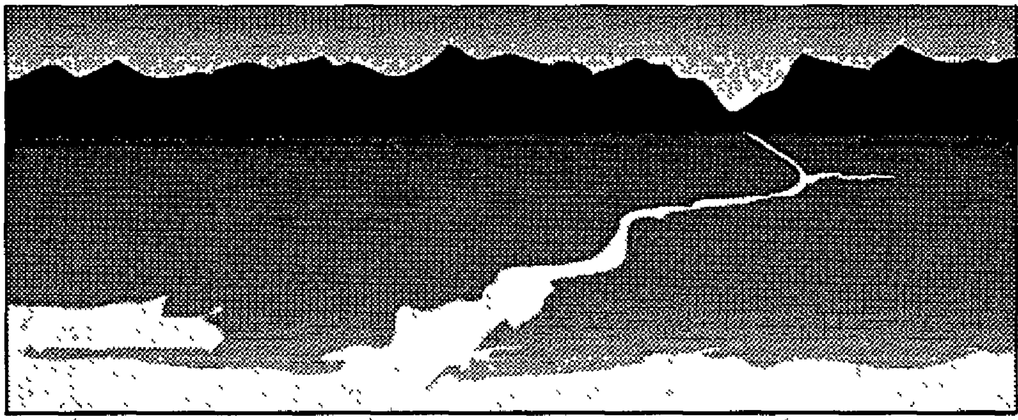
FINAL REPORT
8526-04

LOWER COLUMBIA RIVER



BI-STATE PROGRAM

RECONNAISSANCE SURVEY OF THE LOWER COLUMBIA RIVER

TASK 4: RECOMMENDED BIOLOGICAL INDICATORS FOR THE LOWER COLUMBIA RIVER

JUNE 1992

Prepared By:
TETRA TECH

In Association With:
EVS CONSULTANTS
DAVID EVANS AND ASSOCIATES

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Prepared For:

The Lower Columbia River
Bi-State Water Quality Program

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EXECUTIVE SUMMARY

The Lower Columbia River Bi-State Program was formed at the direction of the legislatures from the states of Oregon and Washington to assess environmental conditions of the lower Columbia River from Bonneville Dam (RM 146) to the mouth of the river The Bi-State Steering Committee identified seven tasks to be completed during the first year of the program Each task addresses separate, but interrelated, goals Task 4 provides recommendations on the biological indicators that would be most useful in a long-term monitoring program for the lower Columbia River The results of the reconnaissance survey were used to refine the initial information about candidate biological indicators (Tetra Tech, 1992) to produce a list of final recommendations that are most appropriate for conditions in the lower Columbia River This final report summarizes those recommendations

Many test organisms and endpoints were reviewed and evaluated prior to selecting those most appropriate for use in the lower Columbia River Criteria used to select biological indicators included occurrence in the lower Columbia River, sensitivity to substances of concern, availability of established test procedures, ease of performance, and ease of interpretation of results. Recommended biological indicators include both exposure and response indicators Exposure indicators consist of bioaccumulation (contaminant residues in tissues) and physiological measurements (detoxification enzyme production). They provide information regarding the presence of specific contaminants within the river and the potential for magnification of these contaminants in the food chain. However, they do not provide information regarding subsequent biological or ecological effects because some contaminants can be accumulated without invoking adverse effects Response indicators are used to address the effects associated with exposure The recommended response indicators consist of reduced survival, impaired growth, and physiological measurements (fish health index and detoxification enzyme production). Although reduced survival, impaired growth, and the fish health index are not contaminant-specific responses, they can be used to demonstrate that effects are occurring because of exposure to a substance or condition. Detoxification enzymes can be used to demonstrate exposure to specific contaminants and that this exposure is causing an effect

The following biological indicators are recommended to evaluate contaminants in the water column and sediments in the lower Columbia River:

Freshwater Water Column

- Survival, growth, and bioaccumulation in transplanted bivalves (i e , *Corbicula fluminea*)
- Bioaccumulation measurements in resident fish species [e g , peamouth (*Mylocheilus caurinus*), bass (*Micropterus* spp.), and crappie (*Pomoxis* spp.)]
- Physiological measurements (Fish Health Index and detoxification enzymes) in resident fish (same species used in bioaccumulation studies)

Freshwater Sediments

- Survival, growth, and bioaccumulation in transplanted bivalves (i e., *Corbicula fluminea*)
- Survival of endemic amphipods (e g , *Corophium salmonis*)
- Bioaccumulation measurements in resident amphipods (e g., *Corophium salmonis*), crayfish (e g., *Pacifastacus leniusculus*), bivalves (e g., *Corbicula fluminea*), and fish species [e.g., carp (*Cyprinius carpio*), largescale sucker (*Catostomas macrocheilus*), white sturgeon (*Acipenser transmontanus*)]
- Physiological measurements (Fish Health Index and detoxification enzymes) in resident fish (same species used in bioaccumulation studies)

Estuarine Water Column

- Survival, growth, and bioaccumulation in transplanted bivalves (i.e., *Mytilus* spp.)
- Bioaccumulation measurements in resident fish species [e.g., peamouth (*Mylocheilus caurinus*)]

- Physiological measurements (Fish Health Index and detoxification enzymes) in resident fish (same species used in bioaccumulation studies)

Estuarine Sediments

- Survival, growth, and bioaccumulation in transplanted bivalves (i e , *Macoma* spp)

- Survival of endemic amphipods (e g , *Eohaustorius estuarius*)

- Bioaccumulation measurements in resident clams (e.g , *Macoma* spp) and fish [e g , starry flounder (*Platichthys stellatus*)]

- Physiological measurements (Fish Health Index and detoxification enzymes) in resident fish (same species used in bioaccumulation studies)

The recommended monitoring approach for the lower Columbia River is based on two types of field studies conducted with a variety of species representing different positions in the food chain. This multi-species, field-oriented approach will provide environmental realism and permit experimental control The first type of study involves collecting resident species directly from the sites in the lower Columbia River that are to be evaluated as part of the monitoring program. This approach cannot always be used because of the potential inability to collect a sufficient number of individuals from each of the monitoring locations for the respective chemical and biological tests The second type of study involves collecting resident species from areas of the river that are considered uncontaminated and transplanting the animals to sites in the lower Columbia River that are to be evaluated as part of the monitoring program This approach offers much more control and has the ability to reduce the variability associated with the former approach The resulting database of information will permit formation of rigorous ecological conclusions regarding the quality of the lower Columbia River Standardized laboratory tests conducted using effluents and sediments collected from the lower Columbia River are possible alternatives that should be considered to address specific concerns or sites

The recommended biological monitoring program would be of greatest value if conducted at least twice yearly to address some of the seasonal variability in river conditions and contaminant inputs. Monitoring events should reflect extreme flow conditions in the river (i e , high and low flow periods). The April to May period would be appropriate to monitor high flow conditions associated with spring rains and snow melt Low flow conditions could be expected during August or September The data would be evaluated after each monitoring event to determine the impact of extreme conditions on results If the results indicate few seasonal differences in contaminant effects, then monitoring frequency should be reduced to once per year It is recommended that annual sampling occur in the fall because this time period probably represents worst-case conditions, the majority of test organisms are available, and deployment of caged animals for exposure and survival studies can be easily performed

ACKNOWLEDGEMENTS

We wish to acknowledge the efforts of the many people that contributed to this report including Ms Sandra Salazar (EVS, primary author), Dr Mark Munn (U S Geological Service), Ms Nancy Musgrove (EVS), and Ms Dena Hughes (EVS) We thank Drs Steve Ellis (Tetra Tech), Ted Turk (Tetra Tech), and Bob Dexter (EVS) for their technical review and comment In addition, Dr Rick Swartz (U. S. EPA) and Mr Bob Emmett (NMFS) provided useful information and suggestions. Final thanks to Ms. Cordelia Shea, Mr Neil Aaland and members of the Bi-State Steering committee for their support and guidance

1.0 INTRODUCTION

The lower Columbia River is a physically dynamic system The habitats common along the lower 146 miles include the turbulent main channel where freshwater is transported to the Pacific Ocean, quiet backwaters and sloughs, brackish water transition zones, and a marine estuary. Each of these major habitat types is populated by a unique assemblage of plant and animal species The lower Columbia River also supports a diverse array of anthropogenic activities, including industry, agriculture, shipping, and recreation The primary goals of the four-year Lower Columbia River Bi-State Program, formed at the direction of the legislatures from the states of Oregon and Washington in January, 1990, are to identify water quality problems, determine which beneficial uses are impaired, and develop solutions to problems identified in the lower portion of the river During this first year, emphasis has been placed on establishing the technical framework for determining the environmental health of the lower Columbia River

The water quality characterization study for the lower Columbia River is in progress. Several of the tasks have been completed, including the initial data review and synthesis, an inventory and characterization of pollutant sources, a review of physical and hydrological characteristics, preliminary evaluation of candidate biological indicators and monitoring approaches, and the identification of beneficial uses and sensitive areas. This report represents one of the final tasks associated with this water quality characterization effort — to review the data collected as part of the reconnaissance survey and use that information to recommend appropriate biological indicators to support a long-term monitoring program for the Lower Columbia River

