Benthic Studies in Alice Arm, B.C. During and Following Cessation of Mine Tailings Disposal, 1982 to 1986

By
R.O. Brinkhurst and B.J. Burd
Institute of Ocean Sciences
and R.D. Kathman
E.V.S. Consultants Ltd. [1]

Institute of Ocean Sciences
Department of Fisheries and Oceans
Sidney, B.C.

1987

Canadian Technical Report of Hydrography and Ocean Sciences No. 89

Fisheries and Oceans   Pêches et Océans

Canada

Canadian Technical Report of Hydrography and Ocean Sciences

These reports contain scientific and technical information of a type that represents a contribution to existing knowledge but which is not normally found in the primary literature. The subject matter is generally related to programs and interests of the Ocean Science and Surveys (OSS) sector of the Department of Fisheries and Oceans.

Technical Reports may be cited as full publications. The correct citation appears above the abstract of each report. Each report will be abstracted in Aquatic Sciences and Fisheries Abstracts. Reports are also listed in the Department's annual index to scientific and technical publications.

Technical Reports are produced regionally but are numbered and indexed nationally. Requests for individual reports will be fulfilled by the issuing establishment listed on the front cover and title page. Out of stock reports will be supplied for a fee by commercial agents.

Regional and headquarters establishments of Ocean Science and Surveys ceased publication of their various report series as of December 1981. A complete listing of these publications and the last number issued under each title are published in the *Canadian Journal of Fisheries and Aquatic Sciences*, Volume 38: Index to Publications 1981. The current series began with Report Number 1 in January 1982.

Rapport technique canadien sur l'hydrographie et les sciences océaniques

Ces rapports contiennent des renseignements scientifiques et techniques qui constituent une contribution aux connaissances actuelles mais que l'on ne trouve pas normalement dans les revues scientifiques. Le sujet est généralement rattaché aux programmes et intérêts du service des Sciences et Levés océaniques (SLO) du ministère des Pêches et des Océans.

Les rapports techniques peuvent être considérés comme des publications à part entière. Le titre exact figure au-dessus du résumé du chaque rapport. Les résumés des rapports seront publiés dans la revue Résumés des sciences aquatiques et halieutiques et les titres figureront dans l'index annuel des publications scientifiques et techniques du Ministère.

Les rapports techniques sont produits à l'échelon régional mais sont numérotés et placés dans l'index à l'échelon national. Les demandes de rapports seront satisfaites par l'établissement auteur dont le nom figure sur la couverture et la page de titre. Les rapports épuisés seront fournis contre rétribution par des agents commerciaux.

Les établissements des Sciences et Levés océaniques dans les régions et à l'administration centrale ont cessé de publier leurs diverses séries de rapports depuis décembre 1981. Vous trouverez dans l'index des publications du volume 38 du *Journal canadien des sciences halieutiques et aquatiques*, la liste de ces publications ainsi que le dernier numéro paru dans chaque catégorie. La nouvelle série a commencé avec la publication du Rapport n° 1 en janvier 1982.

Canadian Technical Report of
Hydrography and Ocean Sciences No. 89

1987

BENTHIC STUDIES IN ALICE ARM, B.C. DURING AND FOLLOWING CESSATION OF MINE TAILINGS DISPOSAL, 1982 TO 1986

by

R.O. Brinkhurst and B.J. Burd
Institute of Ocean Sciences

and R.D. Kathman
E.V.S. Consultants Ltd. (1)

Institute of Ocean Sciences
Department of Fisheries and Oceans
Sidney, B.C.

(1) present address: 10651 Blue Heron Road, Sidney, British Columbia, V8L 3X9.

Cat. No. FS-97-18/089 ISSN 0711-6764

Correct citation for this publication:

Brinkhurst, R.O., B.J. Burd and R.D. Kathman. 1987. Benthic studies in Alice Arm, B.C., following cessation of mine tailings disposal. Can. Tech. Rep. Hydrogr. Ocean Sci. 89: 45p.

CONTENTS

ABSTRACT

Brinkhurst, R.O., B.J. Burd and R.D. Kathman. 1987. Benthic studies in Alice Arm, B.C. during and following cessation of mine tailings disposal, 1982 to 1986. Can. Tech. Rep. Hydrogr. Ocean Sci. 89:45p.

Four million tons of process effluent were discharged into Alice Arm from April 1981 until November 1982. Samples of the macrobenthic infauna were obtained in October 1982, revealing considerable impact on the bottom fauna in the immediate path of the tailings plume well down the fjord at lines C and D (CCN, CCM and DDM), with detectable effects at the other stations in the C and D transect. The effect was demonstrable in terms of abundance of all organisms and of taxa as well as by cluster analysis. Samples from October 1983 showed some recovery in terms of simple abundances at CCN, CCM and DDM, and the stations now clustered together with the other C-D stations. Samples from a new transect (D5) formed a discrete group, as did those from the E line and the control Z line in Hastings Arm. By October 1986 the recovery in terms of numbers of individuals and of taxa was complete, but cluster analysis still revealed a distinction between the original CCN, CCM and DDM cluster and the rest of the stations, based on differences in proportional representation of species present.

Recently developed statistical methods were used to distinguish significant clusters within each dendrogram. Statistically significant differences were found between analytic results for each year and between these and reference dendrograms based on spatial position of sampling points or sediment type. Recovery of the macrobenthic infauna has been extensive in the 4 post-deposition years, but the fauna of the stations nearest the mine is still recognisably different in detail. The statistical methods employed support the previous subjective judgements made about meaningful clusters and differences between sample sets. The epifauna at sites closer to the effluent discharge than stations sampled in the current study still show a reduction in diversity. Accumulation of contaminants by the larger epifauna (crabs) was not considered in this study.

Keywords: benthic invertebrates, mine tailings, fjords, statistics

RÉSUMÉ

Brinkhurst R.O., B.J. Burd and R.D. Kathman. 1987. Benthic studies in Alice Arm, B.C. during and following cessation of mine tailings disposal, 1982 to 1986. Can. Tech. Rep. Hydrogr. Ocean Sci. 89: 45p.

De avril 1981 à novembre 1982, quatre millions de tonnes d'effluents traités ont été déversées dans les eaux du bras Alice. Des échantillons de l'endofaune macrobenthique prélevés en octobre 1982 ont révélé l'existence d'effets importants sur la faune du fond dans la trajectoire même des rejets, ceci bien en aval du fiord, aux lignes C et D (CCN, CCM et DDM). Des effets suffisamment importants pour être décelables ont aussi été notés aux autres stations du transect C et D. Ces effets concernaient l'abondance de l'ensembe des organismes et des taxons et étaient démontrés par analyse de groupes. Les échantillons prélevés en octobre 1983 dénotaient un certain rétablissement de la situation touchant les abondances en CCN, CCM et DDM ainsi qu'aux stations maintenant regroupées avec les autres stations C-D. Les échantillons provenant d'un nouveau transect (D5) formaient un groupe discret tout comme ceux de la ligne E et de la ligne témoin Z, dans le bras Hastings. En octobre 1986, le rétablissement était total, quant au nombre d'individus et de taxons, mais l'analyse par groupes révélait toujours un écart entre le groupe de départ CCN, CCM et DDM et les autres stations si l'on considère la représentation proportionnelle des espèces présentes.

Des méthodes statistiques récemment mises au point ont été utilisées pour déceler les groupes significatifs au sein de chaque dendrogramme. Des écarts statistiquement significatifs ont été notés entre les résultats analytiques de chaque année et entre ces derniers et les dendrogrammes de référence basés sur la position spatiale des points d'échantillonnage ou des types sédimentaires. Le rétablissement de l'endofaune benthique a été important au cours des quatre années qui ont suivi les déversements, mais la faune des stations les plus près de la mine présente encore des charactéristiques qui diffèrent par certains détails. Les méthodes statistiques utilisées confirment les jugements subjectifs antérieurs sur l'utilité des groupes et les écarts entre les ensembles d'échantillons. L'épifaune des sites situés plus près du point de rejet que les stations d'échantillonnage utilisées au cours de la présente étude continue de présenter une baisse de sa diversité. La présente étude n'a pas traité de l'accumulation de contaminants par les plus gros organismes de l'épifaune (crabes).

Mots-clés: invertébrés benthiques, résidus miniers, fjord, statistique.

INTRODUCTION

This study reports on the long-term effects of mine tailing discharges on the benthic invertebrate fauna of Alice Arm, B.C. The AMAX Kitsault molybdenum mine discharged tailings into the head of Alice Arm for 18 months, ending in November 1982 when the mine closed operations indefinitely. Our first benthic survey was carried out in October 1982 to determine the ongoing impact of the mine tailings on the fauna (Kathman et al. 1983). The areas nearest the outfall had very few species and individuals, while the sites further down the inlet had greater individual abundances and diversity. Reduced numbers of species and individuals were noted in the deep middle sites in the inlet approximately 8 km down inlet from the discharge, suggesting that mine tailings were beginning to affect the benthos in the seaward deeper section of Alice Arm.

In order to follow the recovery of benthos following the closure of the mine, a second benthic survey was carried out in October 1983 (Kathman et al. 1984). There were distinct changes in the faunal compositions of Alice Arm between 1982 and 1983. The three stations which had shown the most impact from the mine tailings in 1982 had recovered considerably in terms of species diversity and abundance and cluster analyses linked them closely to other C and D line stations even though they still had the lowest number of taxa and individuals of the C and D stations. A complication in the interpretation of results was caused by the fact that the total number of taxa and individuals declined in all stations in 1983, for reasons not apparent from this study.

In 1986 the third benthic survey of Alice Arm was undertaken to determine the extent and characteristics of the recovery of the benthic fauna. This report includes the 1986 survey results and reviews the results of the 1982 and 1983 surveys.

METHODS

BENTHIC SAMPLING

Sampling in Alice Arm and Hastings Arm, British Columbia (Figure 1), was conducted by personnel from the Institute of Ocean Sciences and EVS Consultants Ltd aboard the CSS TULLY in October 1986. Station coordinates and depths are given in Table 1. Sampling procedures were essentially the same as those used in 1982 and 1983 (Kathman et al. 1983, 1984). Duplicate samples were taken at each station on predetermined transect lines (Figure 2) using a 0.1 m2 Smith-McIntyre grab. Transect D5, initiated in 1983, was resampled in 1986. A single transect in Hastings Arm (Z) was retained as a reference location for comparison with the sites in Alice Arm. A core sample was taken from each grab using a 50-mm (inside diameter) cylinder. Cores ranged from 10 - 18 cm deep. All core samples were stored in sealed plastic bags at four degrees C. The remainder of each sample was washed through a 1.0 mm screen. The contents retained on the screen were placed in labelled plastic buckets and preserved with seven percent formalin with Rose Bengal, a histological stain used to facilitate sorting.

Fig. 1. Map showing general location of study area.

