Canada similar assemblages of organisms occur from streams in the lower Fraser catchment to the Yukon, if habitat conditions are the same. It is expected that a similar finding would apply in the marine environment where barriers to dispersal are less, and sites of similar depth and substrate would have very similar communities, potentially within 100s of kilometres of the study area. Therefore, reference sites may occur up or down the west coast. Initially an exercise to examine either the literature or other data bases may be a suitable first step, for assuring the actuality of the reference sites on the gradient.

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**Figure 1.** Cluster analysis of 2004 sites based on six exposure variables – data were log transformed and normalised Euclidean distance used as the distance



One approach that could be used to define reference sites would be to independently define, *a priori* what constitutes exposed and reference sites. This would strengthen the analyses. For example a cluster analysis/ordination of non-outfall related attributes could be used to identify or confirm that there are no confounding issues related to habitat differences. The same analysis can then be repeated with sewage related attributes e.g., silver, coprostanol, etc., to identify exposure zones. This second analysis was done for the 2004 data to confirm the designation of reference and effects zones.

The cluster analysis (Fig. 1) shows clearly that there are two zones based on six exposure indicators, and that these are very different. Ordination (PCA - log x+1 transformation, Fig. 2a) shows clear differences between putative reference sites (green) and exposure sites (blue), but also two gradients in the exposed sites, one on the second component, where the main loading is fecal coliforms (Table 3) and a second on the first component where all variables have similar weight. Furthermore, this shows that the exposure sites follow a gradient and implies that data analysis using two groups - exposed and reference - would not necessarily be the appropriate model, but rather that exposed sites should be examined individually against reference sites or a

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regression type of analysis be used. Although the two different gradients may confound the latter approach.

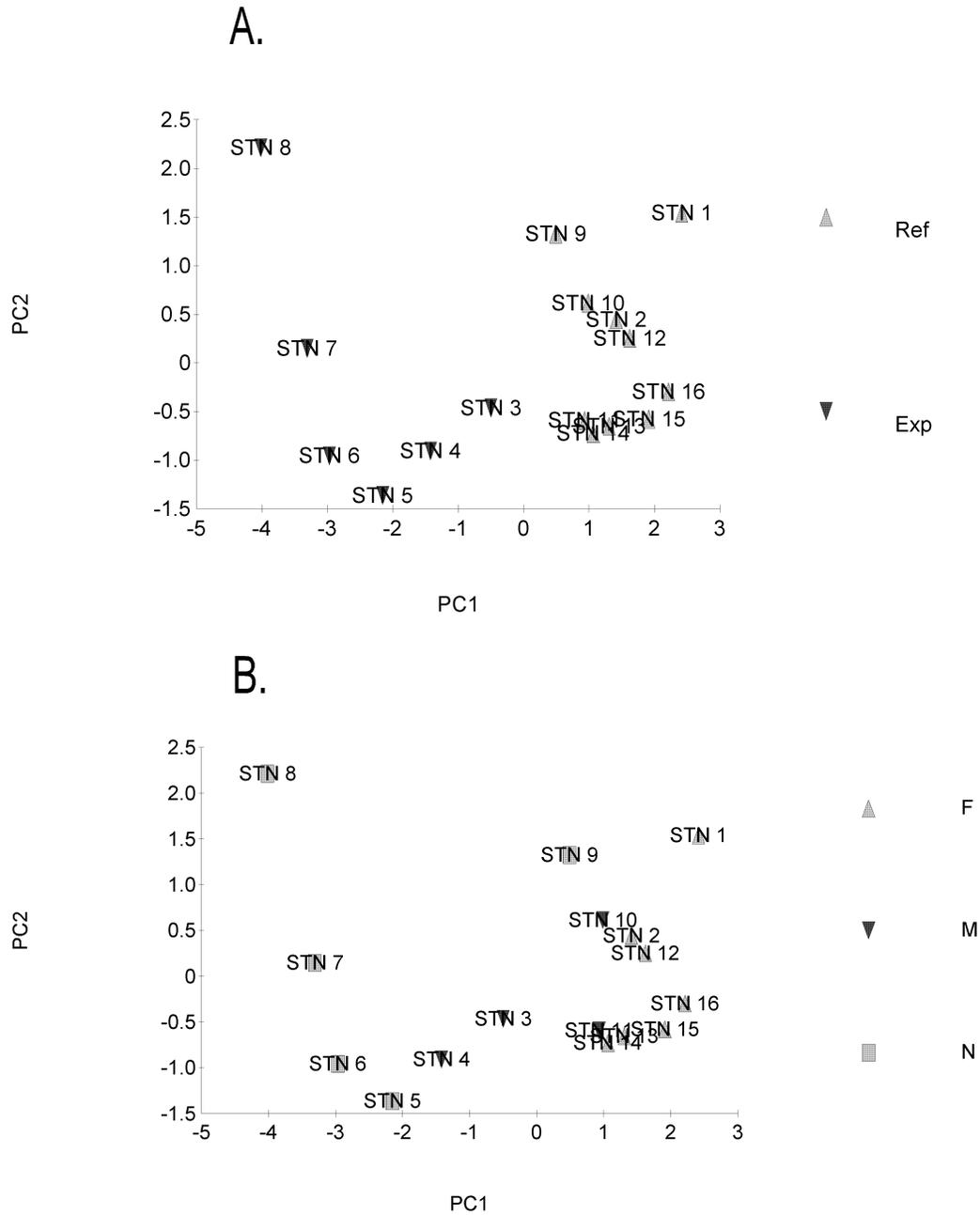
It is also noteworthy that when the sites are labelled by their mid/near/far field designations (Fig. 2b) these do not completely match the exposure indicators. For example station 9 defined as near field, in fact shows little evidence of exposure.

**Table 3.** Results of PCA of 2004 sediment exposure indicators

*Eigenvectors* (Coefficients in the linear combinations of variables making up PC's)

Variable	PC1	PC2
Variation explained (%)	74.1	16.9
AVS	-0.434	-0.235
Fecal coliform bacteria	-0.330	0.633
Total Organic Carbon (%)	-0.307	-0.679
Silver (Ag)	-0.448	-0.129
Coprostanol	-0.444	0.220
4-Nonylphenol	-0.460	0.135

**Figure 2.** A. Ordination (PCA) of six sediment exposure variables showing reference and test sites based on two groups formed from cluster analysis, and B. showing sites designated as near, mid and far-field from benthic invertebrate community data.



In summary (Fig. 2 above), analysis shows that reference sites can be independently defined, using exposure indicators, along the gradient, and that this type of *a priori* definition can be used to establish hypotheses for testing if biological effects have

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occurred. Alternatively independent reference sites can be defined using approaches adapted from large scale freshwater studies, although there is some disagreement among the reviewers on the feasibility of this latter approach.

*17) Articulate the relationship between the design and the analysis and interpretation, and develop a framework for the monitoring program*

Design and analysis should be completely integrated into the annual reports. Although the annual reports describe the objectives and hypotheses for the benthic theme, the reports do not explicitly close the loop by reporting if the hypotheses are true and with what significance and power (where known). It is recommended that formal hypotheses (or questions) be stated then be tested and reported on. Questions can be as simple as whether or not there are significant differences between the effect zones (although they should be defined independently); are there differences between sites defined by exposure indicators; are there relationships between selected community descriptors and exposure indicators. The relationship between stations and replicated grabs at stations should be indicated, as it is not stated how the station replicates are utilized in the data analysis or if, for example, stations are considered as replicates within a zone. Alternately a more complex tiered framework can be established, analogous to the EEM metal mining program, which has a hierarchical approach and actually has provision for reducing or discontinuing monitoring the benthos for a period if it is clearly established that no effects are observed at exposure stations, based on *a priori* criteria for defining disturbance.

