

Benthic Studies in Alice Arm, B.C., Following Cessation of Mine Tailings Disposal

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TAILINGS DISPOSAL

by

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ABSTRACT

Kathman, R.D., R.O. Brinkhurst, R.E. Woods and S.F. Cross. 1984. Benthic studies in Alice Arm, B.C., following cessation of mine tailings disposal. Can. Tech. Rep. Hydrogr. Ocean Sci. 37, 1-57.

Benthic invertebrates were collected and identified from Alice Arm and Hastings Arm, British Columbia, in October 1983 to determine the effect of mine tailings on the benthic community approximately one year after discharge from the Amax/Kitsault mine ceased. Current benthic invertebrate data were compared with data from a study conducted prior to mine closure. Taxonomic analyses indicated that the total number of benthic invertebrates from a group of three stations showing maximum impact of mine tailings in 1982 increased fourfold, while invertebrates obtained from transects further down inlet in Alice Arm and Hastings Arm decreased two- to threefold compared to 1982. Hierarchical analyses indicated that sampling stations along the two transects nearest the discharge (Transects CC and DD) could no longer be clearly differentiated into the pattern observed in the 1982 data. The sites further down inlet (Transect D.5) showed only intermediate or fringe effects in 1983, and the area sampled nearest the mouth of Alice Arm (Transect EE) showed no apparent effects. Transects near the mouths of both Alice and Hastings Arms served as stable reference areas.

Key words: benthic invertebrates, mine tailings, fjords.

RESUMÉ

Kathman, R.D., R.O. Brinkhurst, R.E. Woods and S.F. Cross. 1984. Benthic studies in Alice Arm, B.C., following cessation of mine tailings disposal. Can. Tech. Rep. Hydrogr. Ocean Sci. 37, 1-57.

En octobre 1983, on a recueilli des invertébrés benthiques dans les bras Alice et Hastings (Colombie-Britannique) et on les a identifiés afin de déterminer l'incidence des stériles miniers sur la communauté benthique environ un an après que les déversements de la mine Amax/Kitsault eurent cessé. On a comparé les données actuelles sur les invertébrés benthiques avec celles générées par une étude menée avant la fermeture de la mine. Selon des analyses taxonomiques, le nombre total d'invertébrés benthiques obtenus à trois stations regroupées indiquant les effets les plus importants causés par les stériles en 1982 avait quadruplé, tandis que l'abondance des invertébrés échantillonnés dans des transects plus en aval dans les bras Alice et Hastings avait baissé de deux à trois fois en 1983. Des analyses hiérarchiques portent à croire que les stations d'échantillonnage le long des deux transects les plus près du point de déversement (transects CC et DD) ne pouvaient plus être différencierées clairement selon le schème observé en 1982. Les sites plus en aval (transect D.5) ne révélaient que des effets moyens ou faibles en 1983 et la région la plus

près de l'embouchure du bras Alice (transect EE) ne montrait aucun effet apparent. Les transects près des embouchures des bras Alice et Hastings ont servi de bonnes zones témoins.

Mots-clés: invertébrés benthiques, stériles miniers, fjords.

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E.V.S. Consultants sincerely thanks all the people who contributed to this project. Mr. Doug Moore, Ocean Ecology Division, and the crew of the C.S.S. Vector deserve special thanks for assistance during the sampling. The cooperation of EPS in supplying ship time and information is appreciated. Drs. Peter Chapman and Gary Vigers added valuable comments to the manuscript. Ms. Sarah Irwin coordinated and produced the report. Ms. Jane Saltman prepared the figures. Identifications and verifications were done by Dr. William Austin (Coelenterata, Nemertea, Mysidacea, Caudofoveata, Echinodermata), Mr. Stephen Cross (Amphipoda), Dr. Robert Reid (Gastropoda, Scaphopoda, Bivalvia), Mr. Eugene Ruff (Polychaeta), and Dr. Craig Staude (Amphipoda).

SUMMARY

Benthic invertebrate samples were collected in Alice Arm and Hastings Arm, British Columbia during October 1983. Composition, distribution and abundance of the benthos were analyzed to determine the effects of mine tailings on infaunal benthic communities one year after discharge ceased.

In 1982 Sites CCN, CCM and DDM, contained very few species and individuals, and clustered as a distinct grouping, indicating that these areas were severely stressed from the nearby tailings discharge. In 1983, however, all the sites on Transects CC and DD clustered together. Sites CCN, CCM and DDM could no longer be clearly differentiated, indicating that benthic invertebrates had been recolonizing the stressed areas.

The areas in Alice Arm most adversely affected by tailings deposition in 1982 (Sites CCN, CCM, DDM) had a 256% increase in number of taxa and a 367% increase in number of individuals during 1983. Most other sites in Alice and Hastings Arms had substantial decreases in both numbers of taxa and individuals for 1983. However, both density and diversity increased as distance from the former discharge increased.

Infaunal composition progressively changed from a dominance of polychaetes near the former discharge to a dominance of molluscs near the mouth of Alice Arm and in Hastings Arm. Polychaetes thus appear to be the primary colonizers in Alice Arm following cessation of mine tailings discharge.

INTRODUCTION

A study of the effects of mine tailings deposition on subtidal benthic invertebrates in Alice Arm was undertaken in October 1982 after 18 months of mine operation and tailings discharge (Kathman et al., 1983). The areas nearest the outfall had very few species and individuals, while the sites further down inlet had greater individual abundance 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 November 1982 the Amax/Kitsault mine closed indefinitely and all tailings discharge ceased. The same sites were then resampled in October 1983, 11 months after closure to determine what further changes had taken place in the infaunal benthic community.

The mine closure afforded an excellent opportunity to determine:

- a) the effects of mine tailings on the marine benthic community after cessation of tailings discharge,
- b) the identity and numbers of initial colonizers of the tailings, and
- c) infaunal benthic recolonization of the tailings.

TERMS OF REFERENCE

The overall objective of this study was to determine the composition, abundance and distribution of the benthic invertebrate fauna in Alice Arm and compare these results with findings from 1982. Specific tasks were to:

1. Collect infaunal benthic invertebrates from four transects in Alice Arm and one transect in Hastings Arm.
2. Sort and identify the benthic invertebrates retained by a 1.0 mm mesh screen.
3. Perform hierarchical (cluster) analysis on the taxonomic data, ensuring comparable analytical techniques for 1982 and 1983.
4. Prepare a reference collection of the benthic species identified, to be deposited with Ocean Ecology Division, Institute of Ocean Sciences.
5. Prepare a technical report incorporating the above information to determine whether changes have occurred in the Alice Arm benthic community.

METHODS

Sampling

Sampling in Alice Arm and Hastings Arm, British Columbia (Fig. 1), was conducted by personnel from the Institute of Ocean Sciences and E.V.S. Consultants aboard the C.S.S. Vector in October 1983. Sampling procedures were essentially the same as those used in 1982 (Kathman et al., 1983). Duplicate samples were taken at each station on predetermined transect lines (Fig. 2) using a 0.1 m² Smith-McIntyre grab. Transect D.5, located between Transects DD and EE, was added to more clearly delineate the extent of tailings effects. A single transect in Hastings Arm (Z2) was retained as a reference location for comparison with the sites in Alice Arm. Each sample was washed through a 1.0 mm screen. The contents retained on the screen were placed in labelled plastic bags and preserved with seven percent formalin with phloxine-B, a histological stain used to facilitate sorting. Pertinent information recorded during the sampling is presented in Appendix A.

Sorting and Quality Control

Upon receipt of the samples by the E.V.S. Consultants Taxonomy Centre, each sample was washed through a 1.0 mm sieve to remove excess formalin. Aliquots of each sample were examined using a Wild M5A stereomicroscope until the entire sample was sorted and all organisms removed. Organisms were counted, placed into separate containers filled with alcohol and labelled according to the following major taxonomic groups: Amphipoda, Cumacea, Other Crustacea, Polychaeta, Gastropoda, Bivalvia, Scaphopoda, Coelenterata, Echinodermata and Others. Sample residues were returned to their original sample bags and re-preserved with seven percent formalin.

To ensure accurate sorting, 25 percent (seven 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. Quality control data are provided in Appendix B. Percent error ranged from 0 to 1.6, well within the requisite limits for accuracy of sorting of benthic invertebrate samples.

Identification

Recognized taxonomic experts identified all organisms to the lowest possible taxonomic level consistent with the presently-available literature. A list of the taxonomic references used for identifications is provided in Appendix C, and a listing of all benthic invertebrates collected during this study is provided in Appendix D. Distributional data are provided in Appendix E for Alice Arm and Appendix F for Hastings Arm.

A representative specimen (or specimens) of each genus/species was removed from the collection and presented to the Scientific Authority as a reference set for future use. The bulk of the specimens from the 1982 and 1983 studies was deposited with the B.C. Provincial Museum (Victoria).