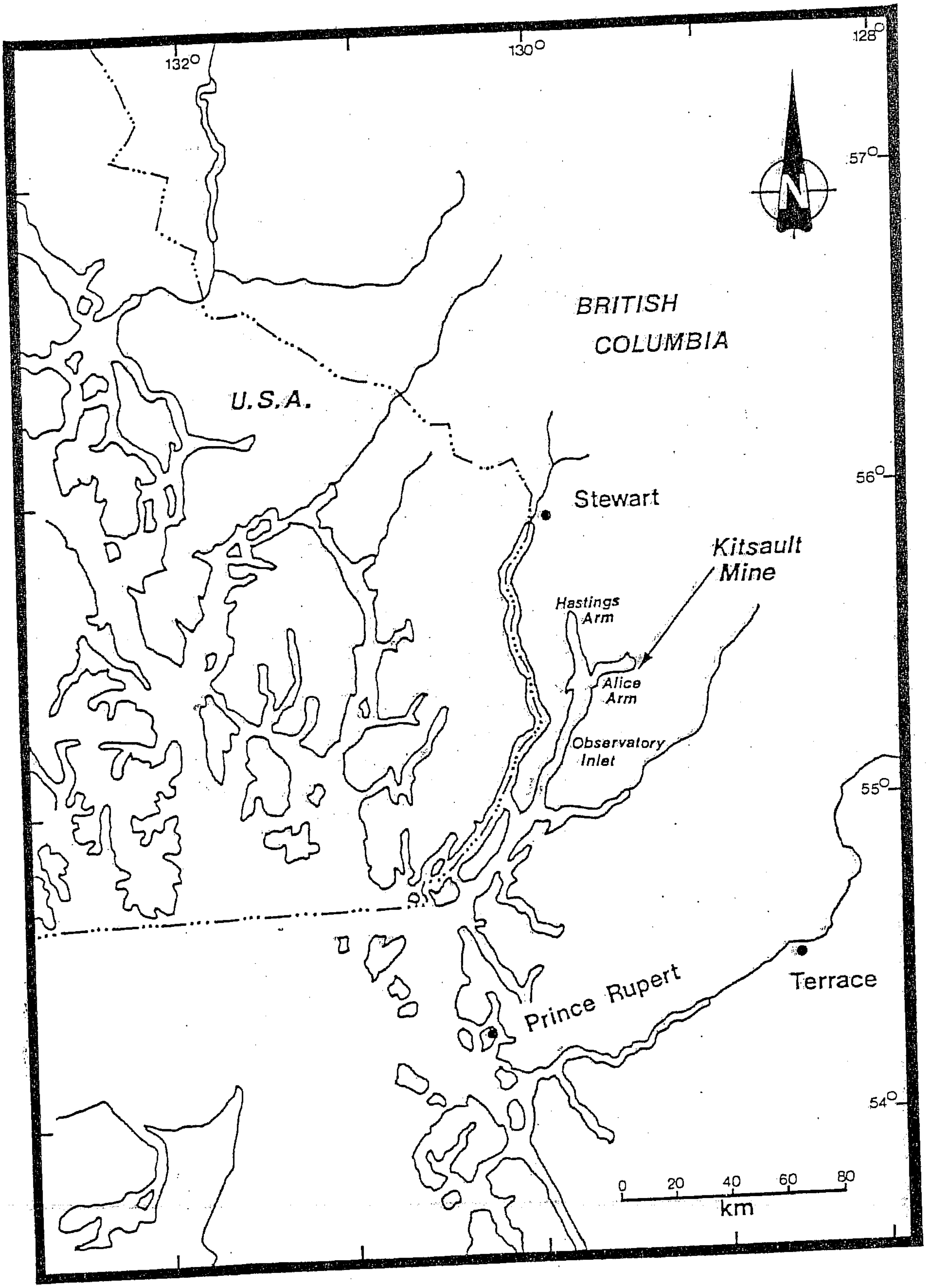
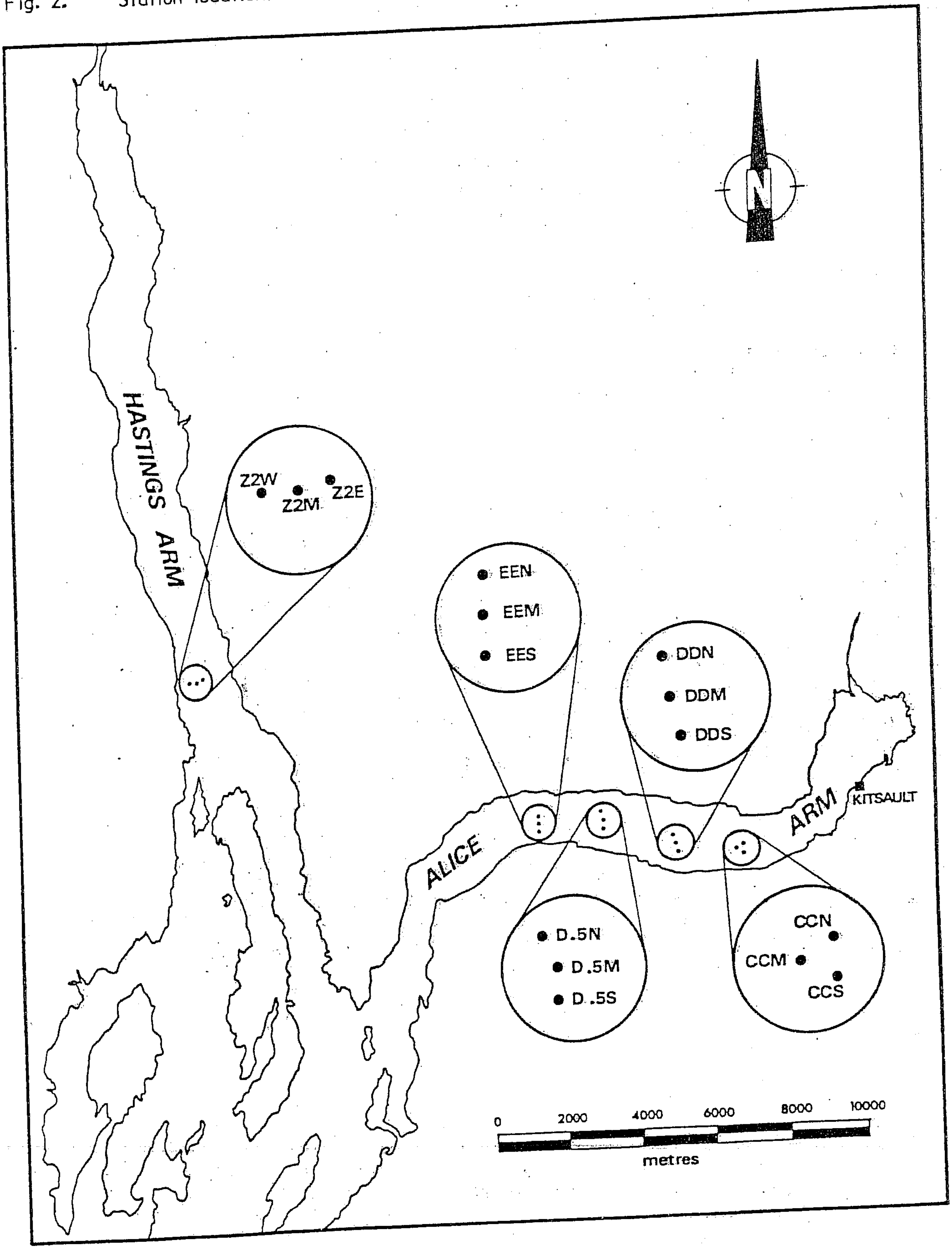


Table 1. Station locations and depths for 1986 Alice Arm benthic survey.

STATION	REPLICATE	LOCATION		DEPTH (m)
CCM	A	55.26.50 N	129.31.88 W	274
	B	55.26.50 N	129.31.88 W	279
CCN	A	55.26.67 N	129.31.70 W	262
	B	55.26.67 N	129.31.70 W	262
CCS	A	55.26.50 N	129.31.74 W	235
	B	55.26.50 N	129.31.74 W	214
DDM	A	55.26.74 N	129.33.59 W	347
	B	55.26.74 N	129.33.59 W	347
DDN	A	55.26.80 N	129.33.60 W	349
	B	55.26.80 N	129.33.60 W	349
DDS	A	55.26.70 N	129.33.50 W	343
	B	55.26.70 N	129.33.50 W	343
D5M	A	55.27.08 N	129.35.38 W	370
	B	55.27.08 N	129.35.38 W	371
D5N	A	55.27.17 N	129.35.45 W	369
	B	55.27.17 N	129.35.45 W	360
D5S	A	55.27.03 N	129.35.38 W	370
	B	55.27.03 N	129.35.38 W	370
EEM	A	55.27.10 N	129.37.00 W	376
	B	55.27.10 N	129.37.00 W	376
EEN	A	55.27.20 N	129.37.00 W	376
	B	55.27.20 N	129.37.00 W	376
EES	A	55.27.00 N	129.37.00 W	371
	B	55.27.00 N	129.37.20 W	373
Z2E	A	55.29.30 N	129.45.60 W	395
	B	55.29.30 N	129.45.60 W	395
Z2M	A	55.29.30 N	129.45.80 W	395
	B	55.29.30 N	129.45.80 W	395
Z2W	A	55.29.20 N	129.45.95 W	395
	B	55.29.20 N	129.45.95 W	395

Fig. 2. Station locations in Alice Arm and Hastings Arm, British Columbia.



All laboratory procedures for sample sorting and quality control were performed at the Institute of Ocean Sciences. Each sample was first washed through a 0.5 mm sieve to remove excess formalin, then re-preserved in 70 percent isopropyl alcohol. All benthic organisms were removed from the sediments, counted, placed into separate containers filled with alcohol, and labelled according to the following major taxonomic groups: Amphipoda, Isopoda, Decapoda, Cumacea, Ostracoda, Copepoda, Other Crustacea, Polychaeta, Gastropoda, Pelecypoda, Scaphopoda, Sipuncula, Holothuroidea, Ophiuroidea, Echinoidea, Asteroidea, Anthozoa, Nemertea, and Others. Sample residues were returned to their original containers filled with 70 percent isopropanol.

To ensure accurate sorting, 17 percent (five of 30) of the sample residues were independently resorted by the taxonomic supervisor following the procedure outlined above. If additional organisms were found, they were placed in the appropriate vial and all necessary changes made to the data sheets. If more than 5% additional animals had been found during the resort, the entire set of samples would have been resorted.

IDENTIFICATIONS

Recognized taxonomic experts identified all organisms to the lowest possible taxonomic level consistent with the presently-available literature. Taxonomic authorities responsible for each group are given in Table 2.

Representative specimens of each genus/species identified in the 1982 and 1983 studies were removed from the collection and retained by the Ecology group at the Institute of Ocean Sciences as a reference set for future use. The bulk of the specimens from the 1982 and 1983 studies, and all from the 1986 study were deposited with the B.C. Provincial Museum (Victoria).

SEDIMENT PARTICLE-SIZE ANALYSES

Core samples were removed to the laboratory at the Institute of Ocean Sciences and passed through sieves to separate the substrate into particle sizes of > 2.000 mm, 0.063 - 1.999 mm, and < 0.063 mm. These fractions were classified respectively as "gravel", "sand", and "mud"or "silt/clay". Each was oven dried and then weighed to the nearest ± 0.01 g using a triple-beam balance. The percentages by weight of each grab sample consisting of the three size classes of particles were subsequently determined.

STATISTICAL ANALYSES

Hierarchical analysis

To compare the results of any two cruises, it is necessary to produce uniform data sets in terms of both the number of species and stations. Zeroes are included for species not present in a specific cruise. The set of matrices used for comparison between the 1982 data set and other years did not include transect D5 or station EEM (since EEM had only 1 replicate

Table 2. Taxonomic authorities used for identification and verification of benthic invertebrates from Alice Arm.

AUTHORITY	TAXONOMIC GROUP
Mr. Howard Jones Marine Taxonomic Services	Polychaeta
Dr. William Austin Khoyatan Marine Laboratory	Crustacea (except Amphipoda), Echinodermata and miscellaneous taxa
Mr. Patrick Shaw University of British Columbia	Amphipoda
Dr. Robert Reid University of Victoria	Mollusca

in 1982 it was discarded), leaving a total of 11 stations and 161 species. The data sets for the 1983 and 1986 comparisons had 15 stations and 134 species.

All data sets were analyzed using the Bray-Curtis classification (Bray and Curtis 1957) to take into account the affinity or similarity of species among sites as a viable measure of discreteness. The complement of the Bray-Curtis coefficient was employed as the index of similarity in all trials, and is defined as:

(1) $C = 1 - [2w - (a + b)]$,

where w = the sum of the lesser abundance for each species common to a pair of samples (in Q-type analysis), and (a + b)= the sum of abundances for each sample under comparison. Values range from 0 for complete dissimilarity, to 1.0 for complete similarity.

Pair-group clustering was weighted (Sneath and Sokal 1973) and output was displayed as an optimally rotated dendrogram. Analyses were performed on the benthic invertebrate data to allow comparison of sites, based on the similarity of species composition and mean abundances (Q- type). Initially, each replicate sample was considered separately. The 1982 dendrogram therefore contains 22 replicates (11 stations), whereas the 1983 and 1986 dendrograms consist of 30 replicates each. As analyses demonstated that in general replicates pair closely, subsequent analyses utilising the mean values of replicates at each station were justified (see Results).

Significance testing and comparison of matrices

The abundance data sets were subjected to further analyses consisting of three computer programs developed for non-parametric statistical testing of abundance data. These programs are called "Sigtree", "Comtree 1" and "Comtree 2" and will be described below. Each of these programs utilizes the Bray Curtis similarity coefficient with weighted pair-group mean averaging (WPGMA-Sneath and Sokal 1973). This method of cluster analysis utilizes the mean value of each pair of station replicates for calculating the similarity between stations, instead of examining each replicate separately. A probability of 0.1 or less was considered to be a significant case.

Sigtree: The linkage groupings were statistically analysed for significance using a "bootstrap" simulation (Diaconis and Efron 1983, Felsenstein 1985), which requires a variance about the mean values for each station to generate the statistical probabilities from the random simulations. The significance levels obtained indicated the probability of a given group of stations being linked together by random chance, based on simulations generated from the original abundance data set (Nemec and Brinkhurst, in prep.). Sigtree tests were done on each of the abundance data sets (one for each year), using 75 simulations.

Comtree 1: The Bray-Curtis coefficient was also used to generate "reference" dendrograms demonstrating the similarity between stations based on (a) geographical distance, and (b) difference in mean percent silt/clay between stations. Comtree 1 involves comparing each abundance data matrix with the pre-determined reference trees (Nemec and Brinkhurst - in prep.) by testing the null hypothesis (Ho) that the random cluster pattern (abundance) is different from the reference (i.e. geographic distance) cluster dendrogram. Significance is determined by using the Fowlkes-Mallows test statistic (Sneath and Sokal 1973). The probability that the two dendrograms are different is given at any linkage level desired for either dendrogram. The following comparisons were done:

a) Comparison of abundance matrix with geographic distance between stations (total of 3 - one for each year)
b) Comparison of abundance matrix with differences in percent silt/clay between stations (for 1986 only)

For this report, only the corresponding linkage levels in each dendrogram were tested for significance (i.e. linkage 1 in reference dendrogram with linkage 1 in abundance dendrogram, etc.).

Comtree 2: The symmetrical abundance matrices were then statistically compared to each other using a "bootstrap" method similar to Sigtree (Nemec and Brinkhurst, in prep.) which tests the null hypothesis (Ho) that two abundance dendrograms are the same. The significance (p) of each pair of linkage levels (one for each dendrogram) is calculated using the Fowlkes-Mallows test statistic. The following data sets were compared using 75 simulations:

Abundance:
- 1982 vs 1983 (11 stations, 161 species)
- 1982 vs 1986 (11 stations, 161 species)
- 1983 vs 1986 (15 stations, 134 species)

Only the corresponding linkage levels in each dendrogram were tested for significance (i.e. linkage 1 in 1982 dendrogram with linkage 1 in 1983 dendrogram, etc.).

RESULTS

BENTHIC SAMPLES

The species identified from each year are given in Appendix 1. Species abundance data for 1986 are presented in tabular form in Appendix 2. Similar data for 1982 and 1983 are presented in Kathman *et al*. (1983, 1984). Appendix 3 contains the QA/QC data for the rough sorting of the 1986 samples. Percent error ranged from 0 to 2.2, well within the requisite limits for accuracy of sorting of benthic invertebrate samples.

