Marine Environmental Effects Monitoring Program: Design and Evaluation for Pacific Coastal Pulp Mills

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Report
to
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Marine Environmental Effects Monitoring Program: Design and Evaluation for Pacific Coastal Pulp Mills

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ABSTRACT

This report provides a review of the Environmental Effects Monitoring Program (EEMP) conducted by the Environmental Protection Service (EPS) of Environment Canada at ten British Columbia coastal pulp mills. In addition, this report evaluates the ability of current and past EEMPs at these ten locations to generate data suitable for detecting long-term trends. Where appropriate, changes are recommended to ensure that data sets and information generated by EEMPs are scientifically defensible, environmentally meaningful, and adequate for detecting trends in environmental quality at coastal sites. Finally, the report offers a more general description of a process by which an EEMP can be developed, based in part on the program developed by the Vancouver EPS Marine Group. This generic description is designed to assist in designing and establishing appropriate EEMPs in other Environment Canada regional offices. It lays the groundwork for the development of a national generic EEMP based on a consistent set of defensible guidelines.

TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

1.0 INTRODUCTION

Although on a global scale pollution of marine near-shore waters by pulp mill effluents is a minor problem (Waldichuk 1983), at a local level it can be not only a significant environmental problem, but also one that is often misunderstood (Pomeroy 1983). For example, before 1950 the pulp and paper industry felt that pulping effluents would be easily absorbed by the environment (Sonntag 1975). Then, when the costs of pulp mill operations rose during the fifties and sixties, more efficient ways were developed to recycle process chemicals and recover lost fibers. This same period was accompanied by increased awareness of the sensitivity of marine ecosystems to pulp mill effluents. Together, the combined economic and environmental considerations set in motion efforts to both improve technologies for pulp mill waste treatment and to monitor environmental effects.

The failure to recognize the seriousness of environmental effects of pulp mill effluents in coastal marine environments resulted in problems both with formulating and gaining agreement on monitoring programs (Pomeroy 1983). Consequently, as a result of compromises made in their design, the monitoring programs were often unable to supply adequate data not only for describing environmental effects on coastal marine ecosystems, but also the dose-response relationships that would assist in designing more effective effluent treatment and diffuser systems.

To determine and document effects that pulp and paper mills in British Columbia were having on aquatic ecosystems and resources, in the early 1970's the Environmental Protection Service (EPS) of Environment Canada initiated monitoring programs at all of the coastal pulp and paper mills. This program has continued until the present.

In light of the increased awareness of the need to establish well-designed environmental effects monitoring programs, and the availability of multi-year data from some of the 10 British Columbia coastal pulp mill monitoring programs, it is appropriate at this time to review trends in environmental quality at those sites (a reflection of technological progress in reducing concentrations of toxic effluents) and the monitoring programs that generated the database.

It is also appropriate to step back from the details of the pulp mill data and evaluate the adequacy of the EEMP as a whole. This evaluation should include both the individual components of the EEMP (i.e. formulation of objectives, study design, data collection, and data analysis), as well as the overall structure for integrating these components. This evaluation can serve as a starting point for designing a national generic EEMP.

1.1 Objectives

The specific objectives of this study were to:

1) review existing data collected by the EPS Marine Group pertaining to effects of ten British Columbia coastal pulp mills on marine habitats and water quality,

2) using these data, determine trends in certain marine environmental quality indicators around selected coastal pulp mills,

3) evaluate the ability of current and past EEMPs at these ten locations to generate long-term data suitable for detecting trends,

4) recommend changes to ensure that long-term data sets generated by existing EEMPs are scientifically defensible, environmentally meaningful, and adequate for detecting trends in environmental

quality at coastal sites, and

5) describe the EEMP developed by EPS, Vancouver in a way that will facilitate construction and establishment of appropriate EEMPs in other DOE regional offices, and lay the foundation for a national generic EEMP.

1.2 Definitions

As used in this report, **monitoring** simply means repetitive measurement. In the context of impact assessment, as described by Beanlands and Duinker (1983), monitoring refers to repeated measurement of specific ecological phenomena to document change primarily for the purposes of (i) testing impact hypotheseses and predictions, and (ii) testing mitigative measures.

Environmental effects monitoring, as defined by Conover (1985), measures changes in environmental factors to establish cause-effect relationships between a natural or human generated environmental factor and affected environmental components.

1.3 Report Organization

This report is organized as follows. **Chapter 2** describes the evolution and current state of the West Coast Marine EEMP. **Chapter 3** evaluates some of the results from this program, with special emphasis on exploratory analysis of key parameters at selected sites, and provides recommendations for changing the monitoring program. **Chapter 4** is focused on the principles, main considerations, and methods for designing environmental effects monitoring programs.

2.0 DESCRIPTION OF WEST COAST MARINE EEMP

2.1 Perspective

In the Pacific and Yukon region, the Environmental Protection Service (EPS) of Environment Canada initiates and supports a number of activities generally designed to identify marine pollution problems and to develop and carry out protection and control measures. These activities are often carried out in conjunction with other federal and provincial agencies. Activities relevant to west coast pulp mill operations include:

- environmental effects monitoring programs (EEMP) around pulp mills,
- surveillance and monitoring of discharges from pulp mills,
- permitting and surveillance of ocean dumping sites (e.g., materials dredged from pulp mill harbors), and
- enforcing effluent regulations.

Several different sections of the Environmental Protection Branch of EPS are responsible for managing and carrying out these various activities. This chapter specifically focuses on activities administered by the Marine Group pertaining to pulp mill effects on coastal marine ecosystems.

2.2 Specific Objectives

The overall purpose of the EEMP, as administered by the Marine Group, is to "evaluate effectiveness of pollution abatement programs at coastal locations where fish habitat loss is real or threatened" (Harding 1986). In this context fish habitat includes both water quality and habitat quality. The specific objective is to "detect long term changes in extent or degree of fish habitat loss caused by point source pollutant discharges" (Harding 1986). The emphasis on "fish habitat" is due to the fact that the legal authority for the EEMP is derived in part from the Fisheries Act. Consequently, the term fish includes not only Pisces, but many other marine organisms as well. To meet this objective, the Marine Group carries out monitoring programs which entail "repeated sampling of physical, chemical, biological, and toxicological parameters to detect change on some time scale" (Harding 1986).

2.3 Program Evolution

Starting in the early 1970's, the EPS began conducting monitoring programs at each of the coastal pulp mills. As the program evolved, the parameters of interest and the methods employed varied not only from mill to mill, but through time (see Tables 2.1 through 2.10). Meanwhile, pertinent data were also being collected by other agencies and by the mills themselves. Consequently, considerable information was gathered about the effects of pulp mill effluents on a variety of marine ecosystem components.

Examining Tables 2.1 - 2.10 the reader can see that cumulatively, across all sites, a substantial quantity of information was collected to describe effects of pulp mill operations on coastal marine systems. Furthermore, these tables only cover routine work on selected components of the systems and do not include special studies that were carried out at certain locations to answer specific questions.

To better understand the extent and nature of the environmental effects that pulp and paper mills in British Columbia were having on aquatic ecosystems and resources, in 1976 the EPS initiated an assessment program. This program resulted in a series of 1979 reports detailing the current conditions at most of the coastal pulp and paper mills. Each of these reports not only described the mill operations and the quality and quantity of the effluent, but also

Table 2.1. Summary of data described in EPS reports for Woodfibre, Squamish.

Parameter	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86
# Stations					13	13	13				15			14		
Fiber bed									R					C		
Toxicity					R											
Metals					R	R	R				T			C		
Organics														C		
D.O.					R	R	R				T			C		
Benthos			R		R	R	R	R		R						
Intertidal						R		R								R

T = Data in paper tables
C = Data in computer tables
D = Single datum, or observational data
R = Referred to in text

References: Nelson 1979; Sullivan 1982; Grooms 1986

Table 2.2. Summary of data described in EPS reports for Port Mellon.

Parameter	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86
# Stations										6	9		8			14
Fiber bed						R					D		C			C
Toxicity				R	R	R	R			R						
Metals										T	T		C			C
Organics										T	T		C			C
D.O.										T	T		C			
Benthos										T						
Intertidal (R)		R	R	R	R		R	R								

T = Data in paper tables
C = Data in computer tables
D = Single datum, or observational data
R = Referred to in text

References: Nelson 1979; Sullivan 1981; Sullivan 1982; Grooms 1986; Unpublished data 1987

Table 2.3. Summary of data described in EPS reports for Powell River.

Parameter	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86
# Stations									10	8	10		11			
Fiber bed								D	D		D					
Toxicity					T	T	T									
Metals								T	T	T	T		C			
Organics									T	T	T		C			
D.O.									T	T	T		C			
Benthos									T							
Intertidal (R)		R	R			R	R		R	R						

T = Data in paper tables
C = Data in computer tables
D = Single datum, or observational data
R = Referred to in text

References: Nelson 1979; Sullivan 1980; Sullivan 1981; Sullivan 1982; Grooms 1986

Table 2.4. Summary of data described in EPS reports for Crofton.

Parameter	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86
# Stations									9	9	8		8			12
Fiber bed (R)					R			R			D		D			D
Toxicity					T	T	T									
Metals									T		T		C			C
Organics											T		C			C
D.O.								D	T	T	T		C			C
Benthos									T	T						
Intertidal (R)			R													

T = Data in paper tables
C = Data in computer tables
D = Single datum, or observational data
R = Referred to in text

References: Nelson 1979; Sullivan 1980; Sullivan 1981; Sullivan 1982; Grooms 1986; Unpublished Data 1987

Table 2.5. Summary of data described in EPS reports for Harmac.

Parameter	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86
# Stations									5	13			15			22
Fiber bed					D			D					C			C
Toxicity						R	R									
Metals									T	T			C			C
Organics									T				C			C
D.O. (R)					R	R			T	T			C			C
Benthos						R		D								
Intertidal (R)		R	R	R		R	R		R	R	R	R				

T = Data in paper tables
C = Data in computer tables
D = Single datum, or observational data
R = Referred to in text

References: Packman 1979; Sullivan 1980; Sullivan 1981; Grooms 1986; Unpublished data 1987

Table 2.6. Summary of data described in EPS reports for Port Alberni.

Parameter	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86
# Stations										14	14			16		6
Fiber bed												D		D		D
Toxicity									R							
Metals										T	T	T		C		
Organics											T	T		C		
D.O.										T	T	T		C		C
Benthos										T						
Intertidal						R	R	R		R		R	R			D

T = Data in paper tables
C = Data in computer tables
D = Single datum, or observational data
R = Referred to in text

References: Sullivan 1978a,b; Nelson 1979; Sullivan 1981; Sullivan 1982; Grooms 1986; Unpub. data 1987

Table 2.7. Summary of data described in EPS reports for Elk Falls.

	Year															
Parameter	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86
# Stations				6					6						9	
Fiber bed																
Toxicity					R	T	T								T	
Metals									T							
Organics									T							
D.O.									T							
Benthos																
Intertidal				R		R			R						T	

T = Data in paper tables
C = Data in computer tables
D = Single datum, or observational data
R = Referred to in text

References: Packman 1979; Sullivan 1980; Grooms 1986; Colodey 1985

Table 2.8. Summary of data described in EPS reports for Tahsis.

	Year															
Parameter	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86
# Stations						8	8									6
Fiber bed							D									
Toxicity					T	T	T									
Metals																
Organics																
D.O.						T	T									C
Benthos							T									
Intertidal (R)					R	R			R							R

T = Data in paper tables
C = Data in computer tables
D = Single datum, or observational data
R = Referred to in text

References: Sullivan and Nelson 1979; Sullivan 1979; Grooms 1986

Table 2.9. Summary of data described in EPS reports for Port Alice.

	Year															
Parameter	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86
# Stations				3	3	3					20		21		9	16
Fiber bed															C	
Toxicity																
Metals															C	
Organics															C	
D.O.				T	T	T				T			T		C	C
Benthos											T				C	C
Intertidal										T					R	R

T = Data in paper tables
C = Data in computer tables
D = Single datum, or observational data
R = Referred to in text

References: Sullivan 1978; Sullivan 1979; Pomeroy and Goyette 1983;

Table 2.10. Summary of data described in EPS reports for Prince Rupert.

	Year															
Parameter	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86
# Stations				14					9	7	9	8		15	21	
Fiber bed									D	D	D			C	C	
Toxicity																
Metals									T	T	T			C	C	
Organics																
D.O.				T					T	T	T	T		C	C	
Benthos				T							T					
Intertidal				D												

T = Data in paper tables
C = Data in computer tables
D = Single datum, or observational data
R = Referred to in text

References: Packman 1977; Pomeroy 1983; Unpublished data 1987 characterized the receiving environment and the nearby biotic natural resources. One of the advantages of this report series is that it offers a relatively uniform "snapshot" of conditions at different pulp mill sites.

During the period 1980-1985, the Marine Group continued monitoring and completed more than 150 marine biological surveys at over 50 locations (Harding 1986). This work produced a considerable amount of valuable data and information pertaining to effects of pulp mills (and other effluent sources such as outfalls from sewage treatment plants and mine tailing sites) on coastal marine systems.

2.4 Program Description

The following paragraphs are designed to provide the reader with a brief description of the types of measurements that have been frequently used in the pulp mill EEMP. Not all of the measurements listed below were necessarily used in an environmental effects monitoring program at a given site in a given year.

Water quality monitoring has typically included measurements of dissolved oxygen (DO) and color. In addition, at the same time that DO measurements were made, temperature, salinity, and depth were recorded, from which oxygen saturation values could then be computed. In some cases, pH and nutrient levels have also been measured.

Monitoring programs for sediments have frequently included measurements of organic content (total volatile content) and organic contaminants (e.g., resin acids, tannins, PCP, oil and grease). Total metal concentrations (especially Zn, Cd) and mercury are measured along with physical analyses for particle size distribution. As well, notes are kept regarding the presence of hydrogen sulfide, and the visual appearance of the sediments. In a few selected cases, visual descriptions and photographs of benthic conditions are also available from dives made in submersibles.

As part of some monitoring programs, samples have been collected from benthic communities. From these samples, species lists have been compiled and the presence or abundance of indicator species noted. In some cases, these species lists have been used to compute indices of species richness/abundance, rough indicators of community diversity. As well, tissues from some benthic organisms have been analysed for the concentration of contaminants (cf. Zn, Hg, Cd, PCB). Additionally, toxicity data from laboratory bioassays on fish are available for all pulp mills.

The clear identification of objectives, as provided in Section 2.2 above, represents an important step toward refining the EEMP. A reasonable second step is to evaluate past programs and the data they generated. Thus, the purpose of the next Chapter is to review certain portions of past programs at selected sites to highlight activities that were both most and least successful. From this review it will hopefully be possible to better assess which strategies of impact monitoring are of the greatest relevance and feasibility for meeting the identified objectives.

3.0 EVALUATION OF WEST COAST MARINE EEMP

3.1 Overview

In this chapter we report findings from our review of past environmental effects monitoring programs at coastal pulp mill sites. Although initially we reviewed the monitoring programs and data for all 10 coastal sites (see Tables 2.1-2.10), the variability in the data available for some parameters and sites indicated that not all sites were amenable to detailed statistical analyses. Thus, based upon the nature, quantity, and quality of data from each site, we divided the pulp mills into three groups, depending upon whether they were to receive (1) detailed statistical analyses, (2) exploratory analyses, or (3) brief reviews. Group 1 included Crofton and Prince Rupert while Harmac, Port Alice, and Port Mellon were in Group 2. The remaining sites (Port Alberni, Powell River, Woodfibre, Elk Falls, and Tahsis) were in Group 3.

To facilitate reporting results of the analyses, a decision was made to focus the report on specific parameters, rather than on particular mills. The reasoning was that much could be learned by examining a particular parameter in detail at a specific site, and then comparing that analysis with other sites. This approach was also appropriate to the objectives for this study: to determine environmental quality trends and to evaluate the ability of the EEMPs to generate data suitable for detecting trends. The monitoring subjects we chose to highlight in this chapter are:

- deoxygenation,
- sediment metals,
- sediment organic contamination, and
- biotic impoverishment in the intertidal zone.

For each problem we (1) describe the importance of monitoring changes in that subject area, (2) evaluate trends (where suitable or representative data are available), and (3) make recommendations for future monitoring. Each problem section contains references to information or results from any pulp mill, as appropriate.

3.2 Deoxygenation

3.2.1 Importance

One important environmental quality concern associated with pulp mill effluents is deoxygenation. This can occur in both the water column and sediments. Because discharged effluents have a high concentration of suspended wood fibers and fragments, they have a high biological oxygen demand (BOD) associated with organic matter decomposition. High biochemical oxygen demand is also associated with the spent sulfite liquor. This high BOD, in turn, is a concern because it results in lowered dissolved oxygen (DO) content in the receiving waters. The flow path of effluents with high BOD influences which portions of the marine ecosystem are directly affected. For example, if under certain conditions (e.g., wind or tide combinations) the effluent plume washes back to the shore, it can contact important intertidal communities. Colored effluents and suspended materials such as wood fibers are also of concern partly because by reducing light penetration into the water column they can decrease photosynthetic oxygen production (Siebert and Parker 1972), thereby indirectly contributing to depressed oxygen concentrations.

3.2.2 Trends Analysis

Following discussion with scientists from EPS, and a review of existing reports, two pulp mill sites were selected for closer scrutiny: Crofton and Port Alice. These two sites represent a contrast in sensitivity to deoxygenation from pulp mill effluent. The Crofton outfall discharges into the relatively well flushed waters of Stuart Channel on the east coast of Vancouver Island. The Port Alice mill, situated on the northwest side of Vancouver Island, discharges into the far end of Neroutsos Inlet, a 15 km long body of water with restricted circulation and thus limited dilution.

The EPS data for Crofton was analyzed quantitatively to explore methods of integrating oxygen measurements over depth, space and time, and assess trends. These data were collected primarily for the purpose of providing a check or "audit" on company measurements. The Port Alice data was not quantitatively analyzed; rather, the available reports were reviewed and possible approaches to data analysis recommended.

Methods

The Crofton water quality data consists primarily of temperature, salinity, and dissolved oxygen measurements, as well as levels of percent oxygen saturation (calculated from the other three measurements), and some data on color and non-filterable residue (NFR). Sampling was performed at nine stations in July and October of 1979, June and November of 1980, and November 1981 (Sullivan 1980, 1981, 1982), at eight stations in November of 1983 (Colodey and Tyers, in prep), and at two stations in April 1986. The locations of the stations are shown in Figure 3.1.

Only the data from the fall periods (October and November) were analyzed. The spring and summer data show much higher dissolved oxygen and percent saturation than fall measurements, and deoxygenation is not an issue at these times. Furthermore, only dissolved oxygen concentrations were examined, not percent saturation calculations. Within the fall period, analysis of percent saturation calculations contributes little useful information in addition to analysis of dissolved oxygen for the following reasons.

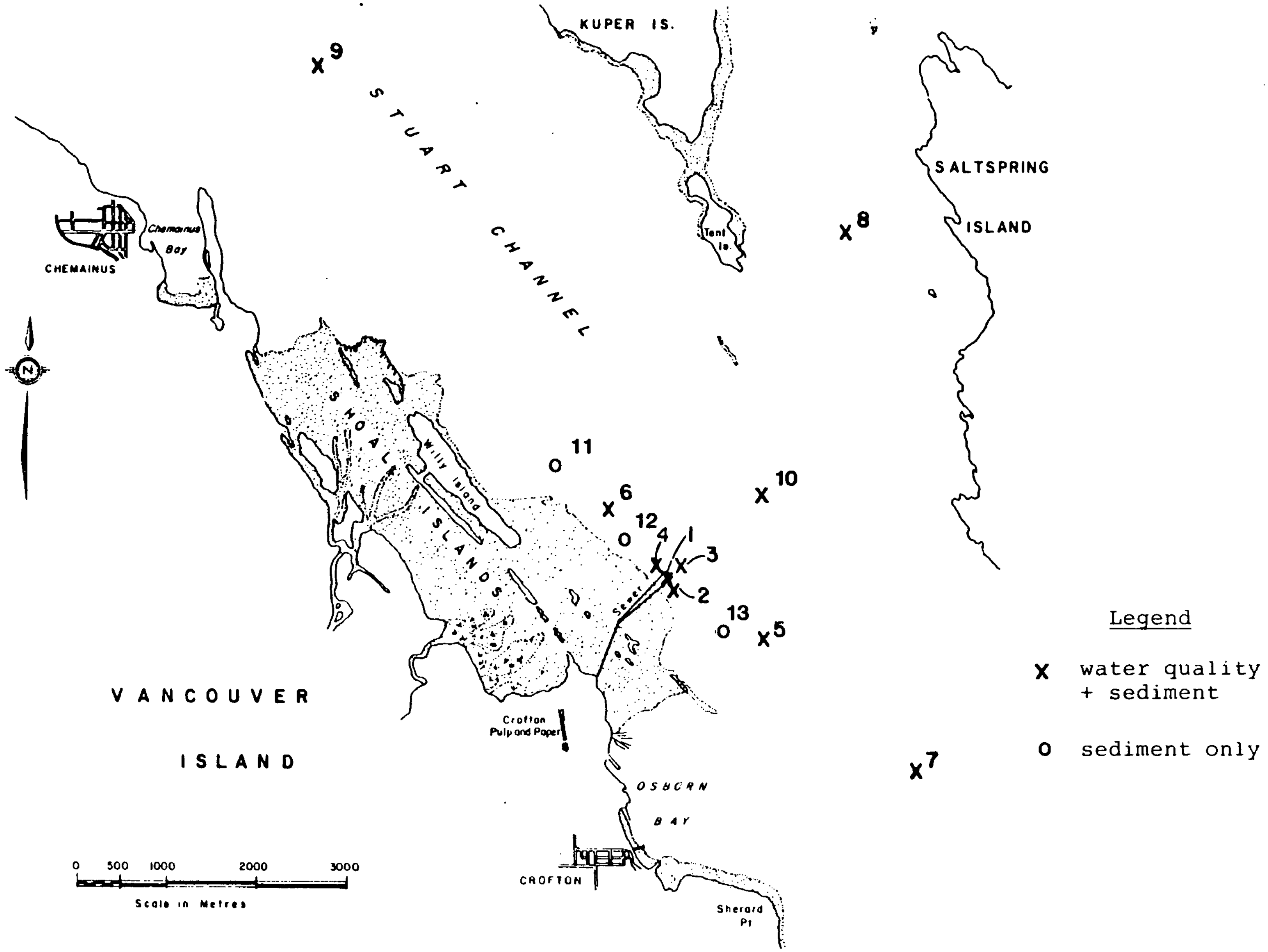


Figure 3.1. Water quality and sediment sampling stations in the Crofton environmental monitoring program (1979-1986). As explained in the text, not all stations were sampled in all years. Station locations approximate. Source: Sullivan (1980), 1981, 1982), Colodey and Tyers (in prep.).

First, there is very little spatial and year-to-year variation in measurements of temperature and salinity, which together determine the 100% oxygen saturation level. Since the 100% saturation level of oxygen in these data varied only 0.6 mg/l (from 8.8 to 9.4 mg/l), actual oxygen concentrations, and percent saturation levels would be highly correlated. Therefore only one of these variables needs to be analyzed. Second, biotic responses are directly related to oxygen concentrations, while they are less related to oxygen saturation levels.