*18) Examine what taxonomic level is most effective for addressing the question of whether or not effects in the community are observed in response to the discharge*

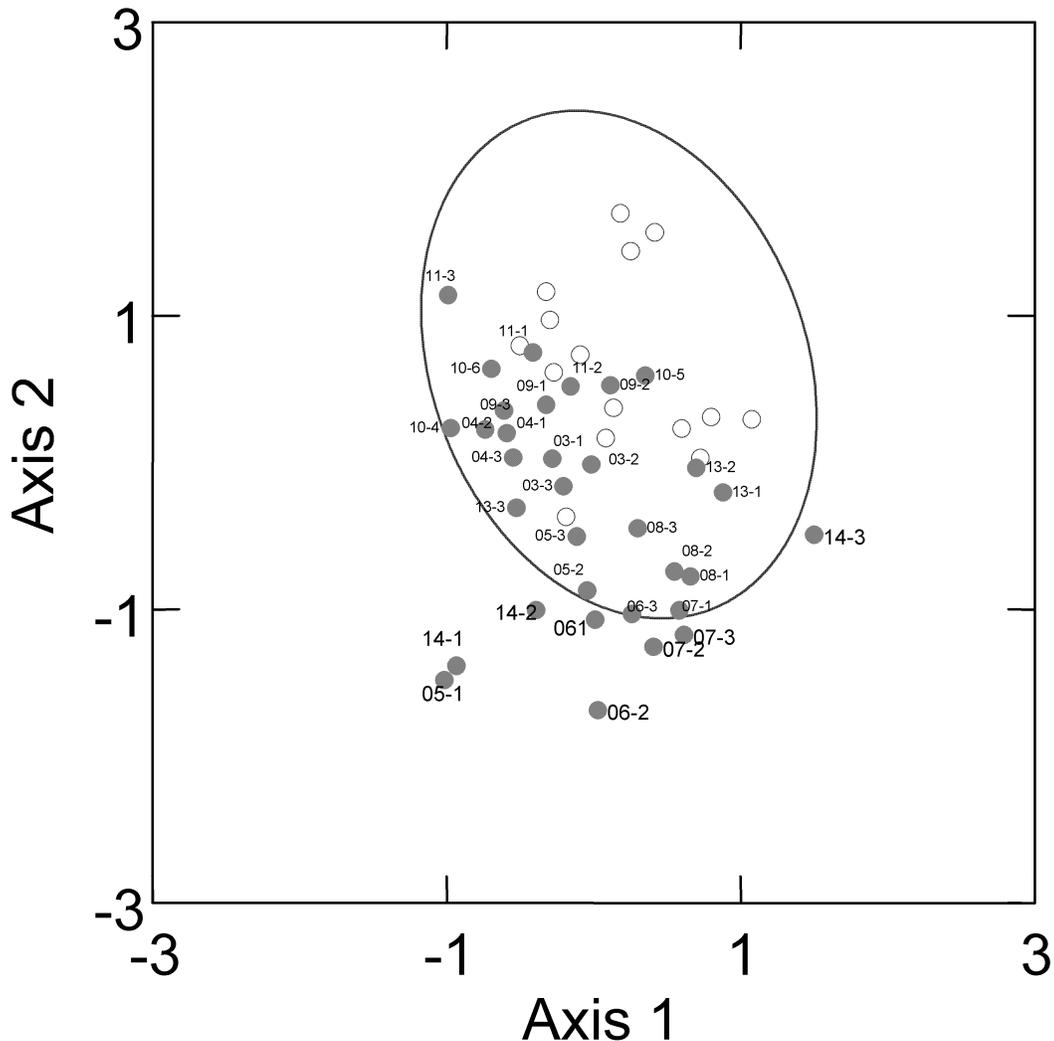
There is ongoing debate in both the marine and freshwater literatures on what is an appropriate taxonomic level. In part the debate is spurious and often confused, both sides tending to be vehement in their position, on the one hand that nothing less than species is acceptable as this is the “true unit of biological function” and that variation among species within genera and families in their response to various kinds of pollution exposure makes it important to monitor individual species to adequately assess changes in aquatic systems, this view was notably argued by Resh and Unzicker (1975) and supports identification to the lowest practicable level. The other view is held that in both marine (e.g. Warwick 1988) and freshwater (Bowman and Bailey 1998) environments where investigation has repeatedly found little effect of varying taxonomic resolution (from genus/species to family or even phylum) on multivariate descriptions of variation among communities, particularly the contrast between reference and exposed communities. This debate was recently aired in a pair of articles by Bailey et al. (2001) and Lenat and Resh (2001). Where Bailey et al. (2001) argued from a pragmatic perspective of maximizing resource use, and Lenat and Resh (2001) identified situations where higher or lower level identification was appropriate. In part the argument is artificial and depends on the questions being asked and also the analytical approach being used. Those arguing for lower level identification tend to use multivariate approaches which capture more information from the data set, those arguing for species level tend to use “metrics” such as species richness or examine specific taxa. It is recommended that these data be examined using both multivariate and univariate

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approaches to in fact test which level is appropriate and if possible free resources for other activities, such as better spatial resolution. Certainly the data as currently presented do not appear to make full use of the species level data.

As a preliminary step the 2004 data have been examined to determine which taxonomic level better differentiates between exposed and reference sites. To make the analysis standard we have used far field sites as reference (as designated in the report) and tested exposure stations against those sites, for ease of presentation we have done a single analysis of all test sites simultaneously. However, each test station should be examined individually against reference stations to avoid interaction effects among test stations. Replicated samples from each station have been used in this analysis, this both increases the description of reference site variation (although this could be argued as pseudoreplication) and also provides some indication of the type 2 error rate for the test site. The data have been examined using hybrid non-metric multidimensional scaling (HMDS), Bray-Curtis similarity was used to describe similarity among samples, and raw counts were used. A site is defined as being in reference condition if it is within 95% of the range of variation observed at reference sites. This is graphically described by constructing a 95% probability ellipse around the reference sites. This is the method described by Rosenberg et al. (2000), Reynoldson *et al.*, (2001) and used by Environment Canada for lake and stream assessment, although in that application multiple ellipses (90, 99, 99.9%) are used to define levels of disturbance.

**Figure 3.** HMDS ordination of 2004 reference (open) and test (solid) benthic invertebrate samples at the species level. 95% probability ellipse constructed around reference samples only. Test sites outside the ellipse designated as disturbed are indicated in bold text. Sample numbers indicate site and replicate.



