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EFFECTS OF WOOD WASTE ON THE RECRUITMENT POTENTIAL OF MARINE BENTHIC COMMUNITIES

by

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Abstract

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Samplers containing varying concentrations of wood waste and natural sediments were placed at depths of 25 m in outer Burrard Inlet, on 1 August 1983, and retrieved after 11 weeks, on 20 October 1983. All benthic macroinvertebrates colonizing the substrates were sorted, identified and enumerated. Taxonomic, hierarchical and ordination analyses of the data indicated that the potential for benthic invertebrate recruitment was enhanced in sediments containing between 10% and 40% wood waste.

Key words: benthic invertebrates, wood waste, recolonization, recruitment.

Resume

Kathman, R.D., S.F. Cross, and M. Waldichuk. 1984. Effects of wood waste on the recruitment potential of marine benthic communities. Can. Tech. Rep. Fish. Ocean Sci. , 1-50.

Acknowledgements

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SUMMARY

Replicate samplers containing varying concentrations of wood wastes and sediments were deployed in 25 m of water in outer Burrard Inlet on 1 August 1983 for benthic invertebrate colonization. After 11 weeks, on 20 October 1983, the samplers were retrieved and the benthic macroinvertebrates were identified and enumerated. Data analyses included dominance and diversity measures, hierarchical (cluster) classification and ordination techniques. Species richness, diversity and evenness values were highest and dominance values were lowest in the 20% wood waste samples, compared to the 0%, 50% and 100% wood waste concentrations. The sample cluster analysis clearly differentiated two groups: one containing almost all of the 0% and 20% samples and the other containing almost all of the 50% and all of the 100% samples. Species cluster analysis indicated three distinct groups of taxa. The first group, comprised of polychaetes and oligochaetes, and the second group, containing polychaetes and bivalves, are both indicative of low concentrations of wood fibres. The third group contained nematodes, the wood-burrowing shipworm *Bankia setacea*, and the polychaetes *Armandia brevis*, *Capitella capitata* and *Prionospio cirrifera*, all typically associated with high levels of organic enrichment (pollution). The similar patterns among all data analyses confirmed the greater recruitment potential of marine macroinvertebrates in sediments containing some wood wastes. Enhancement occurred between 10% and 40% wood content, while higher wood content was detrimental to marine organisms.

INTRODUCTION

Many studies have been conducted relating occurrence, distribution and diversity of marine benthic invertebrates to contaminants and organic enrichment (see, for example, Dean and Haskin, 1964; Kathman et al., 1983; Pearson, 1972 and 1975; Thom and Chew, 1984; and others). Few studies, however, have dealt with in situ experiments determining colonization and succession of the benthos (see, for example, Arntz and Rumohr, 1982; Bonsdorff, 1980; Pearson and Rosenberg, 1978), and none of these has dealt specifically with the effects of wood wastes and fibres on the potential recruitment and maintenance of benthic invertebrates, although Conlan (1977) conducted an intensive quantitative survey of marine infaunal and epifaunal invertebrates associated with a log handling site at Mill Bay, B.C. Observations made from the submersible "Pisces IV" have shown a depauperate benthic fauna associated with sediments containing a high wood fibre content and other contaminants (Hoos, 1977; Packman, 1980), but no quantitative infaunal surveys were conducted.

The present study represents initial experiments to investigate the effects of varying concentrations of wood wastes in sediments on the colonization potential of benthic invertebrates. Long-term studies are needed to delineate specific factors (exposure time, depth of wood waste) influencing recolonization and specific effects (species presence, abundance and survival) of different concentrations of wood wastes.

TERMS OF REFERENCE

The overall objective of this study was to determine the effects of different concentrations of wood waste on the recruitment of marine benthic invertebrates. Specific objectives were:

1. placement of in situ samplers containing 0, 20, 50 and 100 percent wood wastes to allow recruitment of benthic macroinvertebrates;

2. retrieval of samplers with the colonizing benthos;

3. quantification and identification of benthic macroinvertebrates found in each sampler;

4. analyses of substrate particle size, total organic carbon and total nitrogen;

5. statistical analyses of these data to determine whether any significant differences exist among different concentrations of wood wastes; and,

6. preparation of a report discussing the findings of the study.