2.0 OBJECTIVES

There are two objectives for Task 4 The first is to review and summarize data about the benthic taxa and contaminants identified in sediments collected from the lower Columbia River during the reconnaissance survey In addition, the candidate biological indicators presented in the document titled "Reconnaissance Survey of the Lower Columbia River, Task 4: Review of Biological Indicators to Support Recommendations on a Biological Monitoring Approach" (February, 1992) will also be summarized. The second objective is to integrate this information and provide the Bi-State Steering Committee with final recommendations of biological indicators that would be most useful and applicable for long-term water quality monitoring in the lower Columbia River

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July 9, 1992

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Subject Submittal of Final Task 4 Report
Recommended Biological Indicators for the Lower Columbia River

Dear Neil and Cordy

Enclosed for each of you are three (3) bound copies and one (1) unbound copy of the above-referenced final report This report was prepared primarily by EVS Consultants, with some sections and overall review provided by Tetra Tech The report responds to and incorporates, as we felt was appropriate, the comments received from the Bi-State Program The disposition of each comment is described below A numbered list of comments is attached for your reference

Comment No	Disposition
1	Sentence has been rewritten
2	The difference has been defined
3	It was decided that this reference to the funding entities was not needed
4	Phrasing has been changed
5	Change was made
6	Reference to Appendix A clarified.
7	Reference to the report clarified
8	Examples provided
9	Corrected
10	Correction made
11	Species distribution and abundances were analyzed in the Task 6 Report It is not the purpose of the report on biological indicators to address the issues discussed in this question

13. The information provided in Section 5 of the report on "Recommended Biological Indicators for the Lower Columbia River" is in summary format; for specific details regarding numbers and frequencies of occurrences, please refer to the appropriate task reports (e.g., Task 6). The wording has been changed to reflect the concerns.

14. Corrected.

15. Crayfish are not fish; they are invertebrates. "other" is not the appropriate term. "some" has been inserted before "fish tissues contained..."

16. The sentence was rewritten.

17. No. The purpose of this report is to provide recommendations on procedures that can be used to evaluate areas of the Lower Columbia River that are of concern. Recommendations for future studies are addressed in the Task 7 Report: "Conclusions and Recommendations."

18. The recommended studies are applicable for both near-term and long-term assessment of the river and estuary. Different parts of the river can be compared with data collected simutaneously; long-term effects or conditions can be assessed by tracking a particular site over time.

19. A table has been prepared.

20. We would prefer to address comparative costs in a future scope of work; relative importance has been addressed in the table prepared above (#19).

21. The overall preference would be to use resident taxa (i.e., collected from the lower Columbia River) taxa. Transplant studies would be proposed if a sufficient number of organisms is unavailable from the river. Transplant studies are often conducted with animals collected from a different location, including animals provided by commercial suppliers located in different geographical regions. An acclimation period can be used if exposure conditions are considerably different. However, it is not expected that animals collected from other areas (e.g., Willapa Bay, Puget Sound) will be under significant physiological stress due to transplanting and confound the test results.

22. It is highly unlikely that a given species can be used to evaluate all habitats in the lower Columbia River. There are some species that can tolerate a wide range of salinities and have been successfully used as biological indicators (e.g., *Corophium salmonis*). It is recommended that the proposed species be used in as many habitats and under as many conditions as possible. However, this can only be useful if the physical exposure conditions do not introduce additional stress that confounds the results. Additional species can be considered for inclusion in the program. Our overall approach is to maximize the utility of recommended species. The species recommended in our report have broad distributions in the lower river and occur in high enough densities for monitoring work.

23. References have been provided.

24. Section has been rewritten.

25. *M. balthica* is also appropriate for use in the monitoring program; it has been included in the discussion.

26. Size information has been provided in the table.

27. Discussion on salinities has been clarified.

28. Details for individual study approaches will be developed within scopes of work after it is decided which studies will be included in the monitoring program.

29. The report recommends *Mytilus* spp.; not specifically *Mytilus edulis*. Other *Mytilus* species are appropriate (e.g., *Mytilus trossolus*, *Mytilus galloprovencialis*) and occur in the lower Columbia River. According to Dr. Kenn Brooks, *M. trossolus* has adequate distribution in the lower Columbia River for inclusion in the monitoring program.

30. Reference to Scope for Growth has been deleted.

31. Neoplasia has been defined.

32. See 25.

33. Corrected.

34. Selective bioaccumulation has been referenced and an example of selective bioaccumulation has been provided.

35. Stressor is a commonly used and accepted scientific term defined as something that causes stress.

36. Verb tense has been changed.

37. More information has been provided.

38. The EROD discussion has been expanded.

39. "Clean areas" have been defined.

40. Okay.

41. Corrected.

42. Monitoring should be related to conditions in the river as well as season. While it is desirable to collect samples as frequently as possible, multiple-season sampling may not be cost effective for a long-term program of limited means.

43. The first paragraph of the summary has been rewritten.

44. Order has been changed.

45. Corrections have been made.

46. Correction has been made.

47. This sentence has been reworded.

48. The sentences have been deleted.

49. Complete, unabbreviated titles have been provided. However, it should be pointed out that the abbreviations used are accepted by both the scientific community and Council of Biological Editors.

50. The Abaychi is correct as it stands; the title does not have any words missing; typographical errors have been corrected.

We trust that the report meets with your approval, and we look forward to continued progress on this project If you have any questions about this report, please contact me at (206) 822-9596, or Nancy Musgrove of EVS at (206) 328-4188.

Sincerely,

Ted R Turk, Ph D.
Project Manager

TRT/lmf
enclosure

Comments on Task 4 Report: Recommended Biological Indicators for the Lower Columbia River

Generally the reviewers found the proposed studies to be reasonable for the lower Columbia River and overall did not have major problems with the report. Nevertheless, there are comments and suggestions, as provided below. In addition to the more substantive comments, typographical and grammatical errors and suggestions for phrasing are pointed out as noticed. This is not exhaustive and we trust that the report will be reviewed by an editor.

A general note on presentation. All the reports for this project face a similar difficulty -- being a solid scientific report that is also understandable to a lay audience. The comments below will identify some areas where terms need additional explanation or the text appears to assume more knowledge than some readers may have. Conversely, there also are comments noting the need to be more specific in use of terms such as "generally," "sometimes," etc.

<u>Specific Comments</u>

1. p. iii.- Para.2. What do you mean by "relevance to the lower Columbia River?" Please be clearer, more specific.

2. p.v. - The first full paragraph refers to "resident and transplanted, native species." Please explain (briefly!) "transplanted" and "native" in this context.

3. p.1. - Para. 1. Program participants (i.e., state agencies and the steering committee representing diverse interests) should be highlighted, with funding entities being secondary, given the role of the Committee in advising on the study.

4. Para. 2., line 6. This report is not intended to summarize the reconnaissance survey data, but to use the data and make recommendations on indicators. The phrasing is somewhat misleading.

5. p.3. - 3rd bullet. Specify that benthic organism tissue (which could fall under "biological tissues") was not measured for contamination. Only fish tissue was measured.

6. p.4. - Para. 1. It is not clear what report includes Appendix A, particularly because this paragraph begins on page 3 discussing "This report."

7. p.5. - Reference to "Task 4 Report" needs to be more complete. There have been multiple reports under this task.

8 Para. 2. The explanations of exposure and response indicators would benefit from examples of studies (e.g., exposure indicators include testing tissue for chemical residues; response indicators include bioassays, subjecting organisms to contaminated water or sediment and recording the response in terms of death, changes in growth, reproduction, etc.)

9. p.7. - Line 2. Long-<u>term</u> monitoring?

10. p.8. - Sec. 5.1, line 5. Second "station" should be plural.

11. Regarding stations where species were abundant, is there any additional information that can be provided about the stations (e.g., were they distributed throughout the river or located near to each other, particular features of the stations, etc)?

12. p.9. - Sec. 5.2. Please use adjectives such as "only," "some," "frequently," "infrequently," etc., sparingly (if at all) and with clear support. Provide numbers (e.g., how many samples were measured for zinc and in how many of those samples was it detected?). Same with phrases such as "In general, semivolatile ....compounds...were not detected..."

13. p.10. - Last sentence before section 5.2.3. Delete "Again"; begin with "No data..."

14. Sec. 5.2.3, line 2. Capitalize crayfish.

15. p. 11. - Para.2. In the first line, please add "other" before "fish tissues contained..." The last sentence should be rephrased. We suggest: "One PCB, Aroclor 1254, was detected in white sturgeon."

16. p. 12. - Para.2. Need more explanation about contaminants of highest concern. There are a number of factors that would make contaminants of highest concern, in addition to frequency of detection. Who has determined that they are of highest concern? This perhaps should be phrased differently.

pp. 12+ - Questions and comments on this section, generally.

17. a. Is it possible to provide some indication of locations (or types of locations) for the recommended studies?

18. b. Are some of the recommended studies more appropriate for near-term and others more for long-term assessment of the river and estuary? Please distinguish where appropriate.

19. c. It would be helpful to have some kind of table/chart that summarizes all of the studies that are recommended.

20. d. Some estimate of the cost of the various studies, and some indication of relative importance of the studies, are needed for establishing priorities and selecting recommended studies.

21. e. Reviewers raised concerns about bringing in species from other areas (e.g., Willapa Bay, Puget Sound). The primary concern is that test results may be confounded by the fact that the species are not adapted to Columbia River conditions. Please address this concern.