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

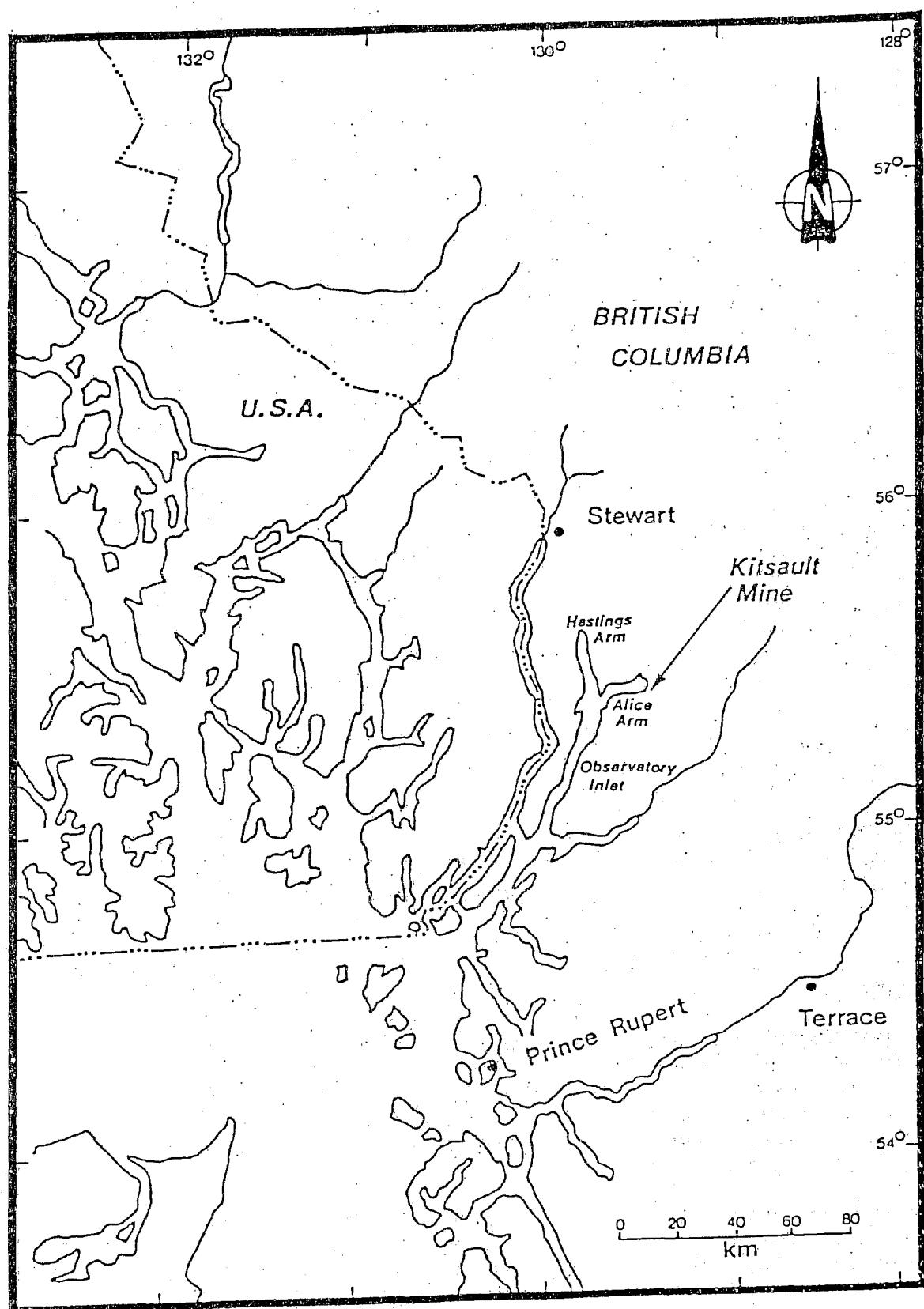
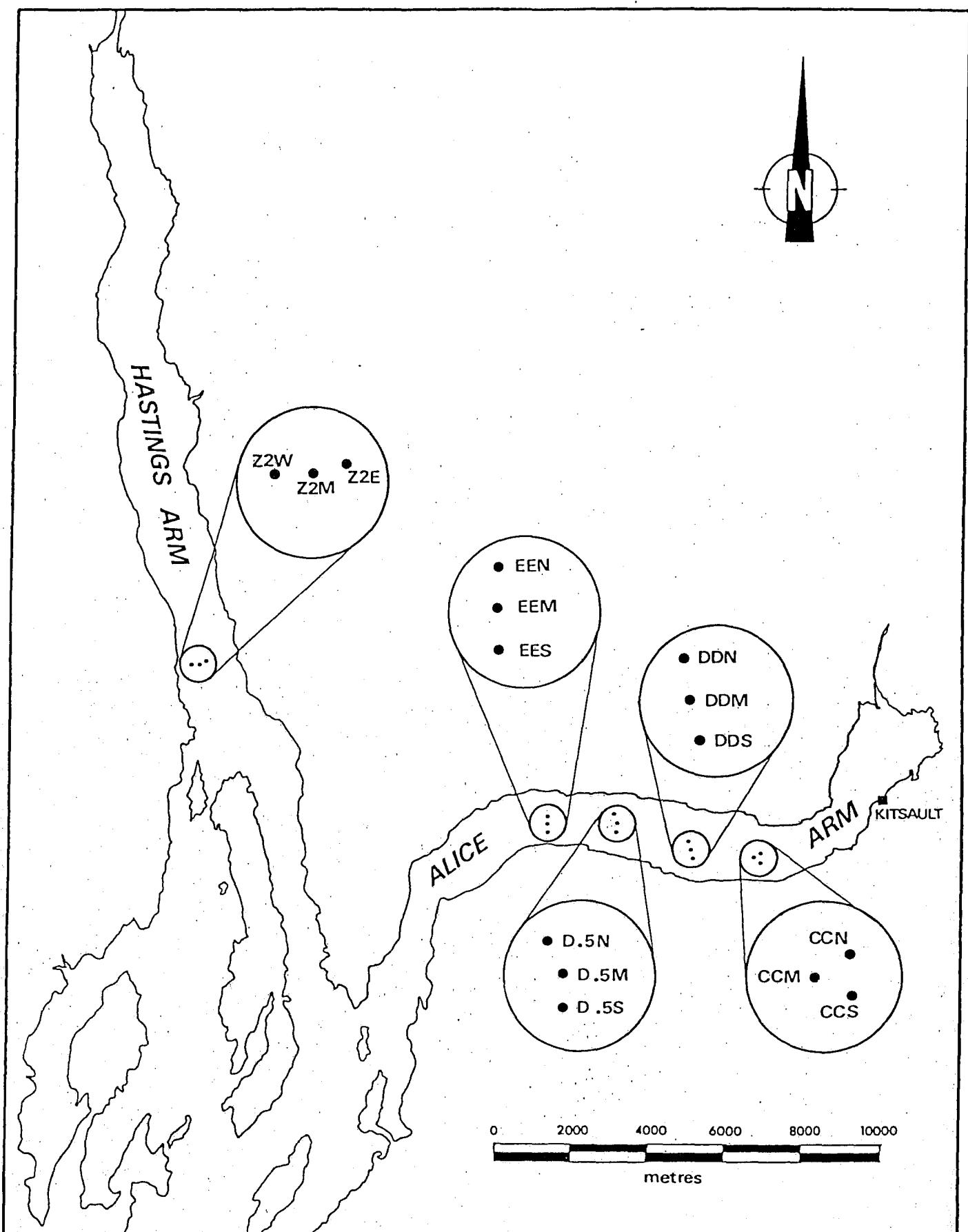


Fig. 2. Station locations in Alice Arm and Hastings Arm, British Columbia.



Hierarchical Analysis

The 1982 data set (Kathman et al., 1983) was analyzed using Ward's (1963) hierarchical classification coefficient, which emphasizes similarity between the number of individuals and number of taxa, but does not utilize information on specific identities. In the present study we used the Bray-Curtis classification (Bray and Curtis, 1957) to take into account the affinity or similarity of species among sites as a more viable measure of discreteness than the Ward coefficient allows. The 1982 data set was re-analyzed using the Bray-Curtis clustering technique to allow comparison with the 1983 data.

The complement of the Bray-Curtis coefficient was employed as the index of similarity in all trials, and is defined as

$$(1) \quad C = 1 - [2w \div (a+b)]$$

where w = the sum of the lesser abundances 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 unweighted (arithmetic means) 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).

The data matrices employed in all subsequent 1982/1983 comparisons were

MATRIX 1 (M1) : the original data minus Site Z5, which was not sampled in 1983. Resultant - 79 species in 1982 and 67 species in 1983;

MATRIX 2 (M2) : a first edit deleting taxa with recorded abundances of 10 or less in approximately 95% of the samples (1982 - 22 of 23; 1983 - 29 of 30). Resultant - 31 species in 1982 and 21 species in 1983;

MATRIX 3 (M3) : a second edit deleting taxa with recorded abundances of 20 or less in approximately 95% of the samples (1982 - 22 of 23; 1983 - 29 of 30). Resultant - 24 species in 1982 and 15 species in 1983;

MATRIX 4 (M4) : a comparison of lists for M3, identifying the number of species in common for 1982 and 1983. Resultant - 9 species.

RESULTS

Hierarchical Analysis

This report focuses on the M1 original data matrices to allow full comparison between the years. However, the results of cluster analysis by site for all four data matrices (M1-M4) showed the same patterns in 1982 and 1983, respectively, (App. G and H), indicating that rare taxa present at low abundances do not contribute significantly to the overall pattern or interpretation of the data.

Comparisons between the Ward and Bray-Curtis cluster groupings for the 1982 15-station data sets showed both similar and divergent patterns among clusters (Figs. 3 and 4). Sites CCN, DDM and CCM comprised a distinct cluster group in both analyses, reinforcing the large differences that existed between the benthic invertebrates at these sites and the remaining sites. Although these three sites separated into distinct clusters using both analyses, the apparent high degree of similarity within the cluster using Ward and low degree of similarity using Bray-Curtis was due to the former considering only diversity and abundance, whereas the latter also incorporated similarity among the species into the analysis. Site DDS was an outlier by Bray-Curtis, while CCS was more closely aligned with DDN, EEM and the Hastings Arm stations (Fig. 4). Sites EEN and EES showed a high degree of similarity in both analyses, but combined were dissimilar to EEM using the Bray-Curtis technique (Fig. 4) compared to being very similar using Ward's technique (Fig. 3).

Because the Hastings Arm Z5 stations were not sampled in 1983, cluster analysis was performed using the 12 sampling site M1 data matrix for 1982 (omitting the three Z5 stations) for comparison with the full 1982 data set (Figs. 4 and 5). Elimination of the three Z5 sites in the analysis resulted in only minor changes in the general pattern. All further 1982/1983 comparisons are made with Fig. 5, the baseline cluster grouping.

