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Changes in marine benthic community structure in Alice Arm (1977 to 1995) after ceasing molybdenum mine tailings discharge

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Prepared By:
Dr. Brenda J.Burd
Ecostat Research Ltd
Box 202 Brentwood Bay
B.C. V8M 1R3

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Report Prepared For:
Environment Canada
Environmental Protection Branch
224 W. Esplanade
North Vancouver, B.C.
V7M 3H7

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Review Notice

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Address comments regarding this report as follows:

Janice Boyd
Industrial Programs
Pollution Prevention and Assessment Division
Environmental Protection
Environment Canada
224 West Esplanade
North Vancouver, B.C.
V7M 3H7

Voice: (604) 666-5908
FAX: (604) 666-7294
email: Janice.Boyd@ec.gc.ca

SUMMARY

Submarine molybdenum mine tailings discharge to Alice Arm occurred from April, 1981 to November, 1982. Tailings discharges from the previous mine operation occurred via Lime Creek from 1968 to 1972. The recovery process in Alice Arm can be inferred from sediment and biological data collected from 1977 to 1995. All of the factors discussed in this report suggest an increasing stabilization of the benthic fauna in Alice Arm. The only indication of continuing change is the increasing dominance by large fauna. This may be a residual effect of disturbance over a long period after the impact. The 1995 data illustrates the longest period of recovery from mining disturbance in Alice Arm since these mining events.

In general, samples were collected from a fairly homogeneous substrate and depth type. The amount of natural sediments which have settled over the tailings should be in the order of 10 cm, and descriptions of grab sample residue confirm the presence of considerable organic debris. Sediment metal levels of Mo, Pb, Zn, Cd were particularly elevated over background levels in the tailings. Values found in 1995 suggest that the levels of metals in sediments in Alice Arm have declined notably since 1981-82. But, a declining gradient in most of these metals and some nutrients away from the outfall suggest that there are still traces of the tailings affecting sediments.

The abundance and taxa patterns suggest a classic pollution recovery response in Alice Arm, with the initial impact in the nearby stations evident in 1982, then the remaining stations later in 1983 as tailings sifted down-inlet. By 1986, a distinct increase occurred in both abundance and diversity, with many small, opportunistic fauna mixed with a few large taxa. By 1989, the abundance and taxa levels declined with the disappearance of many of the colonizers and increase in dominance by the larger fauna, and remained consistent through to 1995. In contrast, biomass has generally shown a slow increase from the beginning of the study in 1982, with biomass levels higher 13 years after mining than they were before mining or in the less impacted stations (E) in 1982. Dominant taxa have not changed much over the study period, except that larger taxa are increasing in importance over time.

The gradient in sediment metals and nutrients away from the outfall in 1995 is reflected in the significant gradient evident in cluster analyses of abundance composition for 1995. As well, similarity/gradient analyses of abundance data for all 5 sample years indicates that faunal similarity declines with distance from the outfall. This pattern is consistent with the theory that in a low-energy, poorly mixed fjord, there will be a geographic "drift" in faunal composition with distance away from any reference point, due to differential settlement and limited lateral mixing of larval forms in the water column. However, the biomass analyses show that larger fauna are much more homogeneously distributed throughout Alice Arm. This result is consistent with findings for a wide variety of B.C. benthic habitats, that large fauna tend to be more ubiquitously distributed in coastal waters than small fauna. It is this consistency which allows researchers to "type" communities based on sediment and depth characteristics, by the presence of ubiquitous large and long-lived taxa (Thorson's 1957 parallel community theory).

The second feature that the similarity/gradient analyses confirm is that the faunal composition is stabilizing over time in Alice Arm. The similarity/gradient analyses for both abundance and biomass data indicate that overall faunal similarity (or homogeneity) increased considerably in the system between 1983 and 1986 then remained fairly consistent up to 1995.

RESUME

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BACKGROUND

Alice Arm is a fjord located on the northwestern mainland coast of British Columbia (Fig. 1). Mining activities have occurred in Alice Arm intermittently for many years (for review see Losher 1985, Goyette and Christie 1982a,b, Littlepage 1978). The most recent mining episode was the subject of this study, and began in April of 1981. Approximately four million tonnes of tailings from the AMAX molybdenum mine at Kitsault were discharged near the head of the inlet between Lime and Roundy Creeks at a depth of 50 m over a period of 18 months. The mine shut down in October 1982 because of a decline in world molybdenum prices. B.C. Molybdenum operated the mine prior to AMAX between 1968 and 1972 (AMAX 1990) discharging about 9 million tonnes of tailings into Lime Creek.

Mining operations discharging tailings in fjords may cause damage to fauna by smothering (c.f. Harding 1983, Jones and Ellis 1975, Waldichuk 1978), or by toxicity from heavy metal contamination (Anderson and Mackas 1986). Chemical analyses of tailings and animal tissues from Alice Arm indicated that bioaccumulation and metal toxicity were not a concern in commercial benthic species in Alice Arm (Thompson *et al.* 1986, Reimer and Thompson 1988, Farrell and Nassichuk 1984). However, Goyette and Christie (1982a,b), and Goyette (in prep) indicated that the bivalve *Yoldia thracieformis* was accumulating metals after the AMAX mine opened in Alice Arm.

The main concern that tailings deposition would smother the benthic fauna, thus directly disrupting the crab and prawn fisheries and indirectly affecting bottom and demersal fish dependent on benthic fauna for food. Burling *et al.* (1983) described the development of a turbidity plume during mine tailings deposition, wherein sediment concentrations in the water exceeded 100 $mg \cdot l^{-1}$ extending from the outfall down the deep central trench of Alice Arm. Such an event creates areas of unstable sediments where deposition rates are abnormally high, and the bottom is subject to slumping, causing turbidity and smothering of fauna well after the event. AMAX (1984) reported that submarine slumping likely occurred based on much lower metals levels at one of the stations closest to the discharge, compared to the previous year.

The Institute of Ocean Sciences, Sidney, B.C., initiated benthic faunal surveys of Alice Arm in October 1982 (Kathman *et al.* 1983) and repeated them three times over the next seven years in October of 1983, 1986 and 1989 (Kathman *et al.* 1984, Brinkhurst *et al.* 1987, Burd and Brinkhurst 1990). An analysis of all four surveys is included in Burd (1992).

Burling *et al.* (1981) recommended monitoring Cd, Pb and Zn in the environmental program as these were higher in tailings versus background. Sediment trace metals data from the annual AMAX environmental monitoring program (AMAX 1982-1991, Yunker *et al.* 1981) and Environment Canada surveys (Goyette and Christie 1982a,b, DOE 1989-unpub.) provided spatial and temporal indications of tailings deposits throughout Alice Arm.

SCOPE

In late September 1995, Environment Canada repeated the benthic invertebrate survey based on the design of the earlier studies. This report summarizes the long term effects of mine tailings deposition by the AMAX/Kitsault molybdenum mine on the benthic invertebrate infauna of Alice Arm, B.C., 13 years after the mine closed. It covers the results of the 1995 survey, and compares the faunal composition from the previous surveys. This contract specifically includes analysis of benthic invertebrate faunal data for 1995. Data on sediment particle size, organic content, volatile residue, and trace metals for 1995 were provided by Environment Canada (J.Boyd). They also tabled historical sediment chemistry data (1980-90) available for the benthic invertebrate stations. Baseline benthic faunal data from June of 1977 and 1980 (O'Connell and Byers 1978, O'Connell, 1983) were collected for AMAX environmental monitoring program, and were compared with data collected after closure of the mine in 1982.

SURVEY AREA

Alice Arm is a glacially fed, typically steep sided fjord about 385 m deep. Shallow sills at the mouth (20 m) separate it from external water bodies. The Kitsault and Illiance Rivers at the head of Alice Arm supply most of the sediment and freshwater to the system (Losher 1985). Core and sediment trap data indicate that Alice Arm has a natural sedimentation rate of about 0.7 cm per year (Macdonald and O'Brien 1996, Macdonald *et al.* 1984a,b,c). Flushing processes, although particularly slow and restricted in Alice Arm, produce partial or complete replacement of bottom water annually (Rambold and Stucchi 1983, Krauel 1981). Therefore, oxygen depletion is not a factor affecting benthic fauna.

METHODS

Sampling Stations

Samples were taken on September 27, 1995 at a series of cross inlet transects (C,D,E) established in previous surveys. They ranged from close to the discharge point at the head of the inlet (transect C) to a location near the sill (transect E) (Fig. 1). Transect D5, added between transects D and E in 1983 and 1986 only, was not included in the current survey due to time constraints. Within each transect, three stations were sampled. The middle station in each transect (CM, DM, EM) was located within the deep, central trough of the inlet, whereas the north (CN, DN, EN) and south (CS, DS, ES) stations were in the shallower, steep areas adjacent to the trough. Three reference stations were sampled in Hastings Arm, adjacent to Alice Arm in 1982-1989. However, the data from these samples was found to be confounding and not representative of a true reference site (Burd 1992). The Hastings stations were not sampled in 1995. The benthic fauna were compared along a gradient within Alice Arm where the most distant stations (E) were considered approaching background (i.e. reference gradient).

Benthic Invertebrate Sample Collections

There were no notable changes in sampling or processing procedures over the thirteen year period. A 0.1m^2 Smith McIntyre grab was deployed twice in the sediments of each station from 1982 to 1989, and increased to three times per station in 1995 due to high variability in past surveys.

The sediment from the grab samples was washed carefully with 0.25 mm filtered sea water through a 1 mm screen. Animals and particles retained were preserved in 10% buffered, Rose Bengal stained formalin. Samples were sorted in the laboratory after washing through a 1 mm screen, then preserved in 70% ethanol. Samples were picked in their entirety (i.e. no subsampling). Ten percent of the sorted residues were reexamined by an independent sorter as a quality control. A five percent error in additional faunal number was the maximum permitted, but no control sample exceeded this limit. Sorted samples were sent directly to taxonomic experts (amphipods: Dr. Craig Staude, Friday Harbour Marine Laboratory; polychaetes: Dr. Howard Jones, Marine Taxonomic Services, Corvallis, Or.; molluscs and various taxa: Dr. W. Austin, Khoyatan Marine Laboratory, Cowichan Bay, B.C.) for identification and production of a reference collection. The 1995 taxonomic identifications were also subjected to a rigorous QA/QC analysis by Val Macdonald of Victoria, B.C. The collection to 1989 has been archived at the Royal British Columbia Museum. Reference collections to 1995 have been retained at the Institute of Ocean Sciences, Sidney, B.C. under the supervision of Mr. Doug Moore. All intact taxa except copepods and nematodes were identified to species and included in the data. Specimens from each taxon were blotted dry and weighed to the nearest 0.01 mg.

Mean wet biomass for each species was calculated from reference specimens of a representative size range and a master list compiled (Burd 1992). Abundance values were multiplied by the mean wet biomass for each species, to estimate total wet biomass per species per 0.1 m^2. There is no way to know what loss in organic biomass occurred over the preservation time of the archived samples (see Ellis 1987). Because of the estimation method used, the mean wet biomass could only be interpreted as approximate scaling factors for each species, and as a relative rather than absolute measure of biomass for a given station.

Multivariate community analyses were done using a Bray Curtis (Bray and Curtis 1957) similarity coefficient and unweighted pair group mean average sort (Sneath and Sokal 1973) for clustering stations according to faunal composition. The groupings were then tested for significance using a bootstrap technique (Nemec and Brinkhurst 1988). The Bray Curtis similarity matrix values were also extracted and plotted against distance from the outfall, using station CM as the reference station located closest to the outfall. This analysis is described in detail in Burd (in review).

Data were also available for benthic faunal samples taken in 1977 (3 replicates each station) and 1980 (2 or 3 replicates per station), using a Van Veen grab and 1 mm sieve (O'Connell 1983). Total biomass for each species in each replicate was measured as either ash-free dry weight (1980) or dry weight (1977). An estimated conversion of 20% of wet weight for 1977 and 10% of wet weight for 1980 biomass was used to compare with data from 1982 onward. The sampling stations were quite different than those used from 1982 to 1995. Therefore, only the data for synchronous station locations has been included in the summary analyses for total abundance, biomass and taxa number. There was great variability among grab replicates in 1980 data versus 1977. The 1980 data included only 2 replicates per station; the 1977 data had reduced variability using three replicates. There was not sufficient overlap in stations to allow the 1977 or 1980 data to be included in the multivariate community analyses.

Sediment Sample Collections

In 1977, 1980, 1986, 1989 and 1995, a 100 ml core was inserted into each grab prior to extraction of the sample from the grab for benthic invertebrates. The contents were processed to determine percent gravel (>2 mm), sand (<2 to 0.063 mm) and mud or silt and clay (<0.063 mm), using the Wentworth method for sieving sediments (Wentworth 1922). The 1995 analyses further separated sand fractions: very coarse sand (<2 to 1 mm), coarse sand (<1 to 0.5 mm), medium sand (<0.5 to 0.25 mm), fine sand (<0.25 to 0.125 mm), very fine sand (<0.125 to 0.063 mm). It also included the pipette method to separate the muds into silts (<0.063-0.004 mm) and clays (<0.004 mm).

A second core sample was collected from each 1995 sample to analyze for trace metals, volatile residue (SVR) and total organic carbon (TOC). Each trace metal and SVR sample was frozen in a kraft bag in a plastic bag for analysis at the Environment Canada laboratory. The TOC sample was place in a heat treated glass jar, stored cold (4°C) then analyzed at a commercial lab.

For trace metals analyses, each sample was dried, passed through a 100-mesh stainless steel standard series sieve and microwave digested in a 3:1 nitric-hydrochloric acid mixture (partial digestion). An ICP (Inductively Coupled Argon Plasma) scan was used to determine most metal values. Cadmium was measured using a graphite furnace atomic adsorption spectrophotometer (GF-AAS) for more accurate low level values (< 4ppm). Mercury was determined by cold vapour atomic adsorption (CVAA). Quality Assurance-Quality Control (QA/QC) included five lab replicates of the 27 samples and standard marine reference sediment replicates (MESS, BCSS and PACS). Detailed methods are available from the Environmental Canada Laboratory.