MATERIALS AND METHODS

Benthic Invertebrates

Sediments were collected by divers at 15-20 m depths near the West Vancouver Laboratory dock facilities in outer Burrard Inlet, B.C. The sediments were frozen (-20°C) for several days to kill existing fauna, thawed, homogenized and mixed with wood wastes. Wood wastes (wood fibres and wood by-products) were collected from a loading dock area in the intertidal zone at Port Mellon in Howe Sound, B.C. Seasoned, pulverized wood chips exposed to water and wave action were used to simulate typical wood-rich material found near dumpsites and to reduce problems associated with soluble extractives (e.g. sugars, humic acids, tannins and lignin) in newly-processed wood. Wood wastes were added to natural sediments in volumetrically-determined proportions (V/V). Ratios of wood wastes to natural sediments were 0:100, 20:80, 50:50 and 100:0. Each mixture was thoroughly homogenized and placed into two replicate wooden containers as shown in Figure 1.

The containers were securely fastened to a large wooden base and the entire device was anchored by divers in outer Burrard Inlet at a bottom depth of approximately 25 m, near the original collection site of the sediment. The containers were retrieved after 11 weeks (01 August - 20 October) exposure. Each container was securely covered with a lid, brought to the surface, and transported to the E.V.S. Consultants laboratory within two hours. In the laboratory, a specially constructed divider-grid was inserted into each container, and the four middle subsections (to avoid any 'edge' effects as discussed in Berge, 1980) individually removed, providing a total of eight subsamples for each wood waste concentration (see Fig. 1). Each subsample was placed into a labelled plastic bag and preserved with 7-10% formalin, for taxonomic analysis. The remaining sediment from one container of each treatment was analyzed by Pacific Soils Ltd. for sediment particle size, total nitrogen, and total organic carbon. Total organic carbon was determined by the Wakley-Black wet oxidation method. Total nitrogen was determined colorimetrically on a sulfuric acid digest, using modified micro Kjeldahl procedures. The pipette method as outlined by Walton (1978) was used for particle size analysis.