The color and NFR data was not analyzed in this study due to time and budget limitations.

Three approaches were taken to synthesize the data:

1) oxygen-depth profiles were produced for each station and sampling date;

2) the depth of the "oxygenated zone" was interpolated from the oxygen profiles as the depth above which all oxygen measurements exceeded 5 mg/l, the recommended level for "ecosystem maintenance" of fish habitat (Davis 1975);

3) stations were grouped into "outfall", "near outfall", and "reference" zones, according to the scheme given in Colodey and Tyers (<u>in prep</u>):

   Outfall: Stations 1, 2, 3 and 4;

   Near Outfall: Stations 5 and 6;

   Reference: Stations 7, 8, 9 and 10.

   Means and standard errors were computed for each group.

Though the "oxygenated depth" is an effective means of compressing profile data, values of dissolved oxygen near the 5 mg/l threshold can create artificially large differences among stations. For example, one station with values of 5.1 mg/l at all depths, and another with 4.9 mg/l would yield very different estimated oxygenated depths. Since this quirk might lead to an unusual statistical distribution of oxygenated depths, analyses of variance were not performed on these derived data. Group means and standard errors (SE) were calculated, however, to give some feeling for the relative significance of differences between spatial zones and years. Group means for each spatial zone were graphed with error bars equal to two times the standard error (approximately 95% confidence intervals for normally distributed data).

Results

Crofton

The intent of this analysis was to evaluate whether there were definable spatial patterns and temporal trends, not to determine the reasons for their existence. Such a determination would require analyses of additional data on winds, tides, and effluent loading.

Oxygen depth profiles are shown in Figures 3.2 (a) - (e), for all the fall data from 1979 to 1983. Note that stations 7, 9 and 10 were not sampled every year. The data are shown with a different depth scale for each station, reflecting the maximum depth to which samples were taken, which varied from 35 m at station 8 to 160m at station 10. It is unfortunate that the only consistently sampled reference station had a maximum depth of only 35m - ideally the reference station would have a depth approximating the depth of other stations. It is not clear to what extent this difference in depth influences oxygen concentration, but it does make the evaluation of trends in deep water oxygen concentrations more tenuous.

Both temporal trends and depth profile patterns are

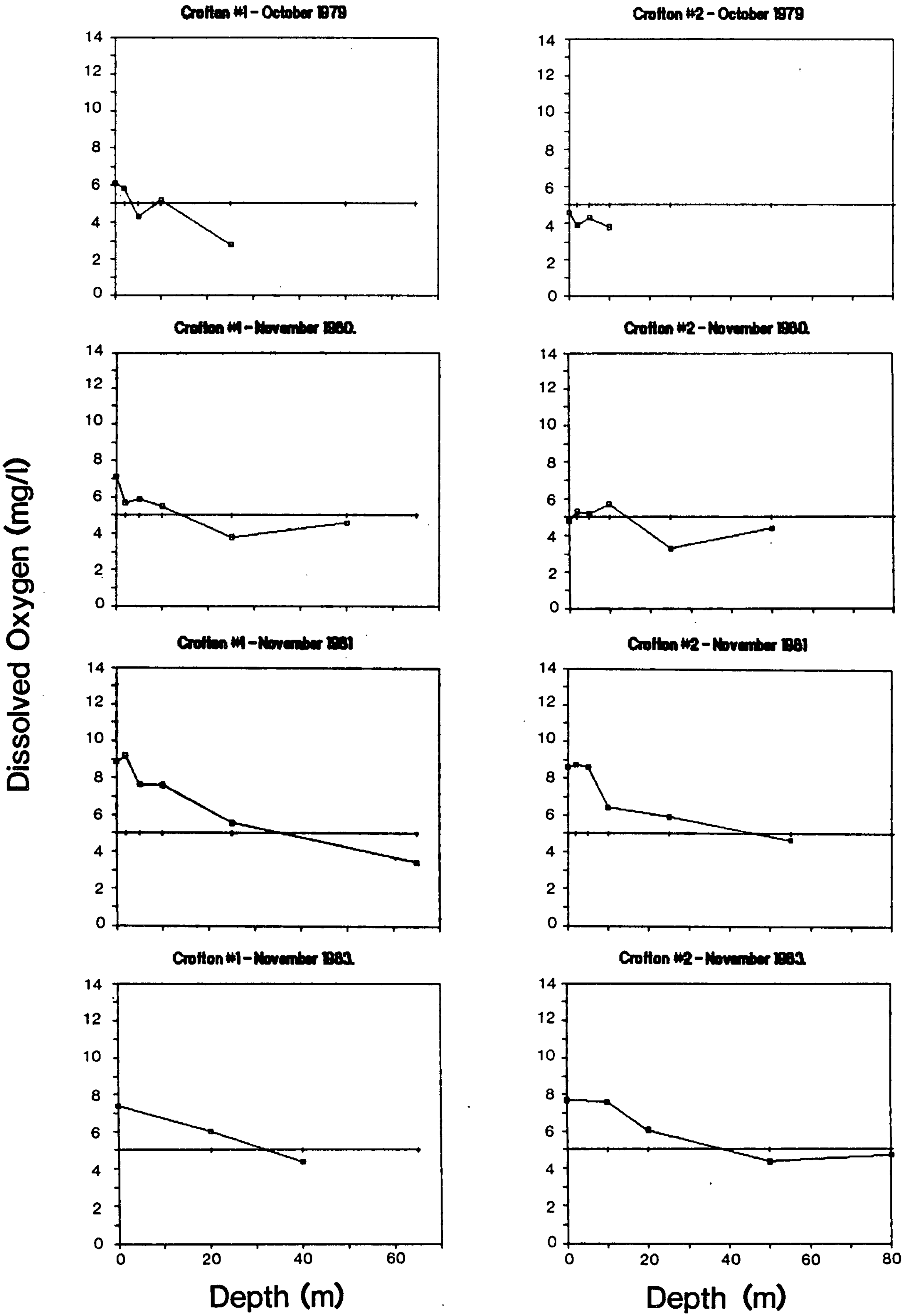


Figure 3.2 (a). Oxygen profiles for Stations 1 and 2 at Crofton.

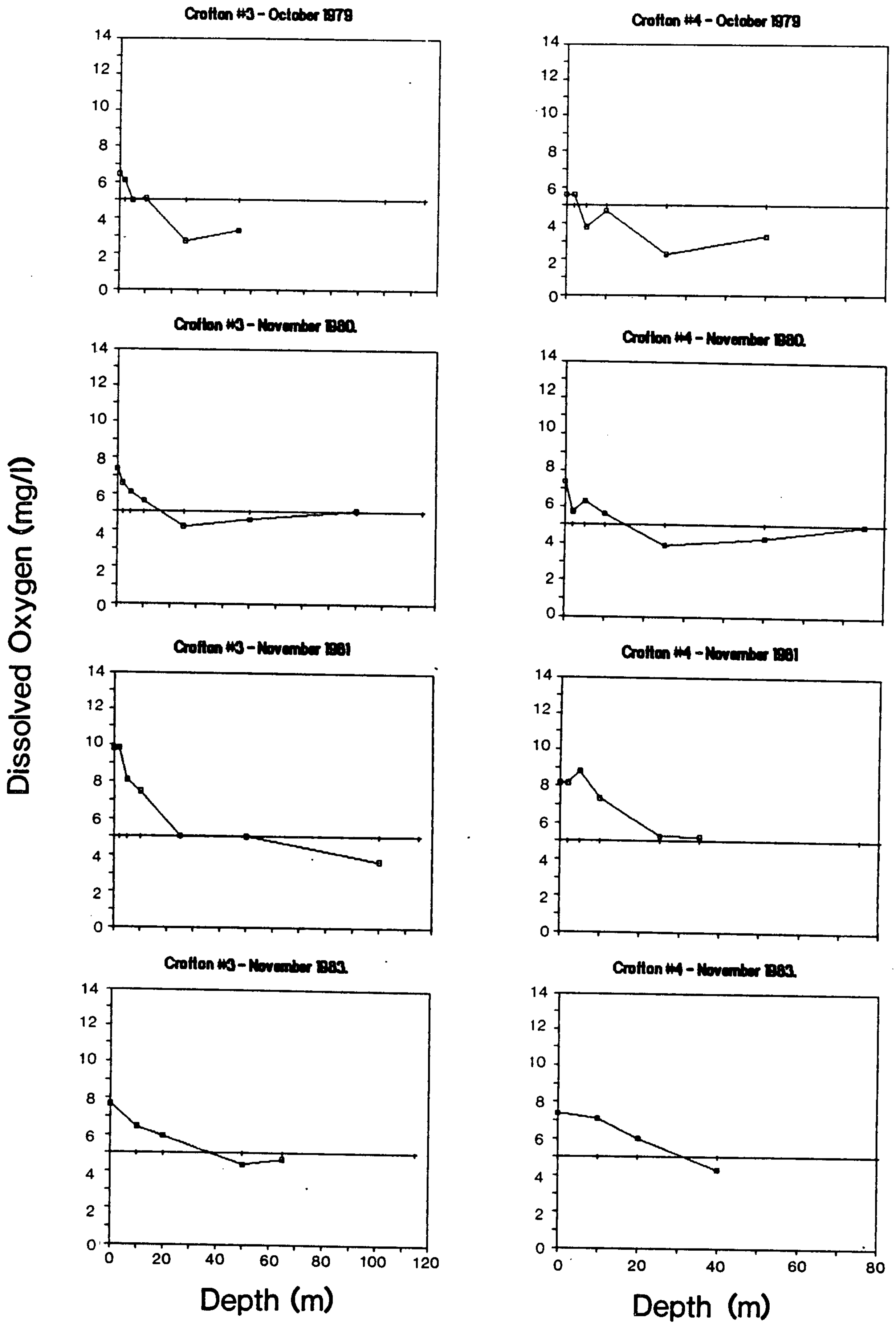


Figure 3.2 (b). Oxygen profiles for Stations 3 and 4 at Crofton.

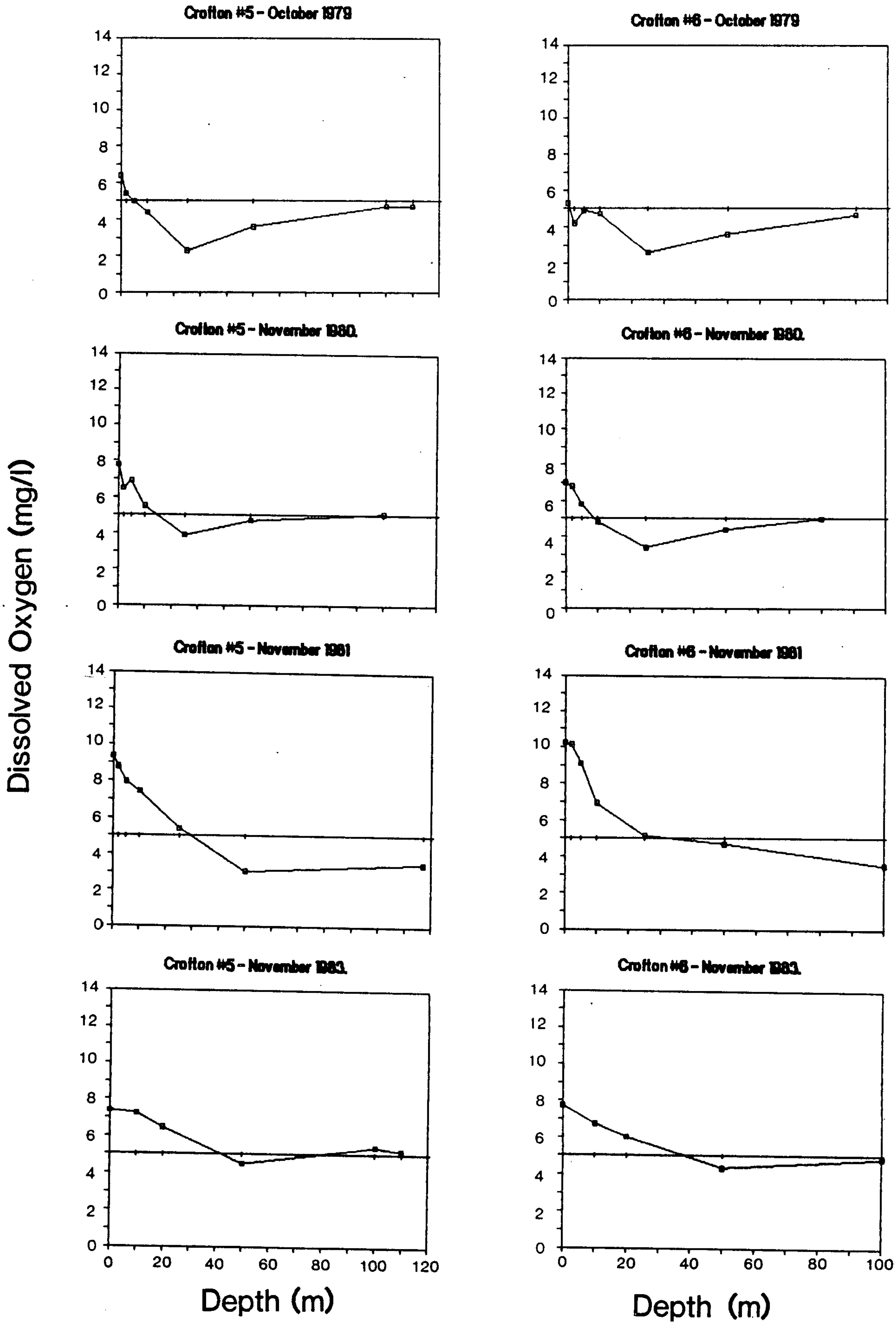


Figure 3.2 (c). Oxygen profiles for Stations 5 and 6 at Crofton.

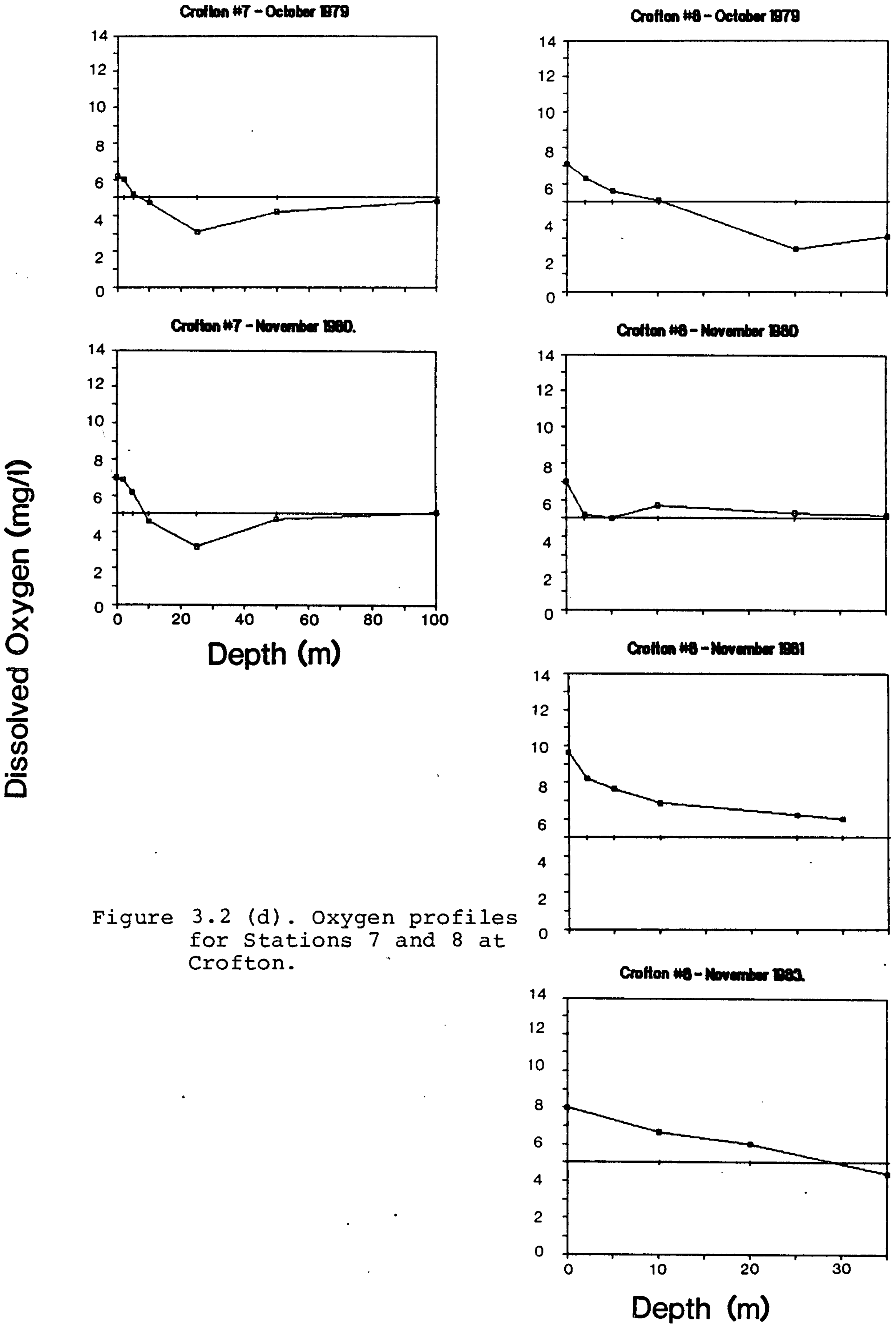


Figure 3.2 (d). Oxygen profiles for Stations 7 and 8 at Crofton.

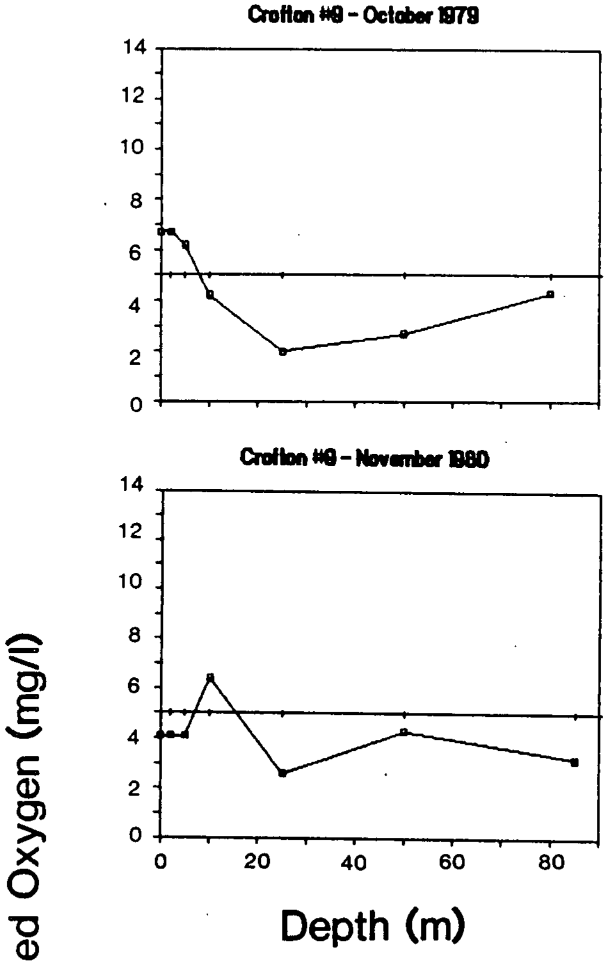
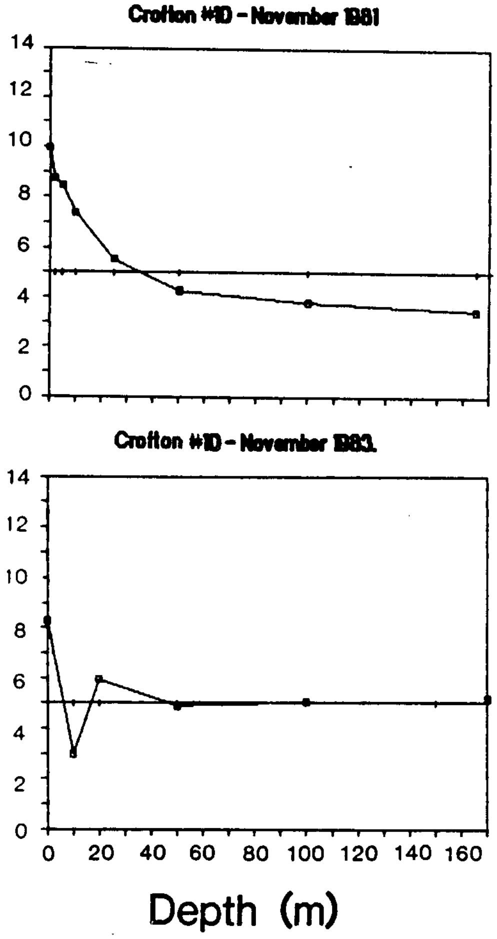


Figure 3.2 (e). Oxygen profiles for Stations 9 and 10 at Crofton.



evident. The most obvious temporal trend is that for all stations with a 4-year time series, oxygen levels were higher in 1981 and 1983 than in 1979 and 1980. This pattern is discussed further below. Surface water concentrations were above 5 mg/l at 33 of 34 stations, indicating acceptable conditions for ecosystem maintenance according to Davis (1975). However, all stations show commonly observed declines in oxygen with depth, and only 3 of 34 station data sets had concentrations above 5 mg/l at all measured depths. In 1979 and 1980, 16 of 18 stations showed pronounced oxygen minima at intermediate depths of 20-30 m, rather than the more commonly observed minimum concentration at maximum depth. Though this pattern could have been due to effluent loading from the mill, this hypothesis seems unlikely because both reference stations 7 and 9 (SE and NW of the mill respectively) showed the same pattern as stations closer to the outfall.

The interpolated depths of the oxygenated zone (> 5 mg/l) are shown in Table 3.1 for all stations and years, together with the group means and standard errors. Scanning this table indicates that:

1) The variation within groups within each year was small except for the reference group in 1980 and 1983. This suggests that the grouping of outfall and near outfall stations was probably reasonable. Reference stations 7 and 9, however, had much shallower oxygenated zones than station 8 in 1980. In 1983, station 10 showed a much shallower oxygenated zone than station 8, as station 10 concentrations dropped from 8.3 to 3.0 mg/l in the first 10m, and then returned to 6 mg/l at 20m (Figure 3.2 (e)). It is not clear whether station 8 is the only "true" reference station (i.e. other pollution sources affect 7 and 9) or whether natural variability is very high.

Table 3.1. Approximate depth (m) with oxygen levels above 5 mg/l.

Station/	Year					
Group	1979	1980	1981	1983	Mean	2*SE
Outfall						
#1	4	14	37	32	21.8	15.4
#2	0	13	45	38	24.0	21.1
#3	10	15	50	37	28.0	18.8
#4	4	15	35	31	21.3	14.4
Mean	4.5	14.3	41.8	34.5	23.8	8.0
2*SE	4.1	1.0	7.0	3.5		
Near Outfall						
#5	5	15	28	42	22.5	16.1
#6	1	9	33	38	20.3	18.0
Mean	3.0	12.0	30.5	40.0	21.4	11.2
2*SE	4.0	6.0	5.0	4.0		
Reference						
#7	6	8			7.0	2.0
#8	11	35	30	28	26.0	10.4
#9	8	0			4.0	8.0
#10			35	7	21.0	28.0
Mean	8.3	14.3	32.5	17.5	18.2	8.6
2*SE	2.9	21.2	5.0	21.0		
MEAN	5.4	13.8	36.6	31.6	21.9	5.2
SE	5.4	6.8	27.5	3.5		
n	9	9	8	8		34

2) All stations show an improvement (increase) in oxygenated depths from 1979-1980 to 1981-1983.