SVR and TOC were measured as estimates of organic carbon present in the samples. For SVR analyses, each sampled was oven dried and ignited at 550 °C in a muffle furnace (Swingle and Davidson 1979). SVR is the measure of the loss of weight (volatile residue) on ignition. TOC analyses involved measuring total carbon by Leco induction furnace and carbonate by Leco gasometer (Tetra Tec 1986). TOC is reported as total carbon less carbonate carbon.

RESULTS

1995 Benthic Invertebrate Data

Faunal abundances, number of taxa, relative biomass values, physical sediment characteristics, station depths and station coordinates for 1995 are summarized in Table 1. A complete taxa list and abundances for each grab sample are included in Appendix 1. Abundances ranged from 10 to 103 individuals per grab (0.1 m^2), with lowest values in station EN, and highest values in stations CS and DM. Values varied considerably between replicates, which was why it was decided to analyse and average all three replicate grabs for each sample. Biomass values ranged from 1.1 to 18 g blotted wet weight per grab. Sample CN2 had an unusually low value because part of the sample was spilled prior to analysis. Sample EM1 and EN2 also had unexpected low values for unknown reasons. Number of taxa ranged from 9 to 31, with the lowest values in station EN and the highest values in DM.

Table 2 shows the 10 dominant taxa in 1995 in terms of both abundance and biomass. Abundance was dominated by the amphipods *Eudorella pacifica, Heterophoxus affinis*, the polychaetes *Aricidea lopezi, Nephtys cornuta, Levinsenia gracilis, Heteromastus filobranchus*, the bivalve *Psephidia lordi* (mainly in the E stations), the echinoderms *Chiridota albatrossi* and *Ctenodiscus crispatus* and the scaphopod *Chaetoderma sp.* Biomass was dominated overwhelmingly by echinoderms, 3 bivalve species, an amphipod, a predaceous polychaete and a nemertean. Gradients in major taxa (Table 3) are evident in that the C stations had high numbers of crustaceans and few bivalves, whereas the E stations had many bivalves and few crustaceans, with the D stations in between. Echinoderms were common in all stations. A new species of amphipod of the genus *Stegocephalus* was discovered in one of the 1995 Alice Arm samples. This species will be verified and described for publication.

Cluster analysis with significance testing (Bray and Curtis 1957, Sneath and Sokal 1973, Nemec and Brinkhurst 1988) for the 1995 abundance (Fig. 2) and biomass data (Fig. 3) show significant station groupings for p<1.5%. This probability level was selected since for a total of 8 linkages tested per analysis, the total p could be as much as 12%. The abundance cluster analysis shows that there is a gradient in faunal composition away from the outfall such that the C stations (closest to the outfall) form a significantly homogeneous group, with the D stations most similar to C, and the E stations least similar. The biomass analysis had no linkages with a p <50%. Therefore, the composition of the biomass dominants or large taxa can be considered to be relatively homogeneous throughout the inlet. The use of three replicates per station increases the power and reliability of the significance testing over previous years, when only 2 replicates were sampled.

1995 Sediment Data

Total organic carbon (TOC) varied considerably from <0.05-1.0 %. Sediment volatile residue (SVR) ranged around 3-5%. Values are reported in Table 1. Observations of grab sample residues from benthic invertebrate processing indicated fairly uniform organic debris consisting of bark, twigs, shells, worm tubes, some leaf pieces and algal debris. Sediment particle size data showed that most samples were over 90% silts and clays with small percentages of fine and very fine sand. Only CS2 was slightly coarser. However, grab residue descriptions also indicated the presence of tiny stones in most samples. Staion depths ranged from 229 to 391 m and consistent sediment particle sizes suggested a fairly homogeneous sedimentary habitat for infauna.

Sediment metals values for 1995 are listed in Table 4. Figure 4 (a-m) shows the distribution of the major elements with distance from the outfall (using CM as a reference). Elements which show a decline away from the outfall include the nutrients calcium (Ca) and phorphorus (P) and metals iron (Fe), copper (Cu), cobalt (Co), cadmium (Cd), molybedenum (Mo), zinc (Zn), and mercury (Hg). Arsenic (As) may have a similar pattern, but some values could not be accurately reported (insensitive detection limits) due to interferences from other metals (J. Boyd, Environment Canada, pers. comm.). In contrast, nickel (Ni) and manganese (Mn) increased away from the outfall. Other elements showed no clear pattern with respect to distance from the outfall.

Comparison of Benthic Invertebrate Survey Results from 1977 to 1995

Figures 5 to 7 show the progression in total abundance, biomass and taxa number from 1982 to 1995, with a few values included for synchronous stations sampled in 1977 and 1980. Abundance shows a classic pollution pattern (Pearson and Rosenberg 1978) in that values had declined almost to zero in nearby stations by 1982, but not in the remainder until 1983. By 1986, a strong increase had occurred in all stations, representing an "overshoot" effect. By 1989, values has declined again, with little change between 1989 and 1995. By 1989, abundance values had returned to levels similar to those in 1977 to 1980. However, the exceptionally high numbers evident in several of the E stations in 1982 have not been seen before or since.

It is difficult to say if the biomass values noted in 1977 and 1980 are reasonable conversions to wet weight from dry weight and ash-free dry weight respectively. Conversions to wet weight are crude, based on factors listed in Thorson (1957) and Crisp (1984). Biomass values were low in 1982, and fell even further at some stations by 1983. By 1986 some recovery had occurred, with a small "overshoot" in some stations evident by the peaks in 1986 and subsequent reduced values in 1989. If the 1977 values are reliable, the 1986 and 1989 biomass values are similar to levels which occurred before the most recent mining episode began in 1981. However, the 1977 values were measured only

4 years after the cessation of the previous mining episode (1968-1972). The 1980 biomass conversions suggest a very low biomass in that year. A considerable increase in biomass is noted in all stations in 1995, with values much higher than at any time during the study. Values were also quite variable in 1995, based on the presence or absence of several large species such as the echinoderms *Chiridota albatrossi* and *Molpadia intermedia.*

Taxa numbers showed a similar pattern to abundance, with lowest numbers in 1982 and 1983, an overshoot in 1986, and levelling off by 1989 to similar values to those in 1977 and the least impacted stations in 1982. Many of the dominant taxa have remained the same over the entire period of the study (1977 to 1995). These include the bivalves *Psephidia lordi*, the polychaetes *Levinsenia gracilis, Nephtys cornuta* and the echinoderm *Chiridota albatrossi.* The bivalves *Psephida lordi* and *Nucula tenuis* were the most abundant taxa in Alice Arm up to 1995, when both were abundant only in the E stations. Some of the opportunists and small species most evident up to 1986 (e.g. *Nucula tenuis, Axinopsida serricata, Cylichna attonsa, Prionospio steenstrupi, Galathowenia oculata*) have since disappeared or declined in dominance.

A similarity gradient analysis (Burd, in review) was used to examine the overall faunal stability in Alice Arm over the period from 1982 to 1995. In both the abundance and biomass graphs (Figs. 8 and 9), the similarity between stations increased considerably between 1983 and 1986, and remained high through to 1995. In the abundance graph, the significance of the regression analysis for the log/linear relationship continued to improve, showing a declining similarity with distance from the reference station (CM). Cluster analyses with significance testing ($p<2\%$) for abundance data also showed a gradient in faunal composition from the C to the E stations, with the C, D and E stations forming more or less significantly homogeneous groups (see Fig 2). In the similarity/gradient analysis for biomass data, the relationship appears to be more or less horizontal (except in 1989), indicating that biomass composition of samples is reasonably homogeneous throughout the inlet when not impacted by tailings. Similarly, cluster analysis with significance testing showed no significant difference in biomass composition between stations in Alice Arm in 1995 (Fig. 3).

Comparison of Sediment Results from 1977 to 1995

Data collected in 1977 (O'Connell 1983), 1980 (ibid), 1986 (Brinkhurst *et al.* 1987), (Burd and Brinkhurst 1989) and 1995 (Table 1) indicate that sediments were predominantly silts and clays for most stations, with some sand in a few (see original data reports). Sediment volatile residue and residue observations in 1995 indicate the presence of some gravel and organic debris in most stations.

Table 5 compares surface sediment metals levels (As, Cd, Cu, Pb, Mo, Zn) at the centre benthic invertebrate stations for each transect (CM, DM, EM). Data sources included the annual AMAX environmental monitoring reports (Yunker *et al.* 1981, AMAX 1982-1991), and Environment Canada (Goyette and Christie 1982a, 1982b, DOE 1989-unpub). Sediment Cd, Pb, Mo levels show a distinct increase in 1981 when the most recent mine discharge started then a decline since it closed in 1982.

DISCUSSION

Biology

The abundance, biomass and taxa patterns (Figs. 5 to 7) suggest a classic pollution recovery response in Alice Arm, with the initial impact in the nearby stations evident in 1982, then in the remaining stations later in 1983 as tailings sifted down-inlet. By 1986, a distinct increase in all three characters occurred, with the fauna composed of small, opportunistic taxa mixed with a few large species (Brinkhurst *et al.* 1987). By 1989, abundance levels declined with the disappearance of many colonizers and increase in dominance by the larger fauna (Burd and Brinkhurst 1990). This remained consistent in the 1995 samples. Abundance never regained the high levels evident in the less impacted stations (E) in 1982. Values for 1977 and 1980 suggest that abundance levels between 50 and 100/m^2 may be more normal for Alice Arm. In contrast, biomass showed a slight "overshoot" effect in 1986, but has generally shown a slow increase from the beginning of the study in 1982, with the continuing increase in dominance by echinoderms and large bivalves. It is curious that biomass levels would be higher 13 years after mining than they were before mining or in the less impacted stations (E) in 1982. However, conversions for biomass in 1977 and 1980 were crude, so that data may not be comparable to that from 1982 onward. Taxa numbers, however, had returned to pre-impact levels by 1989. Dominant taxa have not changed much over the study period, except that larger taxa are increasing in importance over time.

The multivariate community analyses confirm several features evident from the summary data for 1995. First, the gradient in faunal composition evident in the major taxa, and in the sediment metals and nutrients, is confirmed by the significant gradient evident in abundance composition from C to E (Fig. 2) evident in the cluster and bootstrap analysis. This general gradient has been evident in cluster analyses of abundance data for all years (Brinkhurst *et al.* 1987, Burd and Brinkhurst 1990). In addition, similarity/gradient analyses for all 5 sample years indicates that similarity in abundance declines with distance from the reference station, CM. This pattern is consistent with the theory that in a low-energy, poorly mixed fjord, there will be a geographic "drift" in faunal composition with distance away from any reference point, due to differential settlement and limited lateral mixing of larval forms in the water column (Burd, in review). However, this pattern is much less evident in the cluster and bootstrap, and similarity/gradient analyses of biomass data (Figs. 3 and 9). The larger fauna are more homogeneously distributed throughout Alice Arm. Thus, there are no significant linkages (significance values are all higher than 50%) in the bootstrap analysis of cluster groups, and the similarity/gradient analysis is relatively level in all years except 1989 *(Note that the 1989 function is skewed by the Hastings Arm stations furthest from the outfall - these samples were not taken at the same locations as in previous years due to a navigational error which resulted in samples much further up-inlet and in considerably shallower water).* This result is consistent with findings for a wide variety of B.C. benthic habitats, that large fauna tend to be more ubiquitously distributed in coastal waters than small fauna (Burd, 1992). The reasons for this are unknown. However, it is this consistency which allows researchers to "type" communities based on sediment and depth characteristics, by the presence of ubiquitous large and long-lived taxa (Thorson's 1957 parallel community theory).

The second feature that the multivariate analyses confirm is that the faunal composition is stabilizing over time in Alice Arm. The similarity/gradient analyses for both abundance and biomass data indicate that overall faunal similarity (or homogeneity) increased in the system between 1983 and 1986 and has remained fairly consistent through to 1995. In the abundance data, the similarity increased further in 1995, and the log/linear relationship has improved (increased significance or lower p values of regression) steadily over time. Because the biomass data show a more or less horizontal pattern (no correlation between distance and similarity), regression analyses are really not appropriate.

Sediments

Samples were collected from a fairly similar substrate and depth range. This should reduce the influence of natural substrate variations on the results of faunal analyses. Organic content of surface sediments (3-5%) is now similar to values given for natural sediments in Holberg Inlet on Vancouver Island (Pedersen 1984; 4-7%). The amount of natural sediments which have settled over the tailings should be in the order of 10 cm, assuming Macdonald and O'Brien's (1996) estimate of 0.7 cm per year has been reasonably consistent over time. However, this also assumes that there has been no shifting of tailings since the mine closed. The annual report from AMAX (1990) states that there is no evidence of any shifting in tailings since mine closure. However, their 1984 report suggests the occurrence of a slump based on much reduced metal levels in the CCM station in July 1983 (see Table 5). The following year (July 1984) and two years later (July 1986) are similarly lower. In addition, resuspension was evident by the fact that tailings had shifted to between the C and D stations by June 1982 (Demill 1983, Stukas 1983) and up to the sill by 1987 (Reimer 1989).