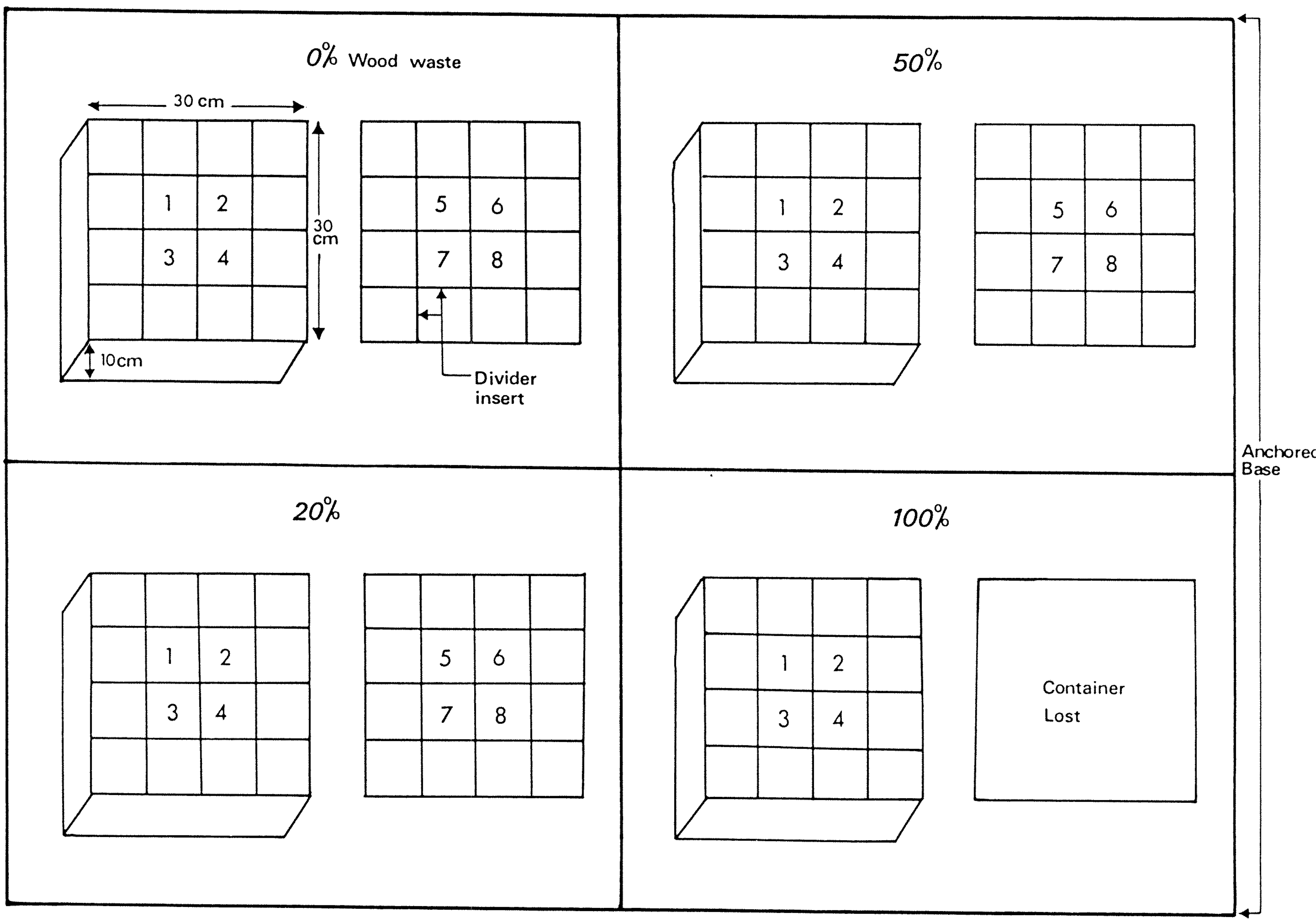

Fig. 1. Base with attached samplers for benthic invertebrate recruitment study.

For taxonomic analysis, each sample was washed in a 0.5 mm mesh sieve to remove excess formalin and fine sediment. Contents remaining in the sieve were placed into a plastic container and enough water added to cover all material. Small aliquotes of the sample were placed into a gridded petri dish and examined under a Wild M5A stereomicroscope. All benthic invertebrates were removed, enumerated by major taxonomic categories (generally Class or Order) and placed into 60 percent isopropanol. This process was continued until the entire sample had been examined and all organisms removed. Where sample volume was excessive, samples were volumetrically divided into two portions, one portion sorted for benthic invertebrates and the other archived. Detailed identification to the lowest possible taxonomic level consistent with presently available literature was performed for all organisms. A list of taxonomic references used for the identifications is provided in Appendix A.

Data Analyses

Initial examination of the matrix of species abundances in response to varying wood fibre concentrations indicated that the proposed parametric statistical approach should be replaced by a descriptive methodology, employing recognized community classification techniques. High variability in abundances of taxa between replicates under any one treatment (wood fibre concentration) prompted consideration of each replicate separately, rather than as single treatment samples represented by average abundances of occurring taxa. High variability, in itself, was an important result of this experiment and was maintained, where possible, throughout the subsequent analyses.

Matrix Editing: The original data matrix (M1) was visually inspected for taxa which could be regarded as rare or incidental. These forms were removed from the original matrix using two editing criteria:

(i) First edit - deletion of taxa with recorded abundances of one or less in approximately 95% (26 of 28) of the treatment samples. Resultant matrix designation M2; and

(ii) Second edit- deletion of taxa with recorded abundances of two or less in approximately 95% (26 of 28) of the treatment samples. Resultant matrix designation M3.

Each matrix (M1-M3) was subjected to the following analyses to allow comparison between matrices, and to thus reveal differences which may have resulted from the editing procedure.

Diversity/Dominance Measures

The species composition and abundance data for each of the 28 samples comprising the three data matrices were compared on the basis of species richness (s), and the Shannon-Weaver (1963) diversity index

(1) $$H' = -\sum p_i \log p_i$$

where p_i = the abundance of species i.

Additional measurements included Pielou's (1966) evenness index

(2) $$J' = \frac{H'}{H'_{max}}$$

where $H'_{max} = \log (s)$

a dominance measure, expressed as the compliment of evenness (1 - J'), and Simpson's (1949) diversity index

(3) $$d = \frac{\sum n_i(n_i-1)}{N(N-1)}$$

where n_i = the number of individuals in the i^{th} species, and
N = the total number of individuals in the sample.