3) The changes over time (reading across the rows) are much more significant than the changes over space (reading down the columns).

Figure 3.3 shows the spatial patterns in mean oxygenated depths for each year. In none of the four years were there clear differences (non-overlapping confidence intervals) in oxygenated depths between the three station groups (outfall, near outfall, and reference). In reviewing the 1979 data, Sullivan (1980) noted lower levels of surface oxygen in outfall stations than in reference stations, and the same pattern is apparent in Figure 3.3 (even lower in near outfall stations). In 1980, station 8 had much greater oxygenated depths than other stations (Table 3.1), but when averaged together with station 7 there are no clear differences between the reference group and the other two groups (Figure 3.3). In 1981, the outfall zone showed greater oxygenated depths than the other two zones, which Sullivan (1982) attributed either to natural environmental variation, the lingering effects from an industry shutdown which ended in late September, or changes in effluent quality. The 1983 data show the lowest mean oxygenated depths at the reference stations, though variability at these stations is very high.

The temporal trends within each spatial zone are illustrated in Figure 3.4. At both the outfall and near outfall zones, the 1981 and 1983 oxygenated depths were much greater (i.e. more than twice the standard error of the mean) than in 1979 and 1980. Near outfall stations showed a significant increase between 1981 and 1983. These clear trends were less strong at the reference stations. Though 1981 oxygenated depths were significantly greater than 1979 levels, the within group variation in 1980 and 1983 obscured the

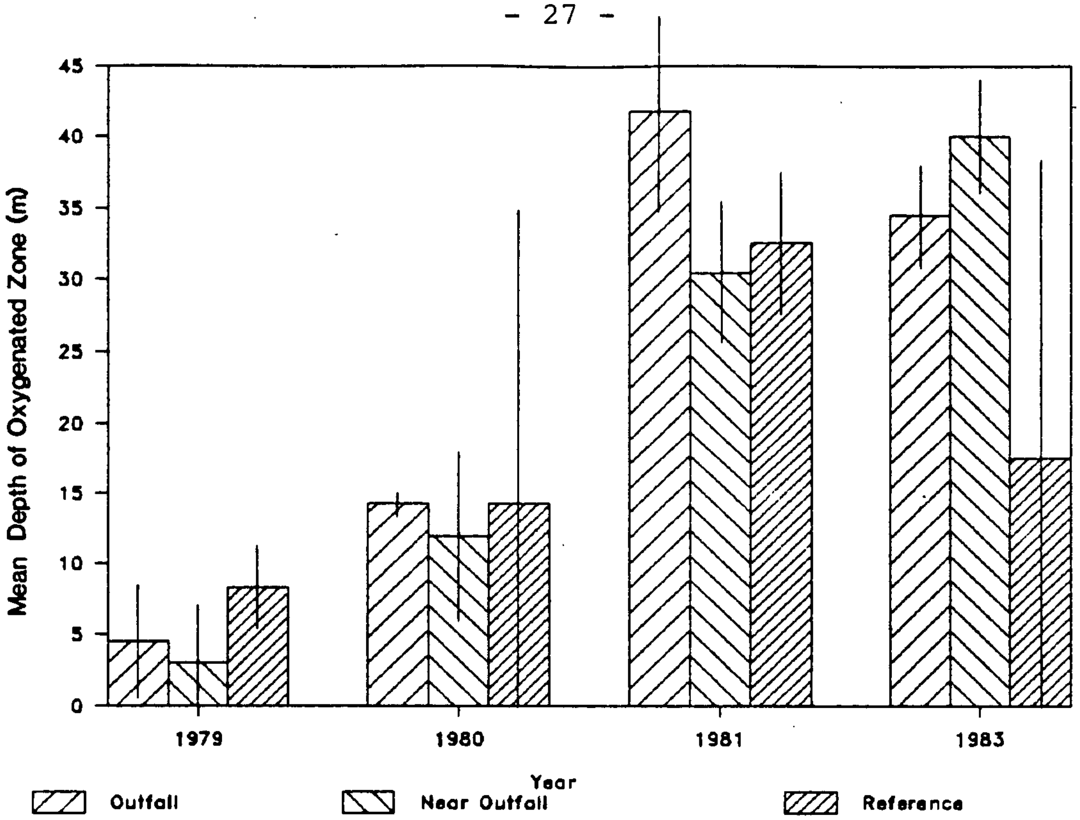


Figure 3.3 Trends across spatial zones in mean oxygenated depth within each of four sampled years. Error bars represent two times SE. Number of stations within each zone in Table 3.1.

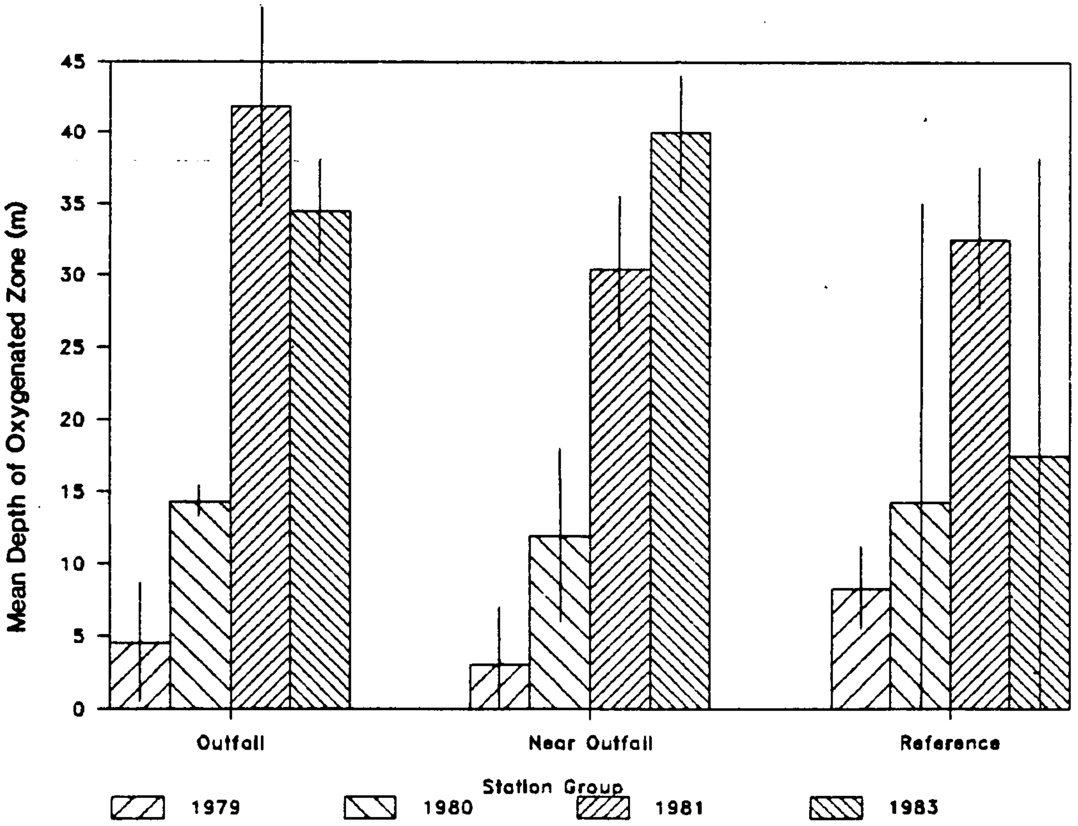


Figure 3.4 Trends through time in mean oxygenated depth within each of three spatial zones. Error bars represent two times SE.

change in mean levels.

Port Alice

Deoxygenation is a more serious problem at Port Alice. Significant oxygen depressions during salmon spawning runs have been detected in the surface waters (Pomeroy and Goyette 1983). Fish avoidance of the spawning stream at the head of the inlet, and probably significant mortality, appears to have occurred as a result of the low oxygen concentrations (Colodey and Pomeroy 1986). High concentrations of colored effluent lead to light limitation and much lower primary production near the mill (Sullivan 1979). The major issues are whether to further restrict the BOD loadings, and whether to change the depth at which effluent is discharged from a deep discharge to a surface discharge.

The data for the Port Alice situation include both EPS and company data. The EPS data is not of much use for analyzing trends, since only one of the 1974-76 stations (Sullivan 1979) was resampled in 1983 (Pomeroy and Goyette 1983). The company data is much more extensive, and overall trends have been neatly summarized by Tollefson and Tokar (1978) (Figure 3.5). In this situation, the best allocation of EPS' effort would seem to be in further analysis of the company data, rather than further data collection. Recommendations for analyses are included below.

3.2.3 Recommendations

Locations

Dissolved oxygen is highly variable in both space and time, even in uncontaminated waters. A more complete survey is required in order to select appropriate reference stations. Once these controls have been selected, they should be maintained. The change in reference stations over the 1979-83 period (Table 3.1) weakened the analysis of Crofton's trends. Integration of the Crofton compliance monitoring stations with the EPS stations might have permitted

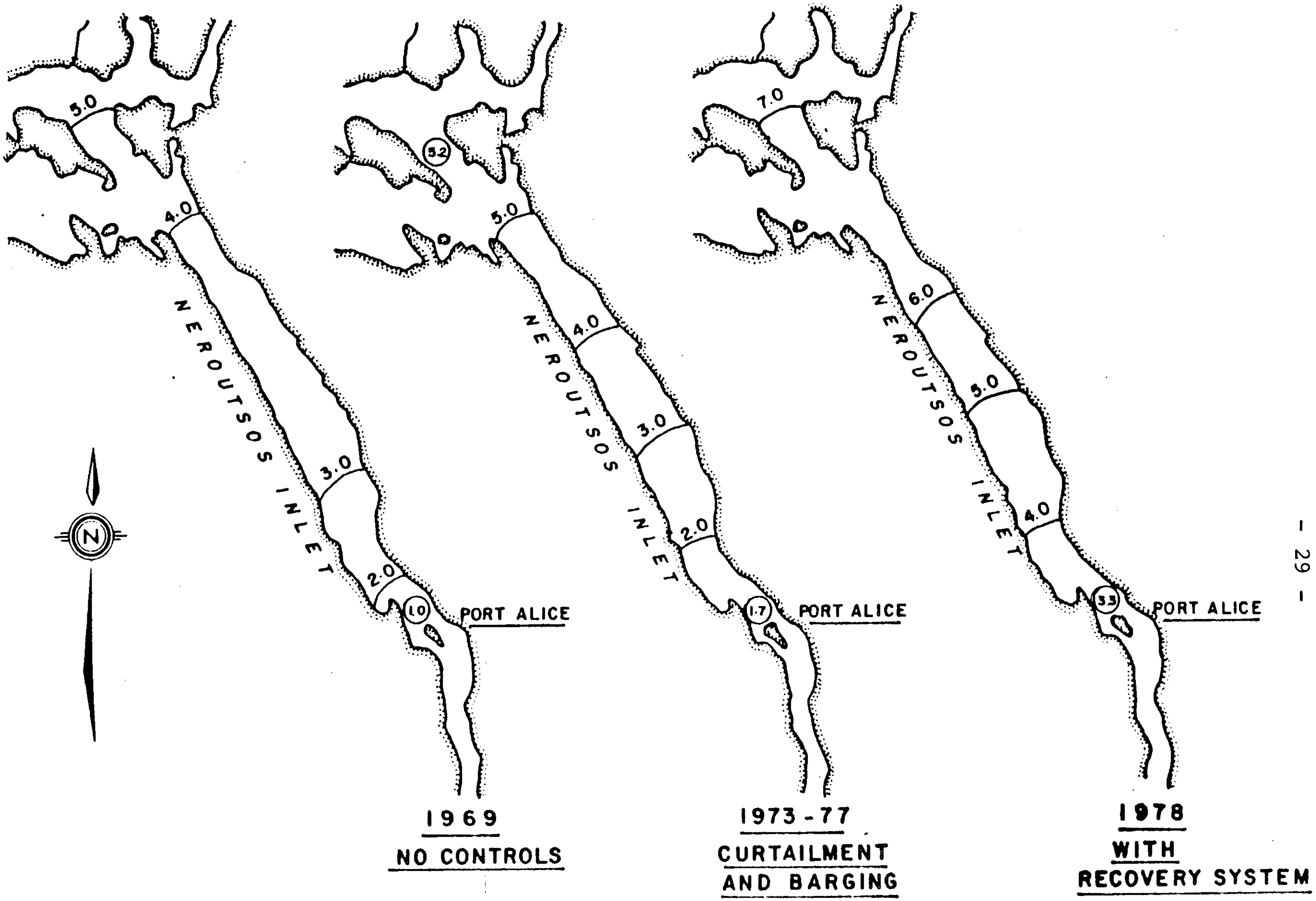


Figure 3.5. Mean dissolved oxygen values (ppm) - Neroutsos Inlet - July - October, top 2 metres (from Tollefson and Tokar 1978).

a stronger delineation of both temporal and spatial variability, provided that methods used were consistent.

The presence of "naturally" deoxygenated waters deep in some basins such as Neroutsos Inlet and Howe Sound is attributed to infrequent replenishment with "new" marine waters. These deoxygenated waters can contain concentrations of H_2S lethal to benthic communities. The extent, frequency of occurrence, and historical development of benthic zones containing high H S concentrations is largely unknown. Consequently, the degree to which pulp mill operations have exacerbated "natural" conditions is not known. To determine this would require a more extensive (space and time) survey than is normally part of an EEMP designed to monitor effects of pulp mill effluent discharges.

<u>Parameters</u>

In the case of oxygen measurements it is essential to collect several other types of data simultaneously, since oxygen solubility in water is a function of temperature and salinity. Water color can also help to identify areas of potential deoxygenation. For example, in an analysis of the relationships between water color (used as an indicator of effluent levels) and dissolved oxygen concentrations at Port Alice, Colodey and Pomeroy (1986) found that color was significantly negatively correlated with dissolved oxygen.

BOD can be directly measured using laboratory methods, and these tests are conducted periodically on effluent samples from each pulp mill. These tests, however, do not appear to have been used directly in the EEMP on seawater samples. This may be useful, because BOD measurements performed at the standard temperature (20° C) will tend to overestimate the <u>in situ</u> BOD under colder temperatures. Use of temperature corrections, or supplementary laboratory determinations at natural seawater temperature, is required to better correlate mill BOD measurements with observed oxygen declines.

When DO concentrations reach zero and the system becomes anaerobic, hydrogen sulphide can be produced. This gas is highly toxic to marine organisms, and through it's characteristic odor (rotten eggs) can be detected by humans at low concentrations. Although qualitative, simply indicating the presence of H_2S is a valuable indicator of anaerobic conditions. If H_2S were measured quantitatively, it could also serve as an indicator of "negative oxygen content", since formation of a hydrogen sulphide molecule is equivalent to the consumption of two oxygen molecules. This might be considered at those sites with extensive oxygen depletion (e.g., Port Alice, Port Alberni).

Frequency/Season

In areas such as Crofton, it is not worth continuing to sample once annually (for the purposes of trends analysis) unless there is more information on within-season natural variability. The high oxygen levels in 1981 could have been due to a storm the previous week; unless sampling occurs under a variety of tidal and weather conditions, it will be impossible to filter out year-to-year changes from day-to-day fluctuations. The compliance monitoring performed by the company is more frequent, and should include periods when the mill is not operating to be of maximum utility. Documentation of "driving variables" is very important.

Data Analysis

Since measurements are taken at various depths and times in the water column, a continuing problem is how to aggregate the data when evaluating long-term trends. The "oxygenated depth" method appears to offer some promise, though other approaches should also be investigated.

At sites like Port Alice with abundant data, a different type of analysis is required, one that can lead to predictions about the fate of effluent discharged at different locations, and the worst case conditions most strongly associated with deoxygenation. This analysis could take two forms, which could proceed in parallel:

1) development of a mechanistic estuarine model, as proposed by the Institute of Ocean Sciences; and

2) multivariate analyses of existing data to determine the best correlates of oxygen depressions (e.g. winds, tides, loadings, runoff).

A mechanistic physical oceanographic model offers the opportunity to link biophysical processes in a predictive way. Multivariate analyses can yield increased understanding of the factor interactions driving the system, without requiring further data collection. For example, all observations could be clustered according to the degree of oxygen depression in the water (e.g. three clusters, of <3 mg/l, 3-5 mg/l and >5 mg/l). Then, discriminant analysis could be used to determine the combination of factors (tides, temperatures, winds, runoff, loadings, time since shutdown, etc.) which best discriminates between these conditions.

3.3 Sediment Metals

3.3.1 Importance

Concentrations of heavy metals in benthic organisms (e.g. shellfish and groundfish) have been measured at coastal pulp mills. These metals may be derived from several sources, including effluents, spills or mill discharges. Cadmium and mercury were both present as contaminants in the bleaching agents that were historically used in the pulping process. Since these bleaching agents are no longer used, one hypothesis is that the concentrations of these metals should have decreased through time.

Unfortunately, the metals issue is complicated by sediment dredging followed by ocean dumping. However, the dumping site is generally far enough away from the dredge site that monitoring programs at the pulp mill are unlikely to receive metal inputs from ocean dumping (L. Harding, EPS Vancouver, pers. comm.).

3.3.2 Trends Analysis

Concentrations of trace metals in marine sediments have been quantitatively measured at 8 coastal pulp mills. Following a review of existing reports and datasets, and in consultation with scientists at EPS, data from EPS monitoring studies at Crofton were selected for detailed quantitative analysis because:

- samples were collected from each of a number of locations in 1980, 1983 and 1986 allowing a search for medium-term trends;
- sampling locations varied in distance from the outfall such that they could be organized into 3 strata: "outfall" (those closest to the outfall), "near outfall" (those intermediate to the outfall), and "reference" (those far from the outfall and hence providing a type of control). This stratification by distance and replication within strata allows a statistical examination of the spatial extent of sediment contamination, depending on the extent to which the stations within each strata in fact act as replicates of each other;
- there is some information on the variability to be expected at particular sampling locations based on a limited set of sampling replicates done in 1986.

This mill discharges into Stuart Channel, a large, relatively well flushed channel.

Potential problems in using the Crofton data set derived both from changes in the laboratory analysis methods used in 1986 compared with earlier years (see below) as well as because the 1986 sample was collected at a different time of year than the 1981 and 1983 samples. The first problem may be the most serious; to some extent it hinders our capability to compare 1986 data with previous data sets, and interpret any long-term trends that appear.

Methods

Samples of sediments using a 0.1 m2 Smith-MacIntyre grab sampler were taken at 9 stations in November 1981 and November 1983 (Sullivan 1982; Colodey and Tyers *in prep*). Additional stations were sampled in April 1986 (see Figure 3.1 for the locations of all sampling stations). Samples from the surficial sediment layer were removed and frozen prior to analysis for trace metals.

In 1981 and 1983 sediment samples were sieved through a 0.15 mm mesh sieve, and extracted using a "hot-block" extraction technique (Sullivan 1982; Colodey and Tyers *in prep*), while sample analysis in 1986 used the following procedure. Samples were dried at 60 C, sieved through a 0.15 mm nylon sieve and placed into a microwave oven for 15 minutes to be digested in a solution of 4.5 ml nitric acid, 1.5 ml hydrochloric acid, and 1 ml distilled water. Concentrations of trace metals were determined by spectrometer using an ICAP excitation source. Cadmium and lead concentrations were obtained by a spectrophotometer with a graphite tube furnace (Colodey and Tyers *in prep*).

Quantitative analysis of these data used both graphical techniques of exploratory data analysis, and statistical analysis to extract trends. We subjected the dataset to a preliminary screening to eliminate trace metals for which too few reliable data points exist for meaningful trends analysis. This process eliminated the metals Mo (coefficient of variation exceeded 100% in some samples), Sn (many data points measured below the detection limit), and Mg and Co (measured in only 1 of the three years) from further analysis. The concentrations of the remaining metals (shown in Table 3.2) were then plotted for each station and sampling year to inspect the patterns of variability in the samples and among years.

Table 3.2. The years for which each trace metal used in the quantitative trends analysis was sampled.

	Year		
Trace Metal	1981	1983	1986
Cd	X	X	X
Cu	X	X	X
Pb	X	X	X
Zn	X	X	X
Hg	X		X
Al		X	X
Cr		X	X
Fe		X	X
Mn		X	X
Ni		X	X

The data from the sampling locations were then grouped into three categories according to their approximate proximity to the outfall (Table 3.3). These categories are the same as those defined for the analysis of dissolved oxygen at Crofton (section 3.2.2); stations 12 and 13 were added in the near-outfall category in 1986.

Any remaining data values not measured or not detected were recoded as missing values before further analysis. In the analyses which follow, the homogeneity of variances between groups was first examined using Bartlett's test and the null hypothesis of equal variances between groups was

Table 3.3. Stratification of the sampling locations used in each year.

	Year		
Strata	1981	1983	1986
Outfall	1 2 3 4	1 2 3 4	1 2 3 4
Near Outfall	5 6	5 6	5 6 12 13
Reference	8 10	8 10	7 9 10

tested using Box's small sample F approximation (Zar 1984). Data values for heterogeneous groups were transformed using a log(x+1) transformation (Green 1979) and variances retested before proceeding with statistical analysis.

To examine trends in sediment metals concentrations through both time and space, a series of one-way analyses of variance for unbalanced designs (for comparisons involving 3 groups) and paired sample t-tests (for comparisons involving 2 groups) were performed. The focus of this analysis was to evaluate patterns in spatial and temporal trends. It was not directly intended to determine the causes of such patterns. For each trace metal, the three spatial strata within each year were compared to test the null hypothesis of no differences in the metal concentrations between the strata (and thus through space). Similarly, for each metal, each of the three spatial strata was compared among years to test the null hypothesis of no difference in the metal concentration between years (and thus through time). When the null hypothesis was rejected for an ANOVA, selected comparisons of stratum means was performed using orthogonal contrasts and tested using the Bonferroni method for a posteriori comparisons. This powerful, but conservative multiple comparison method is exact for unequal sample sizes.

Where possible, the results for this analysis are displayed in graphical form to facilitate comparisons and interpretation. Group means and standard errors (SE) were calculated for a graphical presentation of the relative significance of differences between spatial areas through time. Error bars were plotted as two times the standard error.

Results

For the metals selected for detailed trend analysis, concentrations showed high variability among stations both within and among years; concentrations of only one metal (cadmium) consistently exceeded guideline levels (0.6 mg/kg; Figure 3.6). In general, visual inspection of these results shows little overall trend in concentrations over the 5 year time span, Although some individual metals show particular spatial or temporal patterns.