The total number of taxa was 123 in 1982, 74 in 1983 and 110 in 1986. In 1986 the most abundant species at most stations included the polychaete *Nephtys cornuta cornuta*, the pelecypods *Yoldia martyria* and *Axinopsida serricata* (except in Z stations) and the gastropod *Cyclichna attonsa* (except in Z stations), the ophiuroid *Ophiura sp.* and the amphipod *Eudorella emarginata*. The polychaetes *Galathowenia oculata* and *Spiophanes* kroyeri (though S. kroyeri was generally rare) were only common in CCN, CCM and CCS as was the holothurian Molpadia intermedia, whereas the gastropod Nucula tenuis was common in the E and Z stations only. The polychaete Aricidea seucica was abundant at D5-E, whereas the bivalve Psephidia lordi was common only in the E stations. For a discussion of the faunal composition of the 1982 and 1983 data sets, refer to Kathman et al. (1983, 1984).

The total number of taxa and mean abundance of animals at each station is given in Table 3. It is evident in comparing the different years that in CCN, CCM and DDM the mean abundance and number of taxa increased substantially from 1982 to 1986. The mean abundance declined in 1983 at all other stations, but increased considerably again by 1986. However, in some of the E and Z stations, the 1986 values were still much lower than they had been in 1982. The total taxa per station declined in the E stations from 1982 to 1983 and increased to 1982 levels by 1986, whereas in the Z stations the number of taxa remained fairly consistent through the three years. In CCS, DDN and DDS the abundance declined from 1982 to 1983 and remained at that level through to 1986, and the number of taxa in these three stations fluctuated from year to year. In the D5 transect, the abundance and number of taxa increased between 1983 and 1986.

PARTICLE SIZE ANALYSES

The results of particle size analyses are given in Table 4. This analysis was not done for 1982 and 1983. Virtually none of the station samples contained any gravel. The Z and E and C stations were almost 100% silt/clay. The D stations were a mixture of sand and silt/clay of varying percentages.

STATISTICAL ANALYSES

Hierarchical Analyses

The results of cluster analyses on the 1982, 1983 and 1986 abundance data sets are presented in Figures 3 to 6. The cluster patterns will be discussed in the next section (Sigtree). In most cases, the replicate samples of any given station are fairly similar to each other. In 1982 for example (Figure 3) the only glaring exception to this is replicate 1 of CCN, which is quite different from any other replicates in the data matrix. In 1983 there is some mixing in the C and D station replicates, but the E, D5 and Z station replicate pairs are fairly consistent. In 1986, the replication within pairs is consistent, except that the D5M and D5N pairs are mixed, indicating very little difference between samples on some transects.

Statistical testing and comparison of abundance data

Sigtree: The cluster analyses (WPGMA) and significances of each linkage level are illustrated in Figures 4 to 6. A significance of 0.1 or less was considered to be significant. At each level, the program is testing the null hypothesis that any two clusters are the same, or can be considered replicates of each other.

Table 3. Comparison of total abundance and species number per station for Alice Arm from 1982 to 1986. Values for 1982 and 1983 are taken from Kathman et al. (1984).

Station	*Mean Abundance per 0.1m2			Total taxa per station		
	1982	1983	1986	1982	1983	1986
CCN	2.0	11.5	142.5	4	15	35
CCM	3.0	7.0	148.0	5	7	49
CCS	66.5	22.0	77.0	24	17	35
DDN	52.0	16.5	109.0	20	14	36
DDM	2.5	9.0	202.0	4	9	42
DDS	108.5	20.5	141.5	10	20	38
D5N	–	39.5	86.0	–	21	41
D5M	–	37.0	97.0	–	17	34
D5S	–	22.0	82.0	–	15	33
EEN	312.5	66.5	152.5	37	10	41
EEM	104.0	119.0	141.0	–	20	33
EES	344.0	165.5	272.0	38	23	38
Z2E	183.5	82.0	81.5	38	32	29
Z2M	125.5	76.0	69.0	30	31	30
Z2W	208.5	98.5	48.0	37	32	23

*Mean abundances are based on two replicates per station.

Table 4. Sediment Particle Size Analysis for 1986, Alice Arm benthic survey.

STATION	REPLICATE	% SAND	% MUD	% GRAVEL
CCM	A	3.12	96.43	0
	B	6.53	93.15	0
CCN	A	4.35	95.6	0.04
	B	1.62	98.33	0
CCS	A	15.46	84.53	0
	B	3.61	96.38	0
DDM	A	52.46	47.54	0
	B	51.78	48.22	0
DDN	A	74.06	25.94	0
	B	31.62	68.38	0
DDS	A	11.71	88.29	0
	B	22.71	77.28	0
D5M	A	22.83	77.17	0
	B	17.57	82.43	0
D5N	A	12.99	87	0
	B	4.81	94.43	0
D5S	A	43.69	56.31	0
	B	24.18	75.82	0
EEM	A	1.54	98.46	0
	B	1.67	98.3	0
EEN	A	1.86	98.14	0
	B	1.52	98.48	0
EES	A	2.12	97.88	0
	B	2.89	97.1	0
Z2E	A	0.33	99.65	0
	B	0.51	98.67	0
Z2M	A	0.35	98.78	0
	B	0.3	99.69	0
Z2W	A	0.14	99.83	0
	B	0.16	99.81	0

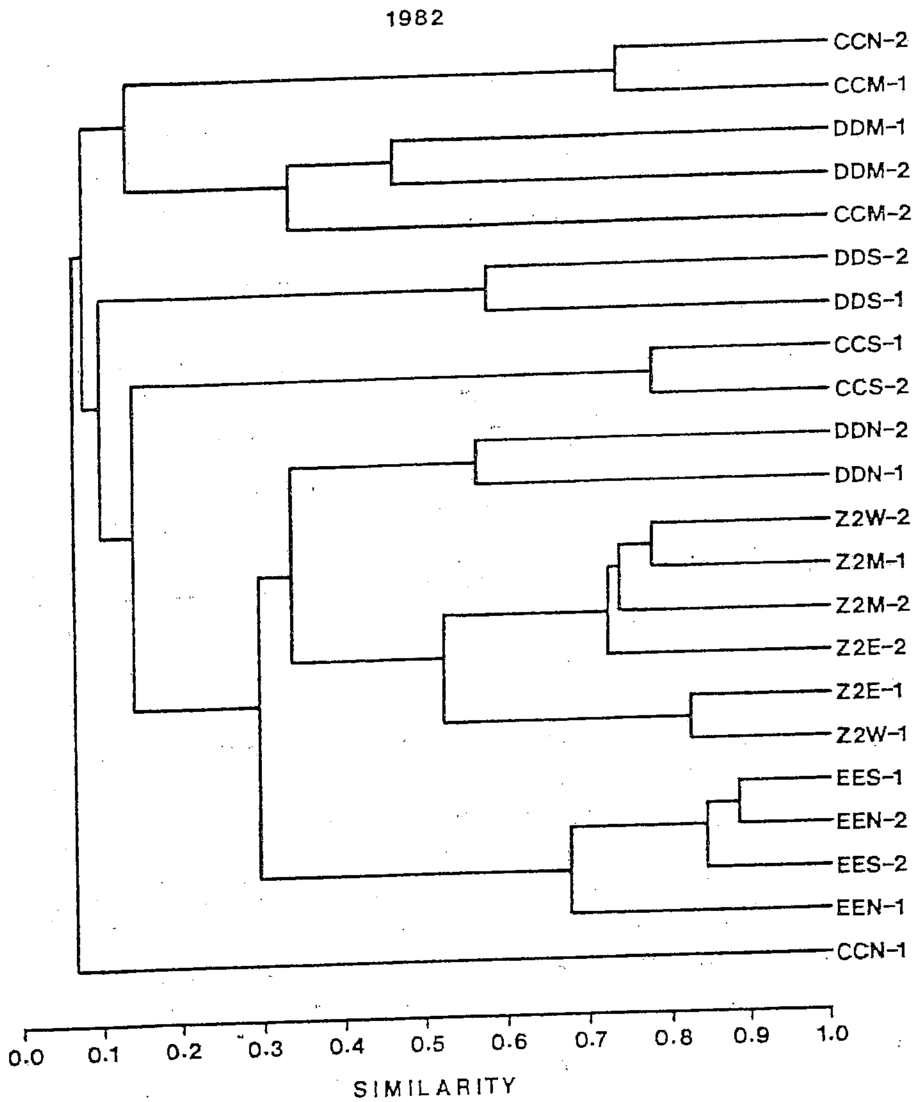


Figure 3. Cluster analysis utilizing each replicate sampled in Alice Arm in 1982.

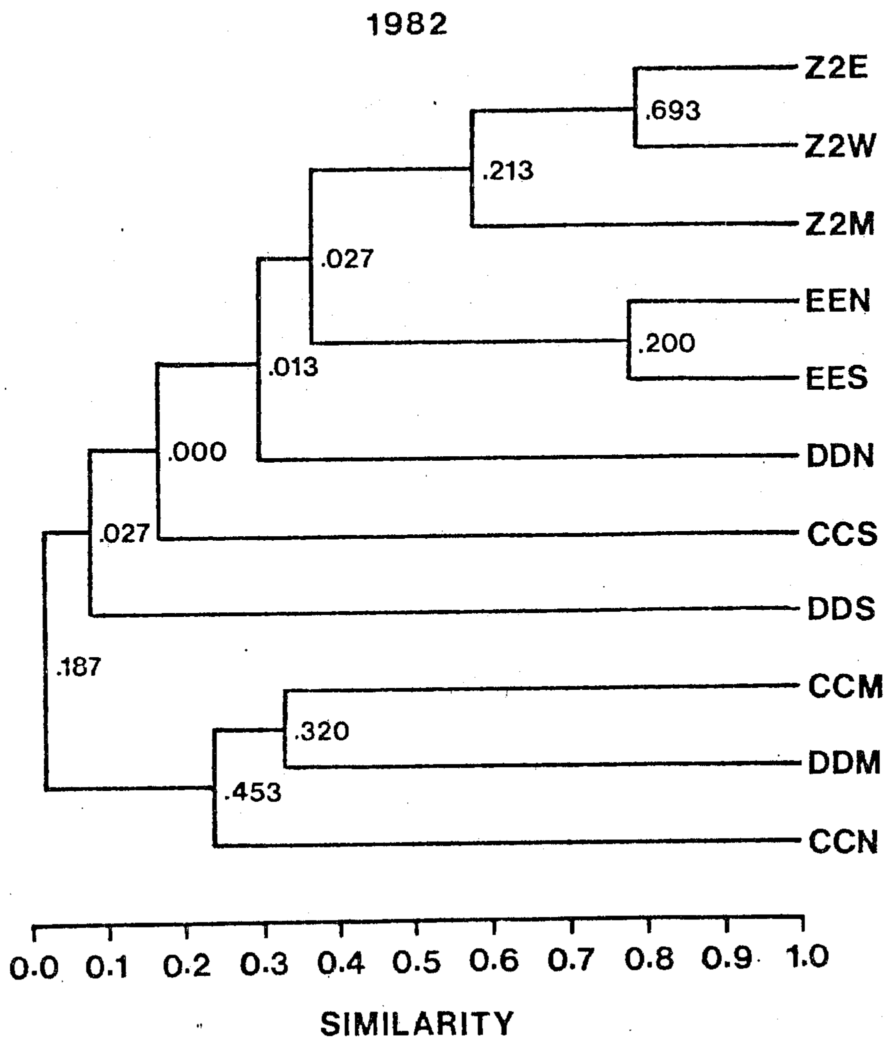


Figure 4. Cluster analysis using the means of replicates for each sample station. The significance of each linkage (from SIGTREE) is shown as well for the 1982 data set.