The 1983 M1 cluster groupings are shown in Fig. 6 and are compared to Fig. 5. The two obvious differences in 1983 are

- (1) the three stations comprising each of the Transects D.5, EE and Z2 cluster together, and
- (2) the sites on Transects CC and DD form a single larger grouping.

The stations on Transect EE, nearest Hastings Arm, are loosely grouped with those stations in Hastings Arm (Z2), but it should be noted that both clusters are linked at a rather low level of similarity (0.3).

Descriptive Analysis

A comparison of the number of individual organisms grouped on the basis of the Bray-Curtis analysis of 1982 data (Fig. 5) shows a large increase in the fauna of the Group I cluster (Table 1), which is also matched by an increase in the number of taxa present (Table 2). There is a contrasting reduction in density and reduction in taxa at all but two of the other stations from 1982 to 1983. These opposite trends combine to remove the distinction between stations on Transects CC and DD, although it is of interest to note that each of the three

Fig. 3. Cluster analysis station groupings using Ward's index
 (from Kathman et al., 1983).

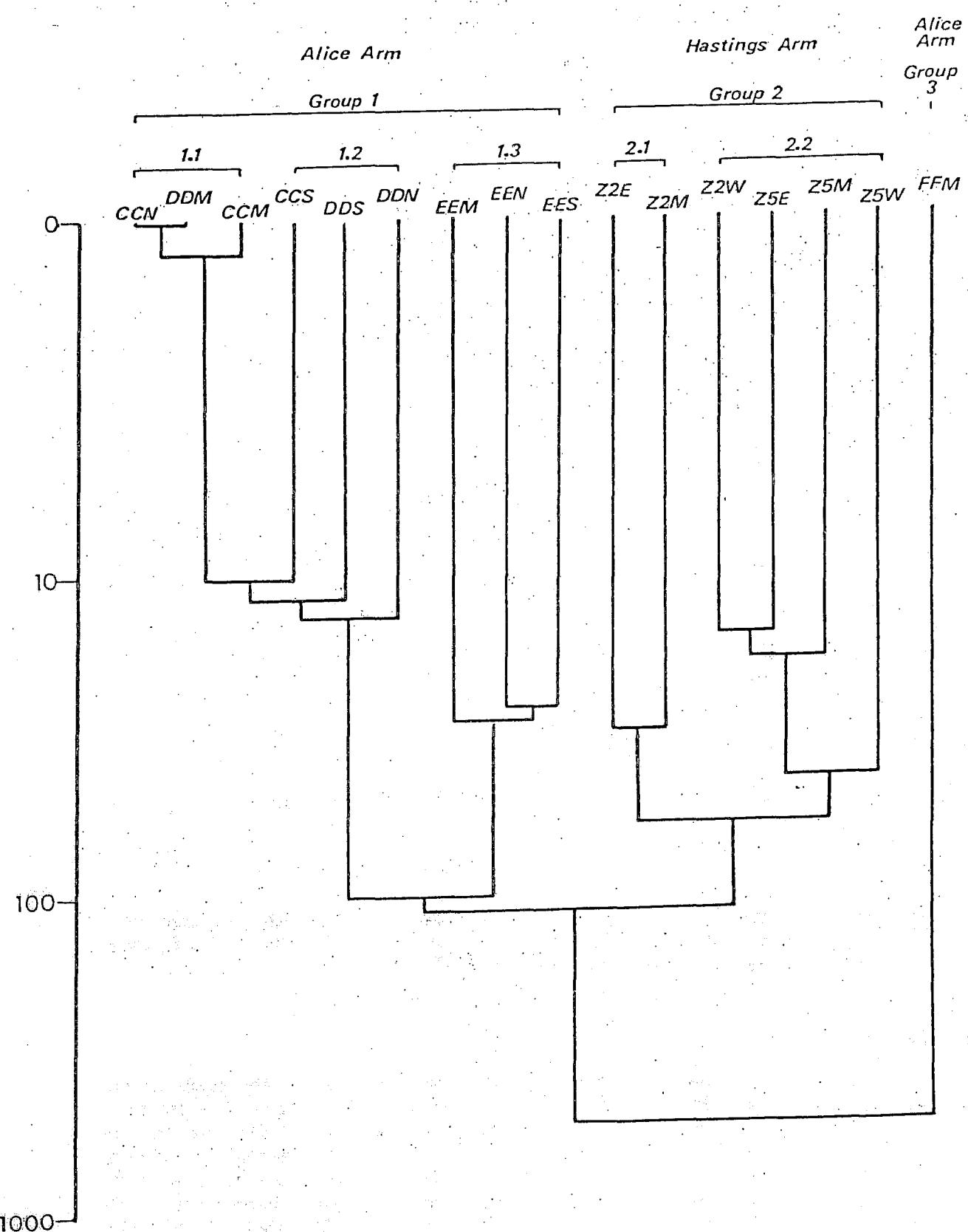


Fig. 4. Cluster analysis station groupings for 1982 original 15-station data matrix using Bray-Curtis index.

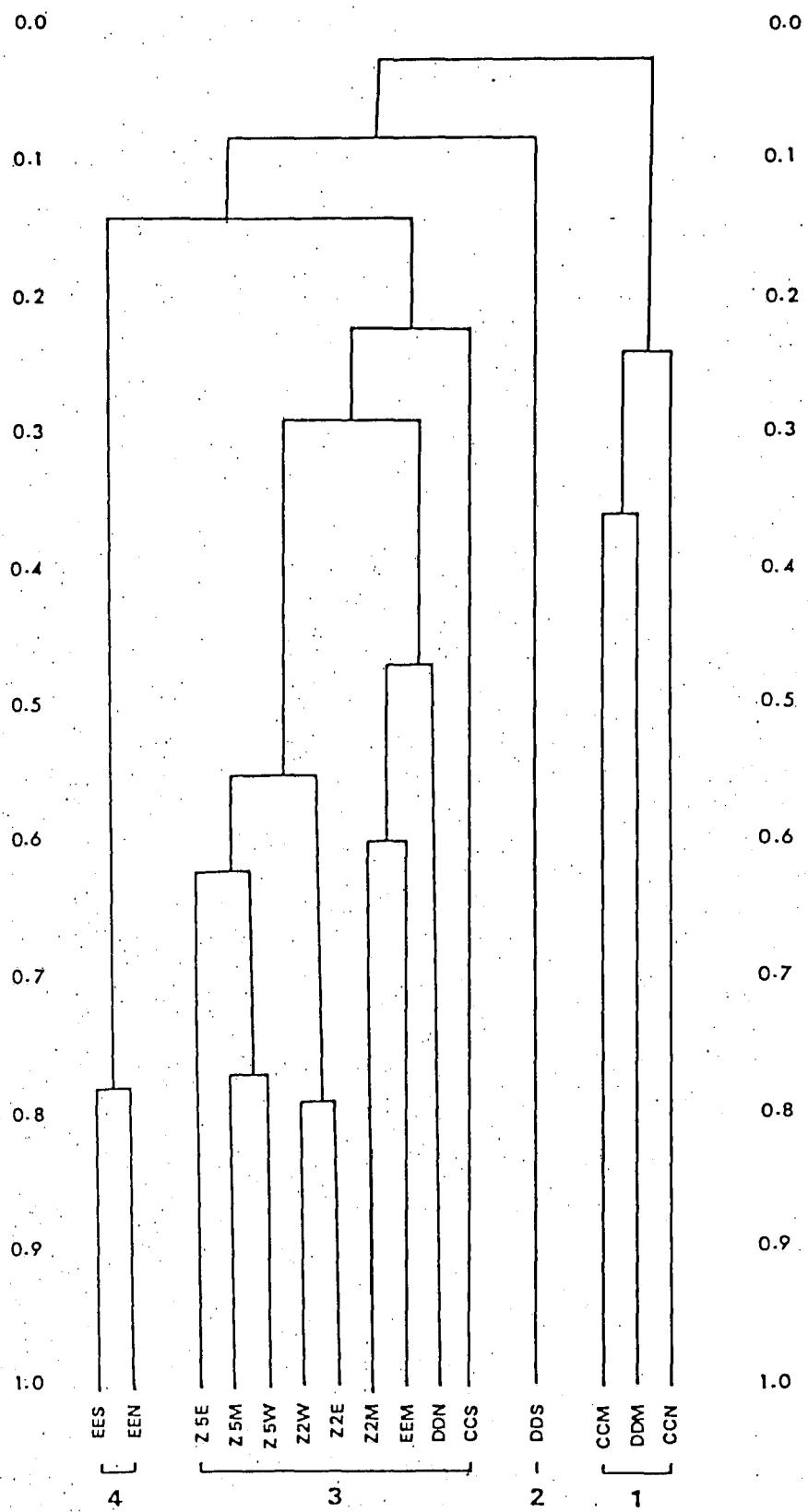


Fig. 5. Cluster analysis station groupings for MI, 1982.