22. f. It was recommended that the same species be used in assays of both freshwater and estuarine habitats where feasible. Corophium salmonis would be viable in both, as would Mylocheilus caurinus, except in the most euhaline areas. Other species suggested as highly viable candidates: Gasterosteus aculeatus (threespine stickleback) and Leptocottus armatus (Pacific staghorn sculpin)

23. g. It was suggested that the report could be improved by including the best technique reference for the various indicators. Examples provided for amphipod sediment toxicity tests are:

- American Society for Testing and Materials, 1990. Guide for conducting 10-day static sediment toxicity tests with marine and estuarine amphipods. American Society for Testing and Materials, Philadelphia. ASTM Standard Methods Series. E 1367-90.

- American Society for Testing and Materials, 1990. Guide for conducting sediment toxicity tests with freshwater invertebrates. American Society for Testing and Materials, Philadelphia. ASTM Standard Methods Series. E 1383-90.

- American Society for Testing and Materials, 1991. Guide for collection, storage, characterization, and manipulation of sediments for toxicological testing. American Society for Testing and Materials, Philadelphia. ASTM Standard Methods Series. E 1383-90.

24. p. 13. - End of para. 1. There seems to be an abrupt transition here from stating why field studies are preferable to laboratory bioassay to recommending two sediment

laboratory bioassays.

25 p. 14. - It has been recommended that Macoma balthica would be preferable to Macoma nasuta for the lower Columbia River estuary. M. nasuta is not normally found in the estuary and typically requires consistently higher salinities than are found in the estuary. M. balthica is common in the estuary and there may be more information available about it.

26 p.15. - Sec. 6.1.1. What size are the adult Corbicula fluminea? Similar information should be provided for all target species as available.

27 pp.15,16- The discussion of salinity levels is a bit confusing for the lay reader. In particular, the environment description at the beginning of section 6.1.1 identifies freshwater as salinities < 15 ppt. The third paragraph on page 16 then identifies estuarine (as distinct from freshwater) portions of the river as <15 ppt. Please clarify.

28 Also, please explain more about the types of studies and how they would be carried out. For example, in this section there are references to bioaccumulation studies. Please explain (briefly) what they are (e.g, measuring the tissue for levels of contaminants).

29 p.17 - Sec. 6.1.2. It was suggested that Mytilus edulis would be a poor indicator for the lower Columbia River because of its natural, limited distribution.

30 What are Scope for Growth measurements?

31 What is neoplasia and why is it of concern?

(Again, since this needs to be a scientific report that is understandable for a lay audience, please add brief explanations of terms.)

32 p. 18 - See earlier comment on recommended species (p. 14).

33 p. 19 - Is the plural of protocol spelled with or without an 's'? Please use consistently.

34 p. 21 - End of sec. 6.2. More explanation and references are needed regarding selective bioaccumulation in fish and the results from the reconnaissance survey that indicated selective accumulation.

35 p. 22 - Line 2. Stressor? It isn't in Webster's!

36. Last two paragraphs. No decisions have been made about studies to be done. Please rephrase from "will provide" and "will be used."

37. Para. 4. Please provide a little more information about the Fish Health Index. What are components of the index? What are examples of things seen in the autopsy?

38. Para. 5. How would you recommend that EROD be performed in conjunction with tissue residue analysis? Why both? What information will they provide and why is it appropriate for this study?

39. p. 24 - Para. 1. Please add some discussion of "clean" areas. How would they be identified? How confident are you that clean areas can be found?

40. Sec. 6.5, generally. While reviewers generally agreed with the decision not to pursue population and community-level indicators, it was with some qualification. One reviewer felt that recommended indicators "are appropriate and expedient for the rather narrow objective of monitoring the bioaccumulation and trophic transfer of chemical contaminants...in water column and sediments...It seems self-evident that in order to demonstrate whether the biota of the river is being impacted it is necessary to monitor community-level parameters." Another reviewer, while accepting the argument against population and community surveys, did suggest screening the contents of a single 0.06 m2 grab through a 1.0 mm screen to check for the presence/absence of <u>Eohaustorius estuarius</u> and <u>Corophium salmonis</u>. He felt that the presence of amphipods is a good indicator of ecological health and that their presence would "generally eliminate the need for the amphipod sediment toxicity test" unless the amphipods had acclimated to sediment contamination.

41. Para. 3. Suggest changing "and ranged" in line 6 to "ranging."

42. p. 25. - Sec. 6.6. One reviewer suggested rethinking when monitoring should occur. His comments are summarized below:

[Take into consideration data on long-term, seasonal datasets and on biological events and chronologies in the system. There are datasets (e.g., CREDDP studies, as reported in Prog. Oceanogr. 25[1-4], 1990) that show high flow period as mid-May to mid-June and fall, low-flow spanning from September to October. Also, fall low-flow may miss many sensitive biological events, such as recruitment of biological populations. It may be worth questioning the assumption that monitoring has to occur at the same time every year. There are reasonable scientific arguments for distributing sampling throughout the year. Extended, low intensity monitoring may be more sensitive than one-time, intense sampling.]

Please consider and address appropriateness. Time and financial constraints may argue against this for the Bi-State Program, but perhaps these could be addressed in recommendations for long-term monitoring.

43. pp. 27+ While the rest of the report is generally well-written and clear (notwithstanding the need for explanations of some technical terms), the summary is disjointed, poorly written and difficult to understand. There are some odd word choices and phrasing, beginning with the first two sentences. Many readers would pause on the use of "unrestricted;" while probably technically correct for the river below Bonneville, the water coming into the lower river has been severely restricted and the flow in the lower part is affected by this control. There are many other examples in the first paragraph, but because it was so awkward to read it is difficult to even make suggestions.

44. In the transition from the second to the third paragraphs, be consistent in the order of discussion of exposure and response indicators from one paragraph to the next.

45. Para. 3. What are the "marine portions of the river?" Is this intended to be estuarine portions of the river, or marine portions of the estuary? Also, do not use "will" as used in lines 8 and 9. No decisions have been made.

46. Para. 4. Enumeration? Maybe you mean evaluation? Line 6: be cautious about the use of the word "best" and define what you mean by "best" if it must be used.

47. Regarding "little seasonal variability" -- how much sampling (or how many sampling events) would be needed to determine this?

48. Last para. Delete the last two sentences. They are inappropriate for this type of report.

49. p. 30. - Sec. 8, References. Please provide complete, unabbreviated titles for journals.

50 There appears to be some typographical errors in this

section (e.g., words missing, letters missing. See Abaychi, 1988 and Graney, 1983 as examples.). Please review.

3.0 APPROACH

The following steps were taken to accomplish the objectives of Task 4

- Review the pertinent literature and interview scientists with experience and expertise in the development and use of biological indicators

- Review the distribution and abundance of species in the lower Columbia River identified during the Reconnaissance Survey

- Review the contaminants measured in sediments and tissues of fish and crayfish collected from the lower Columbia River

- Synthesize, analyze, and integrate the information collected to date with respect to potential use in a biological monitoring program

- Provide final recommendations of biological indicators that would be most useful and applicable for long-term water quality monitoring in the lower Columbia River.

The products of Task 4 include the following reports·

- A detailed work plan (presented August 1991)

- Review of biological indicators to support recommendations on a biological monitoring approach (presented February 1992)

- A report on testing and final recommendations (present report)

- A final summary report

This report integrates information from all previous efforts and provides recommendations for a manageable long-term water quality monitoring program for the lower Columbia River The initial recommendations for biological indicators, presented in February 1992, were refined after evaluation of the data obtained from the benthic survey and chemical analyses of water, sediments, and biota collected during the reconnaissance survey conducted in the fall of 1991 (October to November, 1991) Experts in the field of biological indicators were contacted for current trends and applications The information acquired during these interviews was documented and the contact sheets are included as Appendix A of this report on recommended biological indicators.

It was necessary to investigate biological indicators that could be used in both estuarine and freshwater environments because of the different ecological zones present in the lower Columbia River Physical habitat characteristics and community composition were used to establish ecological zones in the lower Columbia River Water salinity, sediment grain size, and the distribution and composition of numerically dominant taxa were used to describe major zones within the river. Absolute physical boundaries of the zones were not identified because these physical characteristics are present as a continuum or gradient. During the Fall 1991 reconnaissance survey, salinity ranged from approximately 32 parts-per-thousand (ppt) at the mouth of the estuary, decreasing to 10 ppt near River Mile (RM) 19, and becoming entirely freshwater at RM 22. Euryhaline species (e.g , *Corophium salmonis, Nereis limnicola, Eohaustorius estuarius*) were present up to RM 29 Based on this information, the habitats up through RM 27 were characterized as estuarine, habitats upstream of RM 27 were characterized as freshwater for this purposes of this study.