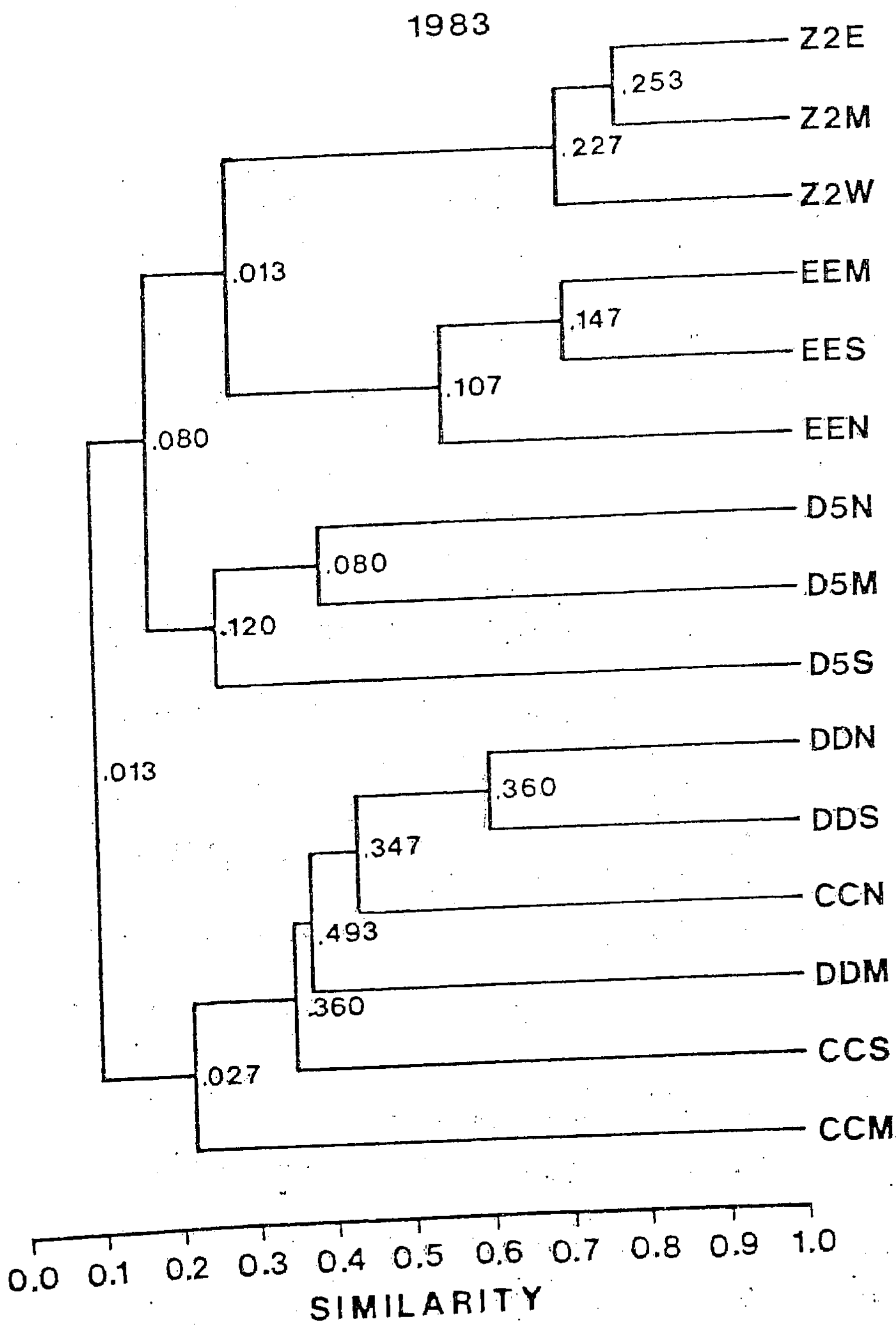


Figure 5. Cluster analysis using the means of replicates for each sample station. The significance of each linkage (from SIGTREE) is shown as well for the 1983 data set.

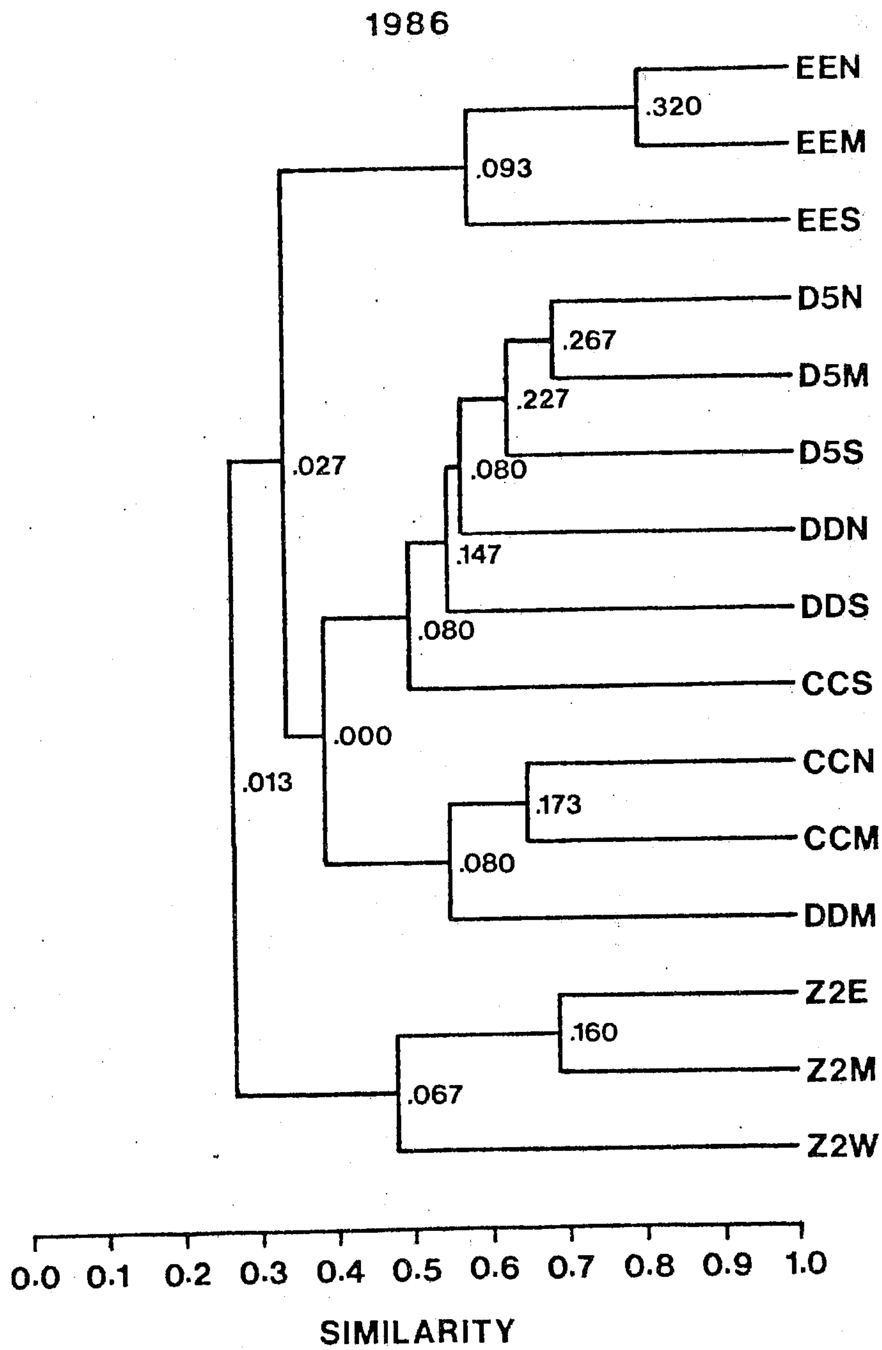


Figure 6. Cluster analysis using the means of replicates for each sample station. The significance of each linkage (from SIGTREE) is shown as well for the 1986 data set.

In 1982 the first significant linkage is level 4 (Figure 4), which distinguishes the Z stations from the E stations (because the linkages within the Z cluster are not significant, the Z stations can be considered to be replicates of each other). The 5th linkage level is significant, indicating that DDN is significantly distinct from all other stations. This is also true for stations CCS (linkage 6) and DDS (linkage 7) in turn. These three stations (DDN, CCS and DDS) were not subject to the same intensive deposition of mine tailings as the following stations. Stations CCM, CCN and DDM seem to form a distinct group visually (similarity to the rest of the stations is less than 0.1), but this is not significant. The low numbers of taxa and individuals in these three stations may be affecting the significance testing (i.e. there may be a large number of zero entries in common between the CCN,CCM and DDM group and the remaining stations).

In 1983 the Z, E and D5 (D5 transect was not sampled in 1982) stations formed significantly distinct groups (Figure 5). The C and D stations were mixed together to form a significantly distinct group. Both the E and D5 groups were more similar to the reference transect in Hastings Arm (Z) than to the other transects in Alice Arm (C and D).

In 1986 the Z, E and D5 stations again formed significantly distinct groups. DDN, DDS and CCS were significantly distinct singletons. Stations CCN, CCM and DDM together formed a significantly distinct group. This time, the D5 and E groups were more similar to the Alice Arm transects (C+D) than to the reference transect in Hastings Arm (Z).

Comtree 1: The geographic distance and percent silt/clay reference dendrograms are presented in Figures 7 to 9. In the geographic distance matrices (Figures 7 and 8) each transect of stations (i.e. E, Z, D5, D and C) clustered separately, as would be expected from a visual inspection of Figure 2. The Alice Arm transects (E,D5,D and C) were most similar to each other, with the Hastings Arm transect (Z) distinctly different. The percent silt/clay dendrogram for 1986 (Figure 9) illustrates that the Z transect was similar to the E transect plus CCN and CCM, all of which had almost 100% silt/clay in the sediment (see Table 4). CCS and D5N formed a cluster with about 90% silt/clay, whereas the cluster of DDS and D5M had about 80% silt/clay. D5S was separate from the other clusters with about 60% silt/clay. Finally, DDM and DDN formed a distinct cluster with a mean silt/clay content of about 50%.

The Fowlkes Mallows statistics and probabilities for Comtree 1 are presented in Appendix 4. The program tested the hypothesis that the reference (i.e. geographic distance between stations) and the random (abundance) dendrograms were different.

a) In the Comtree 1 analysis for 1982, which compared the abundance dendrogram with the geographic distance "reference" dendrogram, there were no significant linkage levels. Therefore the hypothesis could not be rejected at any level, and the two dendrograms were different. For example, at the 12th linkage level, the three clusters in the two dendrograms were:

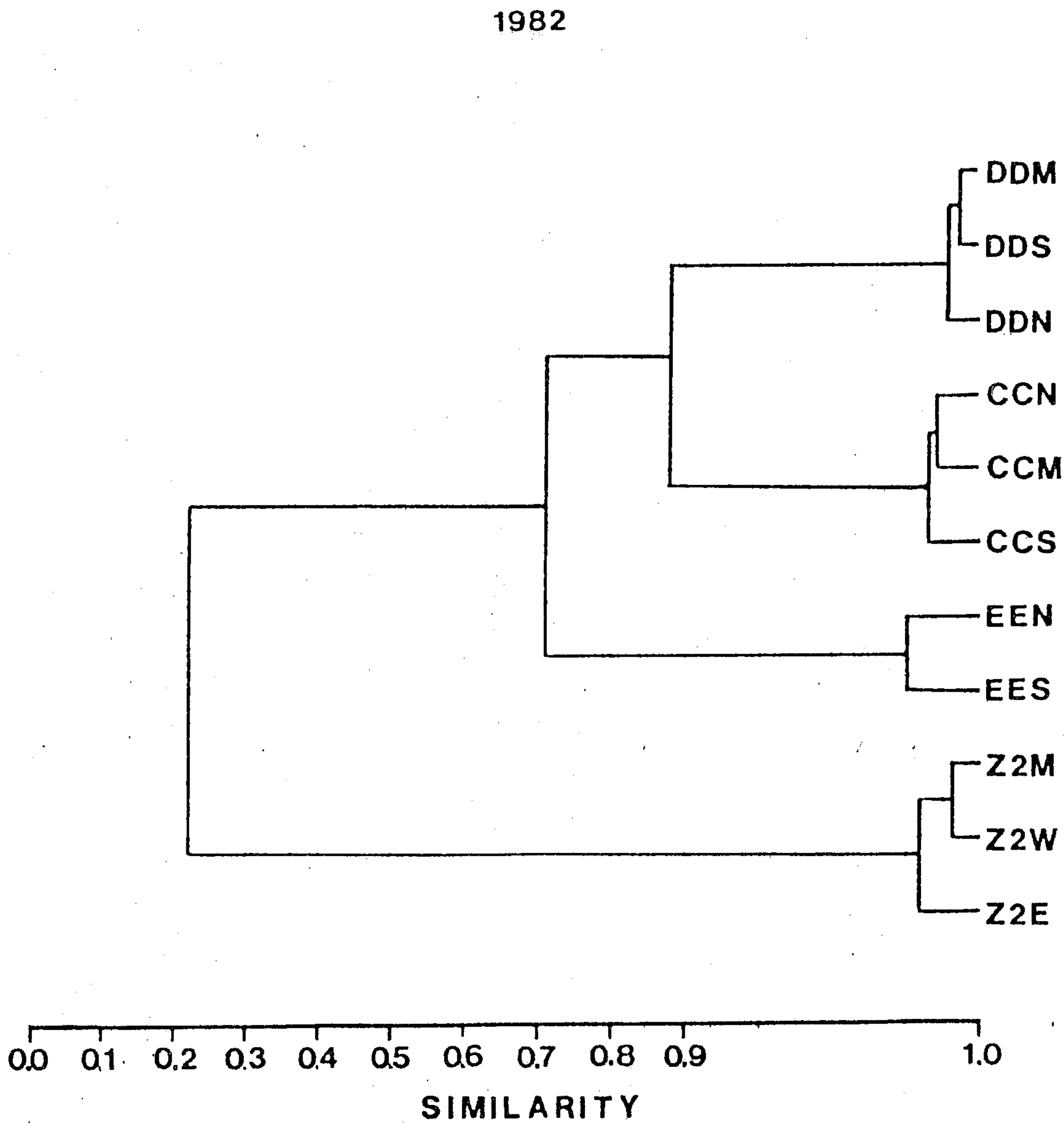


Figure 7. Dendrogram illustrating the cluster analysis of geographic distance between stations in Alice Arm, 1982. The elongated section between 0.9 and 1.0 on the similarity scale indicates that most of the linkage levels were at greater than 0.95. The modified scale facilitates this illustration.