In certain metals (particularly lead), there is both higher and less variable concentrations measured among locations in 1986 than in previous years. This result may be due to modifications in the laboratory technique for analyzing samples in 1986 compared with earlier years (Colodey and Tyers in prep). The microwave digestion technique used in 1986 has a slightly different extraction efficiency than the "hot-block" technique used in previous years (Colodey and Tyers in prep). For example, this technique is more efficient at extracting lead than the previous technique while it is slightly less efficient at extracting other metals (e.g. Al, Cr, Fe, Hg, Ni, Zn; EPS unpublished data). With careful comparisons between these methods, it may be possible to correct the values derived from the different methods

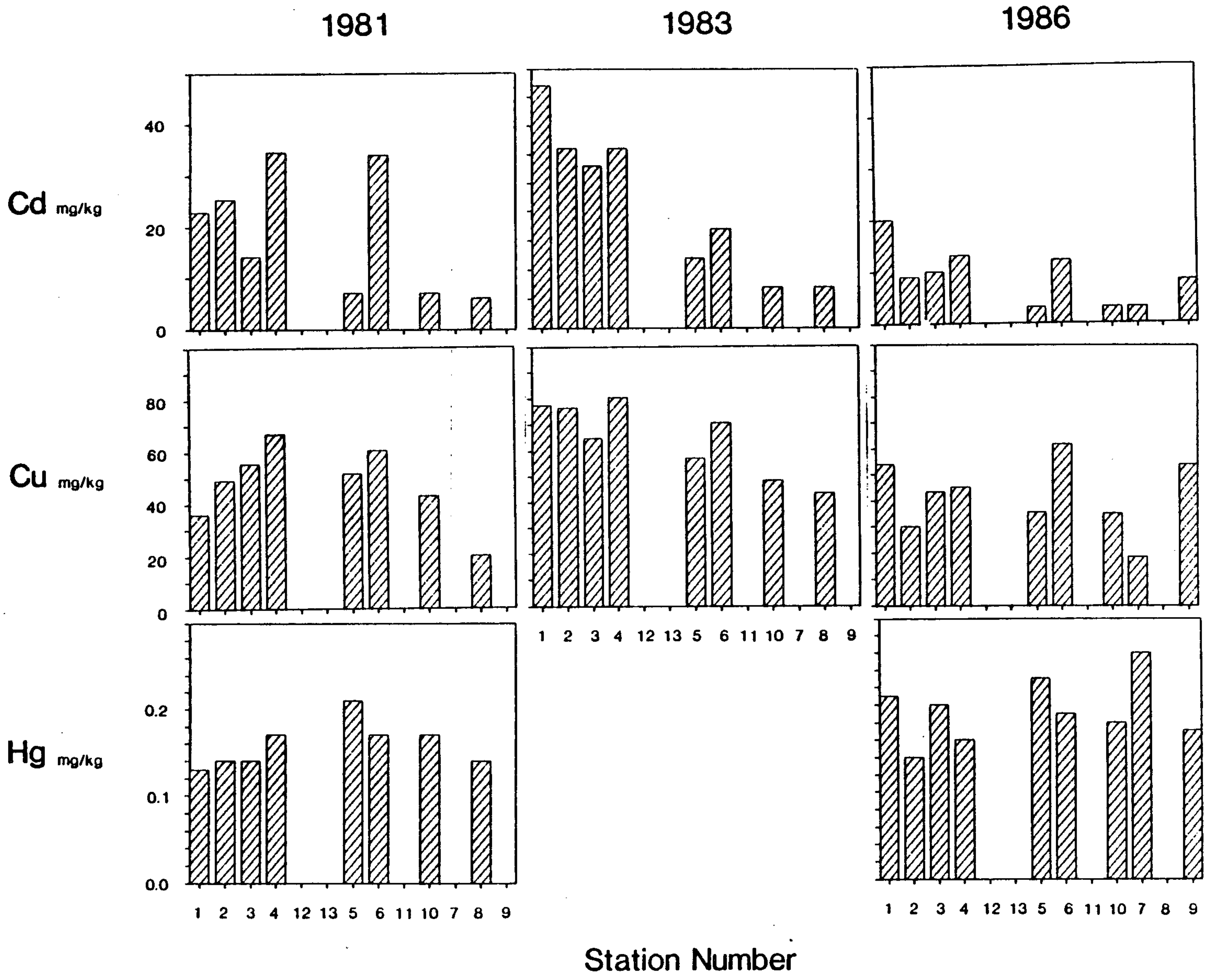
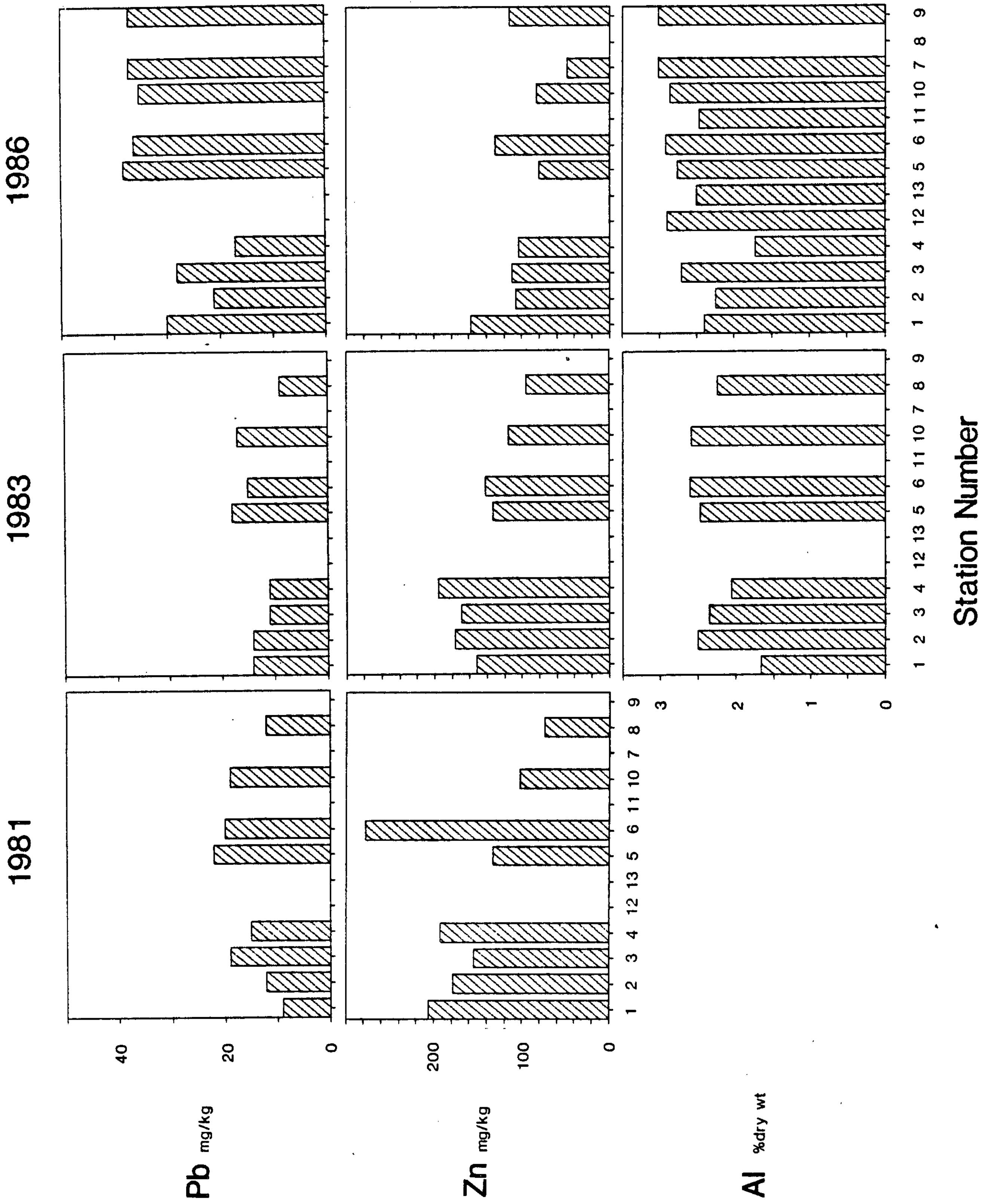
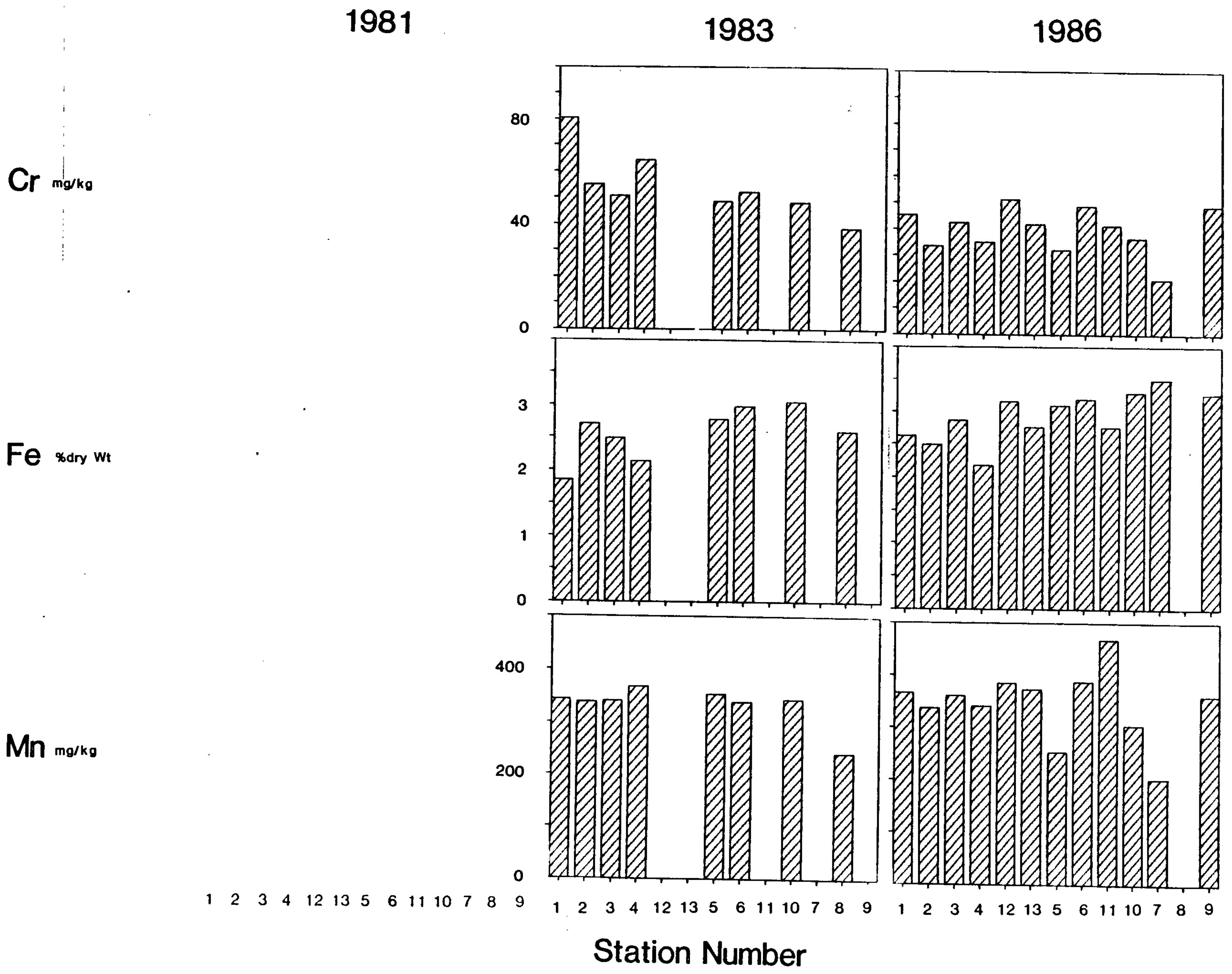
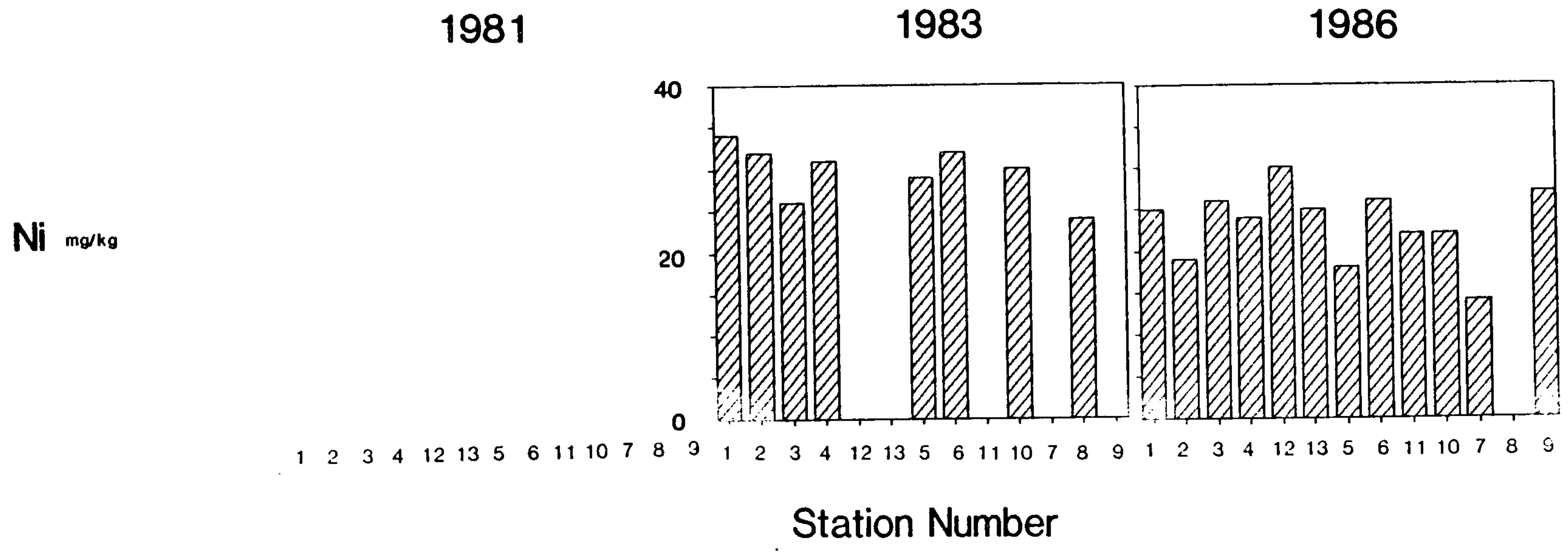


Figure 3.6. Concentrations of each metal used in statistical analysis at each sampling location for Crofton in each year. Locations are arranged roughly in increasing distance away from the outfall.


1981
1983
1986
Pb mg/kg
40
20
0
Zn mg/kg
200
100
0
Al %dry wt
3
2
1
0
1 2 3 4 12 13 5 6 11 10 7 8 9
Station Number


1981
1983
1986
Cr mg/kg
Fe %dry Wt
Mn mg/kg
80
40
0
3
2
1
0
400
200
0
1 2 3 4 12 13 5 6 11 10 7 8 9
1 2 3 4 12 13 5 6 11 10 7 8 9
1 2 3 4 12 13 5 6 11 10 7 8 9
Station Number


1981
1983
1986
Ni mg/kg
40
20
0
1 2 3 4 12 13 5 6 11 10 7 8 9
1 2 3 4 12 13 5 6 11 10 7 8 9
1 2 3 4 12 13 5 6 11 10 7 8 9
Station Number

for future trends analysis.

One possible pattern in the results shown in Figure 3.6 is that individual stations may show consistently higher or lower values than other stations (even those nearby) from year to year. Such patterns in the data may indicate the influence of particular processes, such as the peculiarities of local sediment transport on the monitoring results. for example, station 6 often has higher metal concentrations than station 5, even though they are approximately equidistant from the outfall. To some extent this can be tested by looking for correlations among the relative ranking of stations in their metal concentrations between years. However, only 31 % of such correlations were significant (one-tailed Spearmann rank correlation tests) suggesting that considerable year to year variability exists between the relative concentrations at particular locations. Later we will discuss other possible methods for detecting these kinds of patterns.

As the next step in more quantitative analysis of spatial and temporal trends, the concentrations from each station were grouped into the categories shown in Table 3.3. One interesting result of this grouping is that as expected, the highest concentrations for each metal were obtained from outfall or near outfall stations, and not from reference stations in 1981 and 1983 (Figure 3.7). However, in 1986 the reverse occurred - most of the highest concentrations were measured at reference stations, and relatively few were measured at outfall stations. This anomaly may again be partially due to problems with changes in methodology discussed above.

The spatial patterns in mean metal concentrations within each year is shown in Figure 3.8. In general, only weak differences between spatial locations are detectable. This analysis is dominated by the high degree of variability between sites, as well as the small number of replicates

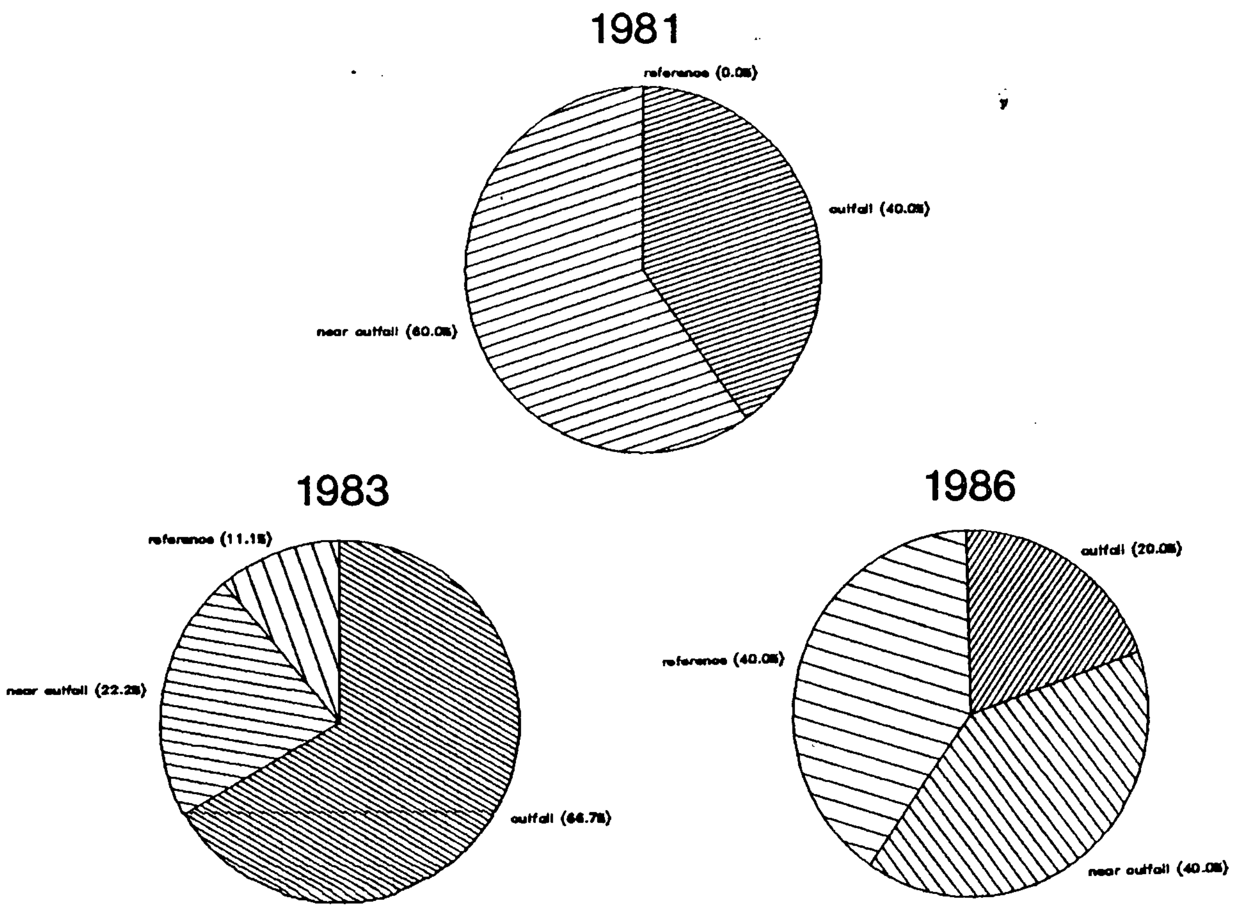


Figure 3.7. Shown are the percentage of the maximum measured metal concentrations (one per metal) in each of the three spatial groups in each year.

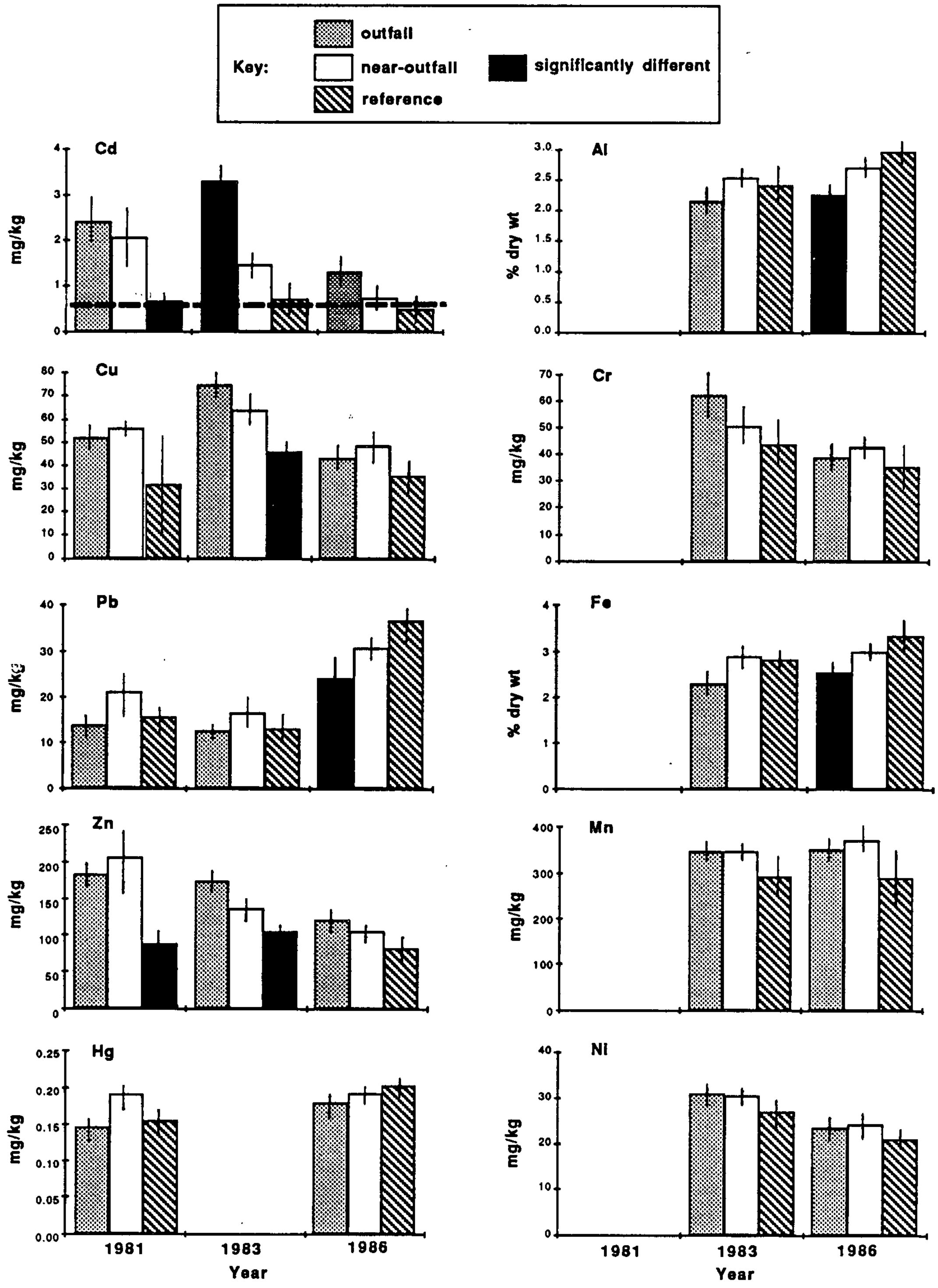


Figure 3.8. Mean concentrations by spatial strata in each of three years for each sediment metal used in statistical analysis. Significant differences determined by orthogonal contrasts of group means (see text). Also shown are standard error bars (width = 2 SE). Dotted line indicates guideline level set by the Canadian Ocean Dumping Act.

within each stratum. Zinc in 1981 is a good example: despite strong differences between mean values in the different strata, statistical separation of these sites was not achieved because of the small (e.g. 2) replicates within one or more of the strata being compared.