At the species level (Fig. 3) the data matrix includes 218 species and several things can be noted:

- Only one station (14) shows all three replicates to be different from reference. Stations 6 and 7 had two disturbed samples and station 5 one sample, the other samples are within the reference range.
- The type of disturbance is similar at Stations 6 and 7, this is indicated by the fact that samples move in the same direction from the reference “cloud” and therefore the same change in taxonomic composition has occurred (except for one of the

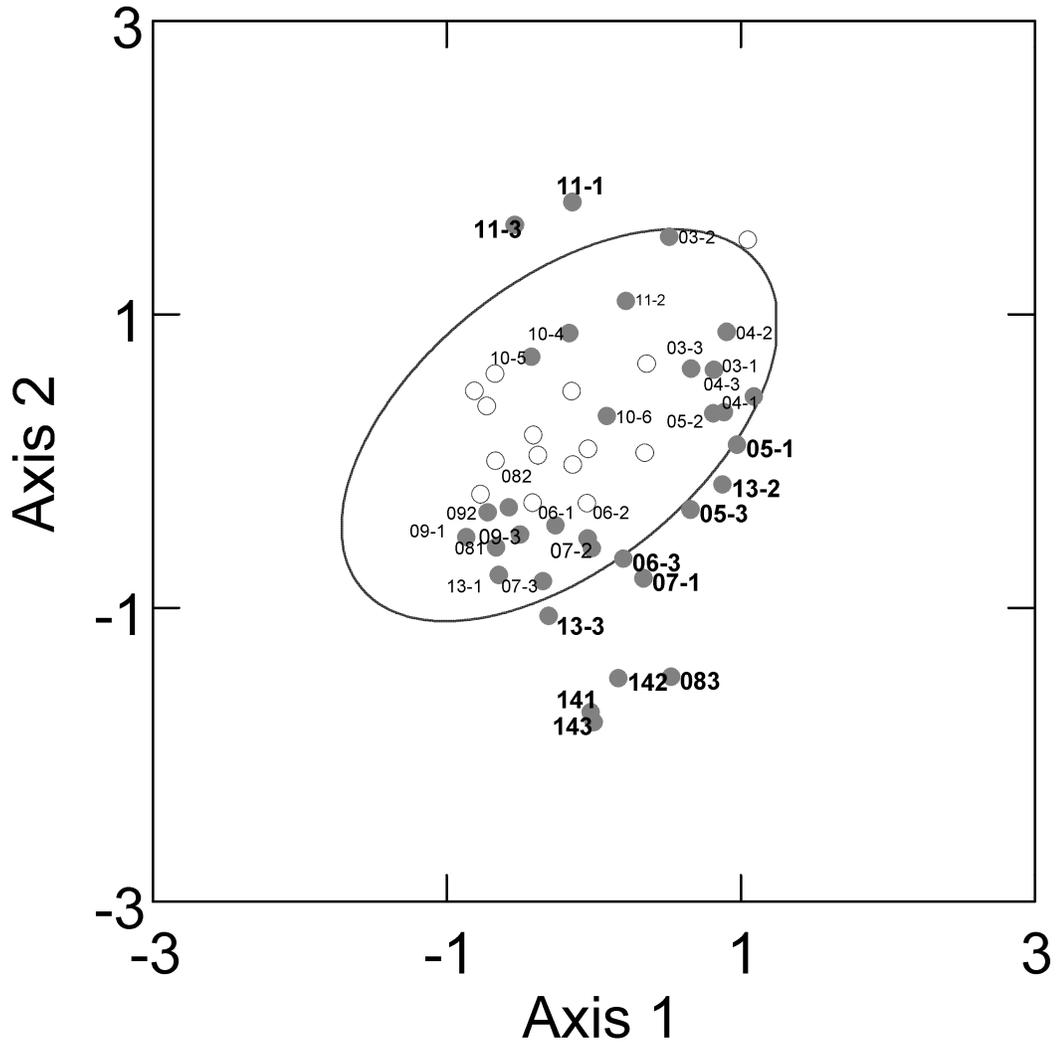
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- samples from station 14). In addition plotting taxa and habitat variables in this same ordination space would provide an indication of the nature of the response.
- There is considerable but varying amounts of intra-station variability. For example samples from Station 8 are quite similar (close on the ordination plot) where others (10, 11) are quite variable (far apart on the plot).
  - The ellipse is large relative to the distribution of the reference sites, suggesting that the sites may represent more than one reference state and or that the reference community is represented by too few samples (this could be resolved by using data from multiple years – see below).

At the family level (Fig. 4) the data matrix consists of 97 families, and there are interesting contrasts between the two analyses:

- At the family level the ordination is a marginally better representation of the community with a slightly lower (0.19) stress (measure of goodness of fit to the similarity matrix) than the species level (0.20). This is expected as there are more than 100 less variables being described at the family level.
- More samples (12) are defined as different to the reference community that at the species level where 8 samples were identified as different – suggesting more sensitivity.
- Again only station (14) had all three samples defined as disturbed, three stations had two samples defined as disturbed (11, 13 and 5) and stations 6 and 7 had only one disturbed sample
- There appear to be two different types of response (disturbance), with station 11 responding differently (moving in a different direction in ordination space relative to the reference sites) to the other disturbed station samples

In summary, this very preliminary analysis suggest that family level analysis is equally or more capable of detecting difference from reference than the species level data. However, this analysis needs to be conducted more thoroughly across years and using more reference data to answer the question of which taxonomic level is the more effective at detecting biological response. Furthermore, examination of the amount of variability among reference sites is critical.

**Figure 4.** HMDS ordination of 2004 reference (open) and test (solid) benthic invertebrate samples at the family level. 95% probability ellipse constructed around reference samples only. Test sites outside the ellipse designated as disturbed are indicated in bold text. Sample numbers indicate site and replicate.



19) *Discontinue or examine the implications of discontinuing biomass estimation*

Community analyses is typically conducted using either count or biomass data. The argument for using biomass is that high numbers of small organism can discount the role of the rarer large organisms. While that is true, estimating biomass is always problematic and is less frequently used as the unit for community analyses. While the program has tried to provide biomass estimation it is done indirectly (using relationships)

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and is not done comprehensively. Furthermore, the biomass data are not being substantially used and are not critical to describing the observed community effects. Finally, the importance of rarer taxa in analyses can be emphasized in multivariate analysis such as multidimensional scaling (MDS) using other techniques such as transformation which downweights abundant taxa and upweights less common taxa. It is suggested that at the least an examination of the importance of biomass data to the program be undertaken.

*20) Improve and simplify reporting of QA/QC data*

A major attribute of the current programme is the quality of the data, something that unfortunately is not that common in similar programs. It is suggested that this be given both more prominence and be reported in a standard manner. The sorting efficiencies are currently reported however, the taxonomic quality data are hard to follow and need to be suitably summarized. Perhaps a simple table indicating total number of specimens identified, number sent for taxonomic QA and how many of these were confirmed or disputed.

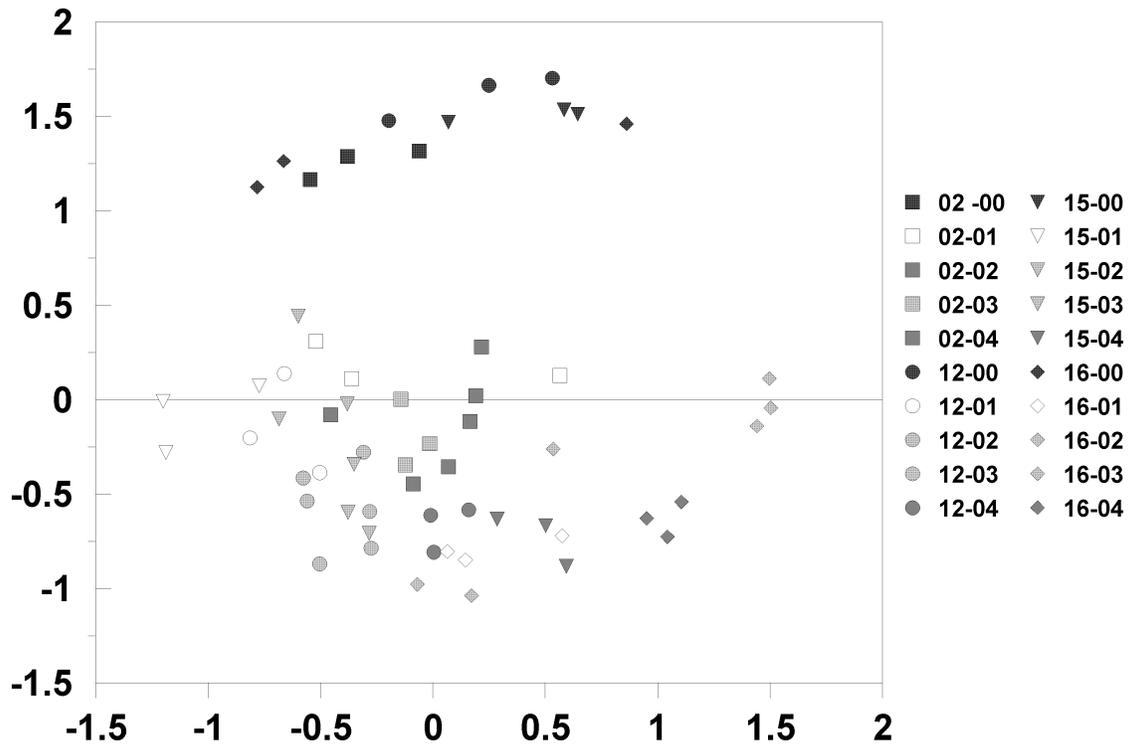
*21) Use of multivariate methods in support of current methods*