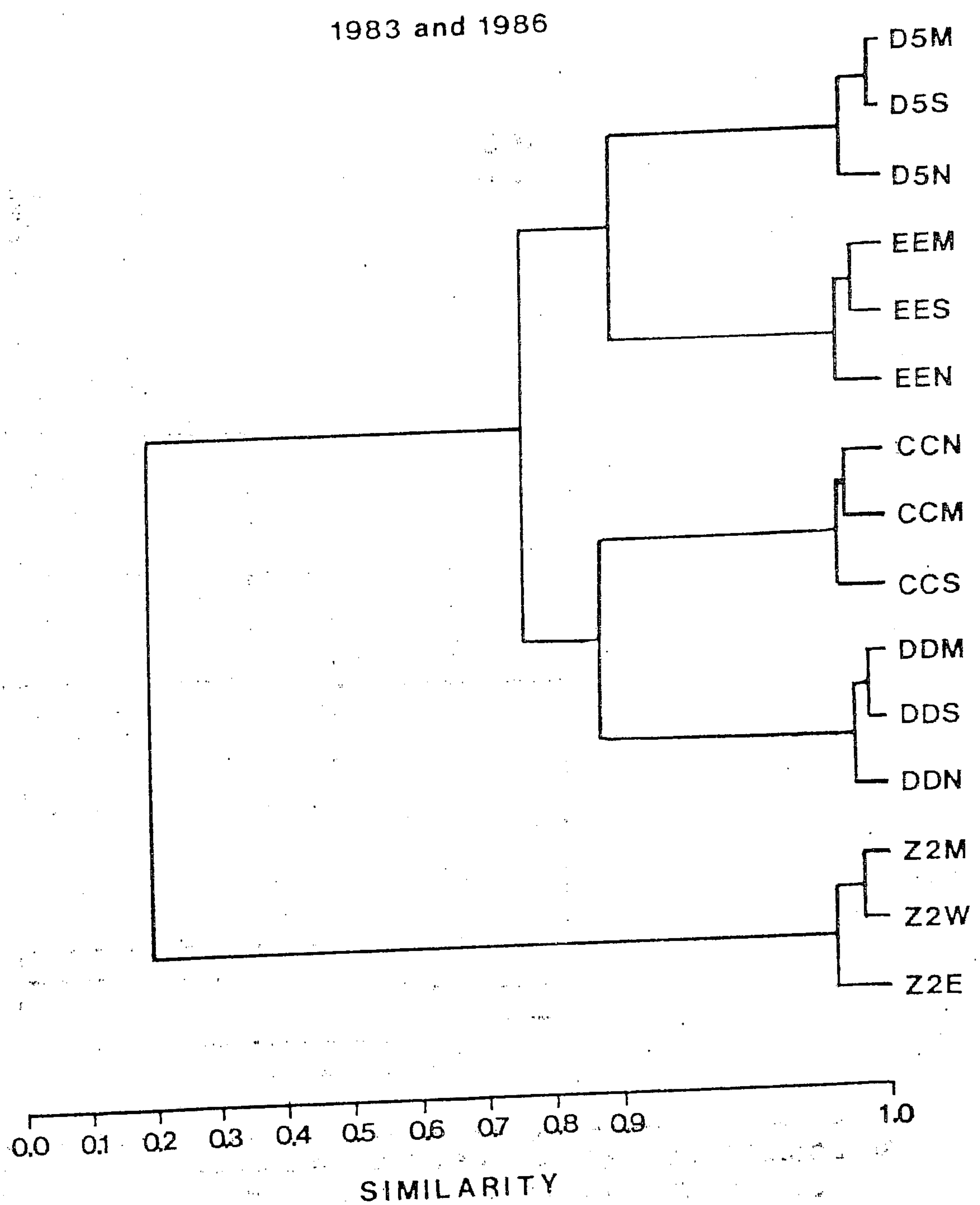


Figure 8. Dendrogram illustrating the cluster analysis of geographic distance between stations in Alice Arm for 1983 and 1986. The elongated section between 0.9 and 1.0 on the similarity scale indicates that most of the linkage levels were at greater than 0.95. The modified scale facilitates this illustration.

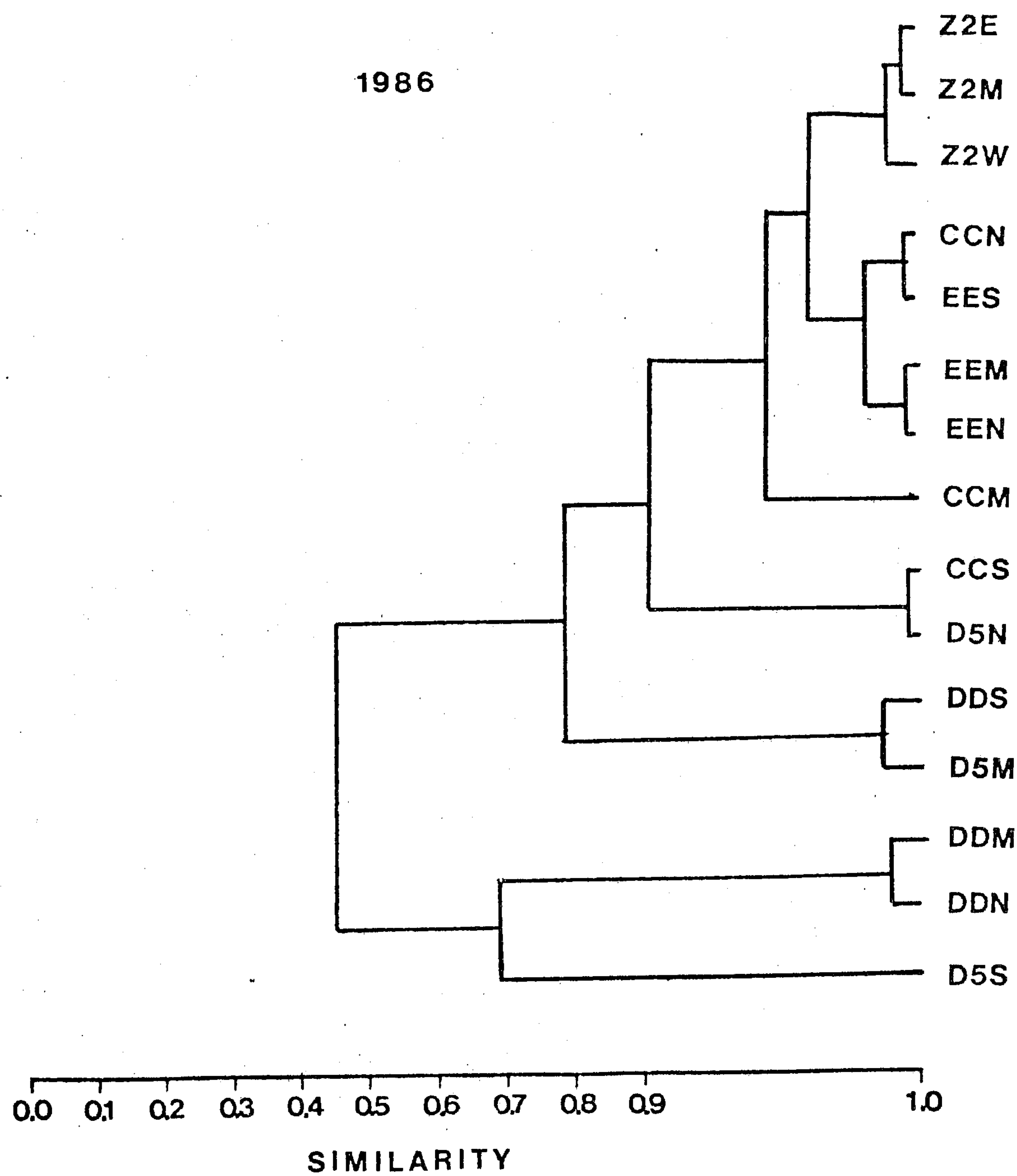


Figure 9. Dendrogram illustrating the cluster analysis of percent silt/clay in the sediment for each station in Alice Arm in 1986. The elongated section between 0.9 and 1.0 on the similarity scale indicates that most of the linkage levels were at greater than 0.95.

Reference (geographic)	Random (abundance)
1) Z	Z+E+DDN+CCS
2) C+D	CCM+DDM+CCN
3) E	DDS

In the abundance dendrogram for 1982 the E transect plus DDN, CCS and DDS were more similar to the Hastings Arm transect (Z) than to the three remaining Alice Arm stations CCM, DDM and CCN.

b) In the Comtree 1 abundance vs geographic analysis for 1983 there were three significant linkages at levels 8 or less. The hypothesis can be rejected at these three linkages. This reflects the within-group clustering of the the three sampling transects Z, E and D5 in both the abundance dendrogram and the geographic reference dendrogram. However, at linkage levels from 9 to 14 the hypothesis that the two dendrograms are different cannot be rejected. For example, at linkage 12, the three clusters in the two dendrograms do not agree:

Reference (geographic)	Random (abundance)
1) Z	Z+E
2) C+D	C+D
3) E+D5	D5

In the 1983 abundance dendrogram the E transect was more similar to the Hastings Arm transect (Z) than to the other geographically closer transects in Alice Arm (C, D and D5).

c) In 1986 there were no significant linkages in the comparison of the random (abundance) dendrogram with the reference (geographic) dendrogram. Therefore the hypothesis that the two dendrograms are different cannot be rejected at any linkage level. For example, the 12th linkage level differentiated three clusters as follows:

Reference (geographic)	Random (abundance)
1) Z	Z
2) C+D	C+D+D5
3) E+D5	E

In the 1986 abundance dendrogram the E transect was more similar to the other Alice Arm transects (C, D and D5) than to the Hastings Arm transect (Z). This is in contrast to the 1982 and 1983 abundance dendrogram results.

d) In 1986 there was one significant linkage (level 2) in the comparison of the random (abundance) dendrogram and the reference (%silt/clay) dendrogram. However, from linkage level 3 to 14 the hypothesis that the two dendrograms were different could not be rejected. For example, at linkage level 12 the three clusters for each dendrogram were as follows:

	Reference (geographic)	Random (abundance)
1)	Z	Z+E+C+D5N+D5M+DDS
2)	C+D	DDM+DDM
3)	E+D5	D5S

In 1986 it can be concluded that the sediment silt/clay content had little effect on the clustering of stations based on the abundance data.

Comtree 2: The Fowlkes Mallows statistics and probabilities for Comtree 2 are presented in Appendix 5. The program tested the null hypothesis that two abundance dendrograms were the same. For this study, the same linkage levels were compared for each dendrogram (i.e. L1 vs L1). For the comparisons of 1983 or 1986 with 1982, stations EEM and transect D5 had to be excluded. The "shortened" dendrograms for 1983 and 1986 are not shown as figures, but the linkages are included in Appendices 5a and 5b.

a) The comparison of the abundance dendrograms for 1982 and 1983 illustrates that the hypothesis can be rejected at levels 6, 7 and 9 out of 10 linkages. The high p values at the lower linkage levels reflects the fact that the within-group clustering of the Z and E transects is similar in both years. However, as the linkage levels increase the p values decline. For example, at linkage level 9 the two clusters are as follows (see Figure 4 and Appendix 5a):

	1982	1983
1)	CCM+DDM+CCN	C+D
2)	Z+E+DDN+CCS+DDS	Z+E

b) The comparison of the abundance dendrograms for 1982 and 1986 shows that the hypothesis can be rejected at levels 8 and 9 out of 10 linkages. The pattern of p values is similar to that for the comparison of 1982 and 1983 (see above). At the 9th linkage level the two clusters are (see Figure 4 and Appendix 5b):

	1982	1986
1)	CCM+DDM+CCN	C+D+E
2)	Z+E+DDN+CCS+DDS	Z

c) For the comparison of the abundance dendrograms for 1983 and 1986 the entire 15 stations were included. The hypothesis that the two dendrograms were the same could be rejected at one (level 13) out of 14 linkages. The p values were high at the lower linkage levels, reflecting similarities in the within-group clustering of the Z, E and D5 transects for both years. However, at linkage level 13 the two clusters were (Figures 5 and 6):

	1983	1986
1)	C+D	C+D+D5+E
2)	D5+E+Z	Z

DISCUSSION

The succession of species in the disturbed and reference stations in Alice Arm and Hastings Arm reflects the long-term recovery process of the deep benthic infauna from an 18-month mine tailings discharge. The study can be of great use in the examination of discharge practices and potential sites for other mining operations.

The changes in number of taxa and abundance at each station from 1982 to 1986 reflect obvious and extensive recovery in the most heavily affected stations (CCN, CCM and DDM) in Alice Arm. By 1986 the abundance of individuals at these stations was actually 100% greater than in the other stations within the respective transects, suggesting that an "overshoot" had ocurred. However, the picture is complicated by the general decline in species number and abundance in 1983 over 1982. The reduction was most noticeable in the E and Z transects - the deepest stations in the study area. In the Z transect the abundances continued to decline in 1986. The cause of these declines is not discernible from the current study.

The succession of species in Alice Arm is of interest for the interpretation of the long-term effects of mine tailings on a benthic population. Species which were common in all three cruises (1982 to 1986) include: the carnivorous polychaete *Nephtys cornuta cornuta*; the gastropod *Cyclichna attonsa*; and the bivalves *Nucula tenuis*, *Psephidia lordi* and *Yoldia martyria*. Several early colonizer species common in 1982 and 1983 were replaced by related species or declined considerably by 1986. For example, the amphipod *Eudorella pacifica* had been replaced mainly by *E. emarginata* in 1986, whereas the bivalves *Macoma carlottensis* and *Cooperella subdiaphana*, and the polychaete *Myriochele oculata*, which were common in 1982 and 1983 (Kathman *et al*. 1984), had declined or disappeared by 1986.

The succession of species in the most heavily affected stations in the C and D group is of most interest in the examination of benthic recovery. In 1982 there were so few specimens and species in the CCN, CCM and DDM group that these stations were virtually defaunate. The changes in 1983 represented a substantial improvement. Species which were common in these three stations in 1983 included the polychaetes *Levinsenia gracilis*, *Decamastus sp*. and *Mediomastus sp*., all of which had declined or disappeared by 1986; the gastropod *Limacina sp*.; and the bivalves *Transenella tantilla* (which was not present in 1986) and *Nucula tenuis*. The 1983 data set could therefore be considered to represent the colonizing phase, with a substantial increase in species diversity and density over 1982 (Kathman *et al*. 1984). It should be noted that the most heavily affected stations in the deep middle trough of Alice Arm (CCM and DDM) had not recovered very much by 1983, compared with CCN. Therefore, these three stations did not cluster together in 1983 as they had in 1982.