Table 5 shows sediment Mo, Pb, Zn and Cd levels considerably elevated over background levels in the tailings deposited by the Kitsault mine. Levels have decline notably since 1981, but a declining gradient in all by Pb (Fig. 4) suggest that there are still traces of the tailings affecting sediments. At present, we do not know if any of these metals has had toxic effects on the fauna. Some tissue accumulation has been noted in the past. Thompson *et al.* (1986) noted significantly higher levels of Pb and Mo in Alice Arm King crab (*Lithodes aequispina*) gill tissues than in Hastings Arm specimens collected in October 1983. Goyette and Christie (1982a,b) and Goyette (in prep) also noted bioaccumulation of Cu, Pb, Zn and Cd in tissues of *Yoldia thracieformis.*

CONCLUSIONS

All of the factors discussed above suggest an increasing stabilization of the fauna, with larger fauna dominating progressively. In an impacted or "natural" marine system, faunal compositions shift over time. Therefore it is difficult to determine health or stability of the system from consistency in fauna. Overall patterns in faunal characters and combinations of faunal types can be more indicative of balance and consistency in the community. The major faunal characters in Alice Arm suggest that the benthic infaunal community is reasonably stable at this point. The only indication of continuing change is the increasing dominance by large fauna. This may be a residual effect of disturbance over a long period after the impact. In addition, the effects of the mining which ended in 1972 may still have been evident by 1981 when the next mine opening occurred. Therefore, the pre-mining data from 1977 and 1980 probably do not represent "natural" or stable conditions in Alice Arm. This is emphasized by the great variability between replicates for benthic grab samples (O'Connell 1983). The 1995 data illustrates the longest period of biological recovery from disturbance of mine tailings discharge to Alice Arm since prior to 1968.

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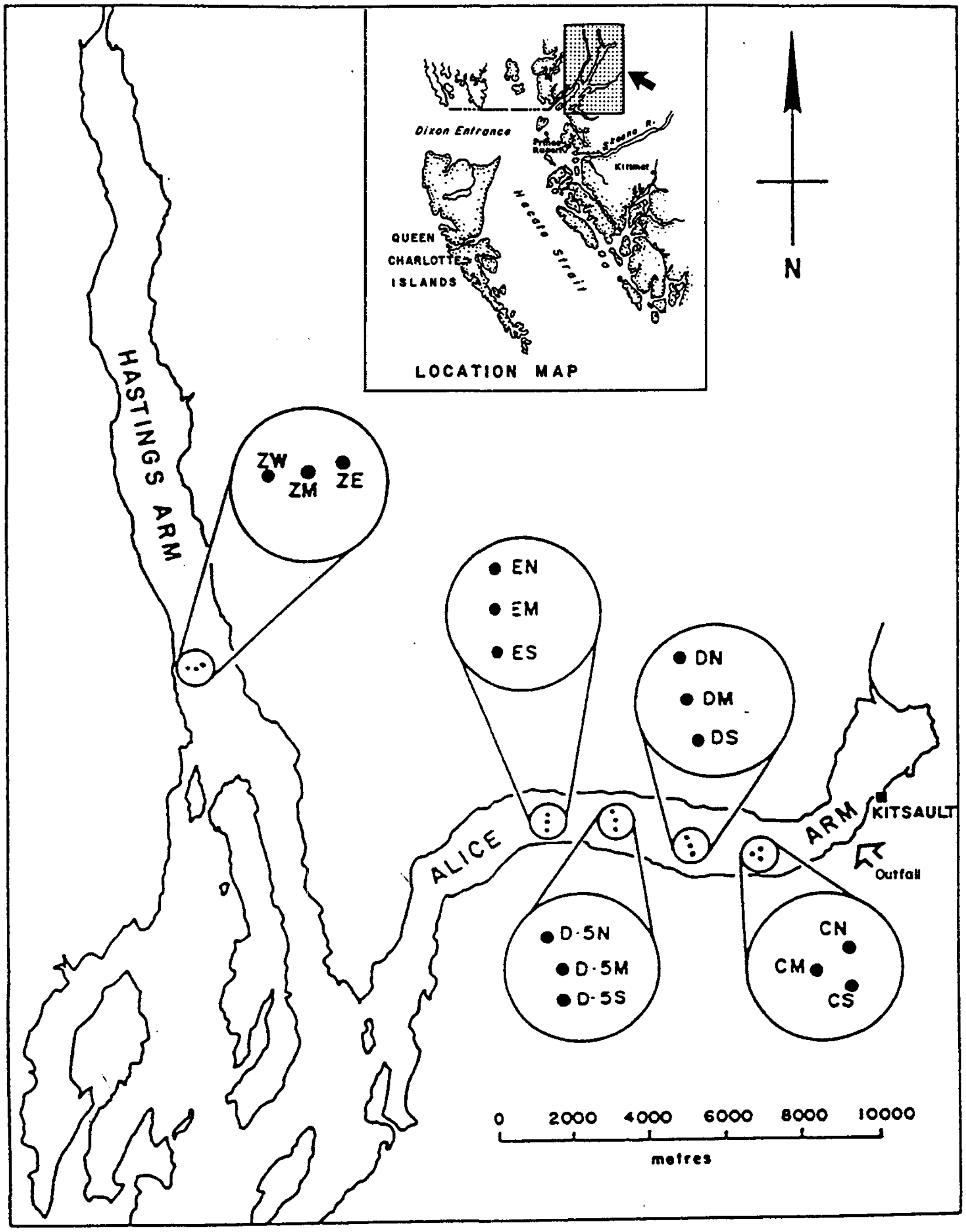


Figure 1. Sampling stations in Alice Arm and Hastings Arm, 1982 to 1995 (Hastings Arm stations and Alice Arm D5 stations were not sampled in 1995)

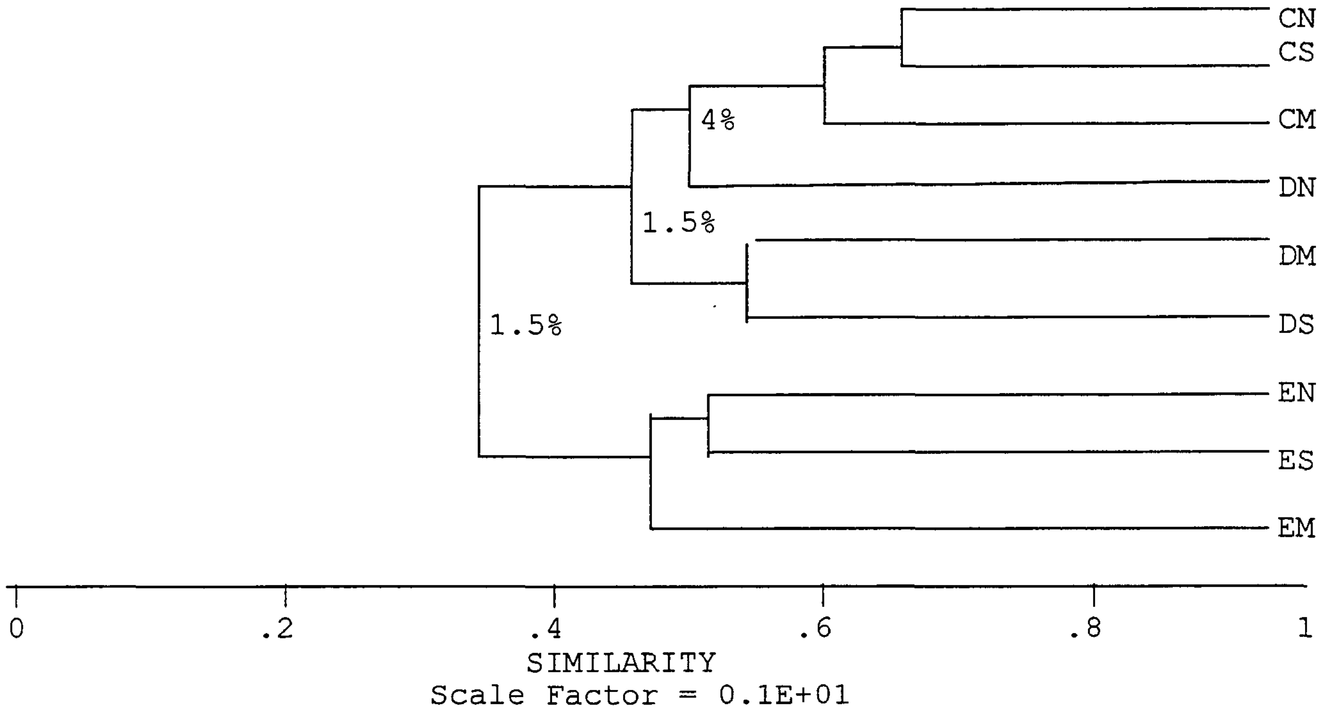


Figure 2. Cluster analysis and bootstrap significance testing of groups for abundance faunal composition, Alice Arm, 1995. Significances less than 5% indicated.

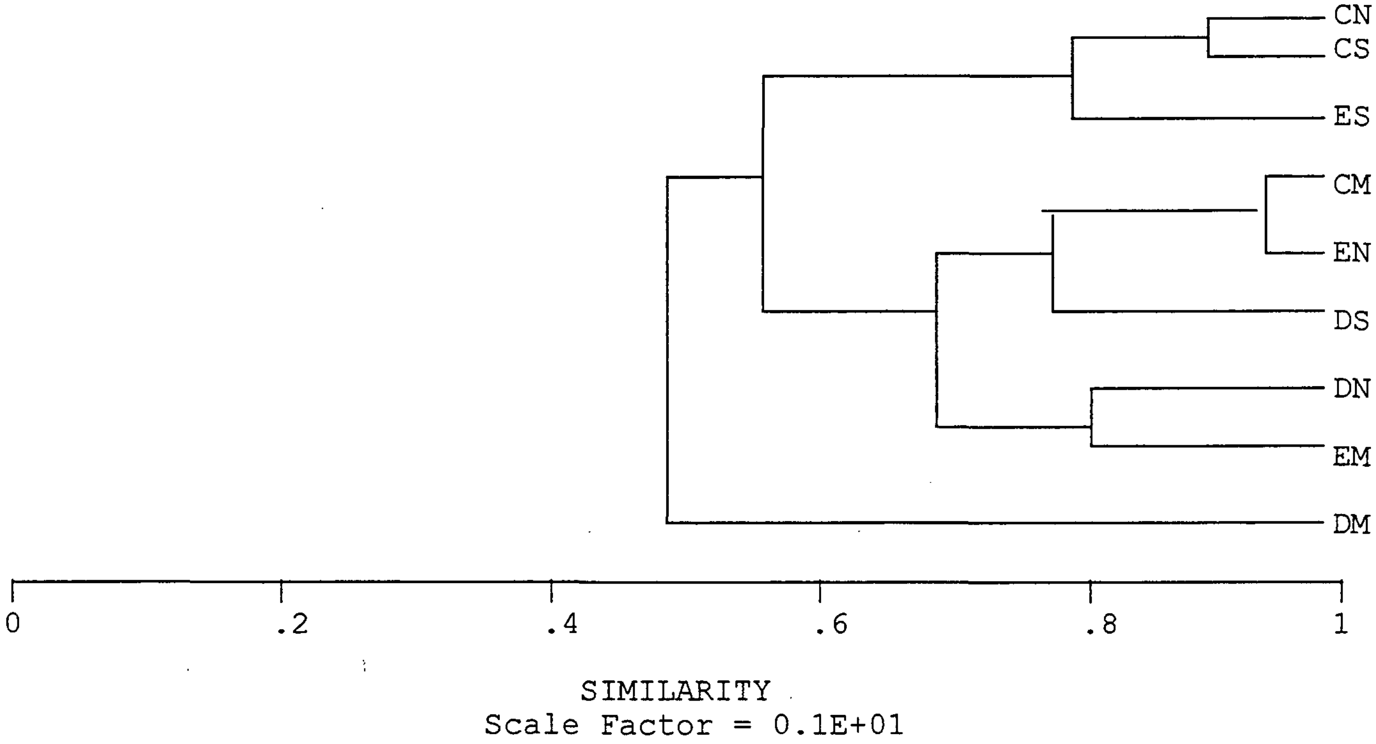
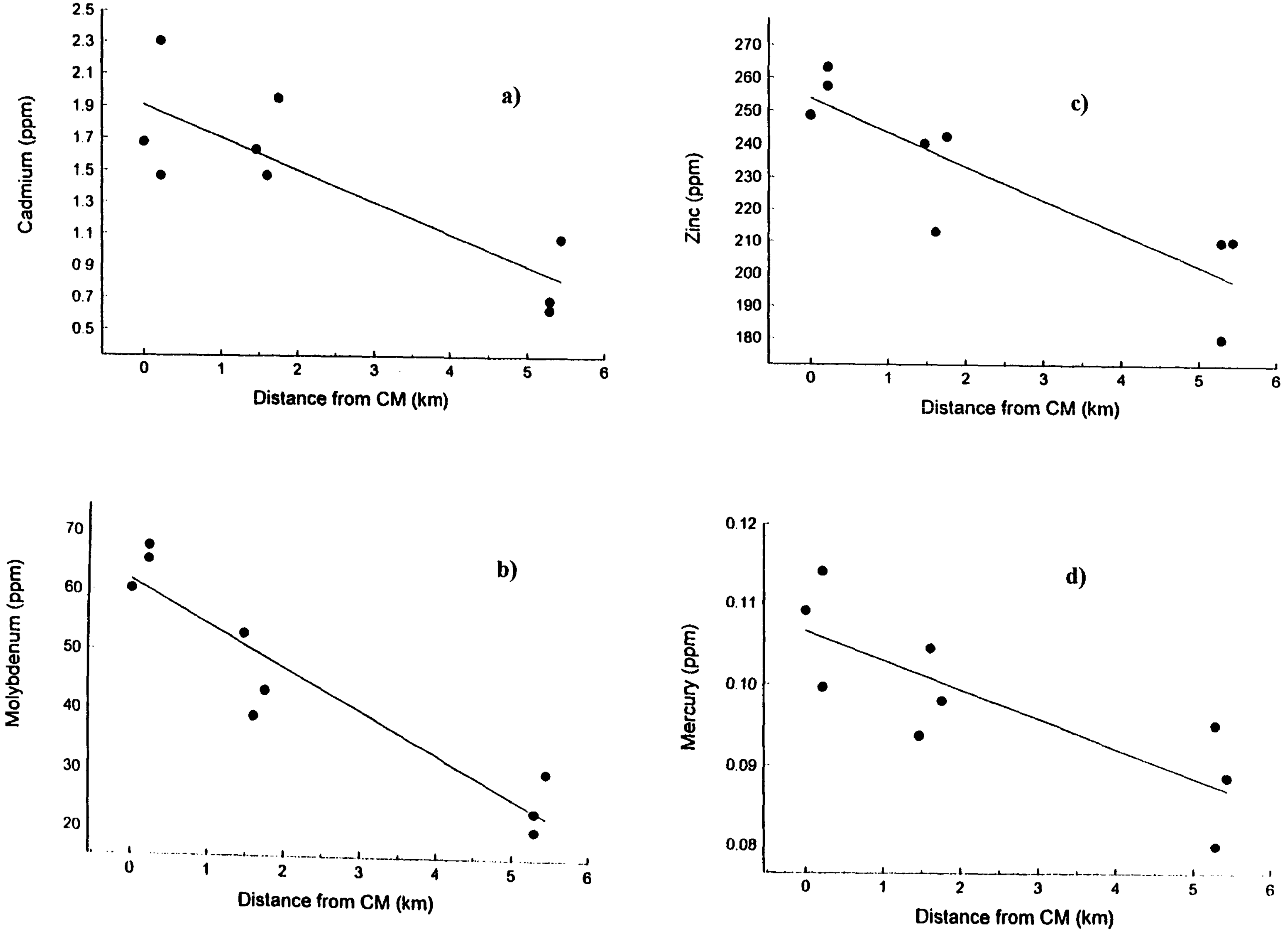


Figure 3. Cluster analysis and bootstrap significance testing of groups for faunal biomass, Alice Arm, 1995. No significance values less than 5% found.