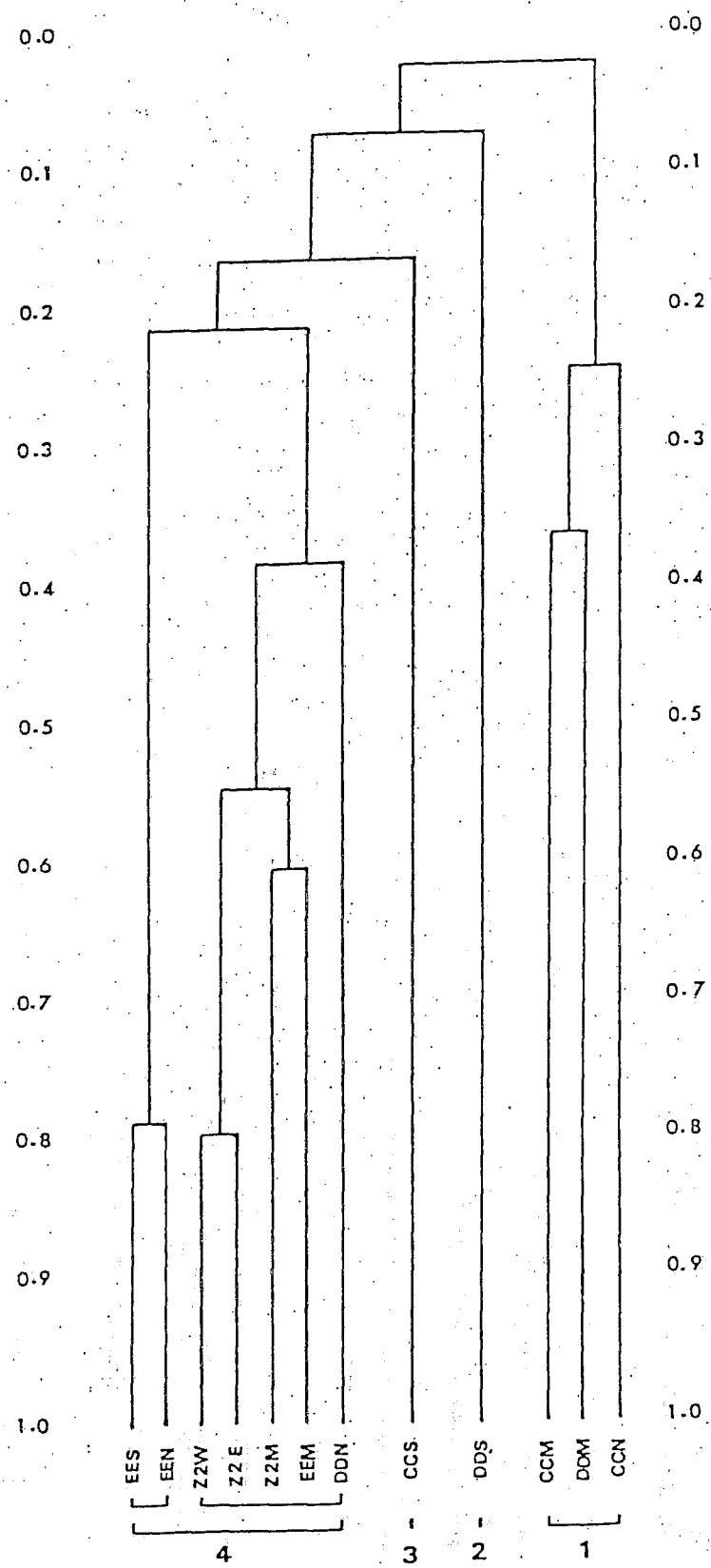


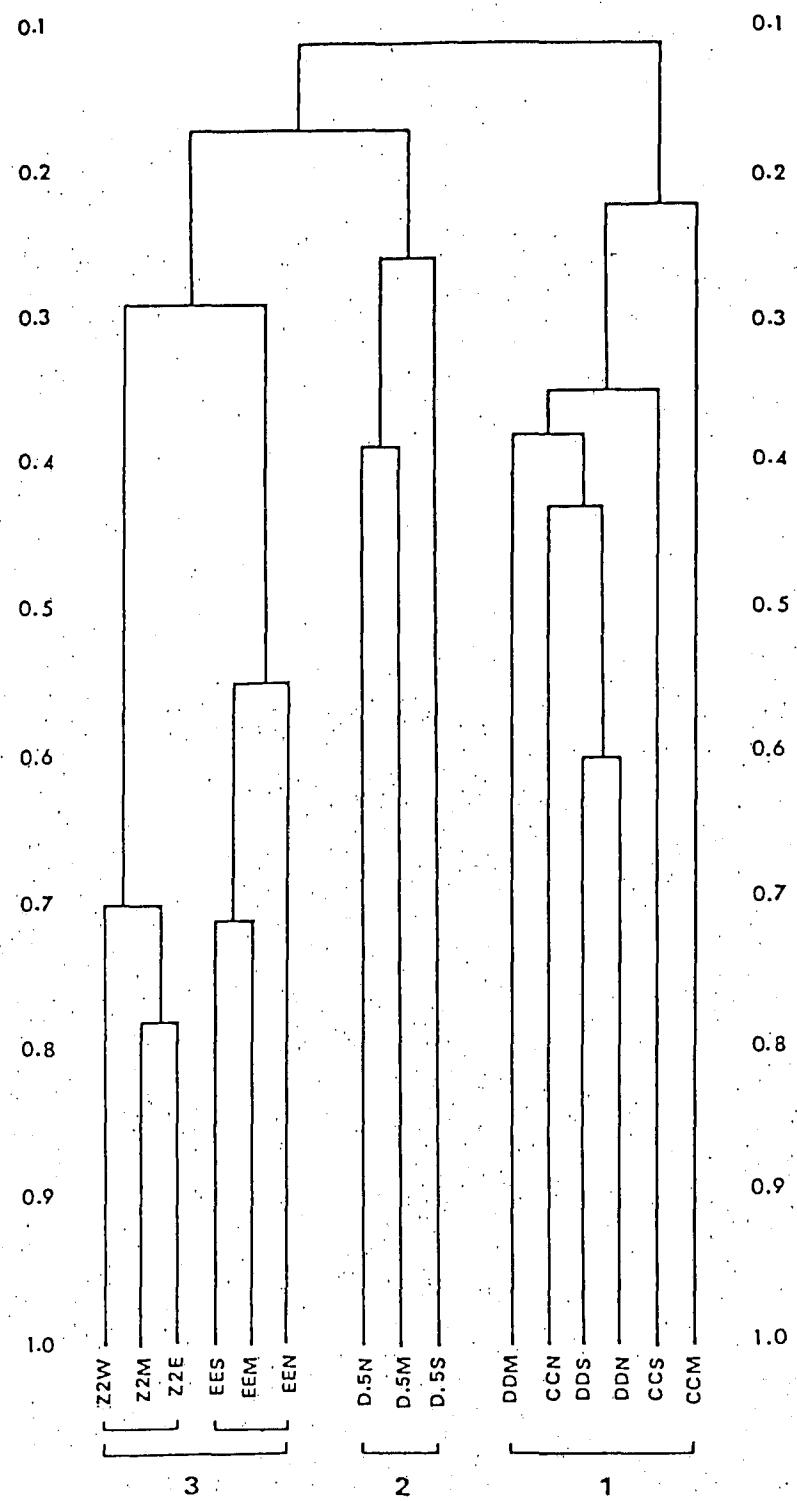
Table 1. Differences in numbers of benthic invertebrates between 1982 and 1983 per cluster grouping (from Fig. 5).

Station	1982		1983		Percent Change in 1983
	Number of Individuals	Number of Individuals/ Cluster Grouping	Number of Individuals	Number of Individuals/ Cluster Grouping	
CCN	20		115		
DDM	25	75	90	275	+367
CCM	30		70		
DDS	1,085	1,085	205	205	- 81
CCS	665	665	220	220	- 67
DDN	520		165		
EEM	1,040		1,190		
Z2M	1,255	6,735	760	3,920	- 42
Z2W	2,085		985		
Z2E	1,835		820		
EEN	3,125		665		
EES	3,440	6,565	1,655	2,485	- 62

Table 2. Differences in numbers of taxa between 1982 and 1983 per cluster grouping (from Fig. 5).

Station	1982		1983		Percent Change in 1983
	Number of Taxa	Number of Taxa/Cluster Grouping	Number of Taxa	Number of Taxa/Cluster Grouping	
CCN	4		15		
DDM	4	9	9		+256
CCM	5		7		
DDS	10	10	20	20	+200
GCS	24	24	17	17	-29
DDN	20		14		
EEM	21		20		
Z2M	30	57	31	50	-12
Z2W	37		27		
Z2E	38		32		
EEN	37		10		
EES	38	51	23	26	-49

Fig. 6. Cluster analysis station groupings for MI, 1983.



stations of Group I (1982) still had the lowest numbers of individuals (115, 90, 70) when compared with the rest of the CC and DD stations (205, 220, 165). Shared species differences presumably prevented recognition of the 1982 Group I stations in 1983.

Polychaetes, molluscs (bivalves) and crustaceans were equally abundant (33%, 31% and 31%, respectively) at Sites CCN, CCM and DDM (App. E and F), while polychaetes were clearly dominant (54%) at the remaining CC and DD sites. Polychaetes and molluscs were both abundant at Transect D.5 (44% and 37%, respectively), while molluscs were overwhelmingly abundant at Transect EE (83%) and the Hastings Arm transect (81%). These results show a progression from high abundances of polychaetes and low abundances of molluscs at the sites nearest the mine discharge area to low abundances of polychaetes and high abundances of molluscs at the reference sites.

DISCUSSION

Changes in infaunal abundance were readily distinguished between the 1982 and 1983 data sets. The three sites that clustered as a distinct grouping (CCN, CCM, DDM) and showed the strongest impact from tailings deposition in 1982 had substantial increases in both numbers of species and numbers of individuals during 1983. There was a threefold increase in polychaete species and individuals, and three- and ninefold increases in species and individuals of molluscs, respectively, from 1982 to 1983. In 1983 these sites could no longer be differentiated from other CC and DD sites, indicating that benthic invertebrates were recolonizing the areas most adversely affected by tailings deposition and a slow recovery was occurring. However, the two deep sites (CCM, DDM) midway along the bottom of the trough in Alice Arm continued to have the lowest number of taxa and individuals compared with the other four sites on Transects CC and DD. These deeper areas remained the most severely affected possibly due to more extensive deposition and accumulation of tailings coupled with slumping and differential recovery rates for deepwater benthic organisms.

The uniform decrease in individuals throughout the system except at the 1982 discharge-affected sites again reflects the recovery taking place in that area. With the exception of Site DDS, all of the sites showed major reduction in numbers of individuals and slight to substantial decreases in numbers of species. Reasons for these declines were not investigated, but seasonal and annual fluctuations in benthic invertebrate abundances in northern fjords have been documented by several workers (Blegvad, 1950; Ellis, pers. comm. and 1960; VTN, 1982a and b). VTN (1982b) found that seasonal fluctuations of the subtidal benthos caused long-term species and abundance variability in Boca de Quadra, a fjord situated just north of Hastings Arm.