In 1986, the same three stations (CCN, CCM and DDN) contained an almost entirely different set of species from the 1983 data set. By 1986, the three stations had again formed a distinct cluster (as they had in 1982). This was due to a dramatic increase in the number of taxa and specimens in CCM and DDM, and less improvement in CCN, which tended to even up the faunal composition across these three stations. The most abundant species in the cluster in 1986 was the polychaete *Galathowenia oculata*, which was not common in the other stations, and was not even identified in 1982 and 1983. The reemergence of this cluster of three stations four years after the termination of the tailings diposal suggests that some long-term changes may have ocurred in the benthic fauna.

The Comtree I analyses indicate that the within-group clustering of the Z, E and D5 transects could be related to geographic proximity of stations, i.e. there is no discernable outside influence that disturbs the expected groupings. However, the clustering within the C and D stations, and particularly of the three most affected stations (CCN, CCM and DDM) in 1982 and 1986 could not be related to geographic proximity of the stations, or sediment silt/clay characteristics. The untested hypothsis is that the clustering within these transects was related mainly to the ongoing impact of the 18 month mine tailings discharge from AMAX Kitsault molybdenum mine. Early evidence suggested heavier deposition at CCN and CCM than at CCS, which provides circumstantial evidence for the basis of the pattern observed in the benthos. It should be noted that samples at CCS were taken from slightly shallower water (10-20m) than other sites in the C transect.

Other indications of impact from the mine tailings include increased levels of lead and molybdenum in the gills of commercial crabs in Alice Arm, but not in Hastings Arm (Thompson *et al*. 1986). Jones and Ellis (1975) illustrated the effects of mine tailings impact on a polychaete species (*Ammotrypane aulogaster* = *Ophelina breviata*) in another Northern B.C. fjord. They concluded that the densities, weights and lengths of this predominant species were inversely related to the rate of tailings deposition. In her MSc thesis (1974) Jones recorded abnormally high seasonal flux in biomass and density of fauna in a fjord receiving mine tailings, compared with studies from Puget Sound (Lie and Evans 1973) and Satellite Channel (Ellis unpub.). She also concluded that a reasonably diverse benthic community can survive under conditions of light tailings deposition. Anderson and Mackas (1986) indicated that there was no evidence of measureable physiological damage in deep zooplankton in Alice Arm.

Kathman *et al*. (1984) indicated that by 1983 the taxa in the affected stations of Alice Arm had fairly balanced numbers of molluscs and polychaetes, with a marginal predominance of molluscs. In a three year study of benthic recolonization of natural sediments, Arntz and Rumohr (1982) found that initially polychaetes predominated the fauna, followed by fairly equal proportions of molluscs and polychaetes 11 months after recolonization. Winiecki and Burrell (1985) carried out a similar study to examine the progression of species in an experimental container in Boca de Quadra, a fjord in south-east Alaska. They found that the crustaceans predominated initially, followed by polychaetes which dominated up until the end of the study at 78 weeks. Winiecki and Burrell (1985) also pointed out the complicating factor of seasonal changes in abundance of different groups, and suggested that polychaetes tend to dominate in winter, whereas crustaceans dominate in summer. The possible reason given by the author for the fact that molluscs did not play an important role in the Boca de Quadra experiments was that there were few molluscs present in the fjord for recruitment. All Alice Arm surveys reported here took place in October so as to avoid seasonal differences in species abundances.

In Alice Arm in 1986, the polychaetes were slightly less abundant (1303) in the three heavily affected stations than the molluscs (1662), with 412 echinoderms and 245 crustaceans. The number of polychaete species increased from 33 in 1983 to 41 in 1986, whereas mollusc species increased from 25 to 27. These numbers suggest that the proportions of these two dominant groups have not changed much since 1983, although the species composition has. This agrees with the results of Arntz and Rumohr (1982), since molluscs continued to dominate numerically in their experimental containers from 11 months to the end of the three year study. Other work on potential toxins in the sediments, uptake of contaminants by crabs, and epibenthic trawl studies will be reported elsewhere. The results of the epibenthic trawls suggested some improvement in the fauna close to the original outfall, but with still substantially lower numbers of invertebrates and fish genera than was reported in 1978 (D. Goyette, Environmental Protection Service, personal communication).

SUMMARY

The current study (1982 to 1986) suggests that the AMAX Kitsault mine tailings deposition in Alice Arm was extremely harmful to the fauna in the direct path of the plume, particularly in the deepest parts of the trough. This can be presumed to be related mainly to the smothering effect of the tailings.

Four years after the cessation of tailings deposition, the recovery in benthic taxa number and abundance and the balance of taxonomic groups appears to have been normal and complete. This indicates that there were no long-term toxic effects on the benthic infauna from the deposited tailings. However, the species composition of the most affected stations was still distinct from surrounding stations, suggesting that either long term changes may have ocurred in the benthic habitat at these locations, making them distinct in nature from their surroundings, or that species succession is still taking place at the most heavily affected sites. The value of full taxonomic analysis and statistical evaluation of the results is especially noticeable in these results.

ACKNOWLEDGEMENTS

The authors extend their thanks to D. Moore and the crew of the C.S.S. TULLY, Department of Fisheries and Oceans Institute of Ocean Sciences for technical assistance during the 1986 field sampling program. The authors also thank D. Bright, Biology Department, University of Victoria.

The identifications of benthic invertebrates were carried out by E.V.S. Consultants Ltd. of Sidney, B.C. and their associates. The authors thank participants in this project, especially Dr. P. Chapman, S. Cross and P. Tchaplinsky for their management and participation, and the staff for field assistance and the drafting of many final figures. Thanks are given again to all participants in the study from 1982 to 1986.

REFERENCES CITED

Anderson, E.P. and D.L. Mackas. 1986. Lethal and sublethal effects of a molybdenum mine tailing on marine zooplankton: mortality, respiration, feeding and swimming behaviour in Calanus marshallae, Metridia pacifica and Euphausia pacifica. Mar. Envir. Res. 19: 131-155.

Arntz, W.E. and H. Rumohr. 1982. An experimental study of macrobenthic colonization and succession, and the importance of seasonal variation in temperate latitudes. J. Exp. Mar. Biol. Ecol. 64: 17-45.

Bray, J.R. and J.T. Curtis. 1957. An ordination of the upland forest communities of southern Wisconsin. Ecol. Monogr. 27:325-349.

Jones, A.A. 1974. Effects of mine tailing on benthic infaunal composition in a British Columbia inlet: with specieal reference to sampling, instrumentation, and the biology of Ammotrypane aulogaster (Polychaeta, Opheliidae). MSc thesis, University of Victoria, Victoria, B.C.

Jones, A.A. and D.V. Ellis. 1975. Sub-obliterative effects of mine-tailings on marine infaunal benthos II: effect on the productivity of Ammotrypane aulogaster. Water, Air and Soil Pollution 5: 299-307.

Kathman, R.D., R.O. Brinkhurst, R.E. Woods and D.C. Jeffries. 1983. Benthic studies in Alice Arm and Hastings Arm, B.C. in relation to mine tailings dispersal. Can. Tech. Rep. Hydrogr. Ocean Sci. 22:30 p.

Kathman, R.D., R.O. Brinkhurst, R.E. Woods and S.F. Cross. 1984. Benthic studies in Alice Arm and Hastings Arm, B.C. following cessation of mine tailings disposal. Can. Tech. Rep. Hydrogr. Ocean Sci. 37:57p.

Lie, U. and R.A. Evans. 1973. Long-term variability in the structure of subtidal benthic communities in Puget Sound, Washington, USA. Mar. Biol. 21: 122-126.

Thompson, J.A.J., M.C. Nassichuk, D.W. Paton, B.J. Reid and M.A. Farrell. 1986. Examination of tissue metal burdens and metal-binding proteins in the golden king crab (Lithodes aequispina Benedict) from Alice Arm and Hastings Arm, British Columbia. Can. Tech. Rep. Fish. Aquatic Sci. 1440: 44p.

Winiecki, C.I. and D.C. Burrell. 1985. Benthic community development and seasonal variations in an Alaskan fjord. In: Proceedings of the 19th European Marine Biology Symposium (Ed: P.E. Gibbs). Cambridge University Press. pp. 299-309.

Appendix 1. Taxa identified from benthic surveys in Alice Arm in 1982, 1983, and 1986. Brackets denote taxonomic synonyms from Austin (1985). Asterisks denote taxa not included by Austin (1985)

TAXON	SURVEY YEAR 1982	1983	1986
PORIFERA			
Hexactinellida			
Rossellidae	x		
CNIDARIA			
Anthozoa			
Pennatulacea		x	
Virgularidae			
Virgularia cf. tuberculata	x		x
Edwardsiidae			
Edwardsia sipunculoides		x	
PLATYHELMINTHES			
Turbellaria			x
Polycladida	x		x
NEMERTEA			
Nemertea	x		x
Anopla			
Lineidae			
Cerebratulus sp.	x	x	x
Micrura alaskensis	x		
Enopla			
Hoplonemertea	x		
NEMATODA			
Nematoda indet.	x		
ANNELIDA			
Oligochaeta			
Tubificidae			
Limnodriloides sp.	x		
L. victoriensis	x		
Polycheata			
Polynoidae			
Polynoidae indet.			x
Antinoella? sarsi*		x	
Eunoe sp.		x	
Gattyana treadwelli		x	
Sigalionidae			
Pholoe minuta [P. caeca]	x	x	x

Appendix 1. Continued

TAXON	1982	1983	1986
Hesionidae			
Gyptis brevipalpa	x	x	
Trochochaetidae			
Ancistrosyllis sp.		x	
A. groenlandica	x	x	x
Phyllodocidae			
Eteone (Mysta) sp.	x		
E. columbiensis*	x		
Phyllodoce groenlandica	x		
[Anaitides groenlandica]			
Nephtyidae			
Nephtys sp.			x
N. cornuta cornuta	x	x	x
N. punctata	x	x	x
Aglaophamus sp.			x
A. malmgreni*	x	x	x
Gonianidae			
Glycinde armigera	x		x
Goniada annulata	x	x	x
Sphaerodoridae			
Sphaerodoropsis sphaerulifer	x		
Lumbrineridae			
Lumbrineridae indet.			x
Lumbrineris sp.	x		x
L. luti	x	x	x
[L. lutei]			
Paraninoe simpla	x	x	x
[P. simpta]			
Orbiniidae			
Leitoscoloplos pugettensis	x	x	x
L. elongatus	x	x	
Paraonidae			
Levisenia gracilis*	x	x	x
Aricidea suecica		x	x
[Allia nolani]			
A. nr. cerruti*			x
Cirrophorus branchiatus	x		
A. lopezi lopezi	x		
[A. lopezi]			
Dorvilleidae			
Schistomeringos sp.	x		
Spionidae			
Polydora sp.		x	
Prionospio sp.	x		
P. cirrifera	x		
P. steenstrupi	x	x	x
Spiophanes sp.	x	x	x
S. kroyeri	x	x	x
Pseudopolydora kempi?	x		

Appendix 1. Continued

TAXON	1982	1983	1986
Trochochaeta multisetosa	x		
Chaetopteridae			
Spiochaetopterus costarum	x		
Cirratulidae			
Cirratulidae indet.	x		x
Caulleriella hamata	x		
C. cf. hamata	x		
Tharyx multifilis		x	x
Chaetozone setosa	x	x	x
Cossuridae			
Cossura longocirrata			x
C. soyeri	x		
Flabelligeridae			
Brada sp.	x		
B. villosa	x	x	x
Flabelligera affinis			x
Pherusa sp.	x		
P. plumosa			x
Syllidae			
Exogone sp.1	x		
E. sp.2	x		
E. gemmifera	x		
[E. naidina]			
Eusyllis cf. blomstrandi	x		
Syllis sp.	x		
S. alternata	x		
Sternaspidae			
Sternaspis scutata	x	x	x
Opheliidae			
Ophelina breviata	x		
Capitellidae			
Capitellidae indet.			x
Capitella capitata	x		
Heteromastus sp.	x		
H. filobranchus	x	x	x
Mediomastus sp.	x		
Decamastus sp.	x		
Maldanidae			
Maldanidae indet.	x		
Maldane glebifex	x	x	x
Praxillella gracilis			x
Rhodine sp.	x		
Oweniidae			
Owenia fusiformis	x		
Myriochele oculata	x	x	
Galathowenia* nr. oculata			x
Pectinariidae			
Pectinaria sp.	x		

Appendix 1. Continued

TAXON	1982	1983	1986
Amphictene moorei	x	x	x
Ampharetidae			
Ampharetidae indet.			x
Anobothrus gracilis	x		
Amage anops	x		
Ampharete finmarchica		x	x
Amphicteis sp.		x	
A. cf. scaphobranchiata	x		
Sosanopsis cf. hesslei	x		
Terebellidae			
Pollycirrus sp.	x		
Artacama conifera			x
Pista cristata	x		
Trichobranchidae			
Terebellides sp.	x		
T. stroemi	x	x	x
Sabellidae			
Euchone sp.	x		
E. hancocki?			x
Jasmineira pacifica	x		
MOLLUSCA			
Aplacophora			
Aplacophora indet.	x		x
Crystallophrissonidae			
Crystallophrisson sp.		x	x
Chaetodermatidae			
Chaetoderma sp.		x	
Gastropoda			
Gastropoda indet.			x
Columbellidae			
Mitrella gouldi			x
Rissoinidae			
Rissoina newcombei		x	
Vitrinellidae			
Vitrinella sp.	x		
V. columbiana			x
Naticidae			
Natica russa			x
[N. clausa]			
Muricidae			
Ocenebra interfossa		x	x
Pyramidellidae			
Odostomia tenuisculpta			x
Turbonilla sp.	x		
Cylichnidae			
Cylichna alba		x	x
C. attonsa	x	x	x
Atyidae			
Haminoea vesicula			x