Additional statistical analysis methods could extract more value from this high quality dataset, thereby improving the program's understanding of structure and variation of the benthic community in time and space. This type of data set is most suited to using multivariate analyses which are designed for dealing with large data matrices. While cluster analyses is used to identify groups nothing is done to examine the group structure, for example ANOSIM could be used to examine the similarity of the groups or the importance of extrinsic groups such as those defined by exposure variables. SIMPER could be used to identify the taxa responsible for characterizing within groups and differentiating among groups. Ordination could be used to examine the reality of the groups (particularly as the design is a gradient and one would expect a gradient response or continuum in the community, perhaps better examined by ordination. Ordination may also be used to define reference site variation (see above), identify different types of response and the community changes characterizing those responses and also by plotting exposure (and other variables) in ordination space develop hypotheses on causality.

To illustrate how multivariate methods could be used to analyse response a subset of sites have been used to examine annual patterns and the relative importance of annual spatial variability at the station and study area scale in the community. The subset of data used in this analysis consists of three samples for each of five years (00, 01, 02, 03, 04) for 4 reference stations (2, 12, 15, 16). To conform with Excel limitations of 254 columns species with less than 10 individuals over the period of record were excluded from the analyses. In addition the rusty form of *A. serricata* was combined with the non-rusty form. This reduced the number of species from 326 to 152 while eliminating less than 0.8% of the organisms. The data were examined to identify if there were any annual patterns and to identify annual variation relative to among and within site (replicate) variation. ANOSIM was used to identify the strength of differences among and within years and among and within sites.

Three aspects of temporal and spatial variability were examined. First, the annual differences among the reference stations sampled each year. The results of MDS ordination of among year variation within the group of reference sites are shown in Figure 5. Years are indicated by colour and sites by symbols. Most notable is that the 2000 samples are quite distinct, and the reasons for this (different sorting techniques) are discussed in the original Cycle 3 report. There are other patterns that can be observed:

**Figure 5.** HMDS ordination of benthic invertebrate community data replicate samples for four far-field sites sampled over five years. Years are indicated by color and sites by symbols.



For example, discounting the anomalous 2000 data year to year variation is greater than among station variation within a year. This can be seen, for example, from the fact that all the 2003 (pale blue) samples cover almost the entire observed range of variation observed among the stations (different symbols), similarly for 2001 (yellow) and 2002 (green). In comparison a single station shows somewhat less variation across years (e.g., station 16 - diamonds, or station 02 - squares). Although variation among years is greater than within years there are small statistical differences between years. The greatest being between 2001 (yellow) and 2004 (red) with an r statistic of 0.51 (Table 4).

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**Table 4.** ANOSIM analysis of among year differences

Sample statistic (Global R): 0.286 *Pairwise Tests (Bold significant at P <0.01)*

Year	2002	2003	2004
2001	0.247	<b>0.285</b>	<b>0.51</b>
2002		0.112	<b>0.374</b>
2003			<b>0.265</b>

The variation within Stations through the years is much less than among the stations. This can be seen by the relative proximity of samples from different years for the same stations compared to samples from different years. Stations 12 and 15 are very similar (almost complete overlap in two dimensions, and Station 16 is the most different. This is clear in the ordination plot. ANOSIM (Table 5) confirms this observation as the lower within station variation makes differences among stations greater, where in pairwise tests station 16 has the highest (greatest difference) r statistic and is therefore the most different.

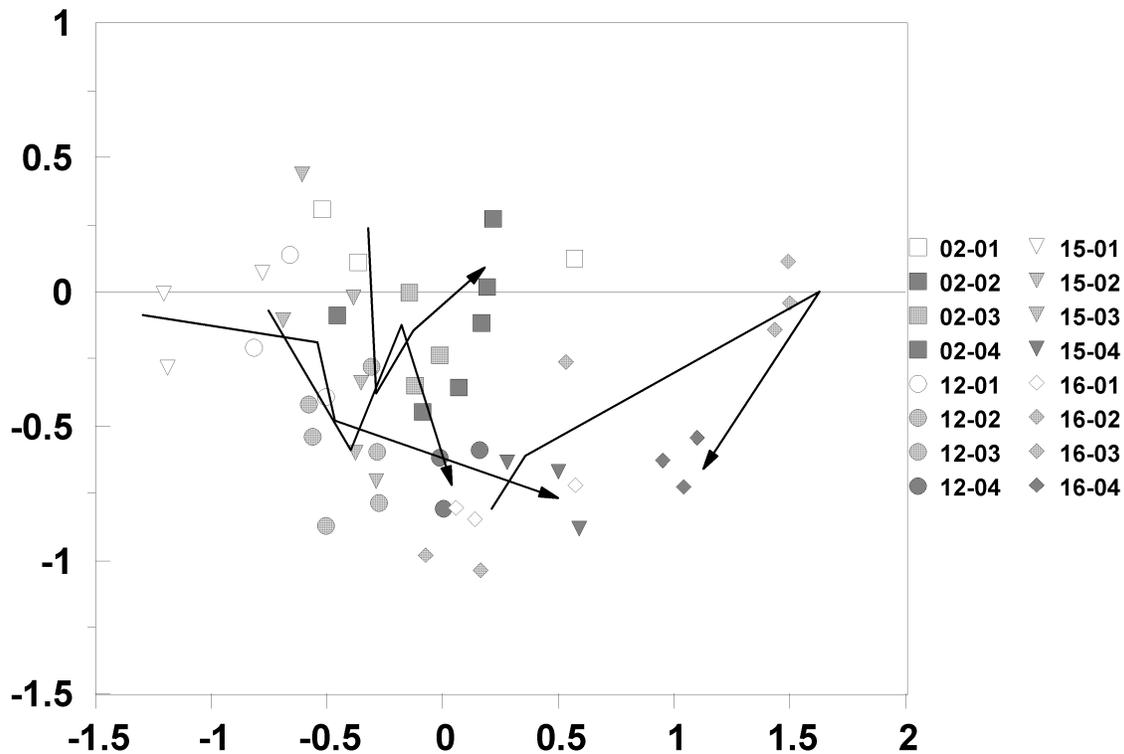
**Table 5.** Results of ANOSIM analysis of among site differences across years

Sample statistic (Global R): 0.371 *Pairwise Tests (Bold significant at P <0.01)*

Station	12	15	16
02	<b>0.348</b>	<b>0.381</b>	<b>0.575</b>
12		0.263	<b>0.475</b>
15			<b>0.371</b>

There are also however still trends in variation that can be tracked in ordination space. There is a clear shift (Fig. 6) in sites along the second axis with almost all sites moving to the right. Because the position of sites in ordination space is determined by the abundance and proportion of taxa this indicates a general annual trend that further analysis would elucidate in terms of both taxa and in relation to associated habitat attributes. This also shows how the condition of a community shows a consistent trajectory in ordination space and can be a powerful graphical tool to plot recovery toward reference condition.