A small number of common species accounted for the major distributional patterns of the infaunal benthos for both 1982 and 1983. Of the nine species common to both years from data matrix M4 (Table 3), all but one were detritivores (filter or deposit feeders). The only exception, the polychaete Nephtys cornuta, was a carnivore. Most of the species found nearest the former discharge (Transects CC and DD) were detritivores, but as the

distance from the discharge increased the number of feeding groups also increased, indicating a greater diversity within the benthic community down inlet and in adjacent Hastings Arm.

Table 3. List of abundant species common to 1982 and 1983 samplings, from data matrix M4.

- Polychaeta: *Myriochele oculata*
Nephtys cornuta cornuta
Levinsenia gracilis
- Cumacea: *Eudorella pacifica*
- Mollusca: *Cyllichna alba*
Cooperella subdiaphana
Nucula tenuis
Psephidia lordi
Yoldia martyria

An increased, but equal, abundance of polychaetes, molluscs and crustaceans was found at Sites CCN, CCM and DDM, the most adversely affected sites in 1982, 11 months after mine tailings discharge had ceased. In a three year study of benthic colonization in natural substrates, Arntz and Rumohr (1982) found approximately equal proportions of polychaetes (45%) and molluscs (55%) after 11 months of colonization. Polychaetes were initially dominant but molluscs increased after the first six months and remained dominant during the following two years of the study. It is too early to determine if succession in Alice Arm will follow a similar pattern.

Recovery of the infaunal benthos was noticeable 11 months after discharge terminated even at the most affected sites in Alice Arm (Sites CCN, DDM and CCM). Diversity of all species groups increased at these sites, together with significant increases in abundances. This pattern agreed with the study by Arntz and Rumohr (1982), who found that species numbers initially increased very slowly, abundance changed from low at the pre-opportunistic stage to high during the opportunistic period, and numerical dominance changed very rapidly during the early stages. Although polychaetes were slightly dominant at these sites in Alice Arm, the largest percentage increases were recorded for bivalves and crustaceans. The cumacean *Eudorella pacifica* and the bivalves *Nucula tenuis* and *Macoma carlottensis* were common early colonizing species. Similar results have been reported by other investigators. In a study of benthic repopulation in the Raritan River estuary following sewage abatement, Dean and Haskin (1964) found *Macoma* sp. to be a pioneer among the species of early invaders. Arntz and Rumohr (1982) found that cumaceans often predominated during the summer. However, it is important to note that although many studies have dealt with marine benthic invertebrate colonization (e.g. Arntz and Rumohr, 1982; Bonsdorff, 1980; Dean and Haskin, 1964; Kathman et al., 1984; Pearson and Rosenberg, 1978), no previous studies have dealt specifically with recolonization following cessation of mine tailings discharge. As such this study is unique, and it provides valuable data related to predicting the ultimate recovery of other coastal areas presently (or proposed to be) impacted by mine tailings discharges.

RECOMMENDATIONS

The study of spatial and temporal marine infaunal benthic colonization at Alice and Hastings Arms provides a unique opportunity to monitor long-term biological effects after mine tailings disposal has ceased. We therefore recommend that greater than minimum effort be expended in benthic monitoring. Specifically, we strongly recommend initiation of a quarterly sampling program, to start immediately and to continue for the next several years. The data from such an intensified program would be fundamental to the development of rates of recolonization/die off, within season fluctuations, biological aspects of slower recolonization in deep areas, and possible limiting factors of recolonization in tailings affected sediments.

At a minimum, an annual benthic sampling program to monitor changes in the distribution and abundance of benthic invertebrates in Alice Arm should be continued at a level consistent with the 1982 and 1983 studies while the mine is closed. If mill operations resume, however, the benthos should be sampled immediately prior to operations, followed by biannual sampling for the first year after startup and annual sampling afterwards. This program would serve to determine immediate and long-term effects of tailings discharges on the infaunal benthic community.

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APPENDIX A
INFORMATION RECORDED
DURING SAMPLE ACQUISITION

Date (October, 1983)	Station*	Avg. Depth (m)	North Latitude West Longitude
05	CCN	261.5	55°26'40" 129°31'42"
05	CCM	271.0	55°26'36" 129°31'53"
05	CCS	249.5	55°26'3" 129°31'44"
05	DDN	340.0	55°26'48" 129°33'37"
05	DDM	347.0	55°26'44" 129°33'35"
05	DDS	350.0	55°26'41" 129°33'31"
06	D.5N	327.0	55°27'10" 129°35'27"
06	D.5M	387.0	55°27'05" 129°35'23"
06	D.5S	376.0	55°27'02" 129°35'23"
06	EEN	375.5	55°27'12" 129°37'00"
06	EEM	394.0	55°27'06" 129°37'00"
06	EES	394.0	55°27'00" 129°37'00"
06	Z2E	296.0	55°29'19" 129°45'37"
06	Z2M	298.0	55°29'17" 129°45'50"
06	Z2W	298.0	55°29'14" 129°45'57"

*Stations CCN through EES are in Alice Arm; Z2E through Z2W are in Hastings Arm.

APPENDIX B

RESULTS OF QUALITY CONTROL (QC)
FOR SORTING BENTHIC INVERTEBRATES

Sample Identification	Total Number of Individuals During Sorting	Total Number of Individuals After QC	Percent Error for Sample
DDS-B	21	21	0
D.5M-A	40	40	0
EEM-B	121	123	1.6
EES-A	122	123	0.8
EES-B	209	210	0.5
Z2E-A	80	81	1.2
Z2W-A	85	86	1.2

APPENDIX C

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APPENDIX D

LIST OF ALL TAXA FOUND IN
ALICE ARM AND HASTINGS ARM

Coelenterata

Anthozoa

Actiniaria

Edwardsiidae

Edwardsia sipunculoides (Stimpson)

Pennatulacea

Virgulariidae

Virgularia sp. aff. tuberculata Marshal

Nemertea

Anopla

Heteronemertea

Cerebratulidae

Cerebratulus sp.

Bryozoa

Annelida

Polychaeta

Capitellida

Capitellidae

Heteromastus filobranchus Berkeley and Berkeley

Maldanidae

Maldane glebifex Grube

Eunicida

Lumbrineridae

Lumbrineris luti Berkeley and Berkeley

Paraninoe simpla (Moore)

Flabelligerida

Flabelligeridae

Brada villosa (Rathke)

Orbiniida

Orbiniidae

Leitoscoloplos pugettensis (Pettibone)

APPENDIX D (cont.)

Paraonidae

Levinsenia gracilis (Tauber)Aricidea (Allia) suecica Eliason

Oweniida

Oweniidae

Myriochela oculata Zachs

Phyllodocida

Goniadidae

Goniada annulata Moore

Hesionidae

Gyptis brevipalpa (Hartmann-Schroder)

Nephtyidae

Nephtys cornuta cornuta Berkeley and BerkeleyNephtys punctata HartmanAglaophamus malmgreni (Theel)

Pilargidae

Ancistrosyllis groenlandica McIntosh

Polynoidae

Harmothoinae

?Antinoella sarsi (Kinberg)

Sigalionidae

Pholoe minuta (Fabricius)

Spionida

Cirratulidae

Chaetozone setosa MalmgrenTharyx multifilis Moore

Spionidae

Polydora sp.Prionospio steenstrupi MalmgrenSpiophanes sp.Spiophanes kroyeri Grube

Sternaspida

Sternaspidae

Sternaspis scutata (Renier)

Terebellida

Ampharetidae

Amphicteis sp.Ampharete finmarchica (Sars)

APPENDIX D (cont.)

Pectinariidae

Amphictene moorei Annenkova

Trichobranchidae

Terebellides stroemi Sars

Arthropoda

Crustacea

Amphipoda

Lysianassidae

Koroga megalops HolmesPachynus barnardi Hurley

Oedicerotidae

Bathymedon pumilis BarnardMonoculodes cf. emarginatus BarnardMonoculodes sp. ?

Cumacea

Diastylidae

Diastylis pellucida Hart

Leuconidae

Eudorella pacifica HartLeucon subnasica Hart

Mysidacea

Mysidae

Holmesiella anomala Ortmann

Ostracoda

Mollusca

Caudofoveata

Chaetodermatida

Crystallöphrissonidae

Crystallöphrisson sp.!