Figure 4. **Selected Sediment Trace Metal and Nutrient Values for Alice Arm, 1995 versus Distance from the Outfall (station CM): a) cadmium b) molybdenum c) zinc d) mercury**



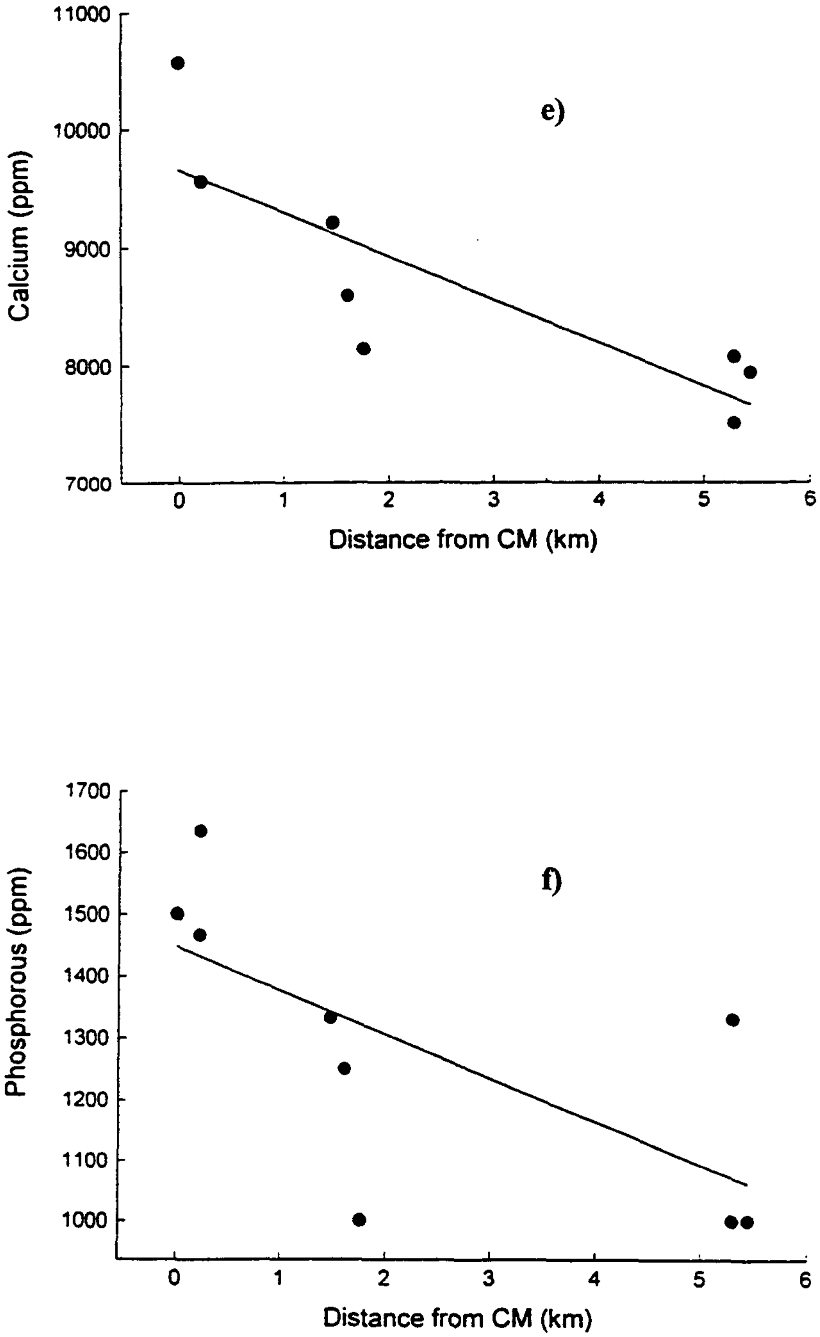
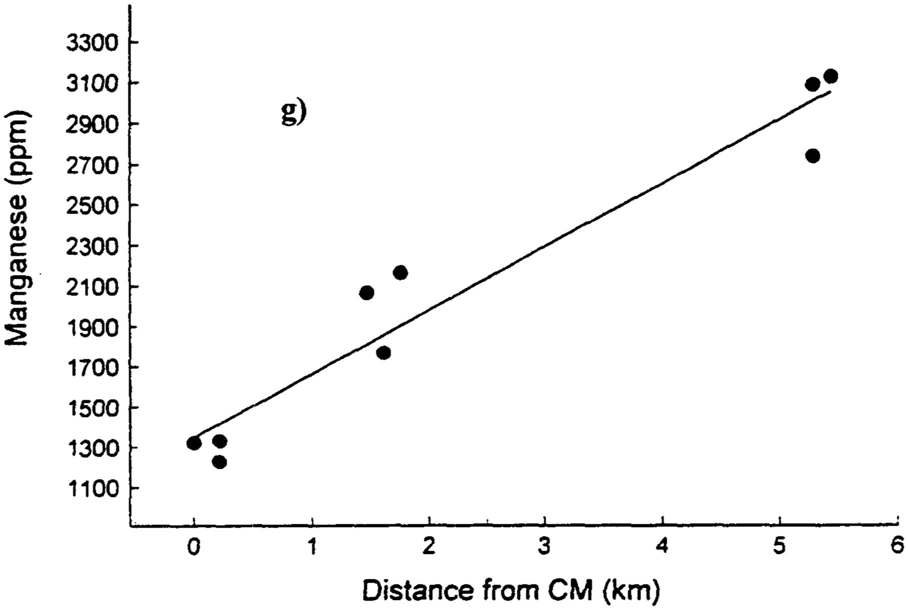


Figure 4 Selected sediment metal and nutrient values in Alice Arm, 1995 versus distance from the outfall (station CM): e) calcium f) phosphorus



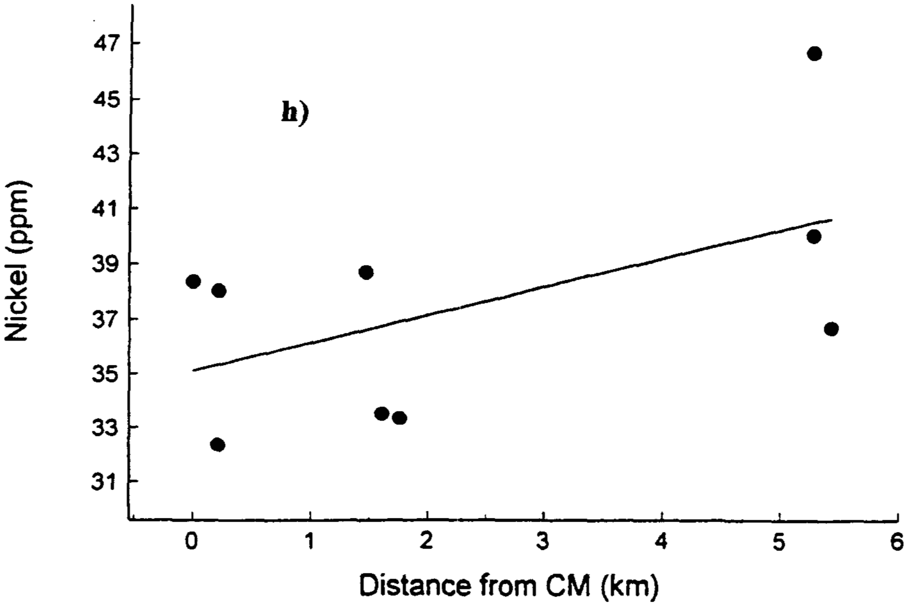


Figure 4 Selected sediment metal values in Alice Arm, 1995 versus distance from the outfall (station CM): g) manganese h) nickel

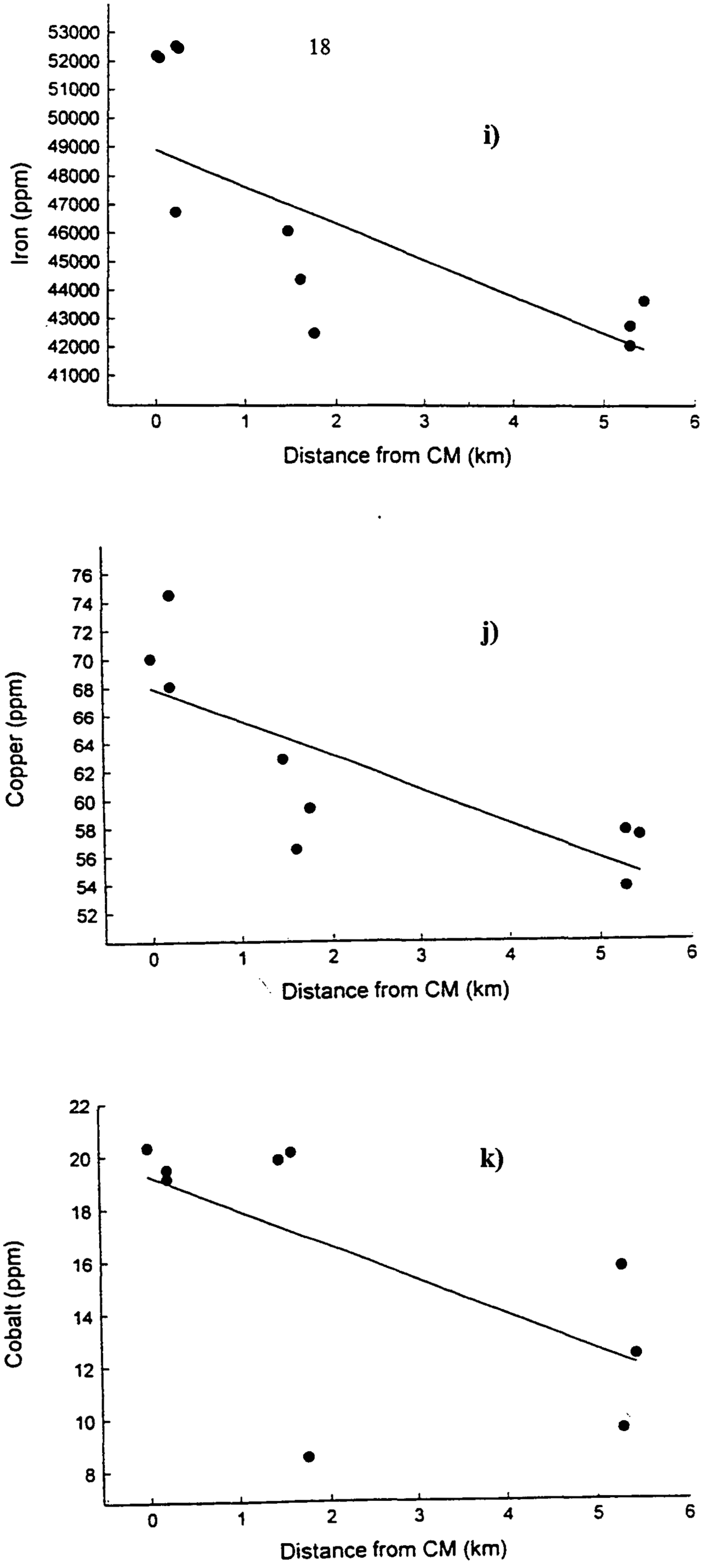


Figure 4 Selected sediment metal values in Alice Arm, 1995 versus distance from the outfall (station CM): i) iron j) copper k) cobalt