The river mile demarcation between freshwater and estuarine environments may not be applicable to selection of indicator species for use in the biological monitoring program for several reasons. First, the transition zone between freshwater and estuarine environments is cyclical, shifting up- and downriver in response to tidal and seasonal cycles. The portion of river between RM 20 and RM 30 probably experiences the greatest salinity changes. Second, interstitial salinities may have greater influence on benthic community composition than water column salinity (Chapman and Brinkhurst, 1981) Interstitial salinity varies according to river flow and tends to change seasonally, rather than diurnally The organisms inhabiting the sediments may represent a different ecological zone than that represented by overlying water salinity. The selection of a particular test species for use within the portion of the river where salinities are neither truly freshwater or marine will be based on the exposure conditions (e.g., water column vs sediment exposures) and the organism's ability to withstand the conditions characteristic of the monitoring site (e g , capable of withstanding wide variations in osmotic pressure or salinity)

4.0 INITIAL RECOMMENDATIONS (TASK 4 REPORT): SUMMARY

An in-depth discussion on the theory and use of biological indicators was presented in the Task 4 Report "Review of Biological Indicators to Support Recommendations on a Biological Monitoring Approach" (Tetra Tech, 1992) Several organisms and measured endpoints were presented as potential exposure or response indicators for inclusion in the lower Columbia River monitoring program. A set of candidate biological indicators appropriate for use in the monitoring program was synthesized from this discussion and presented in this Task 4 Report as initial recommendations A summary of these initial recommendations is provided in the following discussion

The biological indicators were categorized as either exposure indicators or response indicators As the name implies, exposure indicators establish that organisms have been exposed to specific substances or conditions, and, in most cases, quantify the magnitude of that exposure. A commonly used exposure indicator is the testing of tissues for chemical residues Response indicators demonstrate that effects are occurring because of exposure to a substance or condition Response indicators include bioassays, subjecting organisms to contaminated water or sediment and recording a physiological response, such as death, changes in growth, or reproduction It is necessary to use both exposure and response indicators to establish that effects are occurring and to identify the cause of those effects. Some of the biological endpoints commonly used as exposure and response indicators include the following:

- EXPOSURE INDICATORS

  Biochemical Level

  Bioaccumulation, Enzyme Induction, Physiological Measurements

- RESPONSE INDICATORS

  Individual Level

  Reproductive Impairment, Genetic Aberrations, Growth/Development Impairment, Pathological Lesions and Neoplasms, Morphological Abnormalities, Reduced Survival

Population Level

Reduced Abundance, Altered Age Structure, Reduced Growth

Community Level

Reduced Diversity, Altered Community Composition, Reduced Total Abundance, Reduced Colonization Rates

Exposure or response endpoints can be measured in either field studies with resident or transplanted organisms or in laboratory tests Resident organisms provide a direct assessment of environmental conditions This approach is sometimes limited because a sufficient number of species to support a given test cannot always be found within the system, or because natural variability in the test species may substantially reduce the power of the indicator to demonstrate an exposure or effect An indirect assessment of exposure and response can be obtained by transplanting either cultured or field-collected organisms and conducting *in situ* studies. Use of *in situ* bioassays provides the advantage of combined environmental realism and experimental control, selected endpoints can be easily monitored. One limitation for using field collected organisms occurs if an insufficient number of organisms is available from clean source areas.

In the Task 4 Report, use of a suite of biological indicators was identified as the optimum approach for the lower Columbia River monitoring program Fish and benthic invertebrate communities were recommended for use in a long-term monitoring program Recommended test approaches included use of resident species and communities, and surrogate species under both laboratory and *in situ* field conditions Many species of fish (including starry flounder, sturgeon, sculpins, salmonids, perch, carp, and peamouth) were recommended as both exposure and response indicators for elevated concentrations of metals, selected organic compounds (e g , chlorinated hydrocarbons, PCBs, and pesticides) Salmonid bioassays were proposed for measuring site-specific, point-source effects in the lower Columbia River.

The Task 4 Report discussed the use of benthic invertebrates as potential indicators of both exposure and response. The sessile nature of many invertebrate taxa provides site-specific information about exposure not possible with more motile organisms. Polychaetes (worms) and bivalves (mussels and clams) were specifically identified for use in bioaccumulation studies involving metals, PCBs, pesticides, and other chlorinated organic compounds. Laboratory tests of growth and reproductive impairment in mysid shrimp and polychaete species were presented as viable alternatives for assessing the overall water quality in the lower Columbia River

Algal and bacterial populations were believed to have limited use as exposure or response indicators in a long-term monitoring program for the lower Columbia River While it was recommended that these organisms not be used as biological indicators for the overall monitoring program, it was recognized that these organisms, particularly bacteria, may be appropriate for assessing impacts to beneficial uses in the river

5.0 RECONNAISSANCE SURVEY: SUMMARY

Water, sediment, and biota samples were collected during the Fall 1991 reconnaissance survey to characterize benthic community structure, and determine the extent and magnitude of contamination in the lower Columbia River. Data collected as a result of the survey were presented in the Task 6 Report (Tetra Tech, 1992) A summary of selected results and trends identified during the reconnaissance survey is provided in the following discussion.

5.1 BENTHIC INVERTEBRATES

Benthic community structure was evaluated at 54 stations sampled during the reconnaissance survey in the lower Columbia River. Over 100 taxa and 63,000 individuals, represented by annelids (oligochaetes and polychaetes), arthropods (crustaceans, arachnids, and insects), and molluscs (gastropods and bivalves) were identified and counted Annelids were the most prevalent taxa, occurring at 93 percent of the stations, and were numerically dominant at more than half the stations Arthropods were present at 53 stations and were the most abundant taxonomic group at 15 stations. Molluscs occurred at 51 stations and were the most abundant taxonomic group at 9 stations. Nematodes were widely distributed in the river and were the most abundant taxa at 5 stations

Based on the results of statistical analyses, physical factors (e.g , salinity, sediment grain size, and substrate stability) appear to strongly influence community composition throughout the river. Salinity appeared to have the greatest effect on community structure in the estuary while grain size had the greatest effect in freshwater areas of the river High salinity (> 15 ppt) areas were dominated by the polychaete *Hobsonia florida*, oligochaetes, the bivalves *Macoma balthica* and *Mya arenaria*, and the crustacean *Hemileucon* spp The amphipod *Corophium salmonis*, the bivalve *Corbicula fluminea*, and nematodes were among the dominant taxa in lower salinity areas In addition, other euryhaline taxa were present in these areas (e g., *Nereis limnicola*, littorinids)

In freshwater areas, *Corophium salmonis*, *Corbicula fluminea*, oligochaetes, and nematodes were again among the numerically dominant taxa in the freshwater areas of the river, in addition to chironomid midges In these areas, sediment grain size was the dominant factor affecting abundance. Fine-grained sediments had significantly higher total abundances than coarse-grained sediments

Throughout the river, many taxa have adapted to a wide variety of habitat types. This was clearly demonstrated with the distribution of *Corophium salmonis* and *Corbicula fluminea* While these two species are sensitive to physical and chemical stresses, they are able to rapidly recolonize through various reproductive and dispersion strategies Another example are chironomids, which are generally tolerant of a wide range of environmental quality and have adapted to living in very different habitat types Overall, benthic communities in the study area reflect the dynamic nature of the aquatic environment in the lower Columbia River

5.2 CONTAMINANTS

Contaminants were measured in water, sediment, and tissues samples collected over the entire study area A general discussion of the results is provided in the following sections. Specific results are presented in the Task 6 report summarizing the reconnaissance survey results Please refer to the Task 6 report for more complete information.

5.2.1 Water

Total recoverable metals were measured at concentrations above analytical detection limits sporadically in water samples collected from the lower Columbia River during the reconnaissance survey. Concentrations of total cadmium, chromium, copper, iron, lead, and zinc exceeded water quality criteria at locations in the river. There is at least one exceedance at each station, however no single contaminant was elevated at all stations, with the exception of aluminum. These exceedances indicate possible effects on biota may be occurring in the lower Columbia River. One priority pollutant (i e , semivolatile and volatile organic compounds, pesticides, and PCBs) was measured at concentrations above detection limits at two stations in the river. However, detection limits were greater than water quality criteria in some cases and organic contaminants may be present in the water column at very low levels. AOX was measured as an indicator of chlorinated contaminants in the river and was found at most stations at concentrations above detection limits

5.2.2 Sediments

Sediments were collected from 54 stations throughout the lower Columbia River These samples were used to determine the occurrence of selected, potentially toxic contaminants and to characterize major spatial trends in the distribution of contaminants in the sediments In the lower Columbia River, the majority of sediments are coarse grained and distributed among various sand fractions Many of the contaminants introduced into the river adsorb preferentially onto fine-grained, suspended sediment particles as a result of physicochemical interactions (Staples et al , 1985, Wu and Gschwend, 1986, Reuber et al , 1987) These suspended particles are likely either flushed into the ocean or deposited in low-energy regions (e g , backwaters, sloughs, and wetland areas) of the river Trace metals were the most frequently detected substances in all sediment samples Arsenic, cadmium, copper, iron, nickel, silver, lead, and zinc were detected in some samples at concentrations above those associated with adverse biological effects (Long and Morgan, 1990) The organic compounds polychlorinated dibenzodioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs) were detected in all 20 of the sediment samples collected in the lower Columbia River, but lacked effects levels for comparison. Polycyclic aromatic hydrocarbons (PAHs), pesticides, and polychlorinated biphenyls (PCBs) were detected infrequently in sediment samples analyzed, but did occur above concentrations associated with adverse effects in other studies (Long and Morgan, 1990) Organotin compounds, used as biocides in antifouling coatings for boats and ships, were detected in most of the 10 sediment samples analyzed for these compounds, but were high at only one station. No data correlating sediment concentrations with adverse effects were available for comparison.