Gastropoda

Cephalaspidea

Cylichnidae

Cylichna alba (Brown)Cylichna attensa Carpenter

Mesogastropoda

Rissoinidae

Rissoina newcombei Dall

Neogastropoda

Muricidae

Ocenebra interfossa Carpenter

Scaphopoda

Dentaliida

Dentaliidae

Dentalium agassizii Pilsbry and SharpDentalium pretiosum Sowerby

Leavidentalidae

Rhabdus rectius (Carpenter)

Gadilida

Cadulidae

Cadulus tolmiei Dall

Bivalvia

Myida

Myidae

Mya arenaria Linnaeus

Nuculoidea

Nuculanidae

Nuculana hindsii (Hanley)

Nuculidae

Nucula tenuis (Montagu)

Yoldiidae

Yoldia hyperborea TorellYoldia martyria DallYoldia scissurata DallYoldia thraciaeformis (Storer)

Veneroida

Cardiidae

Clinocardium nuttallii (Conrad)

Cooperellidae

Cooperella subdiaphana (Carpenter)

Lucinidae

Lucina tenuisculpta Carpenter

Tellinidae

Macoma calcarea (Gmelin)Macoma carlottensis WhiteavesMacoma eliminata Dunnill and Coan

Veneridae

Psephidia lordi (Baird)²

Echinodermata

Asteroidea

Paxillosida

Gonipectinidae

Ctenodiscus crispatus (Retzius)

Echinoidea

Echinoida

Strongylocentrotidae

Strongylocentrotus prob. pallidus (G.O. Sars)

Holothuroidea

Apodida

Chiridotidae

Chiridota albatrossi Ohshima³

Molpadida

Molpadiidae

Molpadia intermedia (Ludwig)

Ophiuroidea

Ophiurida

Ophiuridae

Ophiora leptocenia H.L. Clark1 of Filatova; = Chaetoderma of Salvini-Plawen2 all Transenella tantilla of Kathman et al., 1983 = P. lordi3 of Ohshima; = C. laevis of Deichmann

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APPENDIX E

DENSITY AND DISTRIBUTION FOR BENTHIC INVERTEBRATES FROM ALICE ARM
All Results are Given in Numbers Per m²

	D.SH	D.SH	D.SS	EEN	EEM	EES						
	A	B	X	A	B	X	A	B	X	A	B	X
Coelenterata												
Anthozoa												
Actinaria												
Edwardsiidae												
<u>Edwardsia stipuloculoides</u>												
Pennatulacea												
Virgulariidae												
<u>Virgularia sp. aff. tuberculata</u>												
Nemertea												
Anopla												
Heteronemertea												
Cerebratulidae												
<u>Cerebratulus sp.</u>												
Bryozoa												
Annelida												
Polychaeta												
Capitellida												
Capitellidae												
<u>Heteromastus filobranchus</u>												
Maldanidae												
<u>Maldane glebifex</u>												
Eunicida												
Lumbrineridae												
<u>Lumbrineris luti</u>												
<u>Paraniconus simplicia</u>												
Flabelligerida												
Flabelligeridae												
<u>Brada villosa</u>												
Orbiniida												
Orbiniidae												
<u>Leitoscoloplos pugettensis</u>												
Paraonidae												
Levinsonidae												
<u>Xricidea (Alitta) suecica</u>												
Oweniida												
Oweniidae												
<u>Myriochele oculata</u>												
Phyllodocida												
Goniadidae												
<u>Gonia annulata</u>												
Hesionidae												
<u>Gyptis brevipalpa</u>												
Nephtyidae												
<u>Nephtys cornuta cornuta</u>	40	20		50	10	30	40	70	55	40	20	30
<u>Nephtys punctata</u>	10	5		10	30	20	20	10	10	20	10	15
<u>Aglaophamus matmgreni</u>	10	5					10		5			
Pillargidae												
<u>Ancistrosyllis groenlandica</u>	10	5										
Polynoidae												
Harmothoinae												
<u>Antinoella sarsi</u>												
Sigalionidae												
<u>Phloeoe minuta</u>	10	5					10		5	10		5
Spionida												
Cirratulidae												
<u>Chaetozone setosa</u>							20		10			
<u>Tharyx multifilis</u>												
<u>Spionidae</u>												
<u>Polydora sp.</u>												
<u>Prionospio steenstrupi</u>												
<u>Splophanes sp.</u>												
<u>Splophanes kroyeri</u>												
	30	15		10	5					10	5	

	D.SN			D.SM			D.SS			EEN			EEM			EES		
	A	B	\bar{x}	A	B	\bar{x}	A	B	\bar{x}	A	B	\bar{x}	A	B	\bar{x}	A	B	\bar{x}
Sternaspida Sternaspidae <u>Sternaspis scutata</u>	100	190	145													20	10	
Terebellida Ampharetidae <u>Amphicteis</u> sp. <u>Ampharete finmarchica</u>																		
Pectinariidae <u>Amphictene moorei</u>																		
Trichobranchidae <u>Terebellides stroemii</u>																		
Arthropoda																		
Crustacea																		
Amphipoda																		
Lysianassidae																		
<u>Koroga megalops</u>																		
<u>Pachynus barnardi</u>																		
Oedicerotidae																		
<u>Bathymedon pumilis</u>	10	5		<u>Monoculodes cf. emarginatus</u>	10	5				<u>Monoculodes</u> sp. ?	10	5				10	5	
Cumacea																		
Diasystylidae																		
<u>Diasystylis pellucida</u>																		
Leuconidae																		
<u>Eudorella pacifica</u>																		
<u>Leucon subnastica</u>																		
Mysidacea																		
Mysidae																		
<u>Holmesiella anomala</u>																10	5	
Ostracoda																		
Mollusca																		
Caudofoveata																		
Chaetodermatida																		
<u>Crystallophrissonidae</u>																		
<u>Crystallophrisson</u> sp.	10	20	15		10	5										10	5	
Gastropoda																		
Cephalaspidea																		
Cyliphnidiae																		
<u>Cyliphna alba</u>																		
<u>Cyliphna attensa</u>	10	20	15		30	15										10	5	
Hesogastropoda																		
Rissoinidae																		
<u>Rissoina newcombi</u>																		
Neogastropoda																		
Muricidae																		
<u>Ocenebra interfossa</u>																		
Scaphopoda																		
Dentaliida																		
Dentaliidae																		
<u>Dentalium agassizii</u>																20	10	
<u>Dentalium pretiosum</u>																		
Leavidentalidae																10	5	
<u>Rhabdus rectius</u>																		
Gadilliida																		
Cadulidae																		
<u>Cadulus tolmei</u>																		
Bivalvia																		
Myida																		
Myidae																		
<u>Mya arenaria</u>																10	5	
Nuculofidea																		
Nuculanidae																		
<u>Nuculana hindsii</u>																20	10	

APPENDIX F

DENSITY AND DISTRIBUTION FOR BENTHIC INVERTEBRATES FROM HASTINGS ARM
All Results are Given in Numbers Per m²

	Z2E			Z2M			Z2W		
	A	B	\bar{X}	A	B	\bar{X}	A	B	\bar{X}
Coelenterata									
Anthozoa									
Actiniaria									
Edwardsiidae									
<u>Edwardsia sipunculoides</u>									
Pennatulacea	10		5	20		10	10		5
Virgulariidae									
<u>Virgularia sp. aff. tuberculata</u>									
Nemertea									
Anopla									
Heteronemertea									
Cerebratulidae									
<u>Cerebratulus sp.</u>									
Bryozoa									
Annelida									
Polychaeta									
Capitellida									
Capitellidae									
<u>Heteromastus filobranchus</u>	20	10	10			5	20	20	20
Maldanidae									
<u>Maldane glebifex</u>									
Eunicida									
Lumbrineridae									
<u>Lumbrineris luti</u>	10		5			10	5		20
<u>Paraninoe simpla</u>									
Flabelligerida									
Flabelligeridae									
<u>Brada villosa</u>	10		5						
Orbiniida									
Orbiniidae									
<u>Leitoscoloplos pugettensis</u>									
Paraonidae									
Levinsenia gracilis	40	20		10	20	15	10	40	25
Aricidea (Allia) suecica									
Oweniida									
Oweniidae									
<u>Myriochele aculata</u>									
Phyllodocida									
Goniadidae									
<u>Goniada annulata</u>				30	10	20	10	10	10

APPENDIX F (cont.)

	Z2E			Z2M			Z2W		
	A	B	\bar{X}	A	B	\bar{X}	A	B	\bar{X}
Hesionidae <u>Gyptis brevipalpa</u>		10	5					10	5
Nephyidae <u>Nephys cornuta cornuta</u> <u>Nephys punctata</u> <u>Aglophamus malmgreni</u>		20	10	20 10	10	10	20	10	10 5
Pilargidae <u>Ancistrosyllis groenlandica</u>				20	10	10	10	5	
Polynoidae Harmothoinae <u>?Antinoella sarsi</u>						10	10	5	
Sigalionidae <u>Pholoe minuta</u>						10	10	5	
Spionida Cirratulidae <u>Chaetozone setosa</u> <u>Tharyx multifilis</u>				10	5	10 10	10	5	10 5
Spionidae <u>Polydora</u> sp. <u>Prionospio steenstrupi</u> <u>Spiophanes</u> sp. <u>Spiophanes kroyeri</u>		30	15	10		10		5	
Sternaspida Sternaspidae <u>Sternaspis scutata</u>		10	20	15	20	20	20		10 5
Terebellida Ampharetidae <u>Amphicteis</u> sp. <u>Ampharete finmarchica</u>				10	5	10	10	5	
Pectinariidae <u>Amphictene moorei</u>									
Trichobranchidae <u>Terebellides stroemi</u>									
Arthropoda Crustacea Amphipoda Lysianassidae <u>Koroga megalops</u> <u>Pachynus barnardi</u>				10	5				
Oedicerotidae <u>Bathymedon pumilis</u> <u>Monoculodes cf. emarginatus</u> <u>Monoculodes</u> sp. ?		10	5	10		10	10	5	
Cumacea Diastylidae <u>Diastylis pellucida</u>									
Leuconidae <u>Eudorella pacifica</u> <u>Leucon subnasica</u>	50	10	30	20	10		30	10	20

APPENDIX F (cont.)