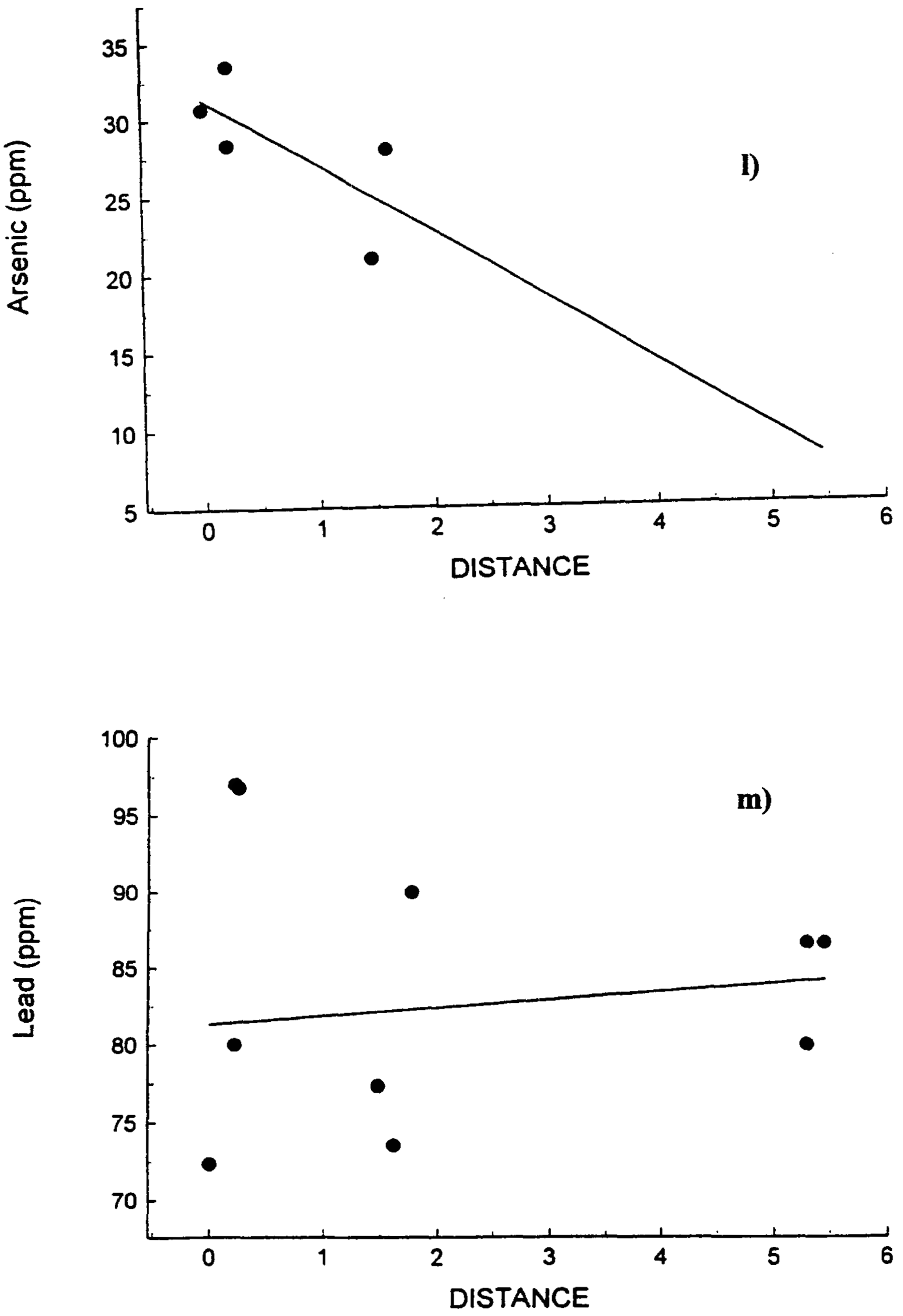


Figure 4 Selected sediment metal values in Alice Arm, 1995 versus distance from the outfall (station CM): l) arsenic m) lead

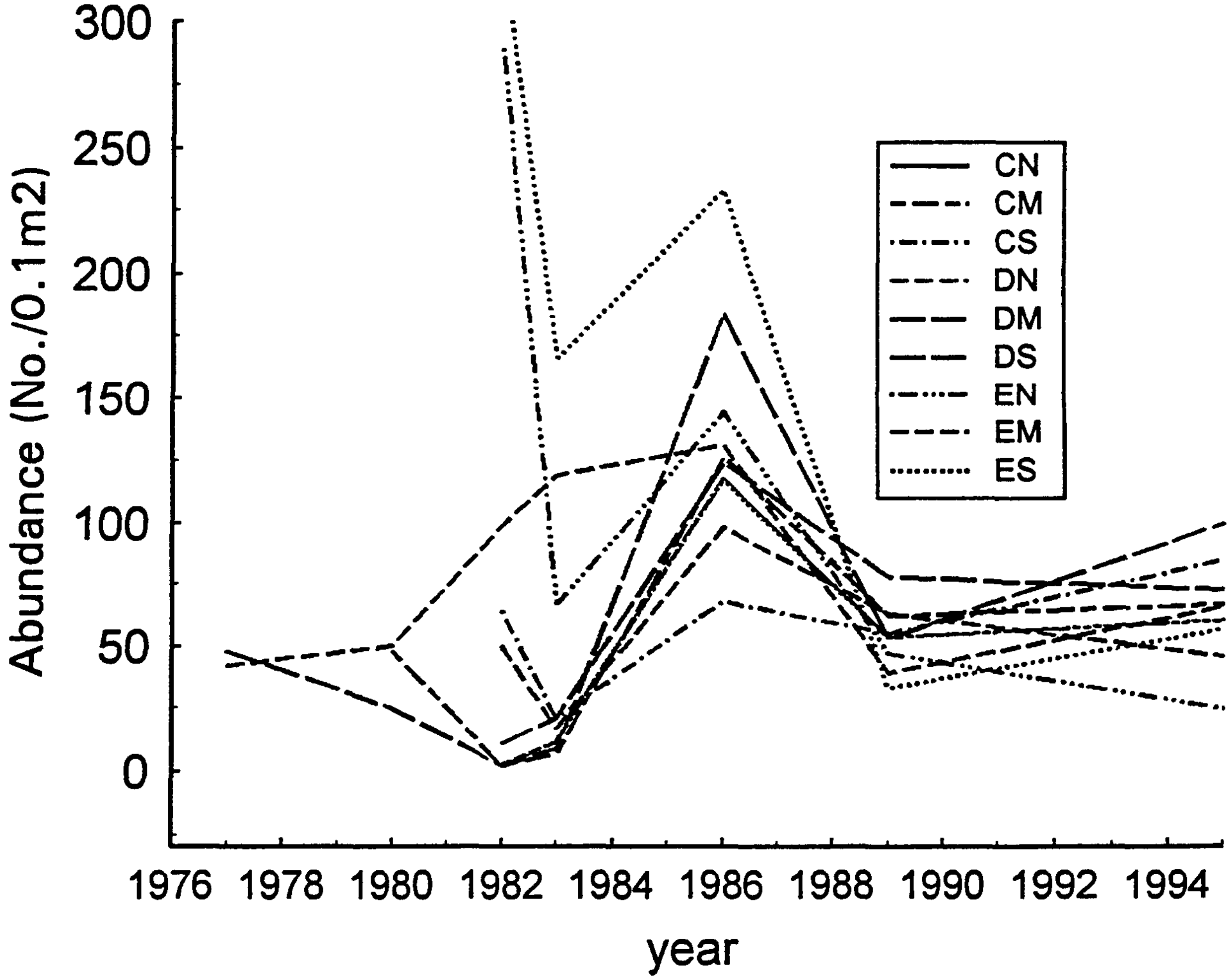


Figure 5. Mean abundance of benthic fauna (number per 0.1 m^2) in Alice Arm from 1977-95

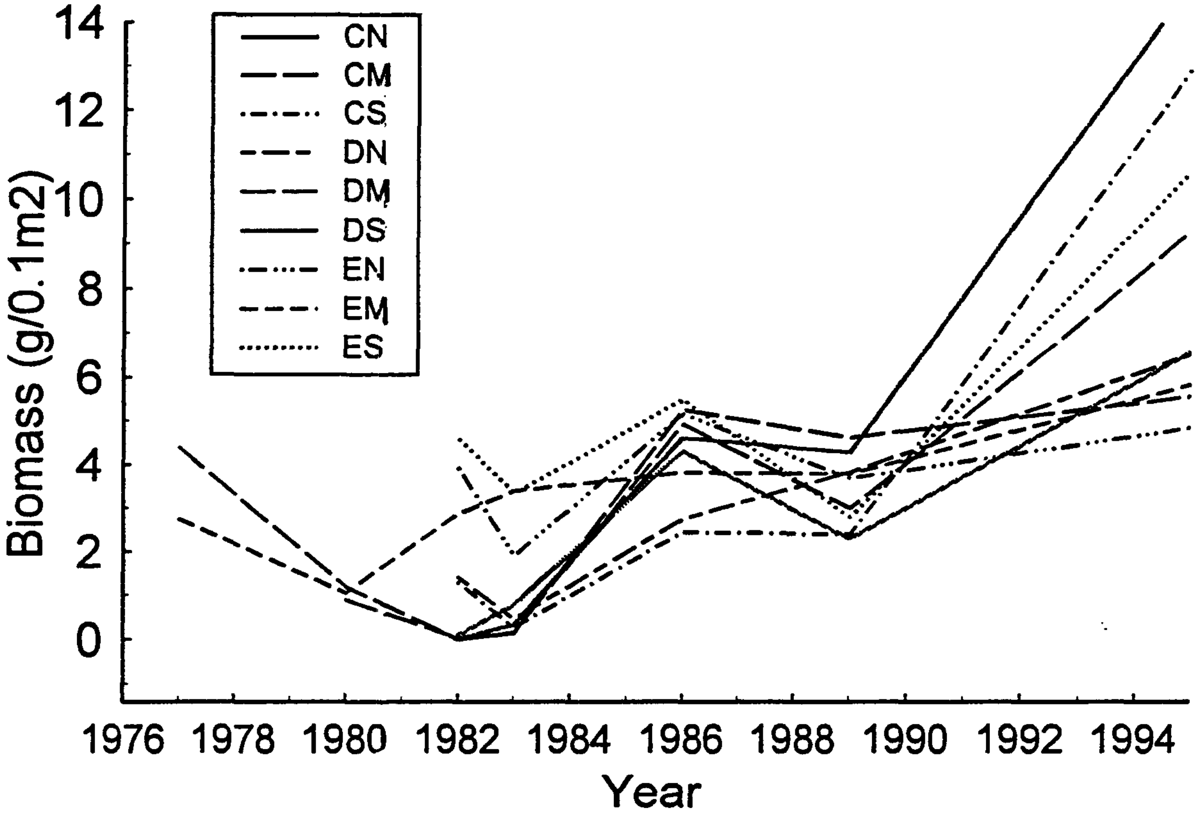


Figure 6. Mean biomass of benthic fauna (number per 0.1 m^2) in Alice Arm from 1977-95

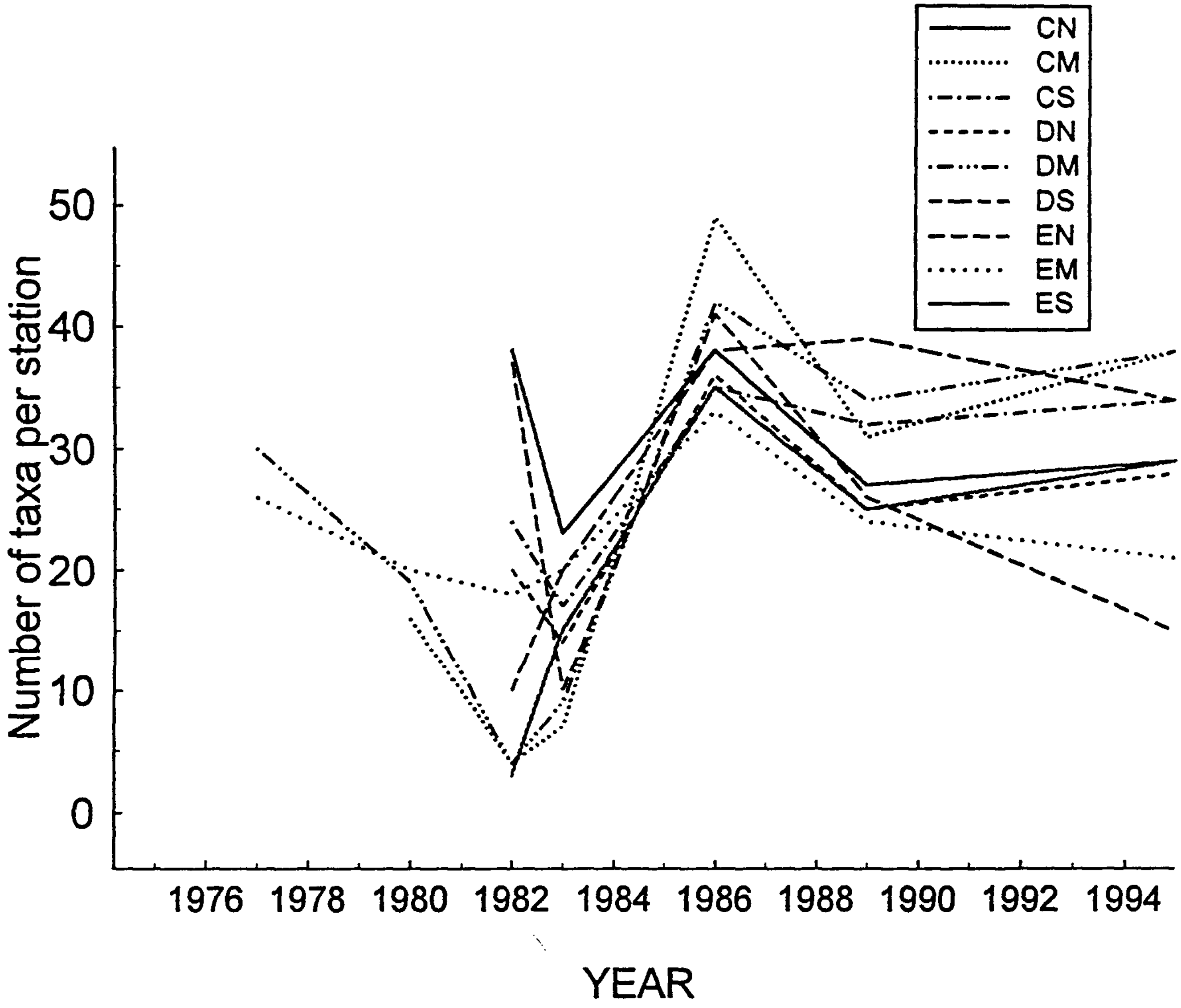


Figure 7. Total taxa number (per two replicates) for Alice Arm stations from 1977 to 1995. Values for 1995 are the mean total of each pair of replicates (from three replicates)