5.2.3 Tissues

Five species of representative resident biota were collected during the reconnaissance survey from the lower Columbia River and their tissues analyzed for chemical contaminants. Crayfish, carp, largescale sucker, white sturgeon, and peamouth were used in the tissue residue studies because of their respective positions in the food chain, ranges of distribution, and variation in lipid composition. Although there is some overlap in their distribution, not all organisms were collected from the same sampling locations. Crayfish and largescale sucker were, for the most part, collected throughout the study area Carp were collected more frequently in the upper portion of the river; peamouth were captured more easily in the lower portion of the river

Tissues were analyzed for 11 trace metals and 104 organic compounds (52 semivolatile organic compounds, 29 pesticides, 8 PCBs, and 17 dioxin and furan congeners) All trace metals, except antimony, were detected in the tissue samples Overall, carp had the highest concentration of total metals, with decreasing concentrations present in crayfish, peamouth, largescale sucker, and white sturgeon.

Thirteen of the 52 semivolatile organic compounds were detected in the tissues of carp collected from one sampling location near the mouth of the Willamette River. Organochlorine and organophosphate pesticides were detected in organisms collected throughout the lower Columbia River; however, the frequency of detection of these compounds was relatively low DDT, DDE, and DDD were detected in 98 6 percent of the samples analyzed

PCBs were not detected in crayfish, 60% of the fish tissues analyzed contained one or more of the detected PCB Aroclors (e g., 1242, 1254, and 1260) The PCBs Aroclor 1242 and 1260 were detected in peamouth Carp and largescale sucker contained detectable concentrations of the PCBs Aroclor 1254 and 1260 One PCB, Aroclor 1254, was detected in white sturgeon.

Dioxins and furans were detected in fish tissues collected throughout the lower Columbia River. Peamouth had the highest tissue concentrations of dioxins and furans. The other organisms collected had lower concentrations of these compounds in their tissues, which was attributed to their lower percent body lipid content.

6.0 FINAL RECOMMENDATIONS FOR BIOLOGICAL INDICATORS

Contaminants are introduced into the lower Columbia River via a number of point- and nonpoint-sources Fine-grained, highly organic sediments and particulates will adsorb greater quantities of contaminants from the water column than coarser grained sediments, such as sand (Staples et al , 1985, Wu and Gschwend, 1986; Reuber et al , 1987) Results of the reconnaissance survey indicated sediments in the main channel of the lower Columbia River were primarily coarse grained and distributed among various sand fractions Of the 54 stations sampled, sediments from 13 stations contained greater than 20 percent fines (i.e., silt + clay) Because of the high-energy nature of the lower Columbia River, fine-grained sediments and particulate material, and their associated contaminants, are either discharged directly to the ocean or deposited in low-energy regions of the river, such as backwaters, slough, and wetland areas. Therefore, it is likely that the areas of highest concern will be the portions of the lower Columbia River receiving point- and nonpoint-source effluents as well as the low-energy depositional regions where contaminants may accumulate

The recommended biological monitoring program for the lower Columbia River addresses contaminants in the water column as well as those associated with the sediments The approach is based on two types of field studies conducted with a variety of species representing different positions in the food chain. This multi-species, field-oriented approach will provide environmental realism and permit experimental control The first type of study involves collecting resident species directly from the sites in the lower Columbia River that are to be evaluated as part of the monitoring program This approach cannot always be used because of the potential inability to collect a sufficient number of individuals from each of the monitoring locations for the respective chemical and biological tests. The second type of study involves collecting resident species from areas of the river that are considered clean or uncontaminated and transplanting the animals to sites in the lower Columbia River that are to be evaluated as part of the monitoring program This approach offers much more control and has the ability to reduce the variability associated with the former approach.

The recommended program stresses field tests over laboratory tests because field tests provide a time-integrated picture of environmental conditions and pollutant bioavailability that is often lost with laboratory studies Laboratory testing can be used to address contaminants associated with the sediments and to verify field measures The recommended biological indicators can provide information regarding the overall environmental health of the lower Columbia River as well as for specific contaminants The contaminants that were detected at concentrations that may pose a threat to Columbia River resources include trace elements, pesticides, PCBs, dioxins and furans, PAHs, and organotins.

Several *in situ* and laboratory approaches were reviewed prior to finalizing the list of recommended biological indicators. The recommended monitoring approach includes both laboratory and field tests, with emphasis placed on field work Current research is addressing the need for alternative methods of assessing environmental conditions, and efforts continue toward increasing the number of organisms that are useful as biological indicators and toward adapting existing bioassay procedures so that the test may be performed *in situ* (Phillips and Segar, 1986). Numerous options exist for *in situ* studies, although methods have not been formally standardized in many cases. A battery of standardized laboratory tests is available for evaluating effluents and sediments (Burton, 1991) In some cases, contaminant exposure and associated biological effects may not be accurately predicted by the testing of sediments or effluents in the laboratory (Cairns, 1983). For example, laboratory tests may induce artificial exposure conditions by altering the contaminant distribution in the sediment layers in ways that benthic, epibenthic, and planktonic organisms would not have been exposed to under natural conditions (Sasson-White and Champ, 1983, Brickson and Burton, 1991). Even though there may be problems associated with extrapolating laboratory results to the field, laboratory tests are commonly used and recommended by regulatory agencies to determine the spatial and temporal distribution of sediment toxicity (Swartz, 1989). Two sediment laboratory bioassays with amphipods are recommended one utilizes the freshwater species *Corophium salmonis*, the other utilizes the estuarine species *Eohaustorius estuarius*. Both of these laboratory tests have proven useful and representative in the evaluation of sediments.

The following criteria were used to select the biological indicators for use in the lower Columbia River:

- The species should be representative of organisms resident in the lower Columbia River.

- The species should be sensitive to substances of concern

- Established procedures must be available for the species and its endpoint.

- The biological monitoring procedure must be easy to perform, use standardized techniques, and utilize readily-available materials

- The results should be easily interpreted and directly comparable with data in the literature

Each of the following recommended biological indicators satisfy these criteria Recommendations are presented for each major habitat type The recommended biological indicators are summarized in Table 1

Freshwater Water Column

- Survival, growth, and bioaccumulation in transplanted bivalves (i e , *Corbicula fluminea*)

- Bioaccumulation measurements in resident fish species [e g , peamouth (*Mylocheilus caurinus*), bass (*Micropterus* spp.), and crappie (*Pomoxis* spp)]

- Physiological measurements (Fish Health Index and detoxification enzymes) in resident fish (same species used in bioaccumulation studies)

Freshwater Sediments

- Survival, growth, and bioaccumulation in transplanted bivalves (i e , *Corbicula fluminea*)

- Survival of endemic amphipods (e g , *Corophium salmonis*)

- Bioaccumulation measurements in resident amphipods (e.g , *Corophium salmonis*), crayfish (e.g., *Pacifastacus leniusculus*), bivalves (e g., *Corbicula fluminea*), and fish species [e g., carp (*Cyprinus carpio*), largescale sucker (*Catostomas macrocheilus*), white sturgeon (*Acipenser transmontanus*)]

Table 1 Recommended biological indicators for use in the lower Columbia River

Species & Endpoint (Indicator Type[1])	Environment	Approach (Reference)	Contaminants	Relative Importance[2]
Corbicula fluminea Survival and growth in juveniles (RI)	FW (up to 15 ‰ salinity) Water Column	2-3 mm (shell length) individuals caged and suspended in the water column for a period of 30 days, after which survival is recorded and growth measurements made (Waller, unpublished)	Not contaminant-specific, response reflects adverse conditions	2
Corbicula fluminea Bioaccumulation in large individuals (EI)	FW (up to 15 ‰ salinity) Sediments	20 mm (shell length) individuals caged and secured to bottom substrates for a period of 30 days, after which animals are retrieved and tissues collected for chemical analyses (Graney *et al*, 1983, Foe & Knight, 1986, Belanger *et al.*, 1987)	Trace metals, pesticides, dioxins/furans, PCBs, organotins.	2
Mytilus spp. Survival and growth in juveniles (RI); Bioaccumulation in juveniles (EI).	Estuarine Water Column	10-12 mm (shell length) individuals caged and suspended in the water column for a period of 60 days, after which survival is recorded, whole-animal length and weight measurements are made, and tissues are removed for chemical analyses (Salazar and Salazar, 1991).	Growth metrics are not contaminant-specific, response reflects adverse conditions Tissue residue analyses appropriate for trace metals, pesticides, dioxins/furans, PCBs, organotins	2

[1]EI = Exposure Indicator, RI = Response Indicator
[2]1 = High priority, easily implemented
2 = Medium priority, greater level of effort required
3 = Low priority, procedures may need more development