Appendix 1. Continued

TAXON	1982	1983	1986
Limacinidae			
Limacina sp.	x		
Thaididae			
Buccinidae			
Buccinum sp.	x		
Gastropteridae			
Gastropteron pacificum	x		
Bivalvia			
Nuculidae			
Nucula tenuis	x	x	x
Nuculanidae			
Nuculana sp.		x	
N. hamata			x
N. hindsii*		x	
N. minuta*	x		
Yoldiidae			
Yoldia amydalea	x		x
Y. hyperborea		x	x
[Y. hyperboria]			
Y. myalis	x		
Y. scissurata		x	
Y. thraciaeformis		x	x
Y. beringiana	x		
Y. martyria	x	x	x
Mytilidae			
Mytilus edulis			x
Lucinidae			
Lucina tenuisculpta		x	
Thyasiridae			
Axinopsida serricata			x
Thyrasira flexuosa			x
[T. barbarensis]			
Ungulidae			
Diplodonta orbella	x		
Cardiidae			
Clinocardium nuttallii		x	
Tellinidae			
Macoma sp.	x		
M. calcarea		x	
M. eliminata		x	
M. brota			x
M. carlottensis	x	x	x
M. cf. nasuta	x		
Veneridae			
Transenella tantilla	x		
Psephidia lordi		x	x
Cooperellidae			
Cooperella sp.	x		
C. subdiaphana		x	x

Appendix 1. Continued

TAXON	1982	1983	1986
Myidae			
Mya arenaria		x	
Hiatellidae			
Hiatella arctica	x		
Scaphopoda			
Dentallidae			
Dentalium agassizii		x	
D. pretiosum		x	x
D. rectius*	x	x	x
Cadulidae			
Cadulus californicus [Polyschides californicus]	x		
C. tolmiei		x	x
ARTHROPODA			
Crustacea			
Crustacea indet.			x
Ostracoda			
Ostracoda indet.		x	
Myodocopa undesc.			x
Halocyprididae			
Spinoecia spinirostris			x
Philomdidae			
Scleroconcha trituberculatus			x
Copepoda			
Calanidae			
Neocalanus plumchrus			x
Metridiidae			
Metridia okhotensis			x
M. pacifica			x
Mysidacea			
Mysidae			
Holmeisiella anomola		x	
Pseudomma truncatum	x		
Cumacea			
Leuconidae			
Leucon sp.	x		
L. subnasica		x	
Eudorella sp.	x		
E. emarginata			x
E. pacifica		x	
Diastylidae			
Diastylis aspera?			x
D. pellucida		x	
D. paraspinulosa [D. parasinulosa]			x
Nannastacidae			
Caampylaspis? papillata [C. rubromacullata]	x		
Tanaidacea			

Appendix 1. Continued

TAXON	1982	1983	1986
Leptognathiidae			
Leptognathia sp.	x		
Amphipoda			
Corophiidae			
Corophium acherusicum			x
Eusiridae			
Eusiridae frag.			x
Rhacotropis? sp.	x		
Lysianassidae			
Cyphocaris challengerii	x		
Menigratopsis sp.			x
Koroga megalops	x	x	x
Pachynus barnardi	x	x	
Orchomene obtussa	x		
Oediceritidae			
Oedicerotidae indet.	x		x
Oediceros sp.			x
[Oediceroides sp.]			
Bathymedon sp.			x
B. pumilis	x	x	
Monoculodes sp.		x	x
M. cf. emarginatus	x	x	
Phoxicephalidae			
Foxiphalus obtusidens			x
Harpiniopsis? sp.			x
Heterophoxus oculatus			x
Paraphoxus oculatus	x		x
Synopiidae			
Syrrhoe sp.			x
Hyperiidae			
Hyperia sedusarum	x		
[H. medusarum]			
Parathemisto sp.	x		
P. pacificus	x		
Decapoda			
Decapoda indet.	x		
Pinnotheridae			
Pinnixa cf. eburna			x
SIPUNCULA			
Sipuncula indet.			x
Golfingiidae			
Golfingia sp.			x
ECHIURA			
Echiura indet.	x		x
BRYOZOA			
Bryozoa indet.		x	

Appendix 1. Continued

TAXON	1982	1983	1986
ECHINODERMATA			
Ophiuroidea			x
Ophiuridae			
Ophiura sp.	x		x
O. sarsi	x		
O. leptoctenia	x	x	x
Amphiuridae			
Amphiuridae indet.			x
Amphioplus strongyloplax			x
Echinoidea			
Strongylocentrotidae			
Strongylocentrotus pallidus			x
Holothuroidea			
Holothuroidea indet.			x
Chirodotidae			
Chirodota albatrossi	x	x	x
Molpadiidae			
Molpadia intermedia	x	x	x
TOTAL TAXA	123	74	110

Appendix 2. Alice Arm species abundance data for 1986.

TAXON	CCN 1	CCN 2	CCM 1	CCM 2	CCS 1	CCS 2	DDN 1	DDN 2	DDM 1	DDM 2	DDS 1	DDS 2	D5N 1	D5N 2	D5M 1	D5M 2	D5S 1	D5S 2	EEN 1	EEN 2	EEM 1	EEM 2	EES 1	EES 2	Z2E 1	Z2E 2	Z2M 1	Z2M 2	Z2W 1	Z2W 2
CNIDARIA																														
Virgularia cf. tuberculata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0
PLATYHELMINTHES																														
Polycladida	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0
Turbellaria	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NEMERTEA																														
Nemertea	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Cerebratulus sp.	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
POLYCHAETA																														
Polynoidae	0	0	0	1	0	1	0	0	1	0	2	1	0	0	0	0	1	0	0	0	0	0	2	1	0	0	0	0	0	0
Antinoella sarsi	0	0	0	0	0	1	0	0	0	1	1	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0
Pholoe minuta	0	0	1	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Gyptis brevipalpa	0	0	0	0	0	0	0	0	1	1	0	0	1	2	4	1	1	1	0	0	0	0	3	0	0	0	0	0	0	0
Ancistrosyllis groenlandica	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	2	0	0	0	0	0	0	0	0	0	0
Nephtys sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0
Nephtys cornuta cornuta	13	5	4	6	11	16	12	17	22	23	17	54	5	15	12	4	16	11	1	11	9	10	13	13	5	2	0	0	1	0
Nephtys punctata	0	1	0	1	0	1	0	0	0	0	0	0	3	2	0	1	1	0	1	0	1	1	1	2	0	1	1	2	1	2
Aglaophamus sp.	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aglaophamus malmgreni	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	0	0	2	1	0	0	0	0	0	0	0
Glycinde armigera	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	1	0
Goniada annulata	0	0	0	0	0	0	0	0	1	0	2	2	1	0	3	1	0	1	0	1	0	0	0	0	0	0	1	0	0	0
Lumbrineridae	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Paraninoe simpla	0	0	0	0	1	2	0	0	0	0	0	1	2	1	0	3	0	0	0	0	0	2	0	3	0	2	1	1	1	1
Lumbrineris sp.	0	0	1	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Lumbrineris luti	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	2	2	1	0	0	0	0
Leitoscoloplos pugettensis	1	0	0	1	0	1	1	0	0	1	0	1	0	0	0	1	1	0	0	1	0	0	0	1	0	0	0	0	0	0
Levisenia gracilis	2	0	3	2	5	4	4	2	1	3	3	14	1	2	5	1	5	8	4	0	7	0	1	0	0	3	1	0	1	0
Aricidea (Allia) seucica	0	2	0	0	0	0	3	2	1	3	0	20	3	12	10	6	5	4	1	5	3	2	4	4	1	0	0	0	0	0
Aricidea nr.cerruti	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0
Prionospio steenstrupi	1	1	2	3	5	6	7	8	2	1	12	9	1	4	7	6	4	3	1	1	1	3	1	7	0	0	0	1	0	0
Spiophanes sp. indet.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Spiophanes kroyeri	3	2	8	7	0	1	0	0	1	1	0	0	0	1	0	0	0	0	0	2	0	0	0	0	2	0	0	0	0	0
Cirratulidae	0	0	0	0	0	0	0	0	1	0	0	5	0	0	1	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0
Tharyx multifilis	0	1	0	1	1	0	0	1	0	0	0	0	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Chaetozone setosa	0	0	0	0	0	0	0	0	0	3	0	7	0	3	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0
Cossura longocirrata	0	1	0	0	0	1	0	1	0	1	0	6	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
Brada villosa	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
Flabelligera affinis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Pherusa plumosa	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Sternapsis scutata	2	2	1	3	1	0	8	6	17	28	1	8	2	1	5	2	2	0	1	2	1	1	1	1	2	2	2	1	0	1
Capitellidae	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Heteromastus filobranchus	0	0	1	0	1	0	0	1	0	2	0	0	1	0	1	1	0	0	3	1	2	1	1	0	0	1	1	0	1	2
Maldane glebifex	0	0	1	0	10	3	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Praxillella gracilis	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 2. continued

STATION

TAXON	CCN 1	CCN 2	CCM 1	CCM 2	CCS 1	CCS 2	DDN 1	DDN 2	DDM 1	DDM 2	DDS 1	DDS 2	D5N 1	D5N 2	D5M 1	D5M 2	D5S 1	D5S 2	EEN 1	EEN 2	EEM 1	EEM 2	EES 1	EES 2	Z2E 1	Z2E 2	Z2M 1	Z2M 2	Z2W 1	Z2W 2
Galathowenia nr. oculata	25	24	43	39	4	1	9	5	30	82	2	3	2	0	0	0	1	0	1	0	3	4	1	0	0	0	0	0	0	0
Amphictene moorei	0	0	1	0	0	1	3	0	0	3	0	0	1	1	4	3	0	0	2	0	2	2	0	0	0	0	0	0	0	0
Ampharetidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Ampharete finmarchica	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Artacama conifera	0	0	0	0	0	0	0	0	1	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Terbellides stroemi	0	0	1	0	0	0	2	2	2	4	1	1	1	2	7	1	2	2	3	1	0	1	1	0	0	0	1	0	0	1
Euchone ? hancocki	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
GASTROPODA																														
Gastropoda	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Mitrella gouldi	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vitrinella columbiana	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Natica clausa	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Natica russa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Ocenebra interfossa	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Odostomia tenuisculpta	1	0	1	0	1	1	1	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	1	0	0	0
Cylichna alba	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Cylichna attonosa	26	24	6	8	3	1	0	2	5	14	8	8	5	9	5	7	6	3	7	5	5	6	10	10	5	0	6	1	0	2
Haminoea vesicula	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
APLACOPHORA																														
Aplacophora	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	1	2	0	0
Crystallophrisson sp.	2	4	1	0	0	7	2	0	1	0	2	1	0	7	0	3	0	0	0	3	0	2	1	1	1	1	0	0	0	0
PELECYPODA																														
Nucula tenuis	8	3	5	6	7	2	3	9	2	2	9	7	3	4	6	5	9	3	9	11	7	11	34	26	37	39	39	30	13	20
Nuculana hamata	0	2	0	0	0	0	0	0	1	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Yoldia amygdalea	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	1	2	0	0	0	0
Yoldia hyperborea	3	0	0	0	0	0	0	0	0	4	2	2	3	0	1	1	3	7	0	0	2	0	1	0	0	0	1	2	0	0
Yoldia Thraciaeformis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Yoldia martyria	0	10	9	7	7	4	2	2	2	4	7	1	1	0	3	4	4	4	3	2	7	2	4	7	5	2	6	7	2	1
Mytilus edulis	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Axinopsida serricata	12	3	7	4	2	0	8	6	7	10	6	1	4	5	11	10	2	7	5	10	5	7	10	2	0	0	3	0	0	4
Thyrasira flexuosa	0	1	0	0	2	4	2	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	1	5	2	1	0	0	0
Macoma brota	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	1	0
Macoma carolottensis	0	0	1	0	0	0	1	0	2	0	0	1	0	0	0	0	1	0	0	1	0	0	0	3	1	0	0	0	0	0
Psephida lordi	0	3	1	0	0	0	7	1	8	20	2	0	7	1	2	6	1	3	58	88	62	60	173	96	6	0	3	0	13	4
Cooperella subdiaphana	0	0	0	4	2	0	1	0	1	5	1	1	1	3	3	1	1	0	0	1	0	0	3	0	1	0	1	0	0	0
SCAPHOPODA																														
Dentalium (=Rhabdus) rectius	0	0	2	0	0	0	0	0	1	0	0	1	1	0	0	1	0	0	0	0	1	0	1	1	1	1	2	0	2	2
Dentalium pretiosum	0	0	0	2	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Cadulus tolmiei	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0
CRUSTACEA																														
Crustacea	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ostracoda																														
Myodocopa undesc.	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spinoecia spinirostris	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Scleroconcha trituberculatus	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Copepoda																														
Copepoda	0	1	1	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Cumacea																														
Eudorella emarginata	7	2	5	8	7	9	17	23	12	15	3	11	4	1	0	11	8	9	9	4	6	8	3	1	6	5	1	1	0	3