**Figure 6.** HMDS ordination of benthic invertebrate community data replicate samples for four far-field sites sampled over four years (2000 removed). Years are indicated by color and sites by symbols. Trajectories of each site are indicated by hand drawn arrows for each site.



Finally, the least variation occurs within a station in a single year (e.g., 16 in 2004 – red diamonds Fig. 7), and this pattern is the case for most sites. This lends support to the argument that in fact single grabs are probably representative and that taking multiple grabs is redundant.

In summary, such an analysis can clearly demonstrate that there is a hierarchy in the variation, with the greatest being variation across the years regardless of station, second is among station variation and the least within station variation. This provides valuable information that when considering any modifications to the sampling strategy.

As well as helping interpret community trends, both temporally and spatially, and response to exposure to discharges multivariate analyses could also be used to develop predictive models of taxa occurrence. This is a relatively straightforward process and was developed in the UK initially by Wright (2000), and later used extensively in Australia, Canada and the USA (Wright et al. 2000). In essence the procedure requires defining groups of sites based on the invertebrate fauna, along environmental gradients (usually natural gradients) and relating these groups to an independent set of habitat attributes. The relationship thus developed is used to calculate the probability of taxa occurrence for a given set of habitat attributes. Details of the methods are extensively described in (Bailey et al. 2004).

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In addition multivariate methods may help address the issue of sorting efficiencies in earlier years for example by using presence-absence transformation and could help clarify a temporal signal. While there are issues of misidentification and missing abundance dominants in such an analysis, exclusion of those taxa may do little to diminish the signal if those taxa have little information content (which can be verified within year) or through redundancy if other taxa contain that information. Regardless, such an approach may help identify long term patterns.

*22) Develop a database*

The data set is already extensive and is already beyond the column limitations (254) of normal Excel spreadsheets. It is strongly recommended that the GVRD invest in a relational database for storing both the biological and habitat data. Such a database should be taxonomically hierarchical so that biological data can be retrieved at various taxonomic levels and relational so that habitat (sediment chemistry, etc.) can also be retrieved for the same sites. This will allow relatively easy analysis and interpretation of interactions between the community and habitat. The database should also be designed so that taxonomic names are already included and data entry simply requires entering counts from bench sheets, thus avoiding spelling errors that can result in data errors. It can also be designed with upper and lower value limits thus avoiding some types of data entry error. Examples of such data bases that would be readily adaptable are that of Environment Canada BIRC database that operates on line or the EEM program database.

## **5.4. Adult Fish Survey**

Although this reviewer did not provide a separate section for recommendations, in the interest of consistency, the recommendations provided by this author in the response to questions section have been brought forward to this recommendation section.

*23) Frequency of the surveys*

With fish health assessments only being conducted every 5 years, it may be difficult to collect enough data to easily detect temporal changes. If sampling could be increased to every 3 years, or supplemented with additional data from other ambient monitoring surveys, that would be desirable, although surveys so far suggest that concentrations of most tissue contaminants, as well as lesion prevalence, are fairly low and show little temporal change. One option would be to do an abbreviated survey focusing on exposure measurements (e.g., bile metabolites and tissue chemistry) every three years, and full histopathological workup every five years.

*24) Modify fish handling and sample collection procedures*

Sample quality might be improved by using shorter trawls (~10 minutes) and a shorter holding period for fish before they are processed. This might reduce the prevalence of lesions such as epithelial lifting in the gills that was common in English sole from all sampling sites.

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### 25) Changes to the study design

It is recommended that the program be expanded to include some additional samples and measurements:

- The number of composite samples is fairly low (2 per sex per site), making statistical comparisons more difficult. Increasing the number of composites from two to three would be an improvement.
- Report lipid-adjusted values and consider including some discussion about what likely contaminant concentrations might be in other species with higher fat content, based on the English sole values. It will still be necessary to report wet weight data for comparison to benchmarks.
- Consider measuring contaminant concentration in fish stomach contents to obtain more data on what they are accumulating from local prey, and how well this correlates with contaminant body burdens and/or concentrations of contaminants bodily fluids (e.g., bile). This would help address concerns about whether effects on the target species are really representative of contaminant concentrations around the outfall, or if there is substantial exposure from other sources.
- Consider providing protein correction on bile samples since this correction can be useful to adjust for variability in PAH metabolite levels associated with the feeding status of the sampled fish.
- Consider determining the comparability of the analytical method for bile metabolites since this information would facilitate comparison of PAH exposure levels in the Iona outfall fish with those at other sites in Georgia Basin and Puget Sound.
- Consider calculating fish health indices on gutted weight because gutted weight could minimize variability associated with recent feeding or stage of reproductive maturity.
- Suggest calculating additional fish health indices such as liver somatic index, gonadosomatic index, and possibly spleen somatic index, as well as condition index. These additional indices could be obtained as part of the current sampling protocol with very little extra effort. Hepatosomatic or liver somatic index is widely used as an indicator of toxicant exposure, as liver hypertrophy is a common response to toxic compounds, while changes in spleen weight have been associated with immunotoxicity. Gonadosomatic indices would be useful for comparing effects on reproductive development of fish.

### 26) Adding a pelagic species

Investigate the feasibility of adding a pelagic, planktivorous fish species, if an appropriate one could be identified, as part of the core program should be investigated. If no suitable species can be identified (i.e., one that was abundant and large to provide tissue samples, and showed reasonable site fidelity) you might consider monitoring water column contaminants with semi-permeable membrane devices.

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## 5.5. Integration of Results

### 27) *Spatial documentation of sediment impacts*

There are excellent data on the sediment impact indicators along the 80-m contour. Better data are needed in the E-W direction on both impact indicators and the benthic infauna health to document the areal distribution of the outfall impacts. At least 4 or more transects should be monitored in detail in the vicinity where the maximum 80-m impacts are measured. This could be done by missing a year or two of monitoring the 80-m contour since it appears to show a fairly consistent pattern over the past few years and does not need to be monitored every year. If several vertical cores are also taken and measured for the predominant indicators such as nonylphenol and coprostanol, then a loading estimate can be made of these contaminants in the immediate impact area and estimates made of how contaminants are dispersed further into the Strait of Georgia.

### 28) *Tissue concentrations of contaminants in keystone species*

There are only one set of data on the distribution of contaminants in the tissues of the sole and crabs. Although there does not appear to be very large differences between reference and outfall area stations, there should be more data collected to confirm this conclusion. It would also be useful to collect these species for analysis from a couple of more pristine estuaries where the impacts of humans are very low. The possibility of measuring trace contaminants in some of the more abundant benthic infauna such as mussels and polychaetes which live in the sediments and are prey for the keystone species, should be investigated. With the importance of hormones in wastewaters demonstrated in the literature it would be very beneficial to determine if these keystone species are being affected. There are a variety of bioassays that can be used such as measurement of the egg protein, vitellogen, in male fish or the standard yeast bioassay.

### 29) *Working with the analytical laboratory to clear up some data irregularities*

Although the data collected are very extensive and of good quality for trace chemical determination, several irregularities were observed that should be cleared up or explained so that no concerns are left to question. See response to Question #37 in Section 4.6 (Pages 28 & 29) for specific details on these concerns.