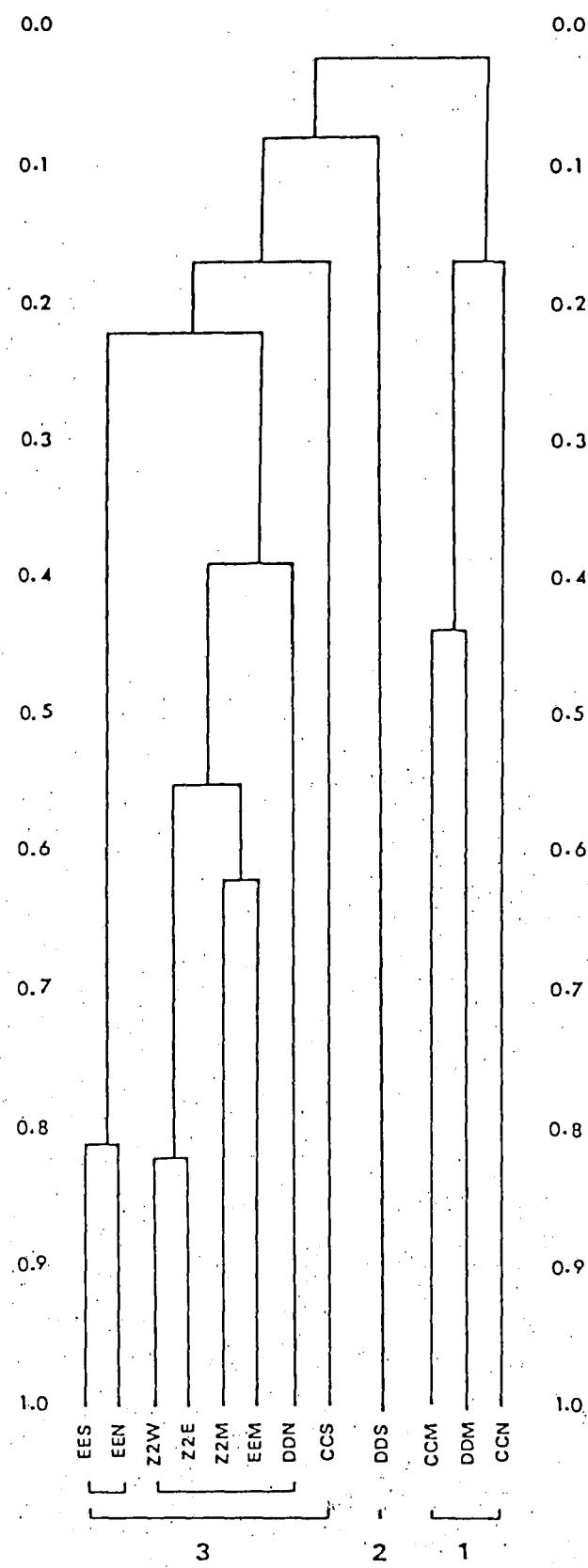
	Z2E			Z2M			Z2W		
	A	B	\bar{X}	A	B	\bar{X}	A	B	\bar{X}
Mysidacea Mysidae <u>Holmesiella anomala</u>									
Ostracoda									
Mollusca Caudofoveata Chaetodermatida Crystallophrissonidae <u>Crystallophrisson</u> sp.	10		5	10		5	10	5	
Gastropoda Cephalaspidea Cylichnidae <u>Cylichna alba</u> <u>Cylichna attsona</u>	10		5	10	50	30			
Mesogastropoda Rissoinidae <u>Rissoina newcombei</u>							10	5	
Neogastropoda Muricidae <u>Ocenebra interfossa</u>	10		5						
Scaphopoda Dentaliida Dentaliidae <u>Dentalium agassizii</u> <u>Dentalium pretiosum</u>	10	20	15	10		5	10	5	
Leavidentalidae <u>Rhabdus rectius</u>							10	5	
Gadilida Cadulidae <u>Cadulus tolmiei</u>	20		10						
Bivalvia Myoida Myidae <u>Mya arenaria</u>	30	60	45	30		15	40	10	25
Nuculoidea Nuculanidae <u>Nuculana hindsii</u>									
Nuculidae <u>Nucula tenuis</u>	350	470	410	360	410	385	430	630	530
Yoldiidae <u>Yoldia hyperborea</u> <u>Yoldia martyria</u> <u>Yoldia scissurata</u> <u>Yoldia thraiaeformis</u>	10	10	10	10		5	20	100	60
Veneroida Cardiidae <u>Clinocardium nuttallii</u>	50	10	30	10		5	80		40

APPENDIX F (cont.)

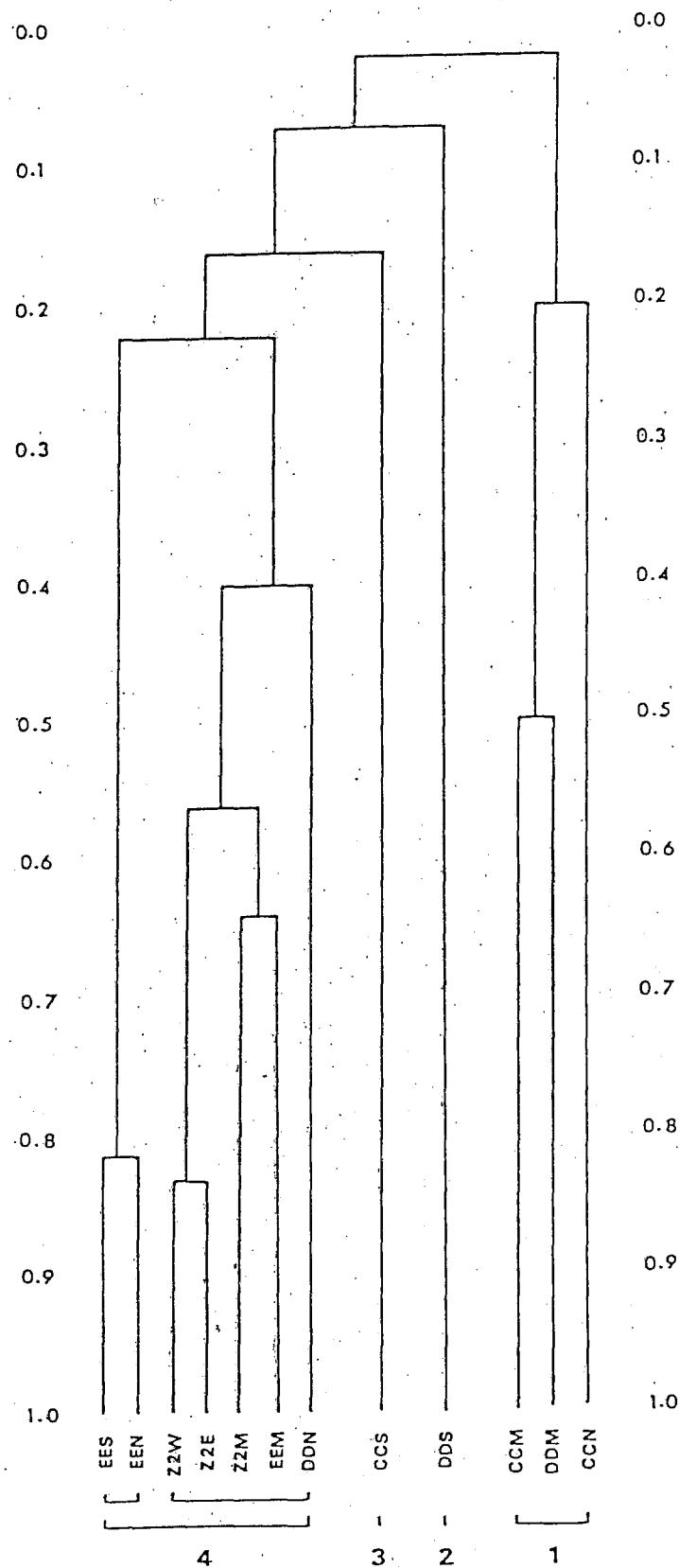
	Z2E			Z2M			Z2W		
	A	B	\bar{X}	A	B	\bar{X}	A	B	\bar{X}
Cooperellidae <u>Cooperella subdaphana</u>				10		5	30	40	35
Lucinidae <u>Lucina tenuisculpta</u>	30	50	40	40	20	30	40	50	45
Tellinidae <u>Macoma calcarea</u> <u>Macoma carlottensis</u> <u>Macoma eliminata</u>	10	30	20	30	30	30	10		5
Veneridae <u>Psephidia lordi</u>	30	20	25	10	80	45	90	60	75
Echinodermata									
Asteroidea									
Paxillosida									
Gonipectinidae <u>Ctenodiscus crispatus</u>	30		15	20	10	15			
Echinoidea									
Echinoida									
Strongylocentrotidae <u>Strongylocentrotus prob. pallidus</u>							20	10	
Holothuroidea									
Apodida									
Chiridotidae <u>Chiridota albatrossi</u>	20	10	15	10		5	10	5	
Molpadida									
Molpadiidae									
<u>Molpadia intermedia</u>				10	5				
Ophiuroidea									
Ophiorida									
Ophiuridae									
<u>Ophiura leptocentria</u>							10		5