TAXON	CCN 1	CCN 2	CCM 1	CCM 2	CCS 1	CCS 2	DDN 1	DDN 2	DDM 1	DDM 2	DDS 1	DDS 2	D5N 1	D5N 2	D5M 1	D5M 2	D5S 1	D5S 2	EEN 1	EEN 2	EEM 1	EEM 2	EES 1	EES 2	Z2E 1	Z2E 2	Z2M 1	Z2M 2	Z2W 1	Z2W 2
															STATION															
Diastylis aspera ?	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Diastylis paraspinulosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Amphipoda																														
Eusiridae frag.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Lysianassidae ?	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0
Menigratopsis sp.	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0
Koroga megalops	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Oediceratidae	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
Bathymeden sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Monoculodes sp.	0	0	1	0	0	0	0	0	0	0	1	0	0	1	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Foxiphalus obtusidens	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Harpiniopsis ?	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Heterophoxus occulatus	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Paraphoxus occulatus	0	0	0	1	0	0	0	1	0	0	0	0	0	1	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Syrrhoe sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Decapoda																														
Pinnixa sp. cf. eburna	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SIPUNCULA																														
Sipuncula	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0
Golfingia sp.	5	2	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ECHIURIDA																														
Echiura	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
ASTEROIDEA																														
Ctenodiscus crispatus	2	7	6	7	1	0	0	0	0	1	2	2	0	1	0	0	0	1	0	1	0	0	2	0	3	2	1	1	0	0
OPHIUROIDEA																														
Ophiuroidea	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ophiura sp.	9	22	11	10	0	0	4	13	12	11	8	6	1	9	3	2	1	0	2	3	4	0	58	8	0	0	0	0	0	0
Ophiura leptoctenia	3	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0
Ophiura sarsi	4	3	3	1	0	0	3	0	2	0	1	0	1	1	0	0	0	1	0	0	0	0	2	0	0	0	0	0	0	0
Amphiuridae	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Amphioplus strongyloplax	0	0	0	1	0	0	0	0	0	0	0	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
HOLOTHUROIDEA																														
Holothuroidea	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chirodota albatrossi	1	4	3	7	1	0	2	0	0	1	0	0	2	10	6	1	6	3	6	7	7	3	7	2	1	0	0	1	4	0
Molpadia intermedia	7	9	1	7	0	1	0	2	5	4	1	2	1	0	0	1	1	0	6	1	0	1	0	0	0	1	0	0	2	0

Appendix 3. Quality assurance/Quality control (QA/QC) for benthic invertebrates from sediments seived through a 1.0-mm screen.

SORTER	STATION	% ORGANISMS REMAINING
B. Burd	CCS-A	2.2 %
	DDM-B	0.3 %
	D5S-A	0 %
	EES-A	0.3 %
	Z2E-B	1.5 %

Appendix 4a. Fowlkes-Mallows statistics for comparison of 1982 abundance dendrogram with 1982 geographic reference dendrogram (K=#clusters in each dendrogram (1=reference, 2=abundance) at a given linkage level - i.e. K10=linkage 1).

CONDITIONAL ON CLUSTERS DEFINED BY PREVIOUS LEVEL
CONDITIONAL ON CLUSTER SIZES
(WALLACE MODIFIED VALUES ARE IN PARENTHESES)

K1	K2	FM STAT	MEAN	STD. DEV.	PROB.
10	10	0.000000	0.018182	0.133609	1.0000
			0.018182	0.133609	
9	9	0.000000	0.020183	0.094085	1.0000
			0.036364	0.131775	
8	8	0.250000	0.031001	0.087861	0.1111
			0.072727	0.127678	
7	7	0.141421	0.216109	0.076472	1.0000
			0.128565	0.114752	
6	6	0.113961	0.141843	0.054861	0.7143
			0.159545	0.109595	
5	5	0.250000	0.308128	0.057801	0.9333
			0.218182	0.091964	
4	4	0.372678	0.329036	0.042063	0.4000
			0.243935	0.088140	
3	3	0.374634	0.425656	0.055292	1.0000
			0.388257	0.090044	
		(0.310253	0.325295	0.099426)	
2	2	0.516129	0.559060	0.059062	1.0000
			0.563636	0.071698	
		(0.285714	0.355844	0.105840)	

Appendix 4b. Fowlkes-Mallows statistics for comparison of 1983 abundance dendrogram with 1983 geographic reference dendrogram (K=#clusters present at a given linkage level of dendrogram 1 (reference) and dendrogram 2 (abundance)).

CONDITIONAL ON CLUSTERS DEFINED BY PREVIOUS LEVEL
CONDITIONAL ON CLUSTER SIZES
(WALLACE MODIFIED VALUES ARE IN PARENTHESES)

K1	K2	FM STAT	MEAN	STD. DEV.	PROB.
14	14	0.000000	0.009524	0.097124	1.0000
			0.009524	0.097124	
13	13	0.000000	0.010989	0.073306	1.0000
			0.019048	0.096349	
12	12	0.288675	0.012248	0.061379	0.0385
			0.032991	0.093817	
11	11	0.400000	0.203901	0.051501	0.0606
			0.047619	0.093493	
10	10	0.462910	0.481686	0.057555	0.8000
			0.061721	0.091844	
9	9	0.353553	0.366885	0.055708	0.6222
			0.080812	0.090119	
8	8	0.421637	0.312544	0.051734	0.1111
			0.090351	0.090003	
7	7	0.501745	0.354374	0.059356	0.0714
			0.113888	0.087405	
6	6	0.605406	0.554999	0.064783	0.1905
			0.141582	0.083236	
5	5	0.557007	0.616318	0.070583	0.8000
			0.188080	0.075550	
4	4	0.501486	0.437714	0.072007	0.3000
			0.246885	0.073753	
3	3	0.727273	0.590979	0.106067	0.1667
			0.314286	0.068312	
		(0.666667	0.161905	0.083492)	
2	2	0.556294	0.624333	0.062917	1.0000
			0.564963	0.037534	
		(0.316228	0.329780	0.058675)	

Appendix 4c. Fowlkes-Mallows statistics for comparison of 1986 abundance data with the 1986 geographic reference dendrogram (K=# clusters present at any given linkage level - dendrogram 1 is the reference and 2 is the abundance dendrogram).

CONDITIONAL ON CLUSTERS DEFINED BY PREVIOUS LEVEL
CONDITIONAL ON CLUSTER SIZES
(WALLACE MODIFIED VALUES ARE IN PARENTHESES)

K1	K2	FM STAT	MEAN	STD. DEV.	PROB.
14	14	0.000000	0.009524	0.097124	1.0000
			0.009524	0.097124	
13	13	0.000000	0.010989	0.073306	1.0000
			0.019048	0.096349	
12	12	0.000000	0.012248	0.061379	1.0000
			0.028571	0.095895	
11	11	0.000000	0.016225	0.056759	1.0000
			0.042592	0.093463	
10	10	0.166667	0.019050	0.054502	0.1091
			0.057143	0.092620	
9	9	0.500000	0.388009	0.053684	0.1111
			0.076190	0.090755	
8	8	0.502519	0.526584	0.058956	0.8333
			0.094761	0.088296	
7	7	0.418121	0.419463	0.054169	0.5714
			0.113888	0.087405	
6	6	0.538138	0.490122	0.054145	0.1905
			0.141582	0.083236	
5	5	0.495434	0.513475	0.061242	0.6667
			0.173009	0.077236	
4	4	0.458333	0.388027	0.075965	0.2000
			0.228571	0.075645	
3	3	0.644658	0.509311	0.097431	0.3333
			0.354562	0.058427	
		(0.577350	0.230940	0.069769)	
2	2	1.000000	0.772235	0.166079	0.3333
			0.657143	0.059428	
		(1.000000	0.507143	0.085428)	

Appendix 4d. Fowlkes-Mallows statistics for the comparison of the 1986 abundance dendrogram with the 1986 %silt/clay dendrogram (K=# clusters present at any given linkage level -dendrogram 1 = reference, 2 = abundance).

CONDITIONAL ON CLUSTERS DEFINED BY PREVIOUS LEVEL
CONDITIONAL ON CLUSTER SIZES
(WALLACE MODIFIED VALUES ARE IN PARENTHESES)

K1	K2	FM STAT	MEAN	STD. DEV.	PROB.
14	14	0.000000	0.009524	0.097124	1.0000
			0.009524	0.097124	
13	13	1.000000	0.492387	0.062385	0.0110
			0.019048	0.096349	
12	12	0.666667	0.643245	0.060122	0.7051
			0.028571	0.095895	
11	11	0.500000	0.480034	0.052583	0.5606
			0.038095	0.095768	
10	10	0.333333	0.352730	0.057080	0.8909
			0.057143	0.092620	
9	9	0.267261	0.281107	0.054666	0.7556
			0.071270	0.091483	
8	8	0.363636	0.389561	0.056148	0.8611
			0.104762	0.087929	
7	7	0.231326	0.258429	0.068330	0.7143
			0.164682	0.078551	
6	6	0.247537	0.243523	0.068534	0.3810
			0.192372	0.081002	
5	5	0.268044	0.290670	0.077959	0.4667
			0.248716	0.081115	
4	4	0.267971	0.292426	0.032918	0.8000
			0.319864	0.064010	
3	3	0.414725	0.438884	0.031482	0.6667
			0.505211	0.072601	
		(0.341432	0.443861	0.082185)	
2	2	0.608696	0.591228	0.024702	0.6667
			0.657143	0.059428	
		(0.437500	0.507143	0.085428)	

Appendix 5a. Fowlkes-Mallows (FM) statistics for Comtree 2 analysis - 1982 and 1983. The dendrogram linkages are shown for the shortened 1983 abundance dendrogram.

LINKAGES FOR 1983 ABUNDANCE DENDROGRAM

LINKAGE	STA 1	STA 2	dissimilarity
1	9	10	0.22
2	9	11	0.30
3	4	6	0.41
4	7	8	0.53
5	1	4	0.57
6	1	5	0.62
7	1	3	0.65
8	7	9	0.73
9	1	2	0.78
10	1	7	0.89

FOWLKES-MALLOWS STATISTIC

LINKAGE	FM(L,L)	p (sig)	MEAN	VAR
1	0.00000	0.92000	0.8000E-01	0.7459E-01
2	0.40825	0.70667	0.2189E+00	0.7006E-01
3	0.75000	0.98667	0.3625E+00	0.6022E-01
4	0.56569	0.77333	0.4299E+00	0.3837E-01
5	0.45584	0.44000	0.5217E+00	0.4006E-01
6	0.31623	0.06667	0.5608E+00	0.4248E-01
7	0.31497	0.01333	0.6108E+00	0.3109E-01
8	0.54772	0.09333	0.7289E+00	0.1998E-01
9	0.57474	0.00000	0.8205E+00	0.1159E-01
10	1.00000	1.00000	0.1000E+01	0.0000E+00

ESTIMATES ARE BASED ON 75 SIMULATIONS.

Appendix 5b. Fowlkes-Mallows (FM) statistics for Comtree 2 analysis - 1982 and 1986. The dendrogram linkages are given for the "shortened" version of the 1986 abundance dendrogram.

LINKAGES FOR 1986 ABUNDANCE DENDROGRAM

LINKAGE	STA 1	STA 2	dissimilarity
1	9	10	0.30
2	1	2	0.35
3	7	8	0.41
4	4	5	0.46
5	1	4	0.50
6	9	11	0.51
7	1	6	0.55
8	1	3	0.58
9	1	7	0.70
10	1	9	0.73

FOWLKES-MALLOWS STATISTIC

LINK	FM(L,L)	p (sig)	MEAN	VAR
1	0.00000	0.89333	0.1067E+00	0.9658E-01
2	0.00000	0.53333	0.2468E+00	0.8505E-01
3	0.57735	0.88000	0.3368E+00	0.5889E-01
4	0.31623	0.26667	0.4456E+00	0.5252E-01
5	0.31980	0.21333	0.4798E+00	0.3401E-01
6	0.39528	0.26667	0.5452E+00	0.3038E-01
7	0.44096	0.17333	0.6013E+00	0.2789E-01
8	0.37463	0.00000	0.6984E+00	0.2180E-01
9	0.51613	0.00000	0.8453E+00	0.1397E-01
10	1.00000	1.00000	0.1000E+01	0.0000E+00

ESTIMATES ARE BASED ON 75 SIMULATIONS.

Appendix 5c. Fowlkes-Mallows (FM) statistics for Comtree 2 analysis - 1983 and 1986. The analysis utilized the full complement of stations (15 stations, 2 replicates).

FOWLKES-MALLOWS STATISTIC

LINKAGE	FM(L,L)	p (sig)	MEAN	VAR
1	0.00000	0.90667	0.9333E-01	0.8577E-01
2	0.50000	0.98667	0.1734E+00	0.5885E-01
3	0.28868	0.60000	0.2743E+00	0.6180E-01
4	0.22361	0.38667	0.3682E+00	0.4432E-01
5	0.30861	0.25333	0.4348E+00	0.3544E-01
6	0.47140	0.46667	0.4981E+00	0.3278E-01
7	0.47673	0.40000	0.5076E+00	0.2347E-01
8	0.46154	0.40000	0.4969E+00	0.1853E-01
9	0.41176	0.32000	0.4842E+00	0.1672E-01
10	0.37631	0.17333	0.5472E+00	0.2154E-01
11	0.50149	0.14667	0.6287E+00	0.1404E-01
12	0.64466	0.42667	0.6852E+00	0.1761E-01
13	0.55629	0.00000	0.7439E+00	0.1882E-01
14	1.00000	1.00000	0.1000E+01	0.0000E+00

ESTIMATES ARE BASED ON 75 SIMULATIONS.