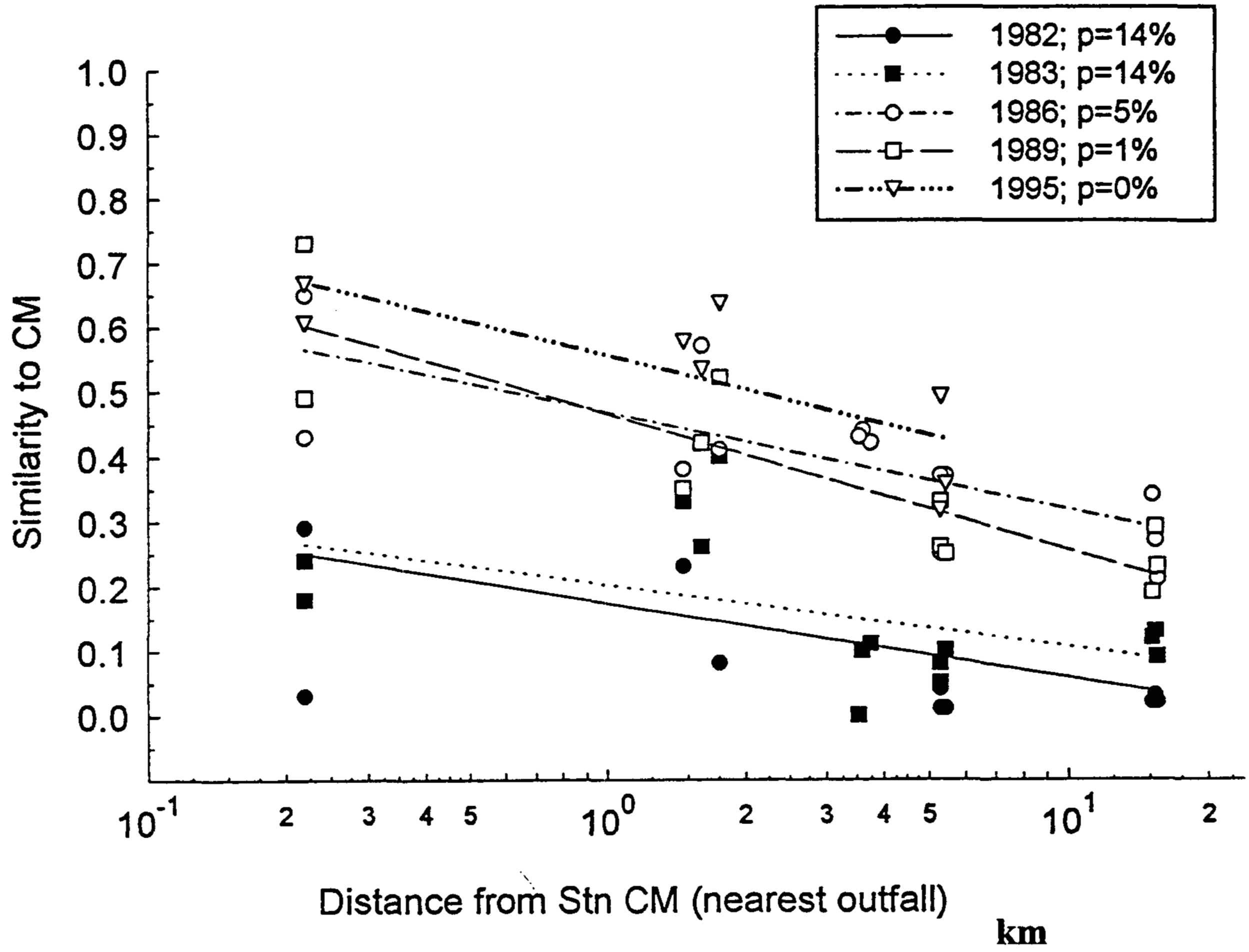


Figure 8 Similarity (Bray-Curtis 1957) gradient for abundance data from Alice Arm and Hastings Arm; 1982 to 1995, using station CM as the reference station closest to the outfall. Log/linear regression p values shown.

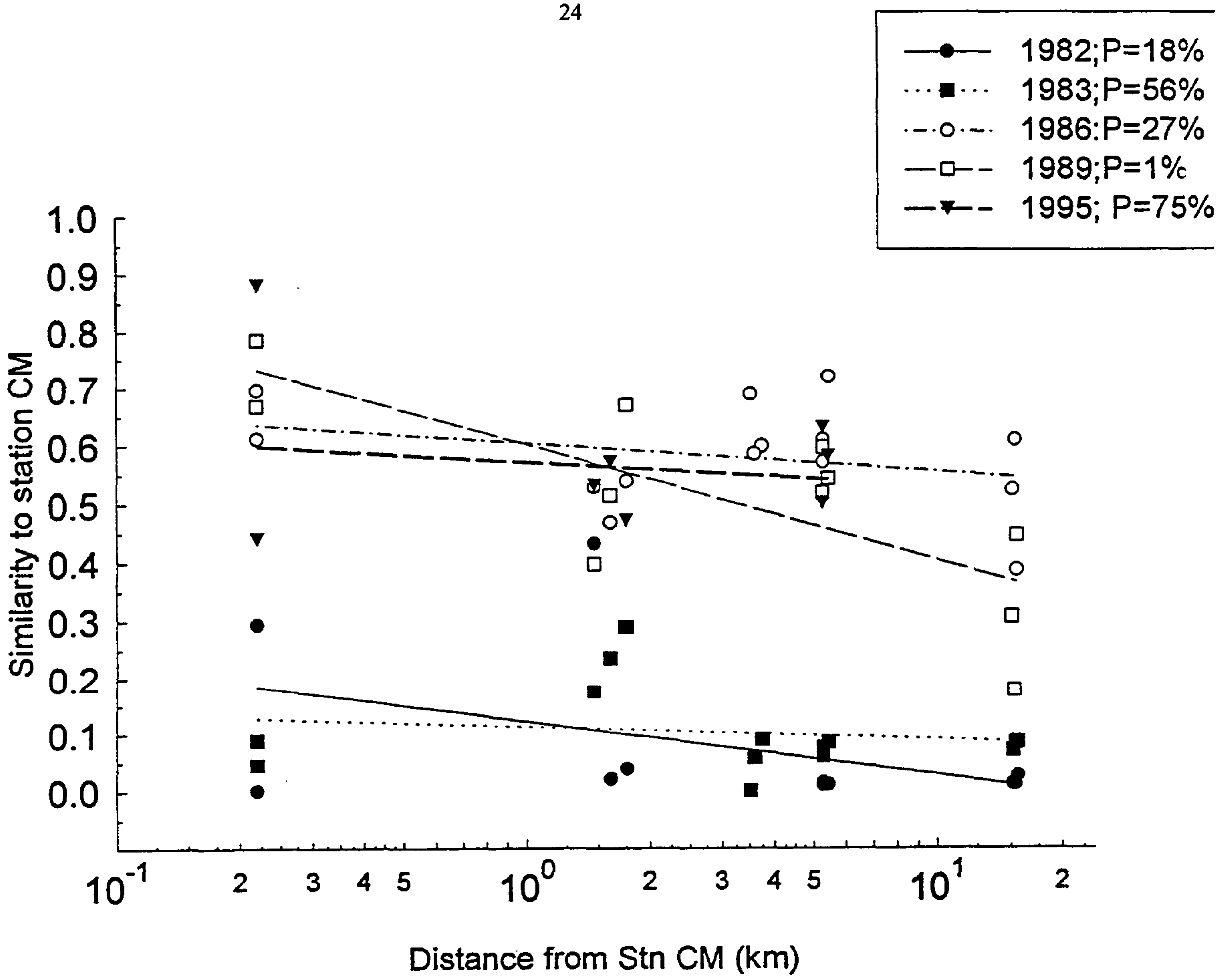


Figure 9 Similarity (Bray-Curtis 1957) gradient for biomass data from Alice Arm and Hastings Arm; 1982 to 1995, using station CM as the reference station closest to the outfall. Log/linear regression p values shown.

Table 1. Alice Arm 1995 Summary Data: benthic invertebrates, sediment characteristics, station depth, and station coordinates

				Sediments		% Particle Size Distribution (size ranges in mm)												
	Benthic			total	sediment	very	coarse	coarse	medium	fine	very fine			Station Coordinates				
	Invertebrates			organic	volatile	gravel	sand	sand	sand	sand	sand	silt	clay					STN
	abund	biomass	no. of	carbon	residue	>2	<2	<1	<0.5	<0.25	<0.125	<0.063	<0.004	longitude		latitude		depth
STN	$/0.1m^2$	$g/0.1m^2$	taxa	TOC %	SVR %		>1	>0.5	>0.25	>0.125	>0.063	>0.004		deg	min	deg	min	(m)
CN1	57	14.1	20	0.67	5.14	0	0	0	0.1	0.6	2.9	53.5	42.9	129	31.72	55	26.66	260
CN2	56	1.1	19	0.22	4.40	0	0	0	0.1	0.3	1.9	50.6	47.1					260
CN3	68	15.8	23	<0.05	4.16	0	0	0.1	0.2	1.0	2.9	51.5	44.3					260
CM1	73	7.1	33	<0.05	4.55	0	0	0.1	0.3	0.9	3.3	49.7	45.7	129	32.00	55	26.60	280
CM2	56	5.1	18	1.06	4.29	0	0	0.1	0.2	2.0	9.8	46.2	41.7					280
CM3	73	4.6	23	<0.05	4.77	0	0	0	0.2	1.5	8.6	48.3	41.4					280
CS1	109	12.8	30	<0.05	3.69	0	0	0	0.3	3.5	7.0	46.9	42.3	129	31.75	55	26.50	229
CS2	39	18.0	19	<0.05	3.23	0	0	0.1	1.1	10.4	13.1	41.8	33.5					229
CS3	108	7.9	29	<0.05	3.55	0	0	0	0.3	3.4	7.8	46.4	42.1					229
DN1	58	9.6	21	<0.05	4.21	0	0	0	0.2	2.1	3.6	43.1	51.0	129	33.60	55	26.80	350
DN2	37	2.4	15	<0.05	4.51	0	0	0.1	0.1	2.3	5.0	44.4	48.1					352
DN3	44	7.6	19	0.19	4.65	0	0	0	0.2	1.1	2.1	42.6	54.0					354
DM1	90	6.6	31	0.05	4.64	0	0	0.2	0.6	2.3	3.7	44.3	48.9	129	33.50	55	26.70	355
DM2	95	9.9	27	0.05	4.88	0.3	0.1	0.1	0.5	2.2	4.7	35.7	56.4					355
DM3	116	11.5	29	0.99	5.30	0	0	0.1	0.6	1.9	3.6	42.7	51.1					355
DS1	61	7.7	24	<0.05	4.65	0	0	0	0.4	2.3	5.6	43.0	48.7	129	33.40	55	26.62	347
DS2	123	7.3	22	<0.05	3.03	0.2	0.1	0.7	3.1	4.6	5.1	40.3	45.9					345
DS3	35	4.8	19	0.19	4.08	0.8	0.2	0.2	0.8	1.9	3.4	42.8	49.9					345
EN1	36	7.0	10	0.16	4.55	0	0	0	0	0.1	1.8	42.9	55.2	129	36.99	55	27.21	391
EN2	10	3.0	9	<0.05	4.37	0	0	0	0	0.1	2.4	47.4	50.1					391
EN3	30	4.7	14	0.24	4.80	0	0	0	0	0.2	2.9	45.0	51.9					391
EM1	64	2.2	13	0.05	4.78	0	0	0	0	0.1	1.9	41.5	56.5	129	36.99	55	27.09	391
EM2	75	10.5	14	0.28	5.12	0	0	0	0	0.1	1.3	40.4	58.2					391
EM3	59	4.9	13	0.39	4.78	0	0	0	0	0.1	1.7	40.9	57.3					390
ES1	46	10.0	20	0.35	3.27	0	0	0	0	0.1	2.1	43.8	54.0	129	37.20	55	27.00	386
ES2	76	8.7	24	<0.05	4.48	0	1.1	0	0	0.1	2.5	45.1	51.2					385
ES3	49	13.2	13	<0.05	5.06	0	0	0	0	0.1	2.4	44.9	52.6					385

Table 2. Top 10 taxa in the 1995 Alice Arm samples from most to least dominant (abundance and biomass).

Abundance		**Biomass**	
amphipod	*Eudorella pacifica*	echinoderm	*Ctenodiscus crispatus*
polychaete	*Aricidea lopezi*	echinoderm	*Molpadia intermedia*
polychaete	*Nephtys cornuta*	echinoderm	*Chiridota albatrossi*
bivalve	*Psephidia lordi*	bivalve	*Macoma brota*
polychaete	*Levinsenia gracilis*	amphipod	*Paraphoxus similis*
echinoderm	*Chiridota albatrossi*	nemertean	*Cerebratulus* sp.
scaphopod	*Chaetoderma* sp.	bivalve	*Yoldia martyria*
amphipod	*Heterophoxus affinis*	polychaete	*Nephtys punctata*
echinoderm	*Ctenodiscus cripatus*	bivalve	*Yoldia hyperborea*
polychaete	*Hetermastus filobranchus*	amphipod	*Paraphoxus gracilis*

Table 3. Relative abundance of different taxonomic groups in Alice Arm, 1995.