Figure 3.9 (illustrated on following page) shows the temporal trends in mean concentration of each metal for each of the sampling strata (outfall, near outfall and reference stations). In only four of the metals (cadmium, copper, lead and zinc) are there significant differences within each strata between years (measured by multiple contrasts); these differences occurred primarily in the outfall group. In their review of the 1981-1986 sediment data, Colodey and Tyers (in prep) noted that cadmium, zinc and copper levels have declined over time in the outfall and near-outfall groups. For cadmium and zinc in particular, these temporal differences are largely due to the sharp declines in the 1986 data (see also Figure 3.8). In general, little significant temporal trend was apparent in the near-outfall and reference groups (Figure 3.9) for all metals except lead.

3.3.3 Recommendations

Locations

Given the high degree of variability among sites and between years, even in uncontaminated "control" areas, an important requirement in future studies is the need to better define the spatial strata before detailed interpretations of spatial patterns can be made with confidence. In particular, defining appropriate background or control levels for metals is important. For example, lead concentrations measured at all locations are well within the natural variation of lead concentrations measured in open sea sediments (see references cited in Colodey and Tyers (in prep)) As in the analysis of oxygen levels, changes in the locations of stations used as reference, as well as small sample sizes, weakened the trend analysis.

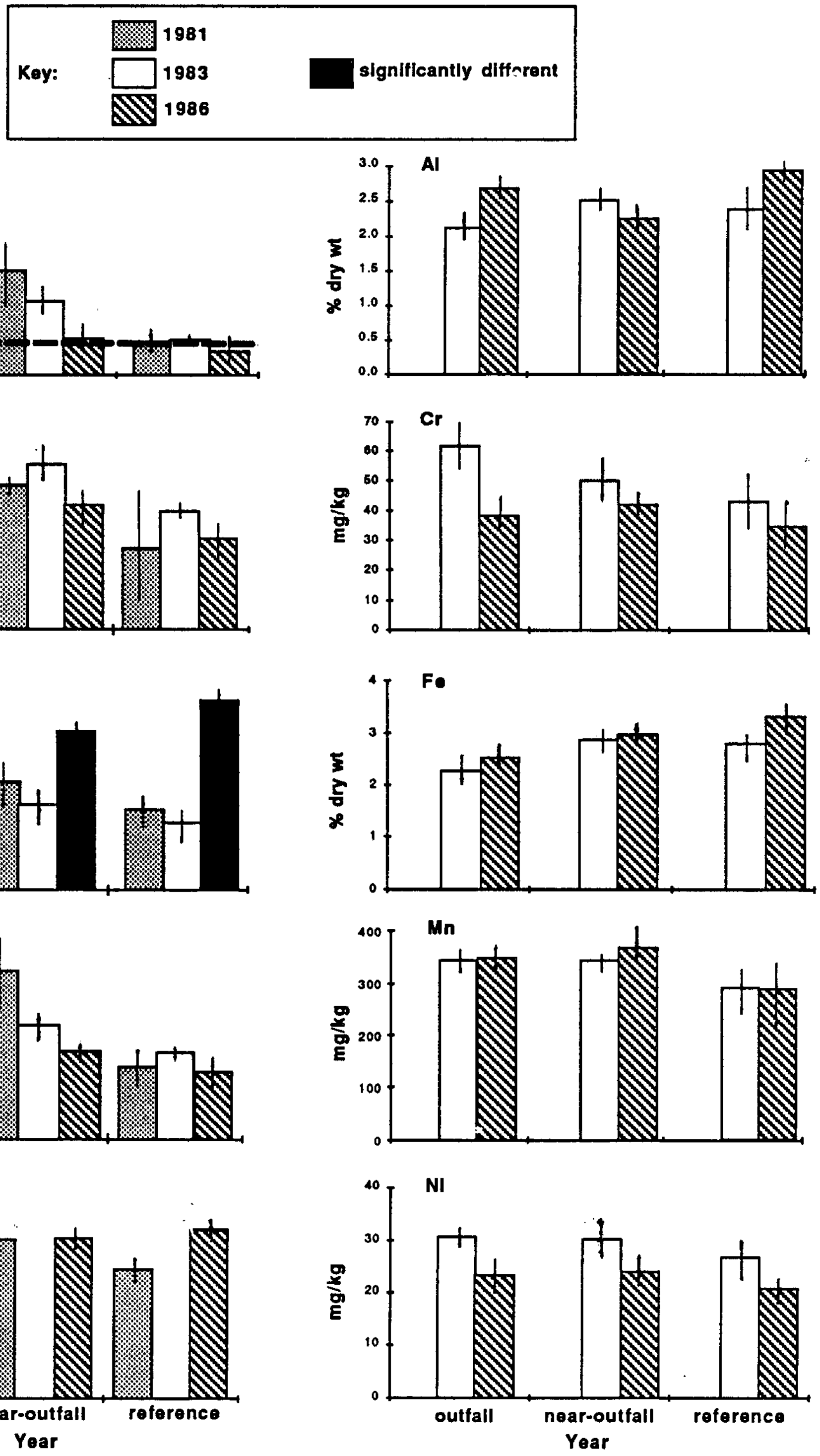


Figure 3.9. Mean concentration for each sediment metal used in statistical analysis by year for each spatial strata. Significant differences determined by orthogonal contrasts of group means (see text). Also shown are standard error bars (width = 2 SE). Dotted line indicates guideline level set by the Canadian Ocean Dumping Act.

Although not analyzed here, sediment data and cores from the BCFP sites might be examined in conjunction with the EPS sites to better define spatial patterns and to help identify long-term trends. In order for these data to be useful in an EEMP, we would make three recommendations:

- companies and EPS should co-ordinate their sediment programs such that sampling locations and analytical methods can be compared between the programs;
- the raw data should be shared between companies and EPS; and
- portions of samples should be archived for future analysis or reanalysis. This would allow the possibility that samples could be retrieved at a later date and used to answer new and different questions.

It would be interesting to compare grid versus transect sampling schemes for their ability to detect spatial trends, particularly in sites where uncertainty exists as to the effect of currents on the sediment contamination. Such comparisons could be graphical (e.g. contour plotting) as well as statistical. Although the best place for such a comparison would be a site where both schemes are in use, side-by-side, useful information could perhaps be derived from comparing data from Harmac's grid stations with Crofton's transect stations.

Parameters

Concerns for metals focus on the degree to which any given metal is toxic and accumulated in marine organisms. With the exception of cadmium, all metals were measured at levels far below the appropriate Canadian and International guidelines established for them. Among the problems this creates in the analysis is the tendency for increasing variation in the measurements as concentrations decrease (e.g. molybdenum measurements at Crofton). Despite having the capability to detect concentrations of a wide variety of metals, not all metals need to be monitored. Measuring and in particular analyzing and interpreting the results for unimportant metals is time consuming, and may confuse the resultant trends analysis, depending on the technique used. As noted by Colodey and Tyers (in prep) tissue sampling in the Crofton area has not been extensively carried out since 1979. Thus quantitatively relating trends in sediment concentrations to those in the biota is not possible with the present data. Care should therefore be taken when designing future EEMPs for sediment contamination to adequately define those metals of concern, and meaningful levels of biotic contamination. How to do this is addressed in Chapter 4.

The uncertainties introduced by differences in laboratory analysis techniques between the years (particularly in 1986) was a factor in preventing defensible interpretations of the spatial and temporal trends in the dataset. No method of data analysis can adequately overcome this obstacle either for analysis of past data or in planning future EEMPs; laboratory techniques will continue to evolve. While care must be taken to develop and implement standardized techniques for sediment analysis wherever possible, retaining and archiving samples for possible reanalysis (as described above) may help in future trends analysis studies.

Data Analysis

The ANOVA approach taken here was designed to take advantage of the explicitly spatial and temporal stratification of the data. While every attempt was made to be conservative in drawing conclusions from levels of significance, and bearing in mind that ANOVA is relatively robust to departures from underlying assumptions (Zar 1984), limited replication reduced the power of the methods to detect trends that may in fact exist.

Among the sources of variation in the data already mentioned is the fact that samples were taken at various depths, and times of year. Thus questions remain as to how best to aggregate the data over space and through time for the long-term trend analysis. Although the groupings used above were designed to test explicit hypotheses about the underlying nature of sediment contamination (stations near the outfall should have higher metal concentrations, etc), other processes may contribute to concentration patterns. Thus in addition to testing a priori hypotheses of effect, additional explorations of the data using multivariate approaches is recommended to gain additional ability to interpret the interactions between the important processes influencing metal concentrations. Although the available data from Crofton represent a small, and potentially biased dataset, both it and other sites (e.g., Harmac) could be used in such an analysis. A recommended strategy would be to cluster all observations against time, location and variables describing the nature of the sediment to determine the most parsimonious structuring in the data. A combination of analytical techniques, including discriminant analysis, to determine the best combination of variables that significantly describes the patterns of variation in the data can then be applied.

3.4 Sediment Organic Contamination

3.4.1 Importance

The main concern here is for the area covered by fiber mats, because areas smothered with fiber are less valuable as habitat for benthic-dwelling organisms. The fiber bed most directly affects groundfish (e.g., cod, flounder, sole), crustaceans (e.g., crab, prawns, shrimp) and mollusks (clams). Data are available from which some estimates can be made of the fiber mat area. However, the area alone is not the only important variable, since metal concentrations, level of organic matter, and H2S content also affect benthic habitat quality.

The secondary concerns here are resin acids, tannins, oils and grease, PCP/TCP, and PCB. The first two of these are associated with the effluent plume, while the last three are associated with activities in the pulp mill yard (e.g., lumber treatment). Part of the concern for these organics is that they can affect fisheries through tainting.

3.4.2 Trends Analysis

Methods

Sediment volatile residue (SVR) data from 11 stations in Porpoise Harbor and Porpoise Channel (Prince Rupert), covering the period 1977 to 1985, and SVR data from 13 stations in Stuart Channel (Crofton), covering the period 1981 to 1986, were analyzed for trends using graphical methods. In both cases, SVR values were derived through laboratory tests on subsamples (upper 2 cm) of sediments collected in field programs. In the laboratory, these samples were sieved before analysis. Subsamples were then subjected to oxidation at high temperatures; weight loss on ignition is considered to represent the volatile organic content.

Porpoise Harbor data were selected for analysis because of both the quality and quantity of the data set, and because, being a relatively blind bay, this harbor is not a through-flow system. In comparison, Crofton's location on Stuart Channel makes it potentially more of a through-flow situation.

For both data sets, stations were clustered or arranged according to their relative distance from the diffuser. Station locations for Porpoise Harbor are shown in Figure

3.10; Crofton stations are illustrated in Figure 3.1.

Results

Porpoise Harbor

Generally, although the diffuser was installed in late 1978 in Porpoise Harbor, SVR concentrations only began increasing noticeably in 1981, and then primarily in the inner harbor (Figure 3.11a). At the same time, SVR concentrations at stations in lower Porpoise Harbor and Porpoise Channel remained relatively low (Figure 3.11b). Closer examination, however, of data for some sites in the the lower harbor (e.g., Station B-9) reveal an increase in SVR concentrations over the period 1977 to 1981 with concentrations beginning to decline after this.

In 1977, SVR concentrations were slightly higher at stations in the inner harbor compared with stations in the lower harbor. This is to be expected; not only is there a prior history of organic contamination in that basin from the old Ridley Island effluent pipeline, but there are other sources of organic contamination in the harbor (e.g., fish processing plant). From 1977 to 1980, mean concentrations in the two areas were similar. Starting in 1981, SVR concentrations began to rise at some stations in both the inner and lower harbors. By 1984, SVR concentrations were marginally higher at most stations in both the inner and lower harbors; the noteworthy exception being the station immediately north of, and adjacent to, the diffuser (Station O-2) where SVR concentrations have been rising dramatically since 1981.

Crofton

The SVR data for Crofton present a somewhat more confusing picture. The diffuser was installed nearly a decade before the first SVR sample values shown in Figure 3.12 were collected. Thus, in 1981, six of the eight stations sampled already had SVR values over 10%. According to

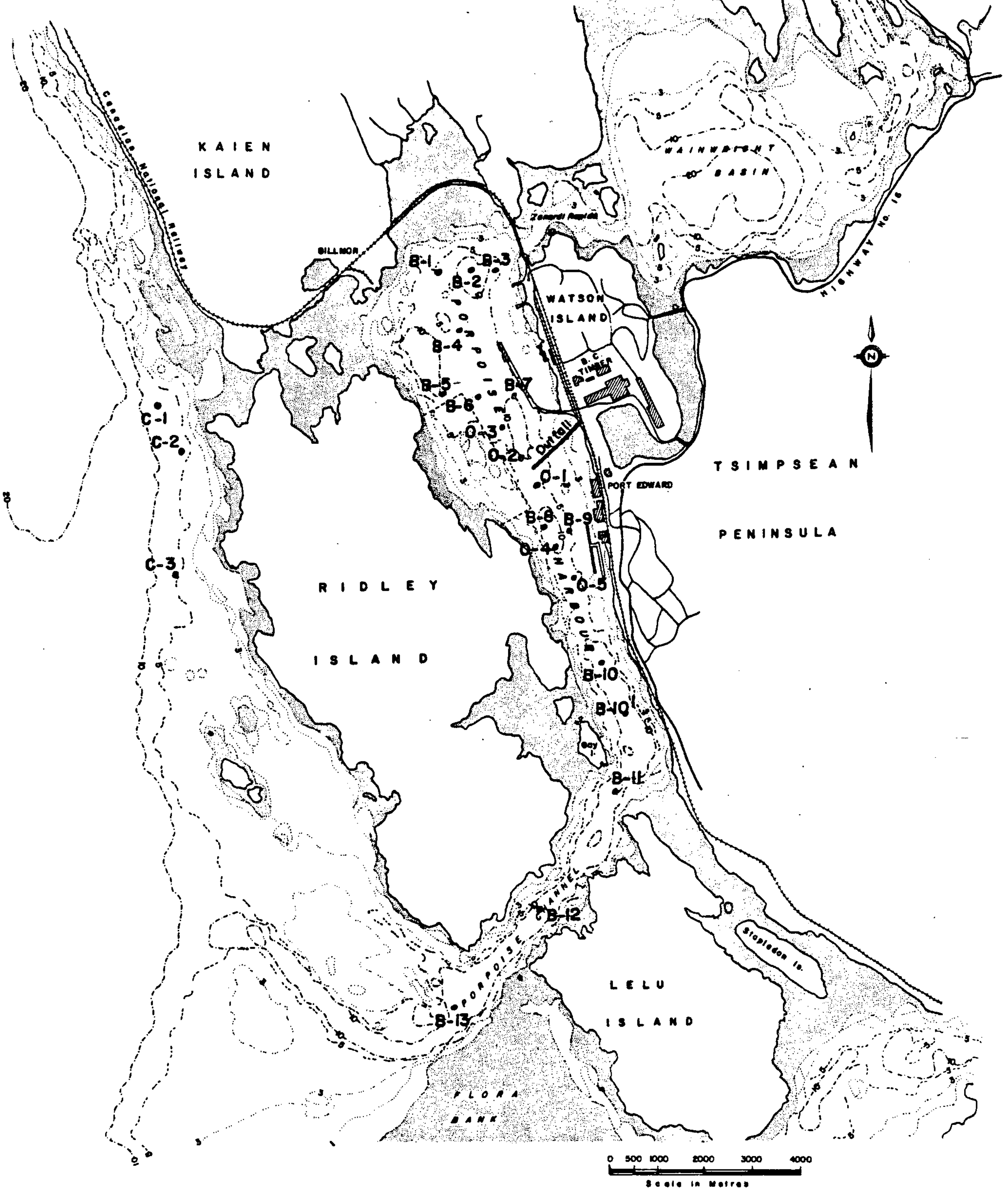


Figure 3.10. Benthic sampling stations at Porpoise Harbor, Prince Rupert: 1977 - 1985.

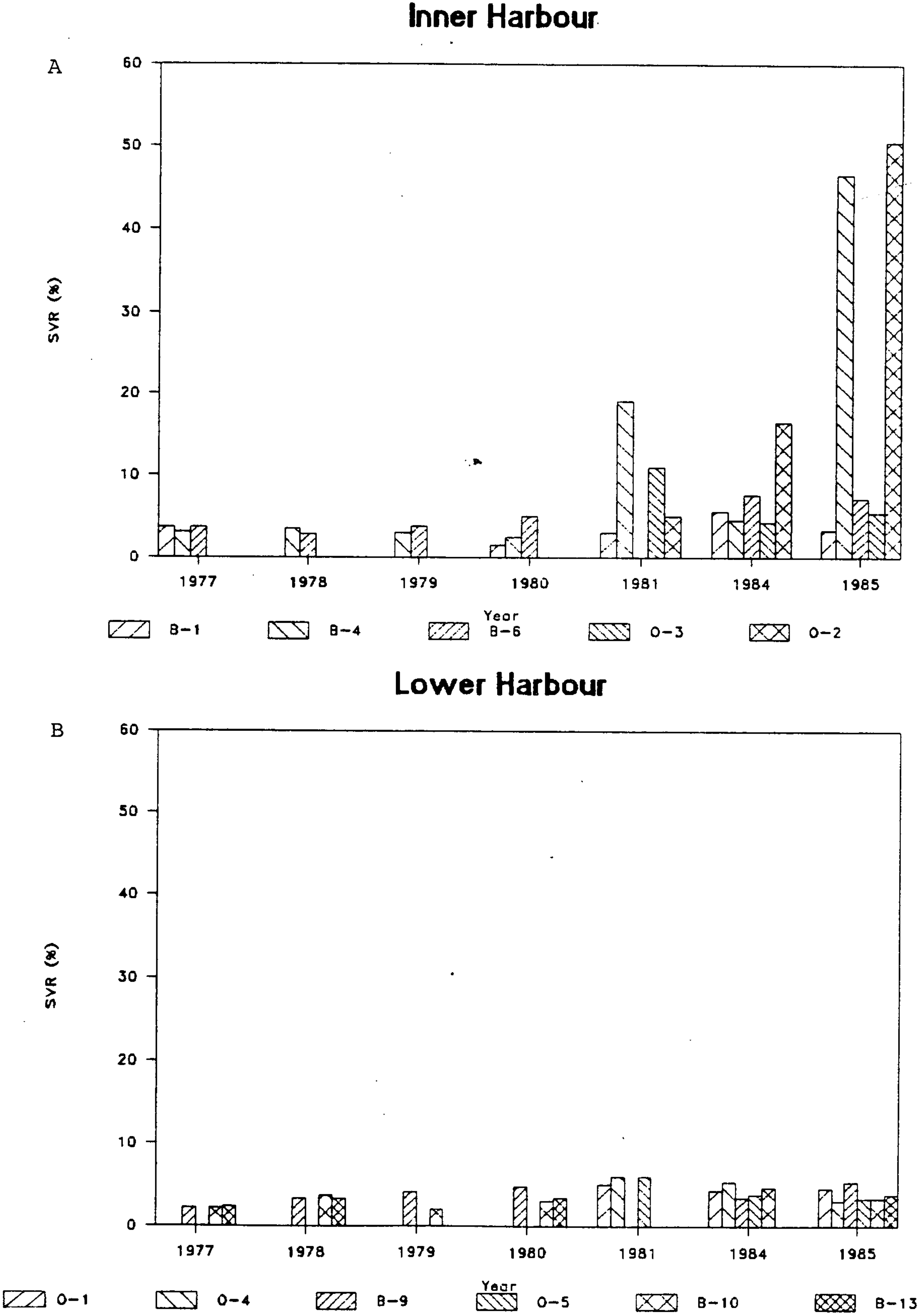


Figure 3.11. Porpoise Harbor sediment organic matter concentration: 1977 - 1985.

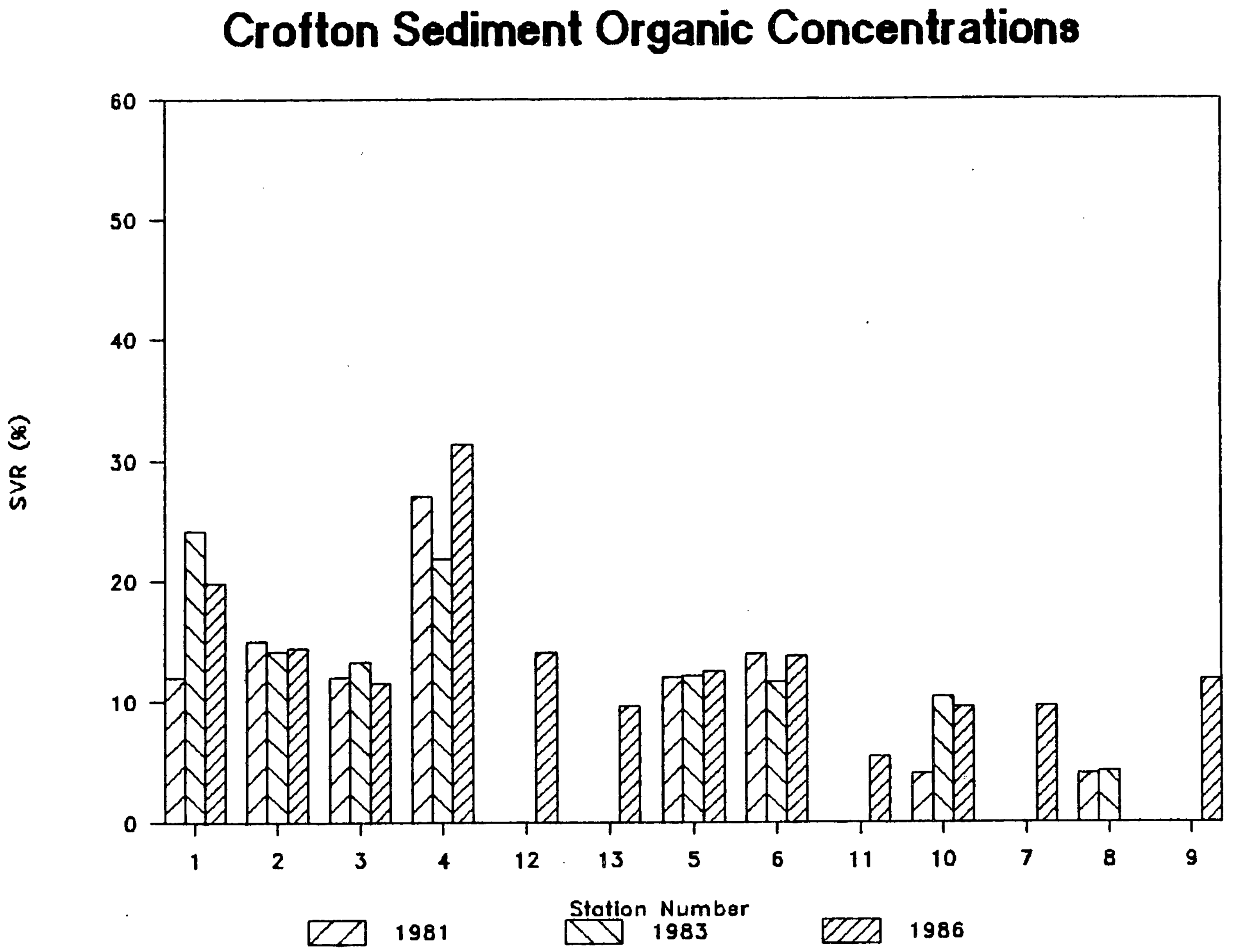


Figure 3.12. Sediment organic matter concentration at Crofton: 1981 - 1986.