Mean diversity and dominance values were graphically displayed as a function of percent wood fibre. General trends observed in these relationships were compared among data matrices M1, M2 and M3.

Cluster Analysis

Each data matrix was subjected to two hierarchical (cluster) analyses in order to allow comparison of

(i) samples, based on the similarity of species composition and abundances (Q-type analysis), and
(ii) species, based on the similarity of occurrence in samples and their respective abundances (R-type analysis).

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

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

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.

Pair-group clustering was unweighted (arithmetic means) and output was displayed as an optimally rotated dendrogram. These analyses were performed using the FORTRAN program "FAUNA I" developed by E.M. Hagmeier at the University of Victoria (© 1983).

Ordination Analysis

The Cornell Ecological Program package ORDIFLEX (CEP-25A: Gauch, 1977) was used to complement results obtained in the Q-type analyses provided by the cluster technique described above. Data from each matrix were first subjected to the double standardization of Bray and Curtis (1957), with species maxima set to 100 and sample totals relativized to 100. Each matrix was subjected to a non-centered Principal Components Analysis (PCA), the percent variation accounted for by each axis recorded, and the first two principal axes reported. Results were compared between matrices M1-M3, and with results obtained using the clustering techniques.

RESULTS

A listing of all benthic invertebrates collected during this study is provided in Appendix B, and distributional data are provided in Appendix C. Homogeneous invasion and distribution within each container was assumed, allowing treatment of the subsamples as eight replicates of each concentration. One of the two containers with 100% wood wastes was lost prior to retrieval, providing only four replicates for this concentration.

Total and mean numbers of taxa were distinctly higher at 20% wood fibre than at the other concentrations (Fig. 2), and total numbers of organisms were similar between 0% and 50%, and between 20% and 100% wood fibre. A more detailed analysis (Table 1) shows large variations for most of the major taxonomic groups, especially the polychaetes and bivalve molluscs. Although the wood fibre 100% treatment had the fewest species of polychaetes, the number of individuals was almost twice that of the next highest abundance, almost entirely due to large numbers of Capitella capitata and Armandia brevis in the 100% samples. Bivalves showed a similar pattern, with equally high numbers of individuals at all concentrations, but a significant decrease in diversity at 100%, where Bankia setacea was heavily dominant.

Species richness (=number of taxa), Shannon-Weaver diversity index, evenness, dominance and Simpson diversity index data are presented in Appendix D and summarized in Figure 3. These values showed a similar pattern to that described above among concentrations for all matrices. Species richness increased at 20% but showed a dramatic reduction at 100%. Diversity and evenness were highest at 20%, with slight decreases at 0% and 50%, and a large decrease at 100%. Dominance, the reciprocal of evenness, indicated that only a few species represented the majority of individuals at the 100% treatment, but that there were no particular species dominant at the other three concentrations.

Sample cluster analyses (Q-type) performed on all three data sets clearly differentiated two distinct groups of samples (Fig. 4, 5 and 6). The same trends were shown with (M1) and without (M2, M3) rare species. This report focuses on M3, the second edit data matrix, containing the 17 most common/abundant taxa. Group I (Fig. 6) contained all of the 0% and all but one of the 20% samples but only three 50% samples and none of the 100% samples. Samples of