### 30) *Cumulative effects of contaminants and contaminant bioavailability*

The organisms living in the sediments must react to or adapt to the whole suite of contaminants that are deposited in the sediments. However, when contaminant environmental impacts are often evaluated, they are done so by comparing them to individual sediment quality values such as PEL or ISQG values set out by CCME. A complete literature evaluation needs to be done to determine if techniques are available to better estimate cumulative effects. A paper showed that even though *Daphnia* were supposed to be healthy in a combination of trace metals below their supposed established healthy criteria, that there definitely were negative health impacts when all of

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these low levels of trace metals where together. Also, just because a contaminant is present in the environment does not mean that it is available to the organism and having an impact upon it. Again, the literature needs to be thoroughly searched to determine the best techniques to evaluate contaminant bioavailability. As mentioned in the answer to question 7, there are techniques such as semipermeable membrane devices which have proven useful in determining hydrophobic trace organic bioavailability. Also, complexing resins and trace metal geochemistry by selective extraction techniques have been demonstrated to be useful techniques to determine trace metal bioavailability.

The aforementioned recommendations are summarized and organized into Tables 6 and 7, respectively by recommendations that are program specific and those that are general in nature.

**Table 4. Summary of Monitoring Program Recommendations**

<b>Activity affected</b>	<b>Recommendations for Monitoring Program</b>	<b>Justification</b>
Modelling, sediment quality	Geochemical normalization with Al or Li for grain size effects for trace elements	To correct for grain size effects
Modelling, sediment quality, integration	Determine sediment accumulation rates and contaminant profiles; review type of corer used	Dated cores critical for determining contaminant fluxes and export of material from area monitored; consider using hydraulically damped corer
Modelling, benthos	Develop a database for the monitoring data, including previous cycles	Coupling a database to a GIS could facilitate analysis and interpretation of data
Sediment quality, benthos	Reduce frequency along 80-m transect	Temporal variation has been low; 80-m depth contour can be monitored every other year. Resources freed up can be used on cores or on the extra lateral lines
Sediment quality, benthos, integration	Add cross-shelf transects	Needed to determine spatial extent of effects; should be done once and a decision made about further sampling strategy
Sediment quality	Statistical treatment of results does not need to be so sophisticated	Van Veen grab tends to disturb the sediment at the time of sampling, the overall precision for organics, strongly limits the capacity to draw solid conclusions on temporal variations, especially over a period of 5 years
Sediment quality, benthos	Consider relaxing the positional accuracy requirement for sampling	Data suggest that the tolerance for sample site acceptance, 5 m, is too restrictive considering the scale of real spatial variability and the questions being asked
Benthos	Review Stations 13 and 14	Confounded sites to the south should probably be discarded in future. While there is no evidence that the effects observed at stations 13 and 14 are related to the discharge it would probably be prudent for the GVRD to determine potential causes.
Benthos	Use of multivariate methods in support of current methods	Further use of multivariate methods could extract more information about structure and variation of the benthic community over time and space
Benthos	Improve and simplify reporting of QA/QC data	Taxonomic quality data are hard to follow and need to be suitably summarized
Benthos	Articulate relationship between the design and the analysis and interpretation	Design and analysis should be completed integrated into the annual reports

<b>Activity affected</b>	<b>Recommendations for Monitoring Program</b>	<b>Justification</b>
Benthos	Discontinue or examine the implications of discontinuing biomass estimation	The data are not being substantially used and are not critical to describing the observed community effects
Benthos	Suggest holding an annual meeting for consultants and researchers involved in the monitoring, ambient and research partnership programs	An annual meeting would improve communication, raising the overall quality of the various program outputs
Benthos, fish health	Add local commercially-fished shrimp species for biomonitoring	There should be some integration between benthic community and species health/bioaccumulation effects. The latter may act as triggers for the former. Since the shrimp fishery is of some importance, it would seem appropriate to include the dominant shrimp in the fishery among the species health/bioaccumulation monitoring programs.
Fish health	Reduce fish trawl duration and shorten holding times	This might reduce the prevalence of lesions such as epithelial lifting in the gills that was common in English sole from all sampling sites
Fish health, integration	Perform additional, modified survey (e.g., bile metabolites and tissue chemistry) once per cycle	Better detection of temporal changes; gather data on new indicators of exposure and effect
Fish health	Increase number of tissue composites to three and report lipid adjusted values	Improve statistical analysis; enable comparison of data from other studies
Fish health	Consider measuring contaminant concentration in fish stomach contents	Could provide information to help determine if contaminant concentrations in fish represent an outfall signal or exposure from other sources
Fish health, integration	Consider adding additional fish health and exposure indicators to the current suite	To provide more information about the contaminants that are specifically associated with the outfall, such as alkylphenols, sterols and related compounds that are known to have estrogenic or endocrine disrupting activity
Fish health	Consider providing protein correction for bile metabolite analyses	Protein correction can be useful to adjust for variability in PAH metabolite levels associated with the feeding status of the sampled fish.
Fish health	Consider calculating additional fish health indices	Useful for indicating other types of effects
Fish health	Consider calculating fish health indices on gutted weight	Minimises variability related to feeding and reproductive status

<b>Activity affected</b>	<b>Recommendations for Monitoring Program</b>	<b>Justification</b>
Integration, fish health,	Enhancement of water column monitoring	Dissolved contaminants are released in the discharge; consider monitoring the water column with semi-permeable membrane devices

**Table 5. Summary of General Recommendations**

<b>Activity affected</b>	<b>General Recommendations</b>	<b>Justification</b>
Modelling	Estimate bottom shear stress over the model domain	Will help identify areas where fine sediments are exported
Modelling	Determine floc fraction and settling velocity	Correct values needed to determine net exports of particulates from monitoring area
Modelling	Determine suspension threshold for deposited sediments	Needed to determine the long term fate of material deposited at the Iona outfall
Sediment quality	Undertake scientific collaborations	Expertise of scientists could realized through the undertaking of collaborative studies
Benthos	Additional review before reducing scope of benthic program	The consequences of changing taxonomic level or sample replication cannot be recovered; therefore this option should be first considered by a review group with the appropriate biological and statistical expertise
Benthos	Determine adequacy of Reference Sites	In principle and theory this is highly desirable, but in practice this may not be attainable
Benthos, fish health	Add local commercially-fished shrimp species for biomonitoring	Since shrimps are a fishery of local interest, it is recommended that they be brought back into the Contamination and Health Studies.
Fish health	Investigate the feasibility of adding a pelagic, planktivorous fish species	Could provide information about contaminant exposure from suspended material in the water column, or through the planktonic food chain
Fish health	Consider determining the comparability of the analytical method for bile metabolites	This information would facilitate comparison of PAH exposure levels in the Iona outfall fish with those at other sites in Georgia Basin and Puget Sound
Integration, fish health, sediment quality	Survey literature to determine if techniques are available to better estimate cumulative effects and bioaccumulation potential	Address shortcomings in CCME guidelines; develop better predictors; There is a general feeling among scientists that CCME's sediment quality guidelines are unsatisfactory. May be better long-term just to quantify contaminant fluxes and biological effects

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## **Appendix A: Résumés of Reviewers**



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## Derek Ellis

Professor Emeritus Derek V. Ellis, Ph.D., R.P.Bio., is a marine benthic biologist, with 50+ years experience in field sampling, statistical analyses, and the sociological relevance of the biodiversity assessment of marine sediments and the intertidal zone. His research, and procedural and conceptual developments in the topics, has resulted in 100+ publications spanning 1955 – 2004 in refereed international journals. He was one of the authors of the 1984 Marine Benthos Methods Manual of the International Biological Program.

Dr. Ellis was a professor in the Biology Department of the University of Victoria 1964-1996, at which time he retired from full-time teaching. He has continued his research to date, and has acted as marine benthic consultant for a variety of government agencies and industries.