		Amphipoda	Nemertea	Aplacophora	Gastropoda	Bivalvia	Scaphopoda	Crustacea	Echinoderm	Pisces	Polychaeta
CCN	1	4	1	0	1	5	0	22	11	1	10
CCN	2	3	0	1	0	3	0	17	4	0	22
CCN	3	4	0	3	3	2	0	16	14	0	22
CCM	1	8	0	5	1	3	0	12	8	0	38
CCM	2	4	1	0	0	1	0	6	3	0	33
CCM	3	12	1	0	0	6	0	19	5	0	28
CCS	1	3	0	6	0	9	0	15	9	0	58
CCS	2	5	0	0	0	1	0	12	11	0	18
CCS	3	12	1	0	0	4	0	26	11	0	42
DDN	1	1	2	0	0	2	0	5	6	0	37
DDN	2	1	0	1	0	7	0	7	2	0	20
DDN	3	3	2	0	0	1	0	3	3	0	24
DDM	1	5	0	19	0	6	1	3	11	0	51
DDM	2	6	1	11	0	4	1	3	14	0	49
DDM	3	5	2	8	0	6	0	11	15	0	58
DDS	1	3	1	9	0	3	0	3	6	0	37
DDS	2	11	0	5	0	1	0	9	6	0	70
DDS	3	2	0	1	0	2	0	0	6	0	20
EEN	1	0	0	0	0	14	0	0	5	0	13
EEN	2	0	2	0	0	1	0	0	4	0	5
EEN	3	0	0	0	0	6	0	1	5	0	14
EEM	1	0	0	0	1	21	0	2	6	0	12
EEM	2	0	0	1	0	31	0	0	10	0	27
EEM	3	0	1	0	1	32	0	1	9	0	12
EES	1	0	1	1	0	13	0	1	6	0	19
EES	2	0	2	5	0	14	0	2	9	0	27
EES	3	0	0	0	0	2	0	0	4	0	25

Table 4. Surface sediment metals data for Alice Arm, 1995 (concentrations in ug/g dry wt.)

STN Rep	Ag ICP	Al ICP	As ICP	Ba ICP	Be ICP	Ca ICP	Cd GF	Co ICP	Cr ICP	Cu ICP	Fe ICP	Hg CVAA	K ICP
CN1	<20	39400	<80	2209	<2	9700	1.6	18	55	79	50700	0.118	11400
CN2	<2	42630	34	1541	1	9690	1.3	21	55	73	54830	0.115	12640
CN3	<2	43250	33	1395	1	9290	1.5	19	53	71	52060	0.109	13150
CM1	<2	41430	31	1382	1	10300	1.6	20	53	68	50540	0.102	12500
CM2	<2	41940	27	1317	1	10200	1.4	19	53	67	50480	0.107	12650
CM3	2	41010	34	1486	1	11200	2.02	23	58	76	55570	0.118	12030
CS1	5	37100	26	1231	1	9820	2.36	20	46	69	47260	0.102	11200
CS2	3	34800	27	1101	1	9550	2.32	19	45	66	45130	0.099	10590
CS3	2	38630	32	1211	1	9300	2.23	19	49	69	47780	0.098	11800
DN1	<20	38780	<80	1330	<2	8500	2.73	<8	62	63	43970	0.101	12100
DN2	<20	31340	<80	1140	<2	7700	1.82	8	56	59	40600	0.095	8970
DN3	<20	37380	<90	1390	<2	8200	1.3	9	35	56	42830	0.098	11500
DM1	<2	38410	28	1213	1	9680	1.84	20	53	64	49980	0.105	11360
DM2	<20	33290	<80	1090	<2	7500	1.1	<8	30	49	38730	0.104	9980
DM3	<2	41540	30	1356	1	9360	1.1	22	56	65	51880	0.099	12310
DS1	<20	36940	<80	1390	<2	9500	1.6	20	50	66	48300	0.096	10700
DS2	<2	36350	21	1305	1	9510	1.6	20	50	57	46910	0.086	10890
DS3	<20	36300	<80	1540	<2	8600	1.69	20	51	65	42990	0.099	11000
EN1	<20	42310	<80	1440	2	8300	0.73	18	50	61	47600	0.088	12900
EN2	<20	36340	<80	1280	<2	7600	1.4	9	31	57	40540	0.091	11100
EN3	<20	36070	<80	1220	<2	7900	1.1	10	25	54	42750	0.087	10600
EM1	<20	38490	<80	1300	<2	7700	0.63	<8	43	51	42870	0.084	11600
EM2	<20	44730	<80	1600	<2	8600	0.77	10	68	65	47550	0.103	13800
EM3	<20	40690	<80	1420	2	7900	0.67	9	60	57	45750	0.098	12300
ES1	<20	39350	<80	1210	2	8100	0.60	17	79	59	45570	0.076	11800
ES2	<20	34650	<80	1060	<2	7200	0.65	20	55	49	41580	0.077	10200
ES3	<20	36830	<80	1220	<2	7200	0.64	10	59	53	41090	0.087	11400
QA/QC Samples													
Rep CN2	<2	38020	32	1432	1	9250	1.3	20	50	70	51650	0.111	10960
Rep CS2	<2	35320	27	1101	1	9450	2.57	19	45	62	44760	0.095	10870
Rep DM2	<20	38100	<80	1270	<2	9400	1.5	8	60	63	45260	0.107	11500
Rep EN2	<20	35150	<80	1260	<2	7600	1.3	21	18	61	40060	0.088	10700
Rep ES2	<20	41470	<80	1240	2	8000	0.69	20	45	59	46360	0.083	12700
BCSS	<2	33260	10	125	1	4220	0.23	11	68	16	31470	-	9488
BCSS	<2	34020	10	119	1	4410	0.21	10	70	16	33080	-	9564
BCSS	<2	35920	10	137	1	4210	0.21	11	72	15	31910	-	10590
MESS	<2	25680	10	92	1	2600	0.61	10	37	23	27710	-	6419
MESS	<2	25300	10	97	1	2560	0.60	10	38	22	27700	-	6243
MESS	<2	24140	10	83	1	2510	0.65	10	34	22	27270	-	5831
PACS	2	28190	193	412	0.9	11300	2.5	16	73	432	44420	4.75	5442
PACS	<2	26150	188	384	0.8	10600	2.4	15	67	417	42440	4.32	5005
PACS	2	25870	197	389	0.7	11000	2.4	16	66	419	43400	4.54	4877

Note: Samples with values <80 or <90 indicate dilutions required due to interferences of other metals resulting in insenstive detection limits

Table 4.	Surface sediment metals data for Alice Arm, 1995 (concentrations in ug/g dry wt.)													
STN	Mg	Mn	Mo	Na	Ni	P	Pb	Sb	Si	Sn	Sr	Ti	V	Zn
Rep	ICP	ICP	ICP	ICP	ICP	ICP	ICP	ICP	ICP	ICP	ICP	ICP	ICP	ICP
CN1	17700	1420	70	8600	40	1700	<80	<80	1500	<80	100	1620	200	275
CN2	17340	1329	61	8880	38	1600	75	10	1520	<8	94	1693	160	235
CN3	16300	1234	65	6910	36	1600	85	20	986	<8	89	1650	160	262
CM1	16200	1265	51	7690	37	1500	64	10	1030	<8	92	1635	160	244
CM2	16300	1311	51	7350	36	1400	64	10	1070	<8	89	1618	160	230
CM3	17760	1379	79	10000	42	1600	89	20	1530	<8	100	1712	160	272
CS1	15000	1114	73	6340	33	1500	100	9	1200	<8	83	1510	140	259
CS2	14200	1328	64	6430	30	1400	100	10	1330	<8	82	1432	130	268
CS3	15200	1231	66	6980	34	1500	91	8	1210	<8	84	1514	140	263
DN1	16000	2281	50	7500	<30	1000	100	<80	880	<80	85	1480	100	270
DN2	15000	2155	40	7200	<30	1000	<80	<80	800	<80	79	1310	100	235
DN3	16000	2042	40	9200	<40	1000	<90	<90	890	<90	85	1470	100	222
DM1	16200	1624	48	7820	37	1500	67	9	1060	<8	89	1645	150	229
DM2	14000	1904	30	7000	<30	1000	<80	<80	1000	<80	75	1310	100	197
DM3	16850	1695	35	7660	40	1500	65	<8	1000	<8	91	1715	160	248
DS1	17500	2622	50	9200	40	1700	<80	<80	1200	<80	95	1610	200	259
DS2	15400	1682	49	8160	36	1300	72	10	1270	<8	87	1638	140	224
DS3	16000	1883	60	7500	40	1000	<80	<80	1000	<80	89	1450	100	237
EN1	18000	3022	30	10000	40	1000	<80	<80	1300	<80	91	1688	200	216
EN2	15000	2244	30	7400	<30	1000	100	<80	920	<80	79	1440	100	198
EN3	16000	4135	30	8100	40	1000	<80	<80	1200	<80	88	1500	100	217
EM1	16000	3172	20	7500	40	1000	<80	<80	1000	<80	84	1580	100	192
EM2	18300	3010	30	9100	30	2000	<80	<80	1300	<80	93	1620	170	221
EM3	17400	3088	20	8600	50	1000	<80	<80	1000	<80	88	1614	200	217
ES1	17300	2898	20	9100	50	1000	<80	<80	1300	<80	84	1714	100	188
ES2	16000	2556	<20	8100	50	1000	<80	<80	1500	<80	75	1530	100	181
ES3	16000	2762	20	9900	40	1000	100	<80	1100	<80	80	1480	100	171
QA/QC S														
Rep CN2	16300	1262	62	8370	35	1500	78	10	1400	<8	89	1574	150	226
Rep CS2	14100	1313	57	6390	30	1400	94	9	993	<8	81	1431	130	272
Rep DM2	16400	2237	50	8500	<30	1700	80	<80	1100	<80	88	1530	200	233
Rep EN2	15000	2215	30	7200	<30	1000	<80	<80	850	<80	76	1430	100	195
Rep ES2	17500	2829	20	8900	50	2000	<80	<80	1200	<80	84	1721	200	199
BCSS	12500	204	3	8150	49	680	30	<8	1610	<8	39	528	67	102
BCSS	13100	211	2	8570	51	730	28	<8	1220	<8	40	530	69	108
BCSS	12800	204	2	8240	50	680	26	9	1040	<8	41	557	73	102
MESS	6940	394	2	6290	22	620	33	<8	1210	<8	35	878	51	166
MESS	6910	396	2	6270	23	610	34	<8	943	<8	35	865	50	166
MESS	6800	385	2	6180	23	600	35	<8	1050	<8	34	824	48	170
PACS	10800	330	10	17550	37	980	384	170	873	39	96	1995	100	822
PACS	10200	313	10	16670	34	940	375	164	938	38	90	1893	96	780
PACS	10300	320	10	16880	35	970	384	160	1040	41	91	1882	97	818

Note: Samples with values <80 or <90 indicate dilutions required due to interferences of other metals resulting in insenstive detection limits

Table 5. Metal levels in Alice Arm surface sediments (stations CM, DM, EM) 1980-95 and mine tailings

STN*	Survey Date	depth (m)	No. rep	Sed Type	concentrations in ppm dry wt.						Data Source
					As	Cd	Cu	Pb	Mo	Zn	
AMAX	1981 Apr-Dec (mean)			tailings	13	18.7	61	150	273	428	AMAX 1982
AMAX	1982 Jan-Oct (mean)			tailings	9	12.9	56	195	165	420	AMAX 1983
CC-3	1980-May	278	1	grab	--	2.2	80	146	105	209	Goyette & Christie 1982a
CCMC	1980-Aug	273	3	grab	36	2.4	--	102	155	--	Yunker *et al.* 1981
CCMD	1980-Aug	268	3	grab	40	1.7	--	87	138	--	Yunker *et al.* 1981
CCM	1981-Aug	278	2	grab	21	14.1	93	239	330	548	AMAX 1982
Q20	1981-Oct	275	0-2	core	15	14.0	104	204	291	521	Goyette & Christie 1982b
CCM	1982-Aug	256	2	grab	6	10.1	50	202	201	406	AMAX 1983
CCM	1983-Jul	273	2	grab	26	1.1	79	60	37	209	AMAX 1984
CCM	1984-Jul	272	2	grab	30	0.8	79	58	47	198	AMAX 1985
CCM	1985-Jul	272	2	grab	23	3.1	71	117	126	298	AMAX 1986
CCM	1986-Jul	270	1	grab	28	1.3	69	63	41	203	AMAX 1987
CCM	1987-Jul	268	1	grab	29	2.0	75	102	104	236	AMAX 1988
CCM	1988-Jul	265	1	grab	33	2.8	75	129	146	253	AMAX 1989
CCM	1989-Jul	263	1	grab	29	0.9	65	73	102	218	AMAX 1990
Q20	1989-Oct	266	3	grab	16	1.1	69	71	70	238	DOE 1989 unpublished
CCM	1990-Jul	264	2	grab	41	0.9	76	82	144	218	AMAX 1991
CCM	1995-Sep	280	3	grab	31	1.7	70	72	60	249	from Table 4
DD-3	1980-May	350	1	grab	--	1.1	71	123	38	186	Goyette & Christie 1982a
DDMC	1980-Aug	357	3	grab	28	1.7	--	94	102	--	Yunker *et al.* 1981
DDMD	1980-Aug	357	3	grab	28	1.6	--	83	106	--	Yunker *et al.* 1981
DDM	1981-Aug	356	2	grab	18	13.4	87	206	308	565	AMAX 1982
O32	1981-Oct	369	0-2	core	17	14.3	74	179	168	561	Goyette & Christie 1982b
DDM	1982-Aug	353	2	grab	16	16.4	86	284	252	628	AMAX 1983
DDM	1983-Aug	361	2	grab	15	10.0	74	234	199	413	AMAX 1984
DDM	1984-Jun	347	2	grab	18	7.0	81	221	177	407	AMAX 1985
DDM	1985-Jul	348	2	grab	18	4.9	74	181	148	322	AMAX 1986
DDM	1986-Jul	348	1	grab	22	3.2	71	153	102	298	AMAX 1987
DDM	1987-Jul	358	2	grab	23	4.2	68	118	73	296	AMAX 1988
DDM	1988-Jul	358	2	grab	21	0.7	65	144	124	321	AMAX 1989
DDM	1989-Jul	360	2	grab	24	4.7	68	137	111	324	AMAX 1990
O32	1989-Oct	357	3	grab	17	2.9	63	89	62	278	DOE 1989 unpublished
DDM	1990-Jul	358	2	grab	35	2.4	70	94	112	255	AMAX 1991
DDM	1995-Sep	355	3	grab	29	1.4	59	66	38	225	from Table 4
EE-3	1980-May	380	1	grab	--	0.7	60	89	<19	164	Goyette & Christie 1982a
EEM	1981-Aug	385	2	grab	20	14.8	90	193	286	620	AMAX 1982
EEM	1981-Oct	390	1	grab	22	4.9	73	98	84	301	Goyette & Christie 1982b
EEM	1982-Aug	385	2	grab	15	9.2	73	174	172	417	AMAX 1983
EEM	1983-Aug	384	2	grab	21	7.0	85	222	217	386	AMAX 1984
EEM	1984-Jun	384	2	grab	20	7.1	85	223	217	386	AMAX 1985
EEM	1985-Jul	383	2	grab	20	3.9	75	158	146	286	AMAX 1986
EEM	1986-Jul	380	1	grab	23	0.6	59	69	41	206	AMAX 1987
EEM	1987-Jul	382	1	grab	19	0.5	48	26	16	151	AMAX 1988
EEM	1988-Jul	382	1	grab	26	1.4	62	62	60	193	AMAX 1989
EEM	1989-Jul	381	2	grab	21	<0.3	51	38	30	181	AMAX 1990
M49	1989-Oct	378	3	grab	9	1.5	57	73	48	226	DOE 1989 unpublished
EEM	1990-Jul	383	1	grab	30	0.6	57	47	45	174	AMAX 1991
EEM	1995-Sep	391	3	grab	--	0.7	58	80	23	210	from Table 4