APPENDIX G**CLUSTER ANALYSIS STATION GROUPINGS****M2 - M4; 1982**

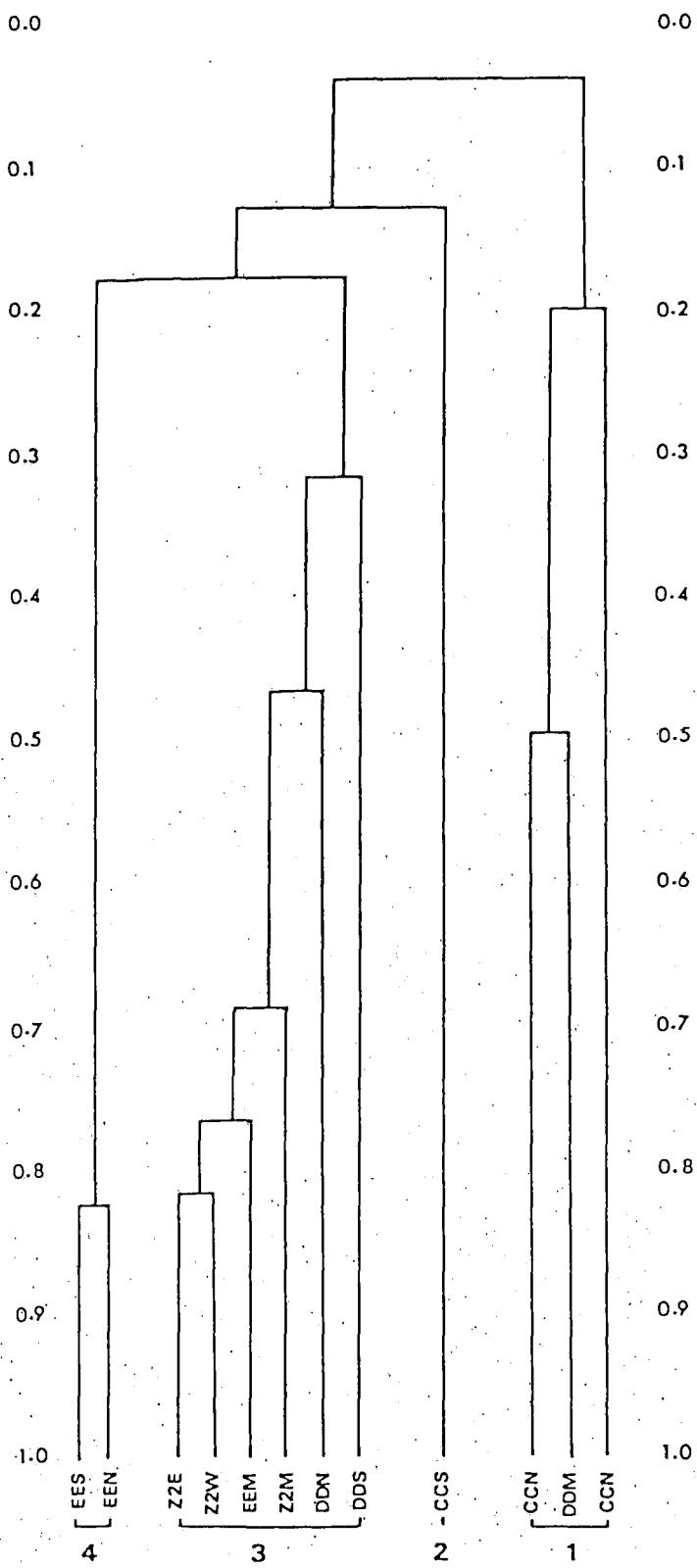
Cluster analysis station groupings for M2, 1982.



Cluster analysis station groupings for M3, 1982.



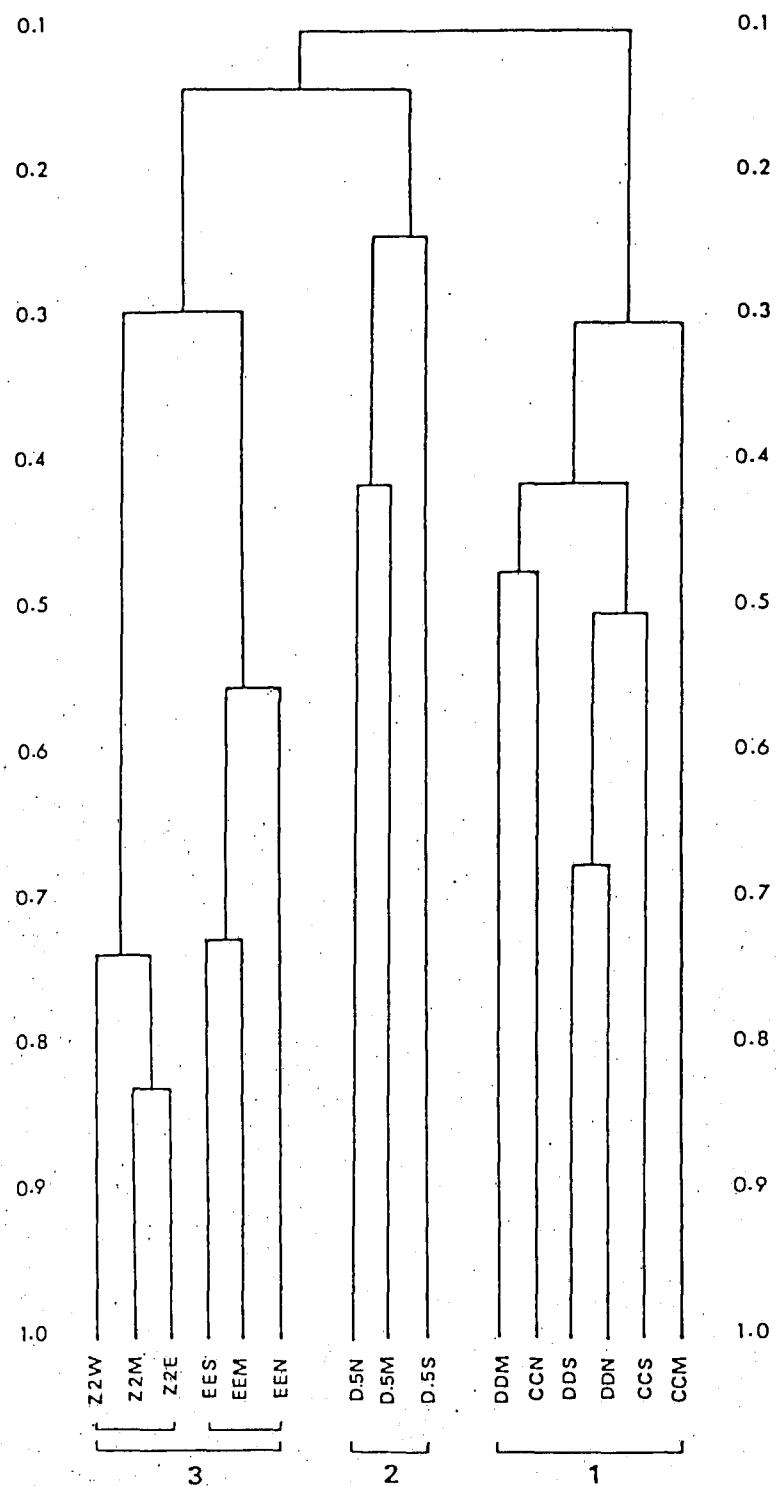
Cluster analysis station groupings for M4, 1982.



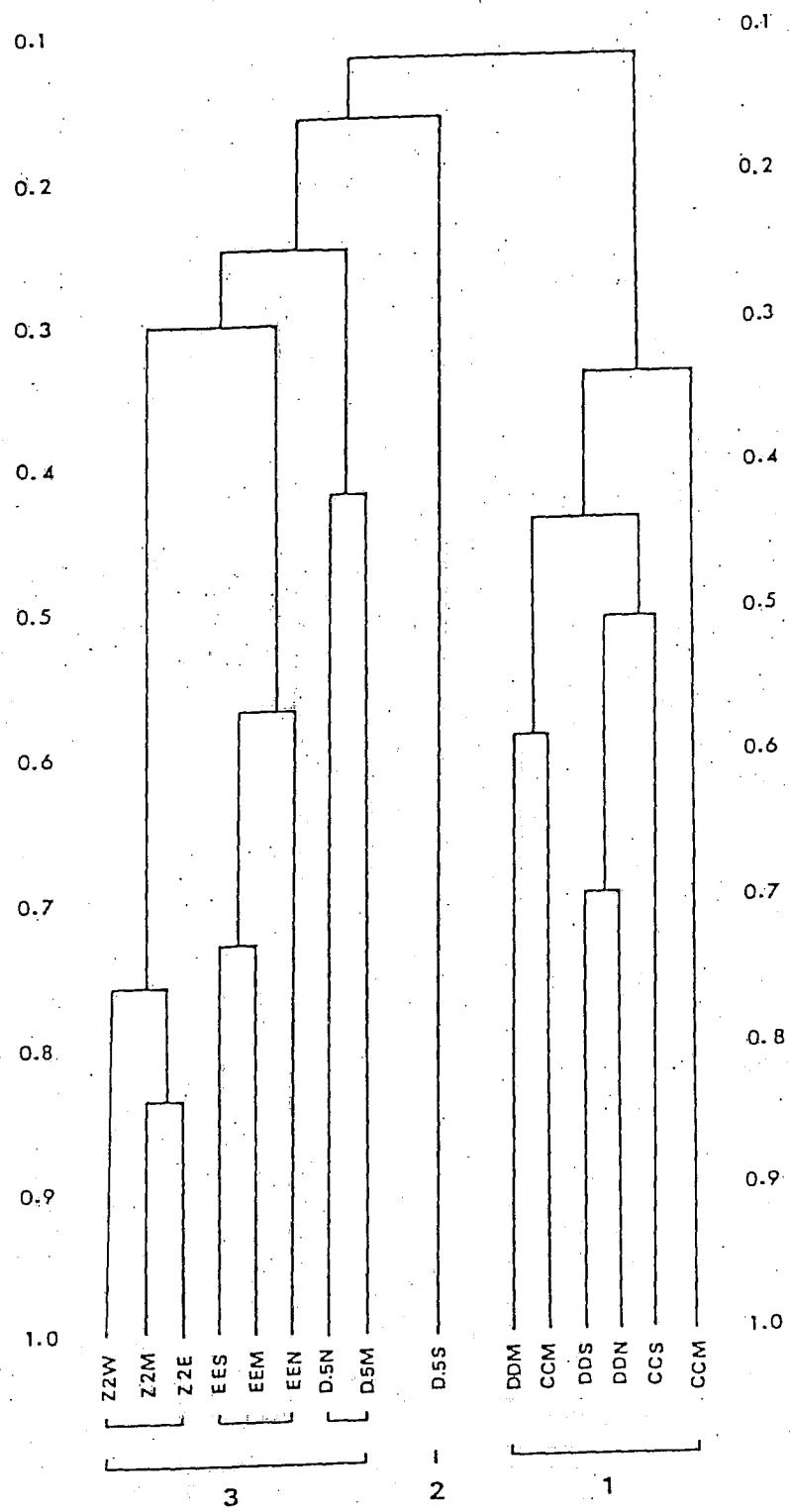
APPENDIX H

CLUSTER ANALYSIS STATION GROUPINGS
M2 - M4; 1983

Cluster analysis station groupings for M2, 1983.



Cluster analysis station groupings for M3, 1983.



Cluster analysis station groupings for M4, 1983.