His marine benthic consulting has included being part of teams assessing the environmental effects of the placement of sewage, pulp mill effluents, and mining residues on the seabed. He played a substantial part in initiating the marine monitoring programs at the sewage outfalls of the Capital Regional District. He was a member of the Technical Advisory Panel at the Public Inquiry which led to the 1975 issue of Pollution Control Objectives for Municipal Type Waste Discharges.

He was trained in biodiversity assessment sampling and analytical methods at Edinburgh, McGill and Copenhagen Universities. He has applied these in arctic, temperate and tropical seas. His results have shown the impacts on seabed biodiversity of urban and industrial developments, and the rate and pattern of seabed recovery following the ending of environmental impact.

Dr. Ellis is a Registered Professional Biologist through the College of Applied Biology of B.C. He is an *ex officio* member of the College's Board of Directors, in his capacity as Chair of the College's Credentials Committee.

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I hold a B.Sc. in chemistry from Université du Québec à Montréal (UQAM) and a Ph.D. in oceanography from Université du Québec à Rimouski (UQAR). I am currently full professor at the Centre Eau, Terre et Environnement of the Institut national de la recherche scientifique, Université du Québec. From 1993 to 2002, I held a position of research scientist at the Maurice Lamontagne Institute of the Department of Fisheries and Oceans.

My main research activities focus on sediment diagenesis and on fluxes and pathways of chemical contaminants in lakes, coastal environments and in the Arctic Ocean. My work is based on observations of fine-scale distribution of trace metals, stable and radioactive isotopes and organic contaminants at the sediment-water interface. The modeling of these results allows one to identify point sources and non-point sources of contaminants in the aquatic environment.

## **Selected Publications**

- GOBEIL, C., B. RONDEAU et L. BEAUDIN. 2005. The contribution of municipal effluents to metal fluxes in the St. Lawrence River. *Environmental Science and Technology* 39: 456-464.
- GALLON, C., A. TESSIER, C. GOBEIL et M.C. ALFARO-DE LA TORRE. 2004. Modeling diagenesis of lead in the sediments of a Canadian Shield lake. *Geochimica et Cosmochimica Acta* 68: 3531-3545.
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## Kenneth JF Hall

Professor, Civil Engineering and Institute for Resources and Environment,  
Westwater Research Unit  
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Ken Hall is a full professor at the University of British Columbia, affiliated with the Department of Civil Engineering and at the Institute for Resource and Environment's Westwater Research Centre. His interests in environmental chemistry, environmental impact, and water resource management span several disciplines. He has worked with graduate students in the Departments of Zoology, Soil Science, Oceanography, Civil Engineering, Forest Science, Bioresource Engineering, Chemical Engineering, in the School of Community and Regional Planning, and at the Institute for Resources and Environment. Prof. Hall has worked extensively on the characteristics and effects of wastewater and is a member of the GVRD's Environmental Monitoring Committee.

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- Rohr, A.C., E.R. Hall and **K.J. Hall**. Use of Semipermeable Membrane Devices for Monitoring Pulp Mill Effluents: a Preliminary Assessment . *Water Qual. Res. J. Canada* 31: 85-100 (1996).
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### Education

B.S., Biology, Western Washington University, Bellingham, WA	1976
M.S., Fisheries, University of Washington, Seattle, WA	1996

Ms. Johnson is a zoologist at the NOAA Fisheries Northwest Fisheries Science Center in Seattle, Washington. She works in the Ecotoxicology and Environmental Fish Health program in the Environmental Conservation Division, as team leader for the program's Reproductive Toxicology Team. This team is one of several research groups within the Ecotoxicology Program, which studies the effects of chemical contaminants and related human activities on the health of marine organisms, and provides technical guidance to resource managers on how to protect marine animals from harmful impacts of toxicants. She works closely with the Washington State Department of Fish and Wildlife to monitor the health of Puget Sound marine fish as part of the Puget Sound Ambient Monitoring Project, and has been taken part in several studies in the Pacific Northwest and Canada to assess damages to marine resources associated with chemical contaminant inputs. Current projects include research on effects of estrogenic compounds on reproduction in Puget Sound flatfish. She is also involved in evaluations of water and sediment quality standards for their utility in protecting listed salmon and other fish species, and in studies to assess contaminant exposure and associated health risks in listed salmon stocks from Puget Sound and the Columbia River. Ms. Johnson earned a B.S. degree in Biology from Western Washington State University and an M.S. degree in Fisheries at the University of Washington. She joined the Division in 1984 as a member of the histopathology research team.

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### Selected Publications

- Lomax, DP, OP Olson, MS Myers, S. O'Neill, J West, and **L.L. Johnson**. 2005. Xenoestrogen Exposure and Effects in English Sole (*Pleuronectes vetulus*) from Puget Sound, WA. (in prep).
- Olson, OP, **L.L. Johnson**, GM Ylitalo, CA Rice et al. 2005. Fish Habitat Use and Chemical Contaminant Exposure at Restoration Sites in Commencement Bay, Washington. NOAA Tech. Memo (in prep)
- Johnson, LL**, GM Ylitalo, J. Buzitis, J. Bolton, T. Lundrigan, B. Anulacion, D. Boylen, M. Arkoosh, AN Kagley, C. Stafford, and T.K. Collier. 2005. Contaminant Exposure

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## Timothy G. Milligan

Timothy G. Milligan is a researcher with the Marine Environmental Sciences Division, Fisheries and Oceans Canada. As head of the Particle Dynamics Lab at the Bedford Institute of Oceanography he leads the group's research into the behaviour of fine particulate material in aquatic environments. He received his BSc in Geology and MSc in Oceanography from Dalhousie University and has been involved with the study of flocculation and its role in sediment transport for over thirty years. Areas of interest include the mechanisms governing the loss of sediment from river plumes, the effect of flocculation on the transport and fate of contaminants, and environmental impacts of offshore oil and gas and aquaculture. Mr. Milligan has led research projects in a wide range of geographical areas, from the Amazon to the Canadian Arctic. While his work concentrates mainly on the marine environment, the fate of terrestrially derived sediments and associated contaminants has led him into the study of fluvial transport as well. Mr Milligan has been involved in many international ventures, several of which have received funding from the US Office of Naval Research. His work combines in situ techniques with process based parameterization of the size distributions of the component grains in suspended and bottom sediment to better understand the fate of mud in both marine and freshwater systems. Over 80 peer reviewed primary publications, book chapters and technical reports have been produced from this work.