Macoma nasuta Survival and growth (RI) and bioaccumulation (EI) in large individuals	Estuarine Sediments	20 mm (shell length) individuals caged and secured to bottom substrates for a period of 30 days, after which survival is recorded, whole-anomal length and weight measurements are made, and tissues are removed for chemical analyses (Graney *et al.*, 1983, Foe & Knight, 1986, Belanger *et al.*, 1987)	Survival and growth data is not contaminant-specific, response reflects adverse conditions. Tissue residue analyses appropriate for trace metals, pesticides, dioxins/furans, PCBs, organotins.	2
Resident Taxa Bioaccumulation (EI)	FW Water Column & Sediments, Estuarine Water Column & Sediments	Collect pelagic fish to evaluate water column conditions; collect benthic invertebrates and demersal fish to evaluate sediments. Tissue residue studies are performed on only edible portions of species (PSEP, 1991)	Trace metals, pesticides, dioxins/furans, PCBs, organotins.	1
Fish Health Index (RI)	FW Water Column & Sediments; Estuarine Water Column & Sediments	Fish collected for bioaccumulation studies are "autopsied" externally and internally (Geode, 1988, PSEP, 1991)	Not contaminant-specific, reflects exposure to adverse conditions	1
Detoxification Enzymes (EI and RI)	FW Water Column & Sediments; Estuarine Water Column & Sediments	Detoxification enzymes are measured in fish collected for bioaccumulation studies or Fish Health Index purposes (Adams *et al.*, 1990)	Pesticides, PAHs, PCBs	3
Corophium salmonis and *Eohaustorius estuarius* Survival (RI)	FW and Estuarine Sediments	Endemic organisms collected and used in laboratory sediment tests, after appropriate exposure period, the number of survivors is recorded (ASTM, 1990, 1991)	Not contamtaminant specific, response reflects adverse conditions	3

[1]EI = Exposure Indicator, RI = Response Indicator
[2]1 = High priority, easily implemented
2 = Medium priority, greater level of effort required
3 = Low priority, procedures may need more development

- Physiological measurements (Fish Health Index and detoxification enzymes) in resident fish (same species used in bioaccumulation studies)

Estuarine Water Column

- Survival, growth, and bioaccumulation in transplanted bivalves (i e , *Mytilus* spp)

- Bioaccumulation measurements in resident fish species [e g , peamouth (*Mylocheilus caurinus*)]

- Physiological measurements (Fish Health Index and detoxification enzymes) in resident fish (same species used in bioaccumulation studies)

Estuarine Sediments

- Survival, growth, and bioaccumulation in transplanted bivalves (i e., *Macoma* spp)

- Survival of endemic amphipods (e g., *Eohaustorius estuarius*)

- Bioaccumulation measurements in resident clams (e g , *Macoma* spp) and fish [e g , starry flounder (*Platichthys stellatus*)]

- Physiological measurements (Fish Health Index and detoxification enzymes) in resident fish (same species used in bioaccumulation studies)

Both resident and transplanted organisms can be effectively used in these studies. The decision to use one group of animals over the other depends on several factors. The use of resident species in monitoring programs may be limited by the ability to collect sufficient numbers or appropriate size classes from the areas under evaluation. Animals for use in transplant studies can be obtained from clean field sources or commercial laboratory cultures. However, not all species are available from culture facilities It may be necessary to further characterize the lower Columbia River and identify "clean" areas as collection sources for animals to be used in transplant tests Depending on the availability of "clean" wild animals, it may be more cost-efficient to use laboratory-reared individuals, if available.

Further details regarding each of these biological indicators are provided in the following sections. A discussion on population and community metrics as biological indicators is also provided

6.1 BIVALVE TRANSPLANT STUDIES

A summary of the application of bivalve molluscs in transplant studies as indicators of environmental contamination is provided below

6.1.1 *Corbicula fluminea*

Environment: Freshwater water column (salinities up to 15 ppt)
Endpoint: Survival and growth in juveniles (2 to 3 mm)
Indicator Type: Response
Approach: Transplanted; caged animals suspended in water column
Contaminants: Not contaminant specific; response reflects adverse conditions

Environment: Freshwater Sediments (salinities up to 15 ppt)
Endpoint: Bioaccumulation of contaminants in the tissues of large individuals (approximately 20 mm)
Indicator Type: Exposure
Approach: Transplanted; caged animals secured to bottom substrate
Contaminants: Trace metals, pesticides, dioxins/furans, PCBs, and organotins

The bivalve clam *C fluminea* is recommended for evaluating conditions in both water column and benthic habitats in freshwater and brackish water environments Caged juveniles (2 to 3 mm) can be suspended to evaluate contaminants in the water column while cages containing larger individuals (approximately 20 mm) can be secured to the bottom substrates to evaluate contaminants in the sediments.

C fluminea is a filter-feeding clam which permits this species to be exposed to contaminants that are in solution or associated with suspended particulate material This species is widely distributed through the lower Columbia River and is abundant in many areas They can withstand salinities ranging from < 1 ppt up to 15 ppt Their preferred habitat is fine sand, but they can also be found in substrates ranging from rock and gravel to sediments with high silt loads (McMahon, 1991) *C fluminea* has been used extensively as a biological indicator in freshwater environments This species has demonstrated the ability to accumulate trace metals (Luoma et al , 1990, Doherty, 1990; Abaychi and Mustafa, 1988; Foe and Knight, 1986, Graney et al., 1983; Cory et al , 1981) as well as organochlorine compounds (Ohyama et al , 1986) and asbestos (Belanger et al , 1987).

C fluminea was found in the lower Columbia River where salinities were less than 15 ppt Use of juveniles (2 to 3 mm) is appropriate to evaluate overall environmental health in the lower Columbia River whereas larger individuals are suited for tissue residue studies (i e , bioaccumulation studies) It is recommended that the endpoints survival and growth be measured as response indicators in transplanted juvenile *C. fluminea* Even though these clams have demonstrated a high sensitivity to trace metals, survival and growth measurements can only be used to address overall environmental health in the river because these are not chemical-specific endpoints. Bioaccumulation studies with large individuals can be used to identify the contaminants of concern and the availability of the contaminants. Results of the survival, growth, and bioaccumulation studies are readily analyzed, easily interpreted, and can be compared with data from the literature.

Procedures have been established for their use in river systems (Luoma et al., 1990, Doherty, 1990; Abaychi and Mustafa, 1988; Foe and Knight, 1986, Graney et al , 1983, Cory et al , 1981). *C fluminea* has been used successfully as a biological indicator of overall water conditions in several river systems, including the Trinity River, Texas Dr Tom Waller, University of North Texas, is currently refining test methods in which juveniles (2 to 3 mm in length) are transplanted for a 30-day exposure period; growth and survival are the measured endpoints (1992, personal communication) It is unlikely that animals used in the 30-day growth studies could be used for bioaccumulation studies because of the limited tissue available. Larger animals (approximately 20 mm) would be transplanted for uptake studies

6.1.2 *Mytilus* spp.

Environment: Estuarine water column

Endpoint: Survival and growth in juveniles (10-12 mm)

Indicator Type: Response

Approach: Transplanted; caged animals suspended in water column

Contaminants: Not contaminant specific; response reflects adverse conditions

Endpoint: Bioaccumulation in juveniles (10-12 mm)

Indicator Type: Exposure

Approach: Transplanted; caged animals suspended in water column

Contaminants: Trace metals, pesticides, dioxins/furans, PCBs, and organotins

Salinity concentrations exceed 15 ppt in much of the lower estuary which may limit the use of *C fluminea* in this area. It is recommended that the mussel, *Mytilus* spp , is be used to evaluate contaminants in the water column in the lower estuary During the reconnaissance survey, *M edulis* was found in the estuarine portion of the lower Columbia River, albeit in low densities. Mussels are sensitive to trace metals and organic compounds and can be used as both exposure and response indicators. Endpoints that are commonly measured include survival, growth, and bioaccumulation in transplanted juveniles The survival and growth data can be used to evaluate overall environmental health in the estuarine sections of the lower Columbia River Bioaccumulation is an exposure indicator and the data can be used to identify the occurrence of selected contaminants in the water column Protocols have been developed for each of these measurements. Juvenile mussels to be used in transplant studies could be collected from an uncontaminated area in the Columbia River estuary or from a clean, off-site location (e g , Willapa Bay or Penn Cove). To avoid potential problems associated with neoplasia, a progressive and fatal disseminated sarcoma, in *Mytilus edulis* during the summer months, the species *Mytilus trossolus* or *M. galloprovencialis* can be used. *M trossolus* occurs in the lower Columbia River (Kenn Brooks, personal communication) as well as in the Puget Sound area It is recommended that a 60-day exposure period be used; during this time juveniles will grow to a size that provides a sufficient amount of tissues for chemical analysis. The growth and tissue residue tests are easy to perform and the results are readily interpreted and compared with literature values

Mytilus spp has been extensively used as test organisms in numerous *in situ* field studies in the marine environment, including the California State Mussel Watch Program to evaluate contaminate concentrations and environmental conditions in bays and estuaries *M edulis* is one of several bivalve species used in the NOAA Status and Trends Program, a national effort to evaluate pollution in coastal areas (NOAA, 1987) Mussels within the 10 to 12 mm size class have demonstrated a sensitivity to adverse conditions, and have been successfully used to identify contaminated areas in San Diego Bay (Salazar and Salazar, 1991). Mussels are filter feeders and provide information regarding water-soluble contaminants as well as contaminants associated with suspended particulate material

6.1.3 *Macoma* spp.