Figure 3.12, SVR concentrations have remained over 10% at all the near and mid-distance stations for the period of record. Meanwhile, sediment organic concentrations have stayed nearly constant at Station 8 and increased at Station 10 to near 10%.

In two of the three years sampled, Station 4 had the highest SVR of any site sampled at Crofton. Since 1981, SVR values appear to be declining at three of the four stations that are in the immediate proximity of the diffuser. Even at Station 1, there appears to have been a decline in SVR values from 1983 to 1986.

Crofton Stations 5 and 6 are roughly equal distances northeast/southwest from the diffuser. From 1981 to 1986 both have had similar SVR content; as well, their values are similar to those at Station 3 -- immediately adjacent to the diffuser. Concentrations appear to be slightly higher at Station 6; one possible explanation for this is that the tidal hydrodynamics may make Station 6 a slightly more depositional environment than Station 5.

3.4.3 Recommendations

Locations

Although the main concern is for the **area** covered with a fiber mat, neither sampling program at these mills provides data that can be used to quantify the spatial extent of the fiber deposits. Two fundamental problems in describing the spatial extent of the fiber mat are (1) where to sample, and (2) how to define a fiber mat in such a way that it can be measured. With respect to the first problem, one possible solution is to use observations made with the submersible to help identify the general location and spatial extent of the fiber mat. This information could then be used to help locate sampling stations in appropriate locations.

The question of how to define a fiber mat is less easily solved. There seems to have been a general "rule of thumb" that sediments with organic matter contents greater than 10% (wt/wt) were contaminated. While this may serve as a useful indicator, there are several problems with it. For example, until sediments reach this arbitrary level it may be difficult to conclude that they are contaminated with organic matter.

An alternative is to have well-chosen control/reference stations where replicate samples are taken. Such a sampling scheme would allow "background" sediment organic concentrations to be measured, along with their variability. Preliminary evidence suggests that SVRs may vary seasonally in response to factors such as plankton productivity (Colodey 1986). Once background values have been statistically established, comparisons can be made between the reference values and those at the sites of concern. Since there are likely to be both seasonal and long-term changes, time series analyses would be appropriate. First, the seasonal component should be removed, and the residual searched for evidence of long-term trends. Of course, to do this type of analysis, the data base will have to include replicates for each sample and requires extensive sampling through seasons. A simpler approach to removing seasonal variation effects is to sample during the same season each year. While this approach simplifies analysis, it does not provide any direct information on seasonal trends; information that may be critical in assessing biological effects.

Another potential approach to the question of sediment organic matter accumulation is to look for depositional environments in the vicinity of the discharge that may serve as natural traps for wood fibers and fragments. Alternatively, sediment traps could be placed on the sea floor and retrieved on a routine basis.

Parameters

Company data at Crofton includes measurements of the depth of organic matter and SVR at a large number of stations (Severn and Sutherland 1986) over several years. However, the lack of replication of measurements at each site reduces greatly the power of the information. Furthermore, the SVR measurements performed on the top 2 cm of a sediment core are multiplied by the depth of the core to yield an overall estimate of volatile residue. This will only be a reasonable estimate if SVR is uniformly distributed throughout the core, which seems very unlikely. The overall estimate, using this technique, is likely to be a considerable overestimate.

To estimate the fiber mat area, it will be necessary to have radial transects running outward from the diffuser. If the emphasis is on changes in area, special attention should be placed on defining and monitoring changes in the location of the boundary zone. However, the area alone is not the only important variable, since the depth of organic matter (and the subsequent generation of H2S when the mat becomes anoxic) also affects benthic habitat quality. Perhaps it would be possible to establish a relationship between organic matter depth and SVR through such techniques as coring or grid system mapping with a submersible.

Currently resin acids, tannins, oils and grease, PCP/TCP, and PCBs are all measured from time to time, in an exploratory manner. This is a useful approach for a pilot study, but if the purpose of such measurements is to establish trends, it will be necessary to characterize background conditions at control stations, natural variability, and variability due to analytical techniques, especially when measuring low concentrations at or near the detection limit. On a related topic, it is important to be consistent in laboratory techniques. For example, sediments collected for organic matter analysis are subjected to sieving. If more than one mesh size is used during collection of a series of samples, This could bias the results. Interpretations are obviously complicated by such lack of standardization.

Frequency/Season

Judging by the SVR data collected at Prince Rupert and Crofton, the rate of organic matter accumulation is sufficiently slow to indicate an annual or bi-annual sampling frequency. It is better to sample extensively, with replication, every other year than to sample less thoroughly annually. However, before such a sampling regime is initiated, it is essential to evaluate the natural spatial and temporal (seasonal) variability at each site of interest. Once this is done, recommendations can be made on appropriate frequency, season, and spatial scale for a monitoring program designed to quantify changes in benthic area contaminated with organic residues from pulp mills.

Data Analysis

Data analysis on existing company data (Severn and Sutherland 1986) is constrained to paired t-tests, because of the lack of replication at individual sites. This makes it impossible to determine the significance of gradients along particular transects, information which would be very useful.

3.5 Intertidal Community

3.5.1 Importance

Intertidal communities are dynamic and often complex ecosystems influenced by a variety of physical environmental factors. Intertidal habitats provide shelter and feeding areas for many invertebrates and some fish. In addition, intertidal habitats serve as nursery areas for many species of marine invertebrates and are important food production areas for fish. Many intertidal organisms are sensitive to water-borne pollutants, and thus the condition of intertidal communities can be used as an indicator of the quality of the local marine environment. Because intertidal areas are exposed and accessible for parts of each day, they provide good opportunities for effects monitoring.

Previous effects measurements on the intertidal habitat have been plagued by (1) difficulties with methods, (2) stations too far apart, and (3) lack of dose/response information. As well, many different groups have been responsible for conducting these studies. Fortunately, Grooms (1986) has done a thorough job of collecting together and summarizing data available from previous studies.

Intertidal habitats can be affected by a wide variety of activities including log booming, accidental spills at the mill site that are permitted to flow down to the ocean, and permitted effluent discharges.

3.5.2 Trends Analysis

Methods

Intertidal monitoring programs undertaken at eight coastal pulp mills in B. C. since the early 1970's have been summarized by Grooms (1986). These programs have used a variety of techniques in efforts to monitor the effects of pulp mill effluent on intertidal organisms and intertidal communities. The techniques include:

- artificial substrates
- quadrat/transect surveys
- beach walks
- photo documentation
- heavy metal analysis.

Results

The monitoring programs at these mills have produced large amounts of data, but generally these data do not lend them to statistical treatment suitable for trend analysis. The general characteristics and limitations associated with data collected using each technique are outlined below.

Artificial Substrates

Artificial substrates made of materials including plexiglass, fiberglass, brick and asbestos aggregate have been used at various mills in efforts to measure colonization rates of intertidal organisms at various distances from effluent outfalls. In recent years the use of artificial substrates has been discontinued because the data they yield are not indicative of natural communities. Furthermore, low recovery rates of artificial substrates may result in very little data or no data for important sampling stations.

Quadrat/transect Surveys

Quadrat/transect surveys of the intertidal are intended to characterize intertidal communities along the gradient between high and low water. Such surveys may be qualitative or quantitative in nature, and a variety of techniques is used to conducts these surveys. Data collected may include percent cover by various flora and fauna, number of dominant species, species lists of all flora and fauna, biomass of organisms, and descriptive field notes. For quadrat/transect survey data to be suitable for trend analysis, the data should be collected at the same stations and at the same time each year. Standard data recording procedures should be used each year, and selected parameters should be quantified and measured in replicate to allow statistical treatment for trend analysis.

Most of the data collected at the coastal pulp mills using quadrat/transect surveys do not lend themselves to trend analysis because of annual variations in sampling procedures, differences in season of sampling, lack of within season replicates, and the generally qualitative nature of the data.

In some cases, quadrat/transect data may be displayed in a format that allows visual evaluation of trends. For example, trends in data collected for Gold River over the period 1977 to 1981 can be clearly seen when presented visually (Figure 3.13). For instance, at no time were *Fucus* found at stations 3 or 4 at any depth, even though this species was found at several depths at all other stations. The location of stations 3 and 4 (Figure 3.14) suggests that this absence could be due to effects of pulp mill discharges; however, ruling out natural phenomena (e.g., lack of suitable substrate) would require additional information.

Beach Walk

Beach walks are a method of quickly obtaining qualitative information on the condition of the intertidal. Beach walks rely on information on the presence/absence of biota to describe the condition of an area around a pulp mill outfall. This technique can be used to qualitatively evaluate the extent of damage related to a pulp mill and to assess over a number of years whether that area is increasing or decreasing in size. However, beach walks do not generate data that can be readily used in statistical analysis unless boundaries of impact can be distinguished and walks stratified accordingly.

Photodocumentation

Photodocumentation has been used to record images of intertidal areas for qualitative evaluation of the conditions of the intertidal areas. Photos of individual quadrats and photos of the entire intertidal zone are taken to prepare a composite record of the intertidal. Photographs

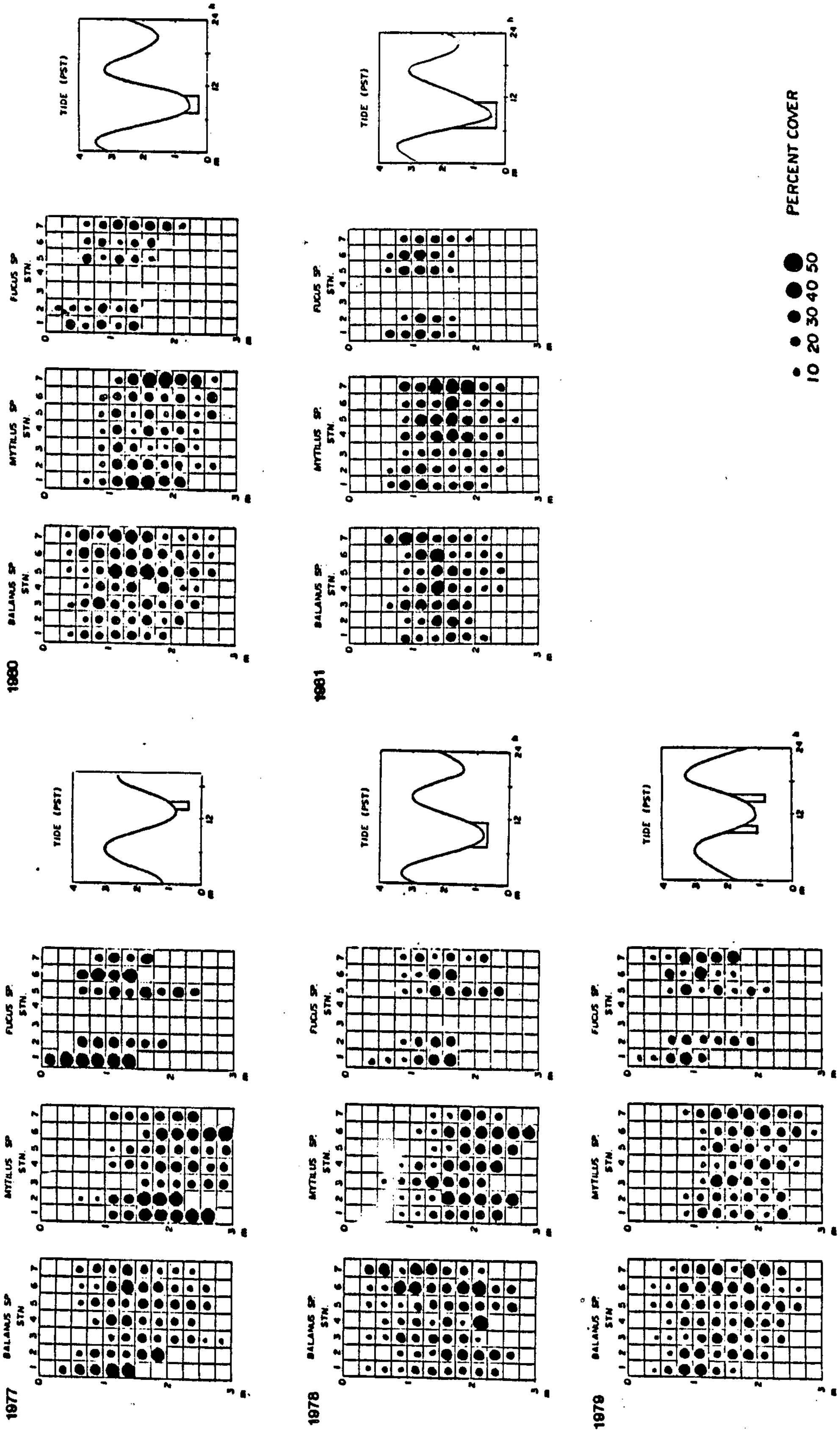


Figure 3.13. Intertidal zonation at Gold River, 1977 - 1981 (adapted from Grooms 1986). For station locations, see Figure 3.14.

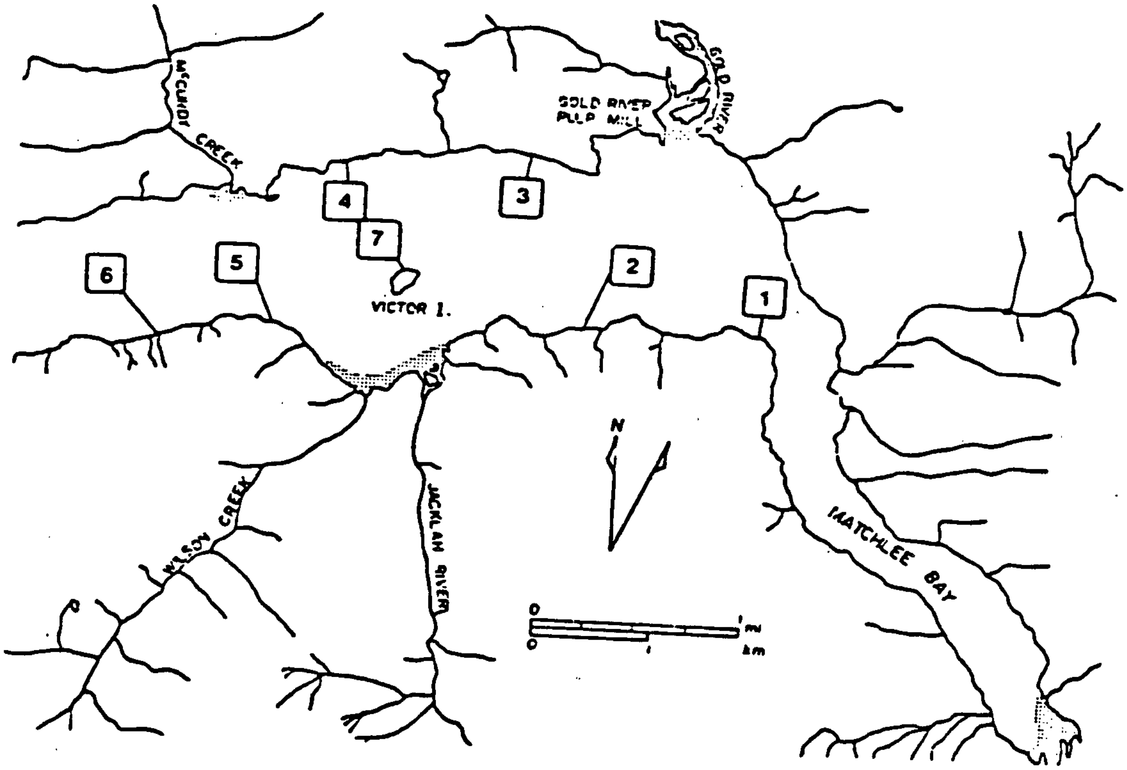


Figure 3.14. Location of intertidal stations at Gold River.

taken under standard conditions over several years can be used to visually evaluate trends. Although it has apparently not been attempted, quantitative photo interpretation techniques could possibly be used to evaluate information recorded photographically.

Heavy Metals

Heavy metal concentrations (i.e. zinc) in various shellfish, most commonly oysters, have been measured at pulp mills along the coast. These measurements can be used to define the area of influence of effluent plumes. Regular sampling of shellfish for heavy metals could be used to produce a database for monitoring trends statistically. However, the sporadic nature of sampling and analysis of oysters for metals makes the existing data unsuitable for trend analysis. Metal levels in shellfish also vary greatly with the condition of the organism, so that trend analyses must correct for this covariation.

3.5.3 Recommendations

A considerable amount of time and money have been invested in intertidal monitoring at coastal pulp mills in B. C. However, an ad hoc approach has been taken to monitoring at various locations on the coast. Intertidal monitoring programs have generated data of local interest, but generally these data collection programs have not been designed to produce data that can be used to evaluate the environmental effects of pulp mill effluent in a quantitative or statistical manner over a period of time.

An EEMP for the intertidal should have the following characteristics:

- standard sampling locations, including controls
- straightforward, clearly defined data collection procedure

- standard data forms for recording qualitative and quantitative data
- standard sampling period
- replicate samples at each station (for statistical purposes)
- standard data tabulation and analysis procedures
- balanced sampling and analysis program.

The level of continuity and replication required for rigorous trend analysis constrains the number of components/stations/sites that can be examined. The amount of data collected must not exceed the capacity of the professional staff and their resources to analyze it. Thus, the need for a balanced sampling and analysis program.

The experience in intertidal monitoring programs at pulp mills on the B. C. coast (Grooms 1986) provides a foundation for developing a standard approach to EEMP. Since the early 1970's intertidal monitoring programs have relied increasingly on quadrat/transect surveys, beach walks and photodocumentation. Together these techniques can provide data that can be used to qualitatively and quantitatively evaluate trends. The intertidal monitoring program proposed for the Woodfibre pulp mill in 1986 (Grooms 1986) is an example of a program that combines these techniques.

Locations

Locations for intertidal monitoring should be selected to meet specific monitoring concerns or requirements. Intertidal monitoring programs might be part of monitoring programs at some but not all coastal pulp mills. Thus intertidal monitoring could be undertaken at pulp mills where there were known problems related to the effects of effluents or there was a need to evaluate the effects of operational changes at a mill. At other pulp mills where the effects of effluents were considered to be within acceptable limits, intertidal monitoring might not be undertaken. Intertidal monitoring programs will be most useful if regulatory agencies systemically select the locations where intertidal monitoring will be undertaken, clearly identify the reasons for selecting a certain site, and make a commitment to continue the monitoring program long enough (5+ years) to produce data that can be used to evaluate environmental effects.

On a site-specific basis, it is important that the locations of sampling stations be carefully chosen. To the extent possible, sampling stations selected should be similar in exposure, aspect, and gradient to control for natural environmental variations. It is also important to select at least one control sampling station. Sampling stations should be easily accessible and easy to locate.

Parameters

The parameters measured in an intertidal monitoring program should be relatively easy to measure using standard methods that can be consistently and efficiently applied by various individuals. Replicate samples must be taken at each sampling station. Substrate, percent cover by dominant species of flora and fauna, and identification of dominant species of flora and fauna are parameters that can be consistently measured using standard methods. Information on these parameters can be recorded photographically and quantitatively on standard data sheets.

Heavy metal concentration is another parameter that can be consistently measured using standard techniques. Results obtained from heavy metal analysis can be used to evaluate the extent of influence of pulp mill effluent and monitor any change in the area of influence.

Frequency/Season

Intertidal sampling should be done on an annual basis. Spring (May-June) is the recommended time for sampling. At this time of year algal growth is most extensive. As the season progresses, some algae species die back due to dessication during day time low tide periods.

Heavy metal analysis can be done at any time of the year, but it should be undertaken at the same time each year to control for any seasonal differences such as changes in currents. Annual sampling for heavy metals with replicates at each sampling station should be sufficient to monitor trends.

Data Analysis

Intertidal monitoring data can be evaluated using quantitative and qualitative approaches. To evaluate trends quantitatively, statistical techniques such as analysis of variance and linear regression can be used to make within and between year comparisons. The former approach requires replicate measurements; regression analyses can be used without replication but are less powerful. If a rigorous statistical approach is desired for data analysis, care must be taken to design the data collection and recording procedures in a way that will permit statistical analysis.

Qualitative approaches can also be taken to evaluating data from intertidal monitoring programs. To a certain extent, these approaches are dependent on the judgement of informed individuals and are, thus, subjective. Beach walks and photodocumentation are both qualitative approaches to intertidal monitoring that depend on an informed individual evaluating a particular site by either comparing the site to its condition at an earlier time or comparing the site to similar "undisturbed" sites familiar to the individual.

Evaluations made using qualitative approaches may be valid, but they depend on interpretations that are likely to vary between individuals. The formulation of guidelines for the interpretation of beach walks and photodocumentation would help to ensure a uniform approach to the evaluation of qualitative information.

The intertidal monitoring program implemented at Woodfibre in 1986 (Grooms 1986) is an example of a program that combines both qualitative and quantitative approaches. The monitoring program at Woodfibre could be used as the basis for developing a set of general guidelines for selection of sampling stations, data collection methods, data tabulation and data analysis procedures.

3.6 Other Issues/Recommendations

In addition to the four specific areas highlighted above, there are other issues and recommendations that have emerged from our examination of past EEMPs. These include:

- identifying objectives
- annual planning for EEMP
- sampling mixing zone
- sampling program coordination
- standardized sampling station and season
- effects of operational changes (e.g., diffuser installation)
- indicator species
- compilation of entire data base

Each of these issues and recommendations are discussed in the following paragraphs.

3.6.1 Identifying Objectives

As described in Chapter 2, the purpose of the EEMP is to "detect long term changes in extent or degree of fish habitat loss caused by point source pollutant discharges" (Harding (1986). To meet this objective, the Marine Group proposes to carry out monitoring programs which entail "repeated sampling of physical, chemical, biological, and toxicological parameters to detect change on some time scale" (Harding 1986).