### Selected Publications

- Milligan, T.G., T. Tedford, D.K. Muschenheim, and C.G. Hannah. 2005. Quantifying fine-grained drill waste in Scotian Shelf suspended sediments. In: S.L. Armsworthy, P.J. Cranford, and K. Lee (Eds.), *Offshore Oil and Gas Environmental Effects Monitoring: Approaches and Technologies*. Battelle Press. pp. 201-226
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- Mikkelsen, O.A., T.G. Milligan, P.S. Hill, and D. Moffatt, 2004. INSSECT - an instrumented platform for investigating floc properties close to the seabed. *Limnology and Oceanography Methods*, 2: 226-236.
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- Curran, K.J., Hill, P.S., and Milligan, T.G. 2002. The role of particle aggregation in size-dependent deposition of drill mud. *Continental Shelf Research*. 22(3):403-414.
- Milligan, T.G., G.C. Kineke, A.C. Blake, C.R. Alexander and P.S. Hill. 2001. Flocculation and sedimentation in the ACE Basin, South Carolina. *Estuaries*, 24(5): 734-744.
- Blake, A.C., G.C. Kineke, T.G. Milligan and C.R. Alexander, 2001. Sediment trapping and transport in the ACE Basin, South Carolina. *Estuaries*, 25(4): 721-733.
- P.S. Hill, T.G. Milligan and W.R. Geyer, 2000. Controls on effective settling velocity of suspended sediment in the Eel River flood plume, *Cont. Shelf Res.* 20, 2095-2111
- W.R. Geyer, P.S. Hill and T.G. Milligan, 2000. Fluid and sediment dynamics in the Eel River flood plume, *Cont. Shelf Res.*, 20, 2112-2120.
- Christiansen, T, P.L. Wiberg and T.G. Milligan, 2000. Flow and sediment transport on a tidal salt marsh, *Estuarine Coastal Shelf Sci.* 315-331.
- Muschenheim, D.K. and T.G. Milligan, 1999. Benthic Boundary Layer Processes and Seston Modification in the Bay of Fundy (Canada), *Vie et Millieu*, 48(4), 285-294.
- Milligan, T.G. and P.S. Hill, 1998. A laboratory assessment of the relative importance of turbulence, particle composition, and concentration in limiting maximal floc size and settling behaviour, *J. Sea Res.* 39/3-4, 227-241.
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- Berhane, I., R.W. Sternberg, G.C. Kineke, T.G. Milligan and K. Kranck, 1997. The variability of suspended aggregates on the Amazon continental shelf. *Continental Shelf Research*, 17(3), 267-286.

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- Hargrave, B.T., G.A. Phillips, L.I. Doucette, M.J. White, T.G. Milligan, D.J. Wildish and R.E. Cranston, 1997. Assessing benthic impacts of organic enrichment from marine aquaculture, *Water Air and Soil Pollution*, 99, 641-650.
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- Milligan, T.G., 1996, In-situ particle (floc) size measurements with the Benthos 373 plankton silhouette camera, *J. Sea Res.*, 36, 93-100.
- Milligan, T.G., 1995, An examination of the settling behaviour of a flocculated suspension, *Neth. J. Sea Res.*, 33(2), 163-171.

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## Trefor B. Reynoldson

Trefor Reynoldson received his Ph.D. from the University of Lancaster, UK in 1983 and his M.Sc. in aquatic ecology from the University of Calgary in 1974. He was a Research Scientist at the National Water Research Institute from 1987 until his retirement in 2004. He is now a research associate located at Acadia University in Nova Scotia and is the coordinator of the North American Benthological Society's Taxonomic Certification program. His research is directed at developing improved techniques for using benthic invertebrate assemblages in diagnostic environmental assessment, and the Reference Condition Approach that he formalised is the basis of a national biomonitoring network for Canada (<http://cabin.cciw.ca/cabin>). He has over 90 publications and reports. Dr Reynoldson's expertise lies in the application of multivariate statistical methods to analysis of invertebrate community structure data, and to linking effects at the community level to organism (e.g. survival, growth, reproduction) and sub-organismal (e.g., porphyrin, metallothionein) levels in benthic macroinvertebrates. He has also worked in developing numeric biological criteria for both invertebrate communities and laboratory tests with invertebrate species.

### **Selected Publications**

- Reynoldson, Trefor B. 1996. Managing collaborative research between practitioners and researchers: a personal experience. *Managing Collaboration for Scientific Excellence: a workshop held at University of Canberra, February 1996*. CRC for Freshwater Ecology, Belconnen, ACT, Australia.
- Krantzberg, G, R. Jaagumagi, T.B. Reynoldson, D. Bedard, S. Painter and H. Ali. 1996. Setting environmental decisions for sediments. Prepared for the COA remedial action plan steering committee.
- Reynoldson, Trefor B. 1996. Managing collaborative research between practitioners and researchers: a personal experience. *Managing Collaboration for Scientific Excellence: a workshop held at University of Canberra, February 1996*. CRC for Freshwater Ecology, Belconnen, ACT, Australia.
- Krantzberg, G, R. Jaagumagi, T.B. Reynoldson, D. Bedard, S. Painter and H. Ali. 1996. Setting environmental decisions for sediments. Prepared for the COA remedial action plan steering committee.
- Reynoldson, T.B. 1996. Sampling strategies and practical considerations in building reference data bases for the prediction of invertebrate community structure. In *Study design and data analysis in benthic macroinvertebrate assessments of freshwater ecosystems using a reference site approach*. Technical Information Workshop. NABS 44th Annual Meeting. Eds. R.C. Bailey, R.H. Norris and T.B. Reynoldson.
- Day, K.E., Reynoldson, T.B. and Rosenberg, D.M. 1996. The reference condition: implications for biomonitoring of water and sediment quality in Canada. *Learned Discourse*. SETAC News.
- Reynoldson, T.B. and K.E. Day. 1997. Collingwood Harbour: sediment assessment 1995. NWRI Report No. 97-. 9 pages.

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**Appendix B: Workshop Agendas, Peer Review Report as well as  
Review and Presentation Materials on CD-ROM**



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**Greater Vancouver Regional District  
Cycle 3 of the Iona Deep-Sea Outfall Environmental Monitoring Program**

***Agenda for Reviewers' Evening Meeting***

**Delta Vancouver Airport Hotel; Bristol Room  
May 3, 2005**

18:30	Arrival
18:45	Group introductions
19:00	May 4 workshop procedures
19:15	Working dinner
19:45	Options for discussion with presenters after the May 4 workshop
20:00	Post-workshop reporting process
20:15	Date for conference call
20:20	Roundtable discussion

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**Greater Vancouver Regional District**

***Draft Workshop Agenda***

**Peer Review of Cycle 3 of the Iona Deep-Sea Outfall Environmental Monitoring Program**

**Delta Vancouver Airport Hotel; Bristol Room**

*May 4, 2005*

08:00	<i>Coffee and muffins</i>	
08:30	Welcome and introductions	<i>Bob Wilson, 2WE Associates Consulting Ltd</i>
08:45	History of the Iona Deep-Sea Outfall Environmental Monitoring Program & related programs	<i>Stan Bertold, Greater Vancouver Regional District</i>
08:55	GVRD's Cautions, Warnings and Triggers Process: how monitoring data are used	<i>Albert van Roodselaar, Greater Vancouver Regional District</i>
09:35	Overview of Cycle 3 of the routine monitoring program	<i>Cathy McPherson, Golder Associates Ltd</i>
10:00	<i>Break</i>	
10:20	Field activities, sample collection, sample transmission to the laboratories	<i>Len Fanning, Integrated Resource Consultants Ltd</i>
10:50	Benthic sample processing and taxonomic identification process	<i>Val Macdonald, Biologica Environmental Services Ltd</i>
11:25	Effluent plume model and solids deposition	<i>Don Hodgins, Seaconsult Marine Research Ltd</i>
12:10	<i>Working Lunch</i>	
13:00	Sediment chemistry data analysis and findings	<i>Michael Paine, Paine, Ledge &amp; Associates</i>
14:00	Benthic community data analysis and findings	<i>Brenda Burd, Ecostat Research Ltd</i>
15:00	<i>Break</i>	
15:20	2001 Crab & Fish Health Study	<i>Dawna Brand, Independent Histology Consultant</i>
16:05	2001 Bioaccumulation Assessment	<i>Cathy McPherson Golder Associates Ltd</i>
16:25	Outstanding scientific questions and concerns	<i>Cathy McPherson and Peter Chapman, Golder Associates Ltd</i>
16:45	Open discussion	
17:15	Wrap-up	<i>Bob Wilson, 2WE Associates Consulting Ltd</i>



Greater Vancouver Regional District  
LWMP Environmental Management

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FINAL REPORT

**PEER REVIEW OF CYCLE 3 OF THE  
IONA DEEP-SEA OUTFALL  
ENVIRONMENTAL MONITORING PROGRAM**