Environment: Estuarine sediments
Endpoint: Survival and growth in large individuals (approximately 20 mm)
Indicator Type: Response
Approach: Transplanted; caged animals secured to bottom substrate
Contaminants: Not contaminant specific; response reflects adverse conditions

Endpoint: Bioaccumulation in large individuals (approximately 20 mm)
Indicator Type: Exposure
Approach: Transplanted; caged animals secured to bottom substrate
Contaminants: Trace metals, pesticides, dioxins/furans, PCBs, and organotins

Clam can be used to evaluate estuarine sediments Because of the elevated salinity concentrations in much of the estuary, it is recommended that *C. fluminea* not be used in this area. Both *Macoma balthica* and *M. nasuta* occurred in the estuarine portion of the lower Columbia River, albeit *M. nasuta* was found in low densities. Clams are sensitive to trace metals and organic compounds and can be used as both exposure and response indicators. Endpoints to be measured are survival, growth, and bioaccumulation in transplanted individuals. The survival and growth data can be used to evaluate overall environmental health in the estuarine sections of the lower Columbia River. Bioaccumulation data can be used as an exposure indicator for selected contaminants associated with the sediments. Protocols have been developed for each of these measurements The tests are easy to perform and the results are readily interpreted and compared with literature values.

Standardized methods have been developed for using clams in both laboratory and *in situ* field studies (Calabrese, 1984) Survival, growth, bioaccumulation, and physiological measurements have been made on these bivalves Clams are sediment dwellers and have the potential to provide information regarding the nature and extent of contamination within this environment Both *M balthica* and *M nasuta* are detrital feeders, but often ingest sediments with their very mobile siphons Clams can easily be caged and the cages secured to the bottom *M nasuta* is a recommended test species in laboratory bioaccumulation tests evaluating dredged material for ocean disposal (U S EPA and ACOE, 1991) A different species, *M inquinata*, was used to assess sediment quality in the intertidal zones of Sequim Bay (Roesijadi and Anderson, 1979). The species used as biological indicators for the lower Columbia River would depend on availability

6.2 BIOACCUMULATION STUDIES WITH RESIDENT TAXA

Environment: Freshwater water column and sediments; estuarine water column and sediments
Endpoint: Bioaccumulation
Indicator Type: Exposure
Approach: Collection of resident animals
Contaminants: Trace metals, pesticides, dioxins/furans, PCBs, and organotins

Bioaccumulation studies are a valuable component of environmental monitoring programs because the tissue concentrations indicate chemicals that may be widespread in the environment, but are present in less than detectable quantities in water. Tissue concentrations also reflect bioavailability and assist in the interpretation of effects data. During the reconnaissance survey, a wider variety of contaminants was detected in animal tissues than in water or sediment samples This suggests animal tissues may provide a more complete and balanced picture of past and current contaminant conditions than do the surrounding media. Bioaccumulation studies must be augmented with response studies because the presence of contaminants in tissues does not always signify adverse effects Toxic materials can be accumulated by an organism and sequestered in the body in such a way that the material is rendered harmless However, the presence of contaminants in the tissues indicates an exposure and the potential bioavailability of contaminants This information, in conjunction with other data, can be used to evaluate the actual threats to resources and make quantitative assessments regarding the health of a particular section of the lower Columbia River

It is recommended that both resident and transplanted species be used as exposure indicators of environmental contamination Studies using transplanted animals provide a level of experimental control that is not possible with resident animals The position and duration of exposure can be well documented in transplanted studies. However, there is some stress associated with the transplant procedure which may influence the final results The use of motile resident species makes it difficult to define the exposure conditions However, the results may be more reflective of the conditions an animals has experienced within its entire natural range. Data obtained from each approach can be used to evaluate the extent of contamination in the lower Columbia River.

In the freshwater environment, pelagic fish (e g. peamouth, bass, and crappie) can be used to evaluate exposure to contaminants in the water column while amphipods, crayfish, clams, and demersal fish can be used to evaluate exposure to contaminants associated with the sediments Peamouth are also found in estuarine conditions and can be used to evaluate exposure to contaminants in the water column Clams and demersal fish (e g , starry flounder) can be used to evaluate exposure to contaminants associated with the sediments in the estuary

The selection of a resident organism for bioaccumulation studies depends to a large degree on the objective of the study. If the goal is to evaluate potential impacts to human health, then the species selected for tissue residue analyses should be one that is commonly captured and consumed by humans. Tissue residue analyses should be performed only on the edible portions of the game species On the other hand, if the objective is to evaluate potential impacts to terrestrial wildlife or higher trophic levels in the aquatic environment, then the organism selected should contribute a substantial proportion of the diet of the wildlife being evaluated Bioaccumulation studies are often used to evaluate the extent of contaminant migration from local sources. Organisms with limited mobility, such as crayfish or bivalves, are best suited to evaluate local conditions. Most fish species, because of their greater mobility, integrate exposures over a larger region. Bioaccumulation studies with mobile species are often used to evaluate contamination in larger geographic areas and the potential for biomagnification of contaminants up the food chain

Bivalves, fish, crayfish, and amphipods are the recommended organisms for bioaccumulation studies. In some cases either resident or transplanted individuals can be used The precise species to be used dependent on the objectives of the assessment Bivalves readily accumulate trace metals and organic compounds, including organotin compounds Fish are good exposure indicators of organic compounds, as was demonstrated in the reconnaissance survey where elevated concentrations of trace metals, pesticides, dioxins/furans, and PCBs were found in the tissues of several species It is recommended that more than one species of fish be collected for bioaccumulation studies in particular, because of the demonstrated selective accumulation within tissues (e g , carp readily bioaccumulate hydrophobic organic pollutants) as discussed in greater detail in the Task 6 report The retention of contaminants within tissues varies from species to species and depends on the lipid content, physiology, and feeding strategy The reconnaissance survey has provided a substantial amount of information on the species inhabiting the river and their capacity to accumulate contaminants This information should be reviewed in light of the overall goals of the study and the appropriate species selected for use in the monitoring program

6.3 PHYSIOLOGICAL MEASUREMENTS IN FISH

Environment: Freshwater water column and sediments; estuarine water column and sediments
Endpoint: Detoxification enzyme production
Indicator Type: Exposure and response
Approach: Collection of resident animals
Contaminants: Pesticides, PAHs, and PCBs

Endpoint: Fish health index
Indicator Type: Response
Approach: Collection of resident animals
Contaminants: Not contaminant specific; response reflects adverse conditions

Physiological measurements (or biomarkers) can be used to reveal a sublethal (and often subtle) response to some stressor. A given physiological response may be ephemeral or sustained, it may be specifically linked to a chemical or it may be associated with a general class of stressors (Murphy and Kapustka,

1990) Research into the use of biomarkers as indicators of environmental stress has resulted in the identification of a multitude of endpoints, even though this field is still comparatively new

Bioaccumulation is the most commonly used biomarker Other physiological endpoints that are measured include metallothionein production, overall fish health (Fish Health Index), ammonia concentration in blood, cholinesterase production, heatshock protein production, glutathioneine concentration in tissues, production of biometabolites, and reduction in genetic variability (Cormier, personal communication, 1992). Many of these endpoints are chemical-specific and can be used to confirm the presence of or exposure to a particular contaminant Standardized protocol have been developed for many of these biomarker tests. Biomarkers can aid in defining relationships between laboratory and field studies as well as relationships between transplanted and wild organisms (Murphy and Kapustka, 1990)

For the lower Columbia River, it is recommended that physiological measurements be made on fish only The recommended endpoints are the Fish Health Index and activity levels of detoxification enzymes, data from these tests can provide corroborating information on overall environmental health and the presence of trace metals, pesticides, PAHs, and PCBs Fish that are collected for bioaccumulation measurements can also be used for these two physiological tests.

The Fish Health Index can provide information on the overall environmental health in the lower Columbia River. The procedure is easy and rapid, it involves conducting both an external and an internal autopsy on freshly collected fish (Cormier, personal communication, 1992). The components of index include the identification of defects or abnormalities in various organs (e.g , eyes, gills, pseudobranch, thymus, fat, spleen, hind gut, kidney, liver, and bile), a blood profile, and weight and length measurements. The procedure was originally developed to identify adverse conditions in aquaculture facilities and standardized protocol are available (Geode, 1988) Fish pathology studies are recommended as part of the Puget Sound Estuary Protocols (PSEP, 1991). The number of components addressed in the PSEP are not as extensive as those in the Fish Health Index The fish pathology studies discussed in PSEP could be used as a minimum approach.

The activity or levels of liver detoxification enzymes, such as 7-Ethoxyresorufin O-deethylase (EROD), can be used to indicate exposure to various environmental contaminants such as PAHs, PCBs, dioxin, and pesticides (Cormier, personal communication, 1992; Adams et al , 1990). Standardized, published protocols are available for this test (Adams et al , 1990) The Oregon Department of Environmental Quality (1990, 1991) has measured EROD activity and P-450 concentration in carp, largescale sucker, and white sturgeon at several sites within the lower Columbia River These data could be used as background information, for comparative purposes, or supplemental information, depending on the sampling locations Most biological indicators, including EROD activity, may be influenced by other physical and natural factors, such as sex, temperature, and feeding history Although there is some variability in EROD activity, the use of this indicator is an informative biomarker of exposure (Adams et al , 1990) and should be used in conjunction with the tissue residue data when assessing the presence of specific contaminants in the lower Columbia River It is possible to perform both EROD measurements and tissue residue analyses on the same fish as only the edible portions of the fish (i e , fillets) are used in tissue residue studies, the livers and other internal organs can then be used for EROD measurements Detoxification enzymes can be used as both exposure and response indicators whereas tissue residue studies are only exposure indicators EROD data is useful because it provides an indication of the effect that exposure to a particular contaminant is having on the fish

6.4 AMPHIPOD SURVIVAL TESTS

Environment: Freshwater and estuarine sediments
Endpoint: Survival
Indicator Type: Response
Approach: Endemic organisms collected and used in laboratory sediment tests
Contaminants: Not contaminant specific; response reflects adverse conditions

It is recommended that laboratory toxicity tests conducted with amphipods be used to evaluate sediments from both the freshwater and estuarine portions of the lower Columbia River. The species to be used are *Corophium salmonis* and *Eohaustorius estuarius*, respectively Amphipod sediment toxicity tests are well developed and widely applied, especially on the Pacific coast of the United States (Swartz, 1989) Research conducted as part of the U S EPA/COE dredged sediment program showed that amphipods were consistently more sensitive to contaminated sediments than other major benthic taxa (Swartz et al , 1979). The method was originally developed for the phoxocephalid amphipod, *Rhepoxynius abronius*, but has been used with a variety of other marine, estuarine, and freshwater amphipod genera including *Eohaustorius* and *Corophium*.