Although identifying the above objective is an important step toward improving future EEMPs, detecting long term changes in habitat availability caused by pulp mill operations will require a detailed, and carefully designed monitoring program. Evolving such a program will entail developing more specific objectives and creating a detailed framework to guide implementation of the EEMP. For example, in the above objective, reference could be made to establishing cause-effect relationships between specific actions (e.g., pulp mill effluent discharges) and affected environmental components. Likewise, decisions should be made as to what specific time scales are considered appropriate for environmental effects monitoring. Some environmental changes, for instance, can be measured over minutes or hours (e.g., depressed dissolved oxygen concentrations) while others may require months or years before becoming measurable (e.g., fiber mat development).

Consideration must also be given to the type of statistical design and data analysis required to satisfy the chosen objectives. The required number of replicates should be computed to satisfy a prescribed level of precision, and desired ability to detect spatial or temporal change. Analyzing simulated data (using variances derived from pilot studies) can be a powerful way to refine an experimental design.

3.6.2 Annual Planning for EEMP

In the absence of well-defined, consistent objectives to guide an EEMP, each year's program is often designed in response to immediate concerns (e.g., recent changes in mill operations) and the latest hypotheses relevant to the situation at each site. In the case of the EEMP, planning has usually been done six months in advance of the new fiscal year. As Harding (1986) points out, this short term planning does not encourage a rational monitoring program designed to quantify long-term environmental changes. Under such a planning scheme, results obtained from field studies at one site in a particular year may not be comparable to other sites or other years.

3.6.3 Sampling Mixing Zone

As defined by EPA (1976), a mixing zone is an area contiguous to a discharge where effluents mix with the receiving water. If the effluent quality is lower than the receiving water the quality is reduced. Waters in the mixing zone may meet none of the water quality criteria otherwise applicable to the receiving water.

The nature of pulp mill effluents is such that, within the mixing zone, there is great potential for damage to aquatic resources and habitat. Since the effluent standards currently in use have been set at levels that permit a lowering of ambient water quality there is an implicit zone of acceptable damage. Furthermore, in some locations (e.g., areas where fiber mats accumulate), the damage may be long-lasting and areas with environmental degradation will persist long after the pulp mill ceases to operate.

Because of complicated mixing patterns and tidal currents, in some cases the location, size, and area of the mixing zone at a pulp mill is only known in general terms.

In fact, mixing zones are not fixed in space, but are more properly conceived as probabilistic clouds. Any given point within the mixing zone may be exposed to effluents for only some portion of time, and then only to some diluted fraction of the full strength effluent.

All this raises the question of where the EEMP should be focused, relative to the mixing zone. Since by nature of the permitting process there is already a zone of "acceptable damage", should the EEMP be limited to evaluating damage and trends outside this zone?. Or should the EEMP be designed to describe the entire extent of the damaged habitat and marine resource losses, regardless of the policy decisions that created the zone of "acceptable damage"?

A better understanding of the extent and degree of impact will be achieved by developing an integrated program which extends out from the mixing zone. Hence, there is need for coordination of sampling programs between pulp manufacturers and the EPS.

3.6.4 Sampling Program Coordination

Obvious benefits would be realized by coordinating sampling programs administered by both the company and federal agencies. Likewise, coordinated programs carried out by different government agencies is also highly desirable. The overall goal should be to minimize duplication of effort, maximize data compatibility, and ensure sufficient overlap to permit cross checking between programs, while pursuing answers to a clearly articulated set of questions. Periodic meetings, with all involved parties present, should be held to review the complete set of questions under investigation, the resulting sampling program, and responsibilities for conducting the sampling program and integrated data analysis.

3.6.5 Standardized Sampling Station and Season

The current interest in describing long term trends in the environmental quality at pulp mill sites has been prompted, in part, by improvements in pulp mill technology (e.g., effluent treatment, diffuser design) and the desire to document any beneficial effects that these changes may have had on receiving ecosystems. Unfortunately, the EEMP in use since the early 1970's did not always have repeated measurements at fixed locations using standardized methods over time. Consequently, for some parameters and sites, the data necessary to detect and describe long term trends are not available.

An example of the type of problem encountered is provided in the data set available for sediment samples taken at Powell River in 1979 and 1983. Unfortunately, not only were the samples taken at different times of the year, but the sample stations were not in the same geographic position. Although the station numbers were the same for the two years, both the depth to sediments and map positions (see Figure 3.15) strongly suggest that despite being given the same station numbers, the stations were not truly the same.

Contrast this with the sampling program used by EPS at Porpoise Harbor (Prince Rupert). Here, the same stations were used for four consecutive sampling trips, spanning three years. Equally important, the results were examined, analyzed, and written up as a unit, resulting in a comprehensive report spanning the three-year period (Pomeroy 1983). Unfortunately, although the sampling and measurement methods used during this period remained constant, only two of the sampling trips were made during the same month.

The season of sampling should be chosen as the "worst case". This can be established through preliminary

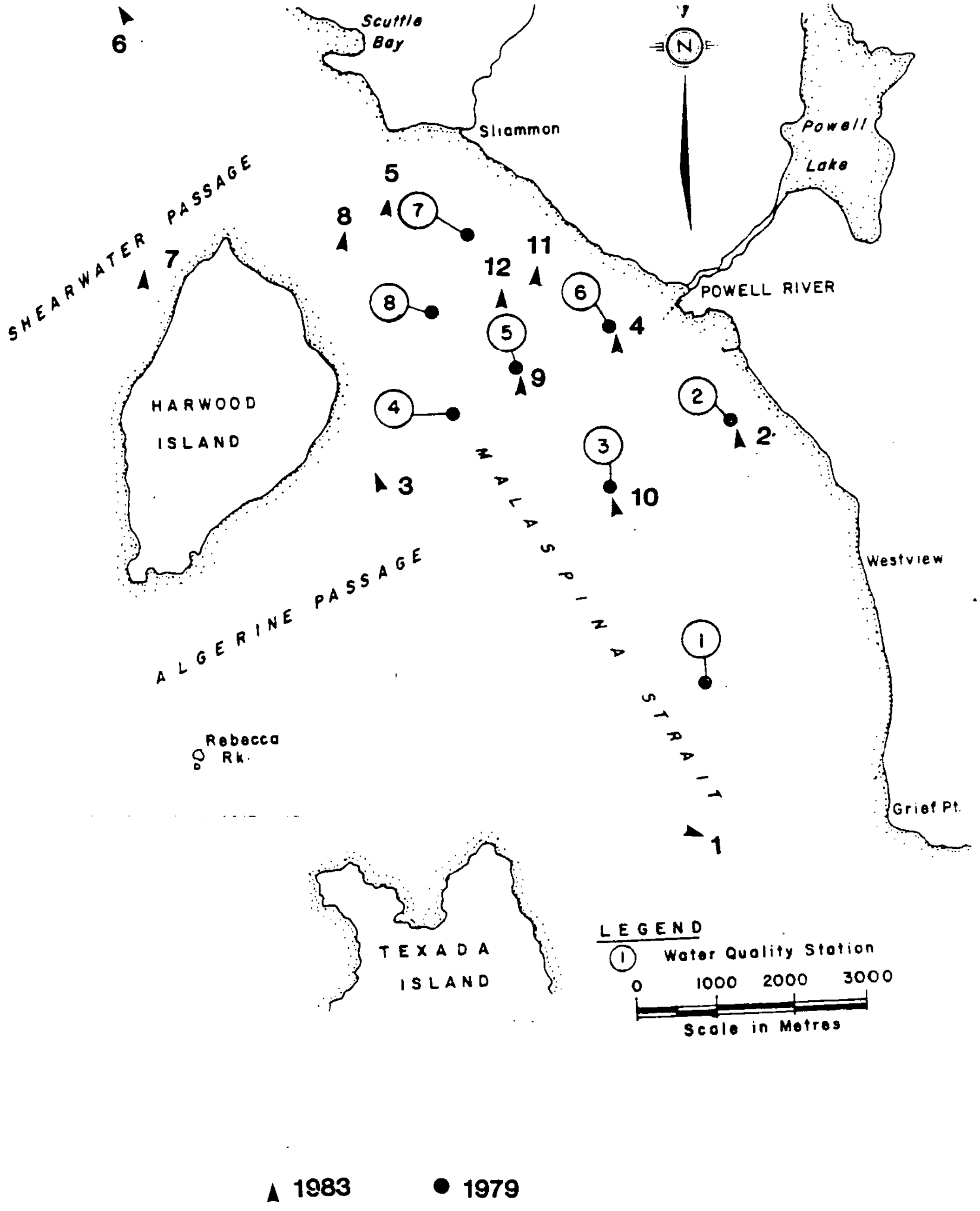


Figure 3.15. Sampling stations at Powell River in 1979 and 1983.

monitoring within-season, although care should be taken to ensure that this monitoring is not strongly biased - for example, that it is not done in an atypical year. Alternatively, for intensively monitored parameters (e.g., oxygen in Alberni/Neroutsos Inlets), the sampling program should select dates to cover maximum contrast in suspected driving variables (e.g., mill operation, wind, tides, rainfall) or biologically critical periods (e.g. periods of salmon migration).

3.6.6 Effects of Operational Changes

In addition to the routine monitoring program, special studies may be required at times. For example, when operational changes occur (e.g., diffuser installation), it may be necessary to devote additional effort and resources to a particular site. These studies may include collecting pre-operational data and information that will serve as a comparison for data collected later in routine monitoring programs. Such studies should, however, be designed either as the start of a well-designed monitoring program, or as pilot studies to answer specific questions.

3.6.7 Indicator Species

Monitoring studies to date have shown that not all organisms are equally sensitive to pulp mill effluents. This suggests that indicator species could be used as a valuable method for establishing a biologically meaningful index of effect in marine benthic and intertidal communities exposed to pulp mill effluents and operations (e.g., intertidal log booms). A few examples of potential indicator species, derived from the existing literature, are provided below. In benthic communities, amphipods and polychaetes (e.g., Capitella) may serve as useful indicator organisms (McGreer 1984). Likewise, for some intertidal sites, Fucus (brown alga) or Enteromorpha (green alga) may be appropriate indicator species (cf. Colodey 1986).

3.6.8 Centralized Database

Once a coordinated sampling program is in place, it would be extremely valuable to have a centralized database (or set of databases) in place containing all data collected by the overall program. The structure of the database should be such that all intended analyses and cross-tabulations can be easily performed, without requiring loading of data irrelevant to the analysis. The best possible arrangement involves easy distribution of the data to interested scientists, which maximizes the value generated by the expense of data collection.

4.0 DESIGNING ENVIRONMENTAL EFFECTS MONITORING PROGRAMS

4.1 Overview

This chapter presents a process for designing an environmental effects monitoring program based upon results described in the preceding chapters. Emphasis here is placed on general principles and guidelines that will be be useful in designing an EEMP. Although this chapter is more "generic" than the preceding chapters, the reader must still bear in mind that it has been written to assist in developing EEMPs for west coast marine pulp mills. Although obviously there will be limits to how applicable the described program is for environmental effects monitoring elsewhere and for other types of projects, the basic process of developing an EEMP should be similar.

Once consensus is achieved on the basic process of developing an EEMP, there are several advantages in having all regions follow the same approach:

1) it will be easier to compare the degree, extent and duration of environmental impacts in different environments, leading to greater understanding, and a better match between resource expenditures and problem magnitudes;

2) it will lead to better quantitative information on the spatial and temporal variability of particular environmental components, which are critical data for formulating workable experimental designs;

3) the creation of an explicit national approach will force a synthesis of the current state of the art in EEMP design, and frequent refinements as new techniques are developed; and

4) the creation of a consistent approach for pulp mill EEMPs will hasten the development of

appropriate approaches for other potentially polluting industries (oil and gas, mining, smelting, etc.).

There are at least three basic types of activities essential to any EEMP: (1) field sampling, (2) sample analysis, and (3) data management and analysis. Each group of activities will have associated with it a set of methods embedded in a procedure. At any given location the specific methods and procedures used will be a reflection of not only the site specific requirements and concerns, but also the overall program objectives.

Over time, the marine EEMP used by the EPS for coastal pulp mills has evolved to include activities in all three categories; what was missing was integration across activities. A prerequisite to integration is a clear focus on a well-defined set of overall objectives, and a statement concerning how the monitoring program results would be evaluated.

4.2 EEMP Objectives

In the context of environmental effects monitoring, sampling and data collection programs can be designed to fulfill one or more of the following objectives:

1) determine compliance of a pollution control program,

2) perform audit sampling to check on company data,

3) describe the extent of environmental effects and resource losses,

4) evaluate alternative mitigation measures, and

5) evaluate the accuracy of effects predictions.

Depending on the mandate and legal authority of a particular agency, not all of these objectives may apply. Nevertheless, it is important that the specific objective(s) underlying any monitoring program be clearly identified. Once that is done, steps can be taken to ensure that the monitoring program is adequate to address the selected objectives. Until there is a well-defined objective for the environmental effects monitoring program, cause-effect relationships -- an important objective for EEMPs, according to Conover (1985) -- are less likely to emerge. In short, monitoring simply to provide general descriptions of existing environmental conditions is not recommended.

In contrast to effects monitoring, interpretation of results from a **compliance monitoring program** must rely upon some externally determined standard. As well, compliance monitoring often requires a different sampling scheme and strategy than would be appropriate for the other objectives. For example, the terms of the permit may specify the sampling program, or there may be need for a random (aperiodic) sampling scheme to ensure that individual operators do not become accustomed to the sampling scheme and adjust their disposal practices accordingly.

When doing compliance monitoring it is essential that sampling be done not only when the mill is operating, but also when it is shut down. Periods when the mill is not operating offer a valuable opportunity to evaluate natural spatial and temporal variability, especially when operations cease for extended periods (weeks or longer), such as during labor disputes. These periods of non-operation are so important to the monitoring program that the requirement to sample during such times should be explicitly written into discharge permits.

Examples of "objectives" that could be applied to compliance monitoring include provincial, national, or international (1) water quality standards, (2) sediment standards or objectives (cf. Long and Chapman 1985), and (3) guidelines for chemical contaminants in fish (cf. DFO 1983). Additionally, objectives could be derived from dose-response data; for example Davis (1975) reviewed minimal dissolved oxygen requirements for aquatic life with special emphasis on those relationships and types of data required for setting standards or objectives. When dealing with complicated issues such as sublethal effects, laboratory studies may be especially valuable. Davis (1973), for example, found that when sockeye salmon were exposed to pulp mill effluents, effects on respiration and blood circulation appeared at effluent concentrations of only 20% of the 4-day LC50.

One potential allocation of responsibility in an EEMP is to have the company collect the bulk of the data, and have EPS perform an **audit sampling** function (objective 2 above). The U.S. Environmental Protection Agency often interacts in this manner with private companies and laboratories performing monitoring studies and surveys (see Linthurst et al. 1986). Responsibilities of EPS could include some of the following: development of quality assurance/quality control protocols; training of field personnel; collection of quality control samples to assure that instruments and data gathering activities were operating within acceptable limits; quality assurance samples to evaluate the performance of field and analytical laboratories and to establish precision estimates; and data verification and validation.

To some degree, **monitoring designed to describe the extent of environmental effects and the loss of aquatic resources** is the cornerstone to any EEMP. Without such activities, it is impossible to quantify trends, or to evaluate the effectiveness of treatment systems such as diffusers in eliminating or reducing adverse impacts. The key to describing environmental effects and the loss of aquatic resources is to have both control sites and a long time series, permitting changes in the affected zone to be compared to natural spatial and temporal variation. Where such variation is of the same magnitude (or greater) than the size of changes expected from the activities, very intensive sampling and a proven method of quantitative analysis (e.g., time series analysis, mechanistic modeling) are required to filter out the environmental effects.

An intensive program is also of potential benefit to the companies because it will allow changes due to their activities to be separated from those caused by natural fluctuations, or other polluters. A consistent, scientifically defensible, intensive monitoring program is probably much more cost effective than one which is sporadic in either sampling frequency or intensity. With an intensive program it will take less time to determine which types of impacts are negligible, and discontinue collection of unnecessary information. Similarly, it will take less time to determine which impacts are significant, and develop appropriate responses.

Evaluating environmental effects depends upon defining some level of change in the measured variable that will be judged to represent an impact. When evaluating results from an environmental effects monitoring program, an impact may be said to have occurred when either some pre-determined level of the parameter is exceeded (cf. compliance monitoring), or when there is a statistically significant change in the measured level relative to some other statistic. For example, the change may be relative to (1) values obtained at a control site, (2) conditions during a "base" period, or (3) a defined ecological threshold. To assist in designing an environmental effects monitoring program to detect effects, it may be necessary to do a pilot study to refine the EEMP design. This pilot study should not be confused with basic research; the objective here is simply to aid in the EEMP design.

If the monitoring program designed to describe the extent of environmental effects and the loss of aquatic resources shows that an impact is occurring, the need to design **mitigation measures** may arise. Initially, there may be several alternative mitigation options. In this case, special studies may be required to help select the best mitigation strategy. Special studies may also be required where the assessment of environmental effects involves the design of new approaches (e.g., new types of acute and chronic toxicity studies, or new analytical methods). In general, such special studies are best performed outside of the EPS monitoring group, by scientists in government research laboratories (such as the Institute of Ocean Sciences), universities, or research-oriented consulting firms.

Finally, a fifth type of sampling is **monitoring explicitly designed to evaluate the accuracy of effects predictions.** Such a program can aid in understanding the mechanisms by which actions cause effects in ecosystem components of interest. If properly designed, such an EEMP provides useful feedback on the effectiveness of the Environmental Impact Assessment (EIA) written prior to the development. Were the effluent controls and other mitigation strategies useful in minimizing impacts? Were the impact predictions confirmed? Post audits of EIAs performed for reservoirs indicate that the accuracy of predictions diminishes with increases in the number of cause-effect linkages in the prediction (Marmorek et al. 1986). A series of well-designed EEMPs oriented to this objective can help to outline the relative merits of different mitigation strategies in different situations, and the strengths and weaknesses of different approaches to prediction.

In this type of program, monitoring is explicitly used to improve understanding of the system under study, for the <u>express purpose</u> of making more accurate predictions in the future. Although not solely designed for this purpose, the monitoring program at Porpoise Harbor (Prince Rupert) has provided information that has been used to make predictions concerning future environmental quality in a bay affected by pulp mill effluent (Pomeroy 1983). At some point, monitoring conducted under this objective falls more into the category of research (i.e. understanding mechanisms, developing new methods of making predictions, etc). Such research activities, like those described above, are generally best undertaken by research scientists outside the monitoring team.

Of course, the reader will recognize that the specific design of any particular monitoring program will determine how well it performs in any of the four categories listed above. The following sections are written largely from the perspective of someone designing an EEMP to fulfill objective 2 -- describe the extent of environmental effects and resource losses.

4.3 Designing an EEMP

Before starting out to design a monitoring program to detect effects and document trends, there are several important issues that should be addressed early in the process. The first of these is to determine the required spatial and temporal bounds and resolution. The second is to establish a framework that will highlight key questions, hypotheses, areas of uncertainty, and unknowns, thereby giving structure and focus to the monitoring program. Despite the conceptual simplicity of these two steps, relatively few monitoring programs have been designed in this manner. Consequently, resulting EEMPs are often poorly suited to answering important questions related to the system under study.

A new approach to designing environmental monitoring programs, based largely on the techniques of Adaptive Environmental Assessment and Management (Holling 1978; ESSA 1982; Walters 1986) and concepts developed by Beanlands and Duinker (1983), was recently described by Everitt et al.

(1986). This approach, as it might be modified for use at west coast pulp mills, has ten basic steps, as follows:

1) state well-defined objectives,
2) identify valued ecosystem components (VEC),
3) identify pulp mill activities of concern,
4) develop impact hypotheses linking VECs and activities,
5) select spatial extent and propose a preliminary spatial resolution,
6) select temporal horizon and propose a preliminary within-year resolution,
7) design preliminary field sampling program,
8) design preliminary sample analysis program,
9) design preliminary data management and analysis plan, and
10) revise steps 5-8 based upon exploratory analyses using existing or model-simulated data.

Each of these ten steps is described in the following paragraphs. Generally, when following AEAM procedures, steps 2 through 7 are done in an initial workshop. Steps 1 and 8 through 10 are carried out by the scientific project manager with technical assistance from specialists in experimental design; workshop participants may also address these issues. An important point to be made here is that these steps are not always carried out sequentially, nor are they done in isolation from one another. The more integrated the steps are, the higher the probability that a well-designed monitoring program will be created.

It is particularly valuable to have wide participation (i.e. industry, academia, government) in steps 2 through 7, and continued involvement of key outside personnel in steps 8-10. Inclusion of representatives from industry in EEMP planning workshops has several advantages. First, it can lead to a team approach to monitoring, improving the relevance, effectiveness and coordination of the EEMP. Second, it builds consensus among all participants concerning the important impact pathways, major uncertainties and necessities for consistency in methods. Finally, the normal adversarial approach is replaced by a cooperative one. Monitoring programs designed through this interactive approach have been shown to be both scientifically defensible and cost effective (LGL Ltd., ESL Ltd., and ESSA Ltd. 1985).

4.3.1 Objectives

The importance of starting the process by identifying and clearly stating a set of well-defined objectives cannot be overemphasized. Addressing this issue in a workshop environment ensures that all important goals and objectives will be identified, and that reasons are provided for abandoning those that are not selected. Regardless of which types of objectives are selected (see Section 4.2), simply stating them clearly will immediately create a much needed focus for the remaining steps.

4.3.2 Valued Ecosystem Components

In order to develop impact hypotheses linking VECs and activities (Step 4, above), it is first necessary to identify VECs and pulp mill activities of concern. Valued ecosystem components, as defined by Beanlands and Duinker (1983), are:

> "... attributes of components of the environment for which there is public or professional concern, or both, and to which the assessment should be primarily directed ... These may be determined on the basis of perceived public concerns related to

> social, cultural, economic, and aesthetic values. They may also reflect scientific concerns of the professional community ..."

Selecting VECs is an important step in the process, since this helps identify areas of potential concern. Examples of VECs relevant to an EEMP for west coast pulp mills could include salmonids, oysters, flounder, and clams. Of course, the actual list used would depend not only on the marine resources present at a specific location of concern, but also on the design and operational characteristics of the particular pulp mill.

4.3.3 Activities

Although design and operational characteristics vary among pulp mills, there are certain common activities of concern that can be identified. In addition to the obvious effluent discharge, these activities may include overland flow of spills (e.g., from wood preserving operations), log booming, and harbor dredging. The choice of which specific activities to include in the impact hypothesis diagrams depends on the spatial and temporal dimensions of the activities and the monitoring program objectives. Other activities which are not related to the pulp mill but might confound results of the monitoring program (e.g., sewage outfalls, ocean dumping, mine tailings) should also be identified, along with mitigation actions currently used or under consideration.

4.3.4 Impact Hypotheses

Simply stated, an impact hypothesis is a set of statements that link industrial activities with their environmental effects (Everitt et al. 1986). When the activities and VECs are arranged so that they form a flow chart with arrows, this is referred to as an impact hypothesis diagram. The arrows symbolicly represent the linking statements.