Table 5. Metal levels in Alice Arm surface sediments (stations CM, DM, EM) 1980-95 and mine tailings											
STN*	Survey	depth	No.	Sed	concentrations in ppm dry wt.						Data Source
	Date	(m)	rep	Type	As	Cd	Cu	Pb	Mo	Zn	
QA/QC SAMPLES											
BCSS	NRC standard			NRC	11	0.25	19	23	2	119	NRC 1990
BCSS**	1980-May		11	NRC	--	<0.50	18	20	--	102	Goyette & Christie 1982a
BCSS**	1981-Oct		11	NRC	--	<0.50	18	20	--	102	Goyette & Christie 1982b
BCSS	1983-Aug		6	NRC	9	<0.25	17	21	<2.5	113	AMAX 1984
BCSS	1984-Jul		5	NRC	10	<0.25	16	20	--	103	AMAX 1985
BCSS	1985-Jul		4	NRC	10	<0.25	16	25	<2.5	110	AMAX 1986
BCSS	1986-Jul		1	NRC	10	0.25	18	21	2	103	AMAX 1987
BCSS	1987-Jul		2	NRC	10	0.24	16	22	3	109	AMAX 1988
BCSS	1988-Jul		2	NRC	10	0.31	16	25	3	104	AMAX 1989
BCSS	1989-Jul		2	NRC	10	0.22	18	23	<2.5	121	AMAX 1990
BCSS	1989-Oct		3	NRC	10	0.18	15	24	2	107	DOE 1989 unpublished
BCSS	1990-Jul		1	NRC	9	0.21	16	22	--	132	AMAX 1991
BCSS	1995-Sep		3	NRC	10	0.22	16	28	2	104	from Table 4
MESS	NRC standard			NRC	11	0.59	25	34	2	191	NRC 1990
MESS**	1980-May		12	NRC	--	0.72	26	39	--	174	Goyette & Christie 1982a
MESS	1981-Aug		9	NRC	9	0.59	23	25	5	186	AMAX 1982
MESS**	1981-Oct		12	NRC	--	0.72	26	39	--	174	Goyette & Christie 1982b
MESS	1982-Aug		9	NRC	9	0.51	23	27	<5.0	182	AMAX 1983
MESS	1983-Aug		6	NRC	8	0.56	25	29	<2.5	187	AMAX 1984
MESS	1984-Jul		5	NRC	9	0.58	23	30	--	176	AMAX 1985
MESS	1985-Jul		4	NRC	10	0.54	23	32	4	183	AMAX 1986
MESS	1986-Jul		1	NRC	9	0.50	22	30	2	177	AMAX 1987
MESS	1987-Jul		2	NRC	11	0.64	24	29	3	182	AMAX 1988
MESS	1988-Jul		2	NRC	10	0.60	22	34	3	174	AMAX 1989
MESS	1989-Jul		2	NRC	10	0.51	26	31	<2.5	199	AMAX 1990
MESS	1989-Oct		3	NRC	10	0.62	22	32	2	175	DOE 1989 unpublished
MESS	1990-Jul		1	NRC	10	0.55	24	29	--	174	AMAX 1991
MESS	1995-Sep		3	NRC	10	0.64	21	34	2	167	from Table 4

Notes:

* Data grouped by same station; name varies depending on data source

** BCSS/MESS for May, 1980 and Oct, 1981 are routine QA lab values, not batch specific

APPENDIX 1. FAUNAL ABUNDANCE COUNTS FOR GRAB SAMPLE, SEPTEMBER 1995. NUMBERS PER 0.1 M^2

Alice Arm benthic identifications, March, 1996														
		CCN			CCM			CCS			DDN			DDM
	REP 1	REP 2	REP 3	REP 1	REP 2	REP 3	REP 1	REP 2	REP 3	REP 1	REP 2	REP 3	REP 1	REP 2
Amphipoda														
Heterophoxus affinis	3	2	3	4	4	10	3	4	8		1	2	3	4
Koroga megalops	1													
Bathymedon caino		1		1					2					
Bathymedon pumulis			1	2					1			1	1	1
Stegocephalus sp. A				1										
Bathymedon cf. flebilis						1		1						
Paraphoxus similis						1				1				
Cephalophoxoides homilis									1				1	1
Paraphoxus gracilis														
unknown?														
Nemertea	1									1				1
Paleonemertea						1						1		
Heteronemertea														
Cerebratulus sp.					1				1	1		1		
Aplacophora														
Crystallophisson sp.		1	3	5			6				1		19	11
Gastropoda														
Collumbellidae indet. juv.			1											
Neptunea sp. juv.														
Cylichna attonsa	1		2	1										
Bivalvia														
Nuculana tenuis	1	1	1	2									2	2
Nuculana minuta														
Yoldia scissurata														
Yoldia martyria			1		1	1				1				
Yoldia hyperborea				1										
Yoldia sp. juv.	1													
Veneroida indet. frag.						5								
Veneroida indet. juv.	3						7	1	4		1		2	2
Axinopsida serricata		1					2						1	
Macoma brota												1		
Psephidia lordi		1									6		1	

ALICE95

		CCN			CCM			CCS			DDN			DDM
	REP 1	REP 2	REP 3	REP 1	REP 2	REP 3	REP 1	REP 2	REP 3	REP 1	REP 2	REP 3	REP 1	REP 2
Nearomya maciformis										1				
Scaphopoda														
Dentalium pretiosum													1	1
Ostracoda														
Scleroconcha trituberculatus						2			1					
Cumacea														
Eudorella pacifica	20	16	14	12	6	16	13	12	24	5	7	3	3	3
Eudorella emarginata							1							
Diastylis umatillensis						1								
Isopoda														
Gnorimosphaeroma oregonensis														
Decapoda														
Pinnixa sp.	2	1	2				1		1					
Holothuroidea														
Pentamera pseudocalcigera	1		2	2					2					3
Chiridota albatrossi	3	3		1	1	3	2	1	4	3	1	1	8	6
Molpadia intermedia	4		3	1		1	1	8					2	2
Ophiuroidea														
Amphioplus strongyloplax		1		2			1					1		1
Ophiura sp. juv.			4						2				1	
Ophiura sp.						1								
Asteroidea														
Ctenodiscus crispatus	3		5	2	2		5	2	3	3	1	1		2
Pisces														
Lycodes brevipes	1													
Polychaeta														
Amphictene moorei														
Ancistrocyllis groenlandica														
Aphelochaeta sp. Indet.					1									
Arcteobea sp. 1														
Aricidea lopezi	3	7	6	5	8	4	11	2	8	8	5	7	3	2
Brada villosa							1							
Bylgides macrolepidus														
Chaetozone sp. A		4	1	3	1	2	3		3	3	2		6	5
Cirratulidae sp. Indet.		1											1	
Cirrophorus branchiatus					3		1	1	2		1	2	1	4

		CCN			CCM			CCS			DDN			DDM
	REP 1	REP 2	REP 3	REP 1	REP 2	REP 3	REP 1	REP 2	REP 3	REP 1	REP 2	REP 3	REP 1	REP 2
Cossura sp. Indet.				2	2	1	2	1		3		1	2	4
Eteone sp. Indet.														1
Galathowenia oculata				1	1	3	2	2	2				1	
Glycera nana							1							
Glycinde armigera		1		1			1	1	1					1
Goniada annulata			1											1
Heteromastus filobranchus	1	2	1	1	1		1	1	3	1	1	1	4	8
Leitoscoloplos pugettensis				1		1						1	1	
Levinsenia gracilis	1		1	1	5	4	17	3	9	2			12	5
Lumbrineridae sp. Indet.	3	2	1	1	2		1		2	1			2	
Maldane sarsi				1			1	2						
Mediomastus sp. Indet.			1	1		2		1		1		1	4	2
Myxicola infundibulum				1										
Nephtys cornuta	1	3	4	11	6	8	4		4	12	8	6	6	14
Nephtys punctata										1			1	
Notomastus lineatus				1										
Paraninoe simpla	1	1		1	2		2		1	2			2	1
Pholoe minuta							2		1			1		
Phyllodoce mucosa														
Podarkeopsis glabra					1		1		1	1	1	3	2	
Polynoidae sp. Indet.		1		1				1				1		
Prionospio lighti						1			1				1	1
Prionospio sp. A				1		1	3	1	1	1				
Scoletoma luti			5	2		1	3		2		1			
Spionidae sp. Indet.			1											
Spiophanes kroyeri				2				2	1				1	
Sternaspis scutata											1			
Syllis elongata										1				
Terebellides stroemi							1						1	

			DDS			EEN			EEM			EES	
	REP 3	REP 1	REP 2	REP 3	REP 1	REP 2	REP 3	REP 1	REP 2	REP 3	REP 1	REP 2	REP 3
Amphipoda													
Heterophoxus affinis	5	2	11	1									
Koroga megalops													
Bathymedon caino													
Bathymedon pumulis													
Stegocephalus sp. A													
Bathymedon cf. flebilis													
Paraphoxus similis				1									
Cephalophoxoides homilis													
Paraphoxus gracilis		1											
unknown?											1?		
Nemertea						1				1	1		
Paleonemertea		1										2	
Heteronemertea													
Cerebratulus sp.	2					1							
Aplacophora													
Crystallophisson sp.	8	9	5	1					1		1	5	
Gastropoda													
Collumbellidae indet. juv.													
Neptunea sp. juv.								1					
Cylichna attonsa										1			
Bivalvia													
Nuculana tenuis	1		1	1			1	2	2	5	5	2	
Nuculana minuta											1		
Yoldia scissurata													1
Yoldia martyria		3					1			1	4	1	
Yoldia hyperborea				1					1		1	1	
Yoldia sp. juv.													
Veneroida indet. frag.													
Veneroida indet. juv.	3							2		1			
Axinopsida serricata	2						1					1	
Macoma brota													1
Psephidia lordi					14	1	3	17	28	25	2	9	

			DDS			EEN			EEM			EES	
	REP 3	REP 1	REP 2	REP 3	REP 1	REP 2	REP 3	REP 1	REP 2	REP 3	REP 1	REP 2	REP 3
Nearomya maciformis													
Scaphopoda													
Dentalium pretiosum													
Ostracoda													
Scleroconcha trituberculatus													
Cumacea													
Eudorella pacifica	9	3	9				1	2		1	1	1	
Eudorella emarginata													
Diastylis umatillensis	2												
Isopoda													
Gnorimosphaeroma oregonensis												1	
Decapoda													
Pinnixa sp.													
Holothuroidea													
Pentamera pseudocalcigera	1			1									
Chiridota albatrossi	8	4	2	3	2	3	2	6	6	8	2	6	
Molpadia intermedia	4	2		1		1	1				1		
Ophiuroidea													
Amphioplus strongyloplax	2						1						
Ophiura sp. juv.			1	1									
Ophiura sp.													
Asteroidea													
Ctenodiscus crispatus			3		3		1		4	1	3	3	4
Pisces													
Lycodes brevipes													
Polychaeta													
Amphictene moorei											1		
Ancistrocyllis groenlandica												1	1
Aphelochaeta sp. Indet.			1										
Arcteobea sp. 1			1										
Aricidea lopezi	3	2	5	1	3	1	9	5	12	6	6	6	4
Brada villosa													
Bylgides macrolepidus	1												
Chaetozone sp. A	4	3			1		1		3				
Cirratulidae sp. Indet.												1	
Cirrophorus branchiatus	3	2	5	2									

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			DDS			EEN			EEM			EES	
	REP 3	REP 1	REP 2	REP 3	REP 1	REP 2	REP 3	REP 1	REP 2	REP 3	REP 1	REP 2	REP 3
Cossura sp. Indet.	2	1		1		1			2			4	
Eteone sp. Indet.													
Galathowenia oculata								1					
Glycera nana													
Glycinde armigera			1									1	
Goniada annulata		1							1				
Heteromastus filobranchus	6	3	5	1	2			1		2		2	2
Leitoscoloplos pugettensis													
Levinsenia gracilis	7	4	7	1		2				2	4	2	6
Lumbrineridae sp. Indet.	4	1	2	3					2			1	3
Maldane sarsi	1	7	28	4									
Mediomastus sp. Indet.	5		2	2							1		1
Myxicola infundibulum													
Nephtys cornuta	13	7	9	4	4			2	4		4	2	5
Nephtys punctata	1	1	1		1			1					1
Notomastus lineatus	2												
Paraninoe simpla		1	1	1	1	1					1		1
Pholoe minuta	1	1											
Phyllodoce mucosa			1										
Podarkeopsis glabra	3	1							1		1	2	
Polynoidae sp. Indet.	1												
Prionospio lighti												1	
Prionospio sp. A	1	1			1		1	1	2	2	1	2	1
Scoletoma luti		1					1	1				2	
Spionidae sp. Indet.													
Spiophanes kroyeri							2						
Sternaspis scutata													
Syllis elongata			1										
Terebellides stroemi													