Both *Eohaustorius* and *Corophium* were found in sediments collected during the reconnaissance survey Amphipods collected from a clean area in the lower Columbia River can be taken to the laboratory where they would be exposed to sediments collected from areas of concern Clean areas can be defined as portions of the lower Columbia River in which contaminant concentrations in the water, sediments, and tissues are below those known to elicit adverse effects in biota Guidelines and criteria such as Effects Range-Low (Long and Morgan, 1990) and ambient water quality criteria (EPA, reference) could be used in the evaluation of clean sites The laboratory toxicity tests can be used to validate and confirm results obtained with other species used in the *in situ* field studies.

6.5 POPULATION AND COMMUNITY LEVEL INDICATORS

All of the recommended biological indicators are based on biochemical and individual level measurements. These types of measurements have been selected over population and community level metrics because of the difficulties and complexities associated with population or community level responses The discussion presented in the Task 4 Report stated that populations are not commonly used in environmental monitoring programs due to insufficient information on the population dynamics or degree of natural variability of most plant and animal species. Green et al (1985) further discuss why community and population studies are not incorporated into environmental monitoring programs. They state that population and community level responses to environmental stress are often very non-specific. For example, an observed shift in species composition often appears straightforward, but on closer examination, the response is less clear due to the complexities of other responses which have been integrated in the measured response The response of a natural population or community to environmental variation is usually complex and multivariate, difficult to describe, and, according to Green et al., even more difficult to analyze statistically.

Although U S EPA's Environmental Monitoring and Assessment Program (EMAP; U.S. EPA, 1990) strongly recommends benthic community structure as a response indicator for both estuarine and freshwater environments, it is not a recommended approach for assessing the overall health of the lower

Columbia River The results of the reconnaissance survey demonstrate that benthic community structure was highly variable in both estuarine and freshwater portions of the river Abundances varied widely ranging from 1 to 7,693 individuals per 0 06 m^2 Richness was less variable, ranging from 1 to 2 5 taxa per 0 06 m^2 Species distributions were strongly affected by habitat characteristics and did not show a clear correlation with sediment contamination concentrations

This variability in benthic community structure was attributed to the high-energy nature of the lower Columbia River and the unstable substrates characterizing the majority of the lower river. This is particularly true of the freshwater portions of the river where sediments consist primarily of sands and gravel. In the lower Columbia River, sands and gravel are characteristic of unstable substrates that move and shift a great deal as currents pass over them There are very few organisms that can successfully inhabit a high-energy environment The communities that often develop in these high-energy systems are responding to the physical environment, and not chemical contaminant concentrations

There may be some individual situations in the lower Columbia River where benthic community structure may be useful as a biological indicator. For example, the substrate in the vicinity of a particular outfall might be stable enough to support a diverse community, which could be used to evaluate the effects of the contaminants associated with the outfall However, in order for this to be an effective approach, additional qualitative surveys must be conducted to ensure diverse, abundant benthic organisms are found in similar "unimpacted" areas for comparison

Population or community level measurements are not recommended as overall indicators of adverse conditions in the lower Columbia River because of the difficulties and complexities associated with population or community level responses. Previous work conducted in the lower Columbia River indicated high variances associated with population or community metrics This variability may preclude the use of benthic communities, in particular, as an effective indicator of environmental conditions

6.6 FREQUENCY OF MEASUREMENTS

The recommended biological monitoring program would be of greatest value if conducted at least twice yearly to address some of the seasonal variability in river conditions and contaminant inputs. Monitoring events should reflect extreme flow conditions in the river (i e , high and low flow periods). The April to May period would be appropriate to monitor high flow conditions associated with spring rains and snow melt Low flow conditions could be expected during August or September. The data would be evaluated after each monitoring event to determine the impact of extreme conditions on results If the results indicate few seasonal differences in contaminant effects, then monitoring frequency should be reduced to once per year It is recommended that annual sampling occur in the fall because this time period probably represents worst-case conditions, the majority of test organisms are available, and deployment of caged animals for exposure and survival studies can be easily performed.

7.0 SUMMARY

The lower Columbia River is a dynamic system that covers nearly 150 miles of territory and a broad spectrum of habitats and environmental conditions The majority of the lower Columbia River is characterized by a high energy flow of freshwater in the main channel with low-energy, depositional regions found in the backwater, slough and wetland areas The river discharges into the Pacific Ocean resulting in about 26 miles of estuarine/brackish water conditions in the lower reach

In the freshwater reaches of the river, the substrate is primarily coarse sand and gravel which, according to the results of the reconnaissance survey, supports limited benthic biota In portions of the river where the flow is subdued, substrates contain a higher percentage of silts, and benthic communities are more diverse and abundant

Contaminant distribution in the lower Columbia River is also highly variable. Many of the contaminants introduced into the river become associated with sediments and particulate material which are either discharged directly to the ocean or deposited in low-energy areas. However, because of the high-energy nature of the majority of the river, it does not appear that sediments act as a major sink for contaminants. Biota residing in the river indicated that many contaminants are present and are bioavailable. More contaminants were detected in animal tissues than in any other media analyzed The contaminants that were detected at concentrations that may pose a threat to Columbia River resources include trace elements, pesticides, PCBs, dioxins and furans, PAHs, and organotins.

The recommended monitoring program is structured to address contaminants associated with sediments as well as contaminants in the water column originating from point- and nonpoint-sources. It is an integrated approach that is based on field studies utilizing both transplanted and resident species, and both exposure and response indicators Exposure indicators must be used in conjunction with response indicators in order to identify potential contaminants of concern and whether these contaminants are impacting the biota. Exposure indicators provide evidence of the occurrence or magnitude of exposure to a physical, chemical, or biological stress, in most cases they cannot be used to identify impacts or adverse effects to the exposed individuals Response indicators provide evidence of the conditions to which an individual is exposed; there are very few response indicators that are chemical- or stressor-specific

Bioaccumulation, detoxification enzyme activity, and the fish health index are recommended exposure indicators. The response indicators survival and growth are recommended endpoints for evaluating overall environmental health in the lower Columbia River *Corbicula fluminea* are recommended for both water column and sediment studies in the freshwater reaches of the river *Mytilus* spp and *Macoma nasuta* are recommended for the water column and sediment studies in the estuarine portions of the river Bioaccumulation studies can be conducted with each of these bivalve species as well as resident invertebrate and fish species. The overall environmental health of the lower Columbia River can be evaluated with growth and survival studies in transplanted bivalves and the Fish Health Index in resident fish species. Bioaccumulation studies can be used to identify past or current exposures to contaminants of concern Based on the data obtained during the reconnaissance survey, analysis of benthic community structure in the lower Columbia River does not appear to be of utility for assessing impacts of sediment contamination Benthic communities in the study area reflect the dynamic nature of the aquatic environment in the lower Columbia River. Physical elements (e.g , salinity, sediment grain size, and substrate stability) rather than chemical contaminants appear to strongly influence community composition throughout the river.

The reconnaissance survey measured tissue residues of contaminants in several species with differing degrees of mobility and feeding strategies. Evaluation of these data indicate that the best organism for use in bioaccumulation studies depends on the pollutant being evaluated and the distribution of the organism within the river For example, tissues of the peamouth fish contained the highest concentrations of dioxins but were difficult to catch in the upper river. Of all the species analyzed, concentrations of PCBs in tissues of largescale sucker had the highest degree of correlation with environmental concentrations of PCBs, PCBs were absent in the tissues of crayfish However, tissues from crayfish and carp contained elevated concentrations of trace metals which corresponded to the environmental concentrations. Carp may be one of the most promising candidate species as their tissues contained the largest number of detected pollutants.

It is recommended that monitoring be conducted during high and low flow periods to reflect the potential seasonal variability in contaminant inputs This could be accomplished by sampling during spring freshet and fall low flow periods If the resulting data indicate no statistically significant difference in seasonal data, monitoring could be reduced to an annual event

Although these are final recommendations for monitoring the quality of the environment in the lower Columbia River, the acquisition of additional data and biological indicator techniques may result in modifications in a monitoring approach. In addition, the effectiveness of the recommended monitoring program should be evaluated after a period of one year with respect to the applicability of tests and the ability of tests to identify adverse conditions within the lower Columbia River.

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