Formulating impact hypotheses is a key step toward linking specific project activities with ecosystem components that are expected to be affected by those activities. An example for coastal pulp mills is shown in Figure 4.1; in this diagram each of the arrows represents a hypothesis. For example, the highlighted linkages could be expressed as follows:

Linkage 1a: Pulp mill operations result in production and discharge of effluents containing large quantities of wood fibers and fragments.

Linkage 1b: Discharge of wood fibers and fragments into coastal marine waters will result in degradation of water quality (e.g., high concentrations of suspended solids).

Linkage 2: Wood fibers and fragments will settle out from coastal waters and will create a fiber mat on the benthos.

Linkage 3: Formation of a benthic fiber mat will lead to decreased habitat availability (e.g., smothering) and quality (e.g., dissolved oxygen concentrations, increased hydrogen sulphide concentrations). These changes, in turn, will result in detrimental effects to populations of benthic organisms (e.g., flounder, crab, clams).

To be useful in helping determine which parameters to measure in a EEMP, a more detailed diagram is needed. Figure 4.2 represents major functional linkages between pulp mill effluents and biota. Again, each arrow represents a hypothesis. Careful examination of Figure 4.2 reveals a hierarchy of hypotheses that differ in their testability. For example, it is much easier to measure changes in dis-

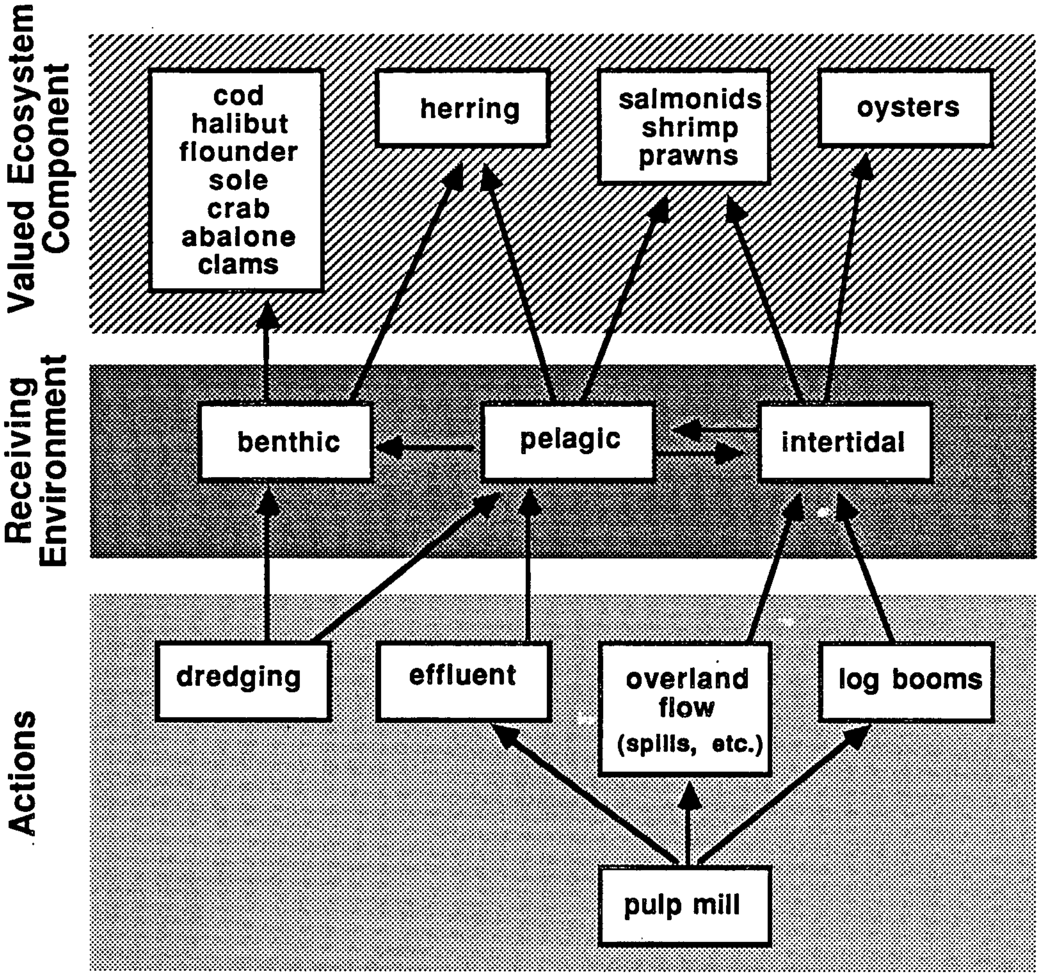


Figure 4.1. Impact hypothesis diagram featuring one set of linkages.

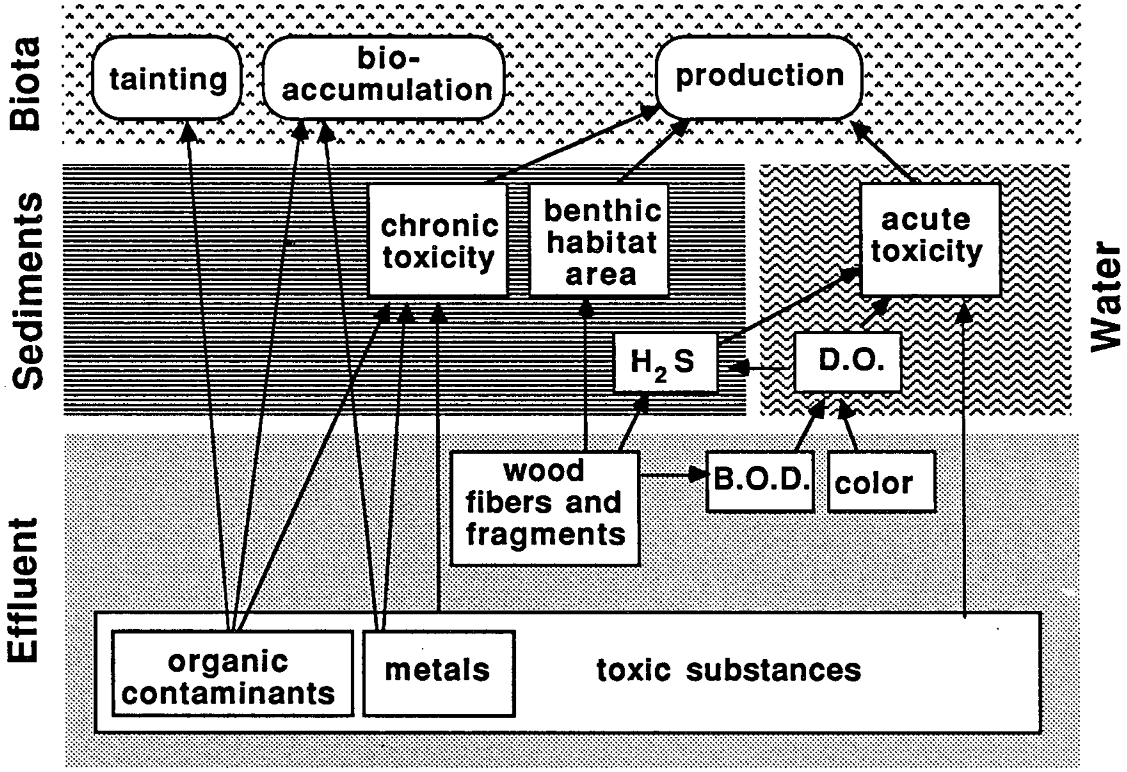


Figure 4.2. Functional linkages between pulp mill effluent and marine biota.

solved oxygen content in water than decreased productivity rates in benthic populations. By clearly displaying relationships between system components the task of selecting parameters appropriate for routine monitoring can be made easier. As well, the implications and potential significance of measured changes in any given system component are more easily determined when the linkages are diagrammatically displayed.

The impact hypotheses displayed in Figures 4.1 and 4.2 would be very different in a freshwater system. For example, in freshwater streams (the usual location for pulp mills):

- the fauna are different,
- the water is of lower alkalinity and therefore more vulnerable to pH depressions,
- shallower depths prevent development of a significant deep water anoxic zone,
- there is generally greater scouring of bottom sediments,
- the shape and seasonal variability in the mixing zone is very different; and
- impacts on drinking water are a potential problem.

This partial list of differences highlights the importance of developing different impact hypotheses for each site. Generic impact hypotheses can be very useful, however, as a starting point for developing site-specific hypotheses (see Marmorek et al. 1986 for an example of this approach).

4.3.5 Spatial and Temporal Horizon/Resolution

A very important step in designing an EEMP is to select the appropriate spatial extent and temporal horizon for the program. When making the selection, consideration should also be given to rates of change and the required spatial and within-year resolution. For example, issues relating to time may include whether the type of impact is slow and cumulative (e.g., fiber mats), or fast and sporadic (e.g., toxic spills). Likewise, whether effluents cause chronic or acute effects is also a time-related issue.

An important question, relating to time and space, is what is the natural variation in the environmental components of concern? In a temporal context, this question becomes what is the variation on short (day), medium, (month), and long (annual) time scales? In contrast, in terms of spatial variability, we can also ask what is the natural variation on small (meters), medium (100s of meters), and large (km) spatial scales? For benthic sampling programs, it would be important to know what the natural spatial variability is in substrate composition and chemistry. Sediments in depositional environments (e.g., blind bays) may have naturally different chemistry from erosional environments (e.g., high velocity tidal channels). For all of these scales, an equally important adjunct question is how does this variation interact with spatial and temporal patterns of the actions of concern?

Regarding spatial and temporal horizon, there are important questions relating to the response time of measurable environmental components (e.g., life span of sessile organisms). Another important question is what is the shape and size of the expected mixing zone, and what are the maximum possible spatial limits of the expected impacts?

4.3.6 Field Sampling Program

Only in unusual circumstances should a monitoring program be initiated without a statistical design. Designing a statistically defensible field sampling program involves a number of steps which have been concisely summarized by R. Green (pers. comm., U. Western Ontario; see also Green 1979) as follows:

1) Clearly state the question.

2) Establish a control.

3) Have replicate samples.

4) With respect to the factors of interest, allocate samples equally and at random, but if there is a large-scale spatial pattern, consider a stratified sampling design.

5) Do a pilot study.

6) Evaluate the sampling method for consistency.

7) Estimate the necessary sample number (or adequacy of feasible sample number) and optimum sample unit size.

8) Decide how to handle problems in the data (e.g., transform, nonparametric statistics, simulation, sequential sampling).

9) Stick with the design and the results.

While the above steps undoubtedly represent the ideal measurement system, for various reasons (e.g., time and financial constraints) it may not always be possible to design the monitoring program to conform with the ideal. Furthermore, in some instances all that is required is to collect data or information to support a "weight of evidence" case. In such cases, it is still important to at least consider the issues raised by Green's list of steps.

A well-designed field sampling program will specify the:

- parameters of interest,

- locations where samples will be routinely be taken,
- frequency and proper timing (e.g., season, stage in tidal cycle) for sample collection,
- duration of sampling program (e.g., fixed time period, subject to periodic renewal, permanent), and
- methods for sample and data collection.

In such a program, consideration will also have been given to issues of quality assurance, especially in cases where the data may be required for legal purposes.

In reviewing the west coast pulp mill EEMP (see Chapter 3), there seems to have been a gradual evolution toward a relatively short list of parameters of interest. As well, there has been some standardization of locations where samples were taken, frequency and season of sample collection, and methods for sample and data collection. For example, at least some of the sampling done at the Prince Rupert site was conducted on a rising tide to maximize effects of pulp mill discharges (Packman 1977).

In contrast, there seems to have been little or no consideration given to rigorous statistical design (e.g., establishment of permanent control stations, sample replication, random allocation of samples, methods evaluation, ensuring that an adequate number of samples was taken) or periodic review of the overall EEMP and the underlying objectives. However, in recent years this situation has been improving, especially with reference to taking replicate samples.

It is extremely important that statistical significance not be confused with ecological significance. Yunker (1986) describes the appropriate 'middle ground' in developing an experimental design:

> "At the outset, an estimate should be made of what constitutes a a **biologically (chemically) significant impact,** and than a sampling program with a specified probability (power) of detecting this change at a given level of significance should be designed...Poorly funded and/or designed studies will detect 'no significant' change, and studies with intensive sampling will find even small changes to be 'significant'."

A realistic allocation of effort is also extremely important. There are several different options ranging from dividing the total available effort equally throughout, to focusing on 1-2 sites. An alternative is to ensure that a fraction of the available effort is allocated to monitoring, another portion to data analysis, and the remainder to special projects, for example evaluating alternative mitigation measures.

Implementing even a well designed monitoring program requires careful planning and dependable logistical support. Unexpected events can cause deviations from the monitoring design, and plans should be made to accommodate these inevitable deviations. For example, if the logistical support for sampling is outside the control of the monitoring team (e.g. vessel time is scarce), then the EEMP should not include components which are very sensitive to the timing of sampling. In such a case, it would be better to sample sediments than surface water chemistry.

EEMPs, like any other program, are vulnerable to failures in funding and changes in policy. Innovation is required to ensure that the most critical components of the EEMP are carried out through a budgeting process which secures repeated funding for several years. Including such components of the monitoring plan as part of the industry's permit may be one useful approach. Developing useful articles, analyses and other products on an ongoing basis is generally a necessity for maintaining a long term program.

4.3.7 Sample Analysis Program

In designing the sample analysis program, attention should be given to ensuring that proper analytical and quality control procedures will be followed. This means considering not only the measurement methods, but also variability estimation and subsample selection (where necessary). In most cases, though, sufficient attention has already been given to developing and adopting standardized methods and procedures for sample analysis to justify dropping this topic from further consideration here. In fact, past programs have often put disproportionate emphasis on laboratory sources of variability, while virtually ignoring natural sources of spatial and temporal variability.

4.3.8 Data Management and Analysis Plan

Data analysis is a crucial step in any EEMP, for this is where answers are provided to the questions that were originally formulated when the EEMP was established. An important point to emphasize here is that the optimal relationship between data collection and data analysis is one that is formulated <u>prior</u> to data collection. Retrofitting analytical methods to an existing data set can, of course, be done, but often with a loss of statistical power due to unforseen problems that could have been corrected with little additional effort during the sampling program.

In the absence of replicate sampling (in space for sediment samples, and in time for water quality samples), it is impossible to determine the statistical significance of observed trends over space and time. The number of replicates required should be determined early in the monitoring program by examination of existing data sets, or where none exist, intensive sampling to assess temporal and spatial variability. Then it is possible, given the expected level of changes over time or along a gradient from an outfall, to design a sampling program which will distinguish between degraded and unaffected habitat at some specified level of confidence and precision. Monte Carlo analyses of uncertainty can be very useful for more complex sampling problems.

If the variable of interest is known to vary across environmental features (e.g., oxygen concentrations with tides; sediment concentrations with type of substrate) then a stratified sampling program (with random selection of dates or sites within each stratum) will greatly reduce the required number of samples. Often analyses of pilot study data will indicate that it is not feasible to sample at an intensity sufficient to detect trends or spatial gradients at the necessary level of precision. If so, the objectives of the monitoring program will need to be readjusted. Perhaps only a smaller area, or a smaller fraction of the year can be adequately monitored.

Selection of adequate controls (or reference stations), continued sampling of these reference stations over the entire duration of the monitoring program, and consistency in sampling methods are all critically important. Without adequate controls, statistical analyses cannot separate out natural temporal variation from changes due to trends in effluent loading. In coastal settings it may be difficult to determine a control station, and changes in currents may affect which station acts as a control (i.e. is "downstream" from the effluent source). In these situations, careful documentation of all factors that are known to affect the monitored variable (e.g., tides, winds, effluent loading) and randomization of sampling across the known range of these variables, is essential. For water quality variables, one of the most effective "controls" are periods with no loading. All quantitative methods depend upon contrast in the assumed driving factors to test hypotheses. Under the current regulations, compliance monitoring programs unfortunately do not sample these periods of no effluent loading, with a consequent tremendous loss of information.

Changes in reference stations or methods of sampling confound the detection of trends. If new stations or analytical methods are introduced, the old stations/methods should be continued until precise calibrations between the old and new stations/methods are determined. Then at least old data can be converted to the new measurement method, and statistically analyzed using a procedure which recognizes the uncertainty in the conversion. Rigorous documentation of station locations and methods of sampling is essential, particularly with changes in staffing.

Although in many EEMPs little attention was historically given to data management, recent activities have substantially improved the ability to store and retrieve data for analysis. Nevertheless, in many programs data are still not being stored in a properly designed database. This seriously hampers efforts to compare data between sites and years.

Data management activities should be an integral part of all EEMPs. Establishment of a well-organized database will not only facilitate assembling, retrieving and storing data, but also writing annual data reports, and carrying out detailed graphical and statistical analyses across years and sites. Data management activities include data entry, error checking and verification, data editing, substitution and replacement.

As suggested in Section 3.6, it is important to have coordination of sampling programs between the company and EPS. Likewise, consistency in data coding, entry and storage should be established to facilitate data exchange and analyses. A centralized database provides for a much greater degree of quality control, though adequate staffing is essential to ensure that data do not become "locked up" for long periods of time in the data processing system.

4.3.9 Revise EEMP

The final step in the process is to revise the preliminary experimental design based upon exploratory analysis using existing or model-simulated data. During the revision, specific attention should be given to the following concerns: spatial extent and resolution, temporal horizon and within-year resolution, design of the field sampling program, and details of the sample analysis program.

How does the current EEMP compare to an ideal EEMP? How can one move closer to the ideal? Figure 4.3 illustrates one set of answers to these questions. On the positive side, the current environmental monitoring program has been successful in gathering a large amount of data for many different sites (the large box in the middle of the first row of Figure 4.3). On the negative side, many of these data have been gathered without an explicit experimental design and method of data analysis. Partially for this reason, and partially due to lack of resources, only a small proportion of the collected data has been analyzed in existing EPS reports. Nevertheless, the existing program is enormously valuable as a pilot study of the effects of pulp mill effluents on important habitat indicators.

The EEMP should evolve towards a more balanced allocation of effort between experimental design, peer review, data collection, and data analysis. This is illustrated in the bottom row of Figure 4.3, with iterative improvements to the design occurring regularly as previous data are analyzed. These iterative improvements should be directed towards fine tuning methods of analysis, while still maintaining the consistency necessary for the detection of long term trends. The amount of data collected should be scaled

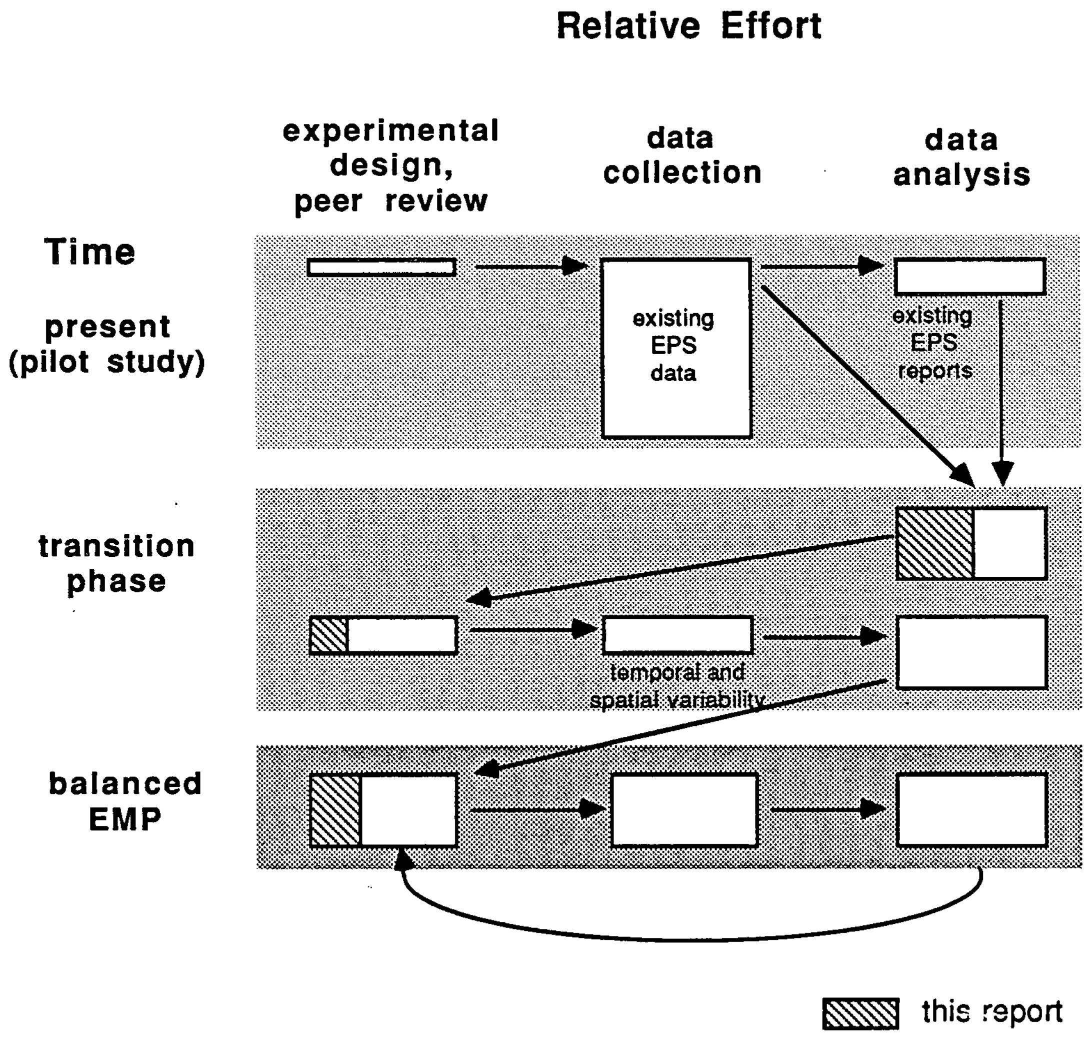


Figure 4.3. Conceptual model of the evolution of the Vancouver pulp mill environmental monitoring program.

relative to the resources available to analyze it, so that the program does not become mired in data collection without the ability to determine what the data indicate.

To reach this balanced and blessed state, the EEMP must move through a "transition phase" (the second row of Figure 4.3). In this phase, four things should occur:

1) existing data are examined to see if it is possible to determine trends over time and space relative to natural variability, and if it is, quantitative analyses are performed (the top right box of the second row);

2) where trend determination is not possible from existing data and the impact hypothesis is still of interest, the requirements for an improved experimental design are specified, particularly with respect to documenting the level of temporal and spatial variability (the leftmost box in the second row);

3) data are gathered documenting temporal and spatial variability (either from existing studies or from the field), and then analyzed (the middle and bottom right boxes in the second row); and

4) the information gained from supplementary sampling is used together with the insight of experts in experimental design to develop a balanced EEMP.

This report, as shown on Figure 4.3, fulfills some of the necessary steps of the transition phase, and begins to specify in a general way some components of the experimental design for a balanced EEMP. A considerable amount of further work is necessary before such a balanced program can be realized.

On a national scale, there is a need to first of all achieve a consensus that a set of explicit guidelines to the design of EEMPs is worthwhile. The next step should be to take the skeletal framework presented here and fill in the details. There is a clear need for tools to be developed to assist scientists in EEMP design, data management and analysis, and staff training. Eventually, the approach developed for pulp mills should be applied to other industries.

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