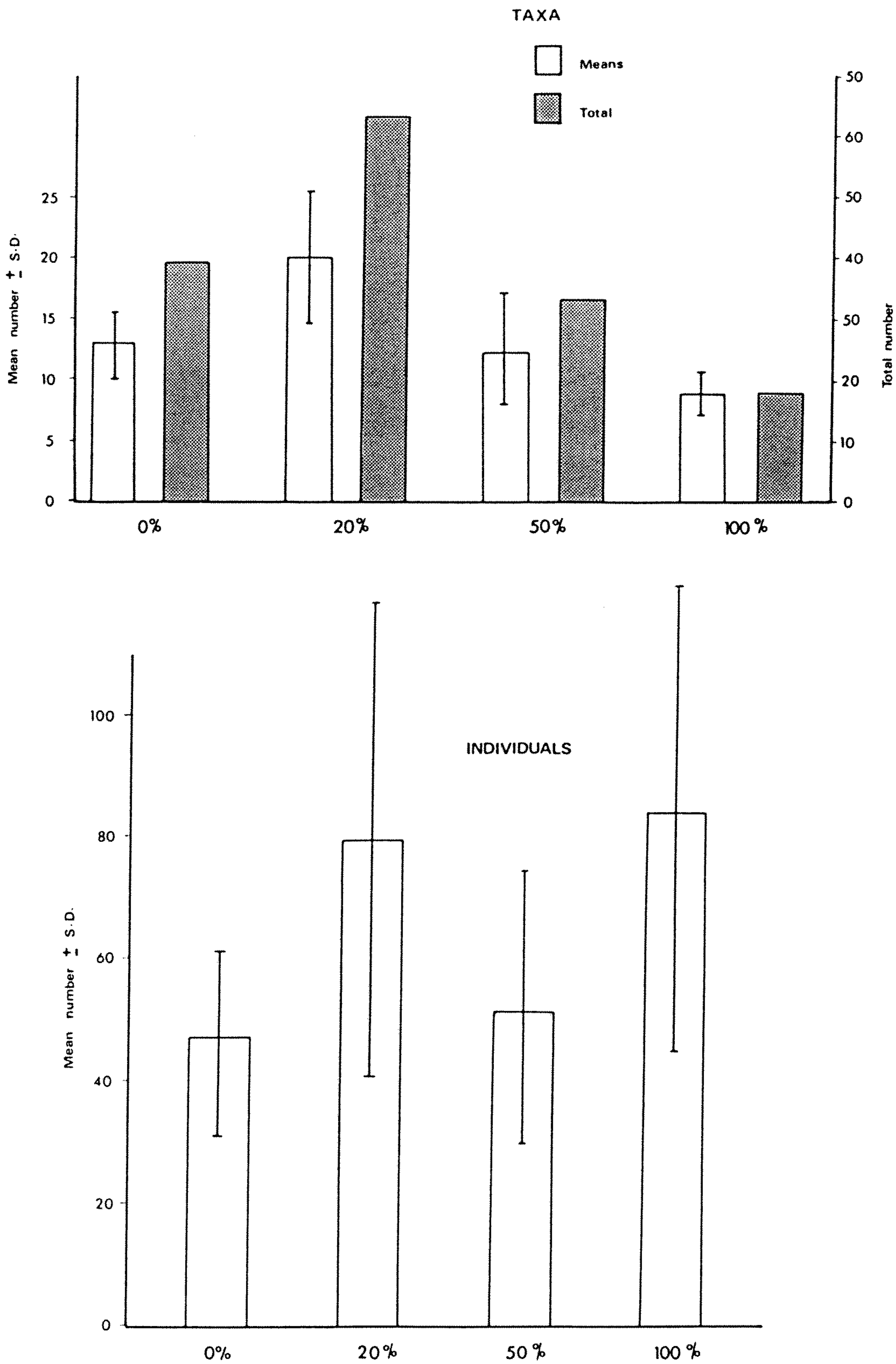

Fig. 2. Numbers of taxa and numbers of individuals in original data matrix (28 samples x 81 taxa).

TABLE I

TOTAL NUMBER OF SPECIES AND MEAN NUMBER OF INDIVIDUALS COLLECTED FROM EACH TREATMENT FOR EACH MAJOR TAXONOMIC GROUP

	Percent Wood Waste							
	0		20		50		100	
	Taxa	Indiv.*	Taxa	Indiv.*	Taxa	Indiv.*	Taxa	Indiv.*
Nematoda	-	2.75	-	11.88	-	6.38	-	2.50
Oligochaeta	2	2.38	4	7.25	2	1.50	-	0
Polychaeta	24	22.25	41	31.38	20	21.50	11	59.00
Ostracoda	-	0.88	-	0.63	-	0.88	-	0.50
Amphipoda	2	0.63	3	1.75	-	0	2	1.50
Isopoda	-	0	-	0	-	0	1	0.25
Leptostraca	-	0	-	0	-	0	1	0.25
Hydrozoa	1	0.13	1	0.25	-	0	-	0
Bivalvia (excl. Bankia)	9	17.63	13	19.88	9	9.00	2	2.00
Bankia setacea	1	0.50	1	6.25	1	12.75	1	18.00
Gastropoda	-	0	-	0	1	0.25	-	0

*based on means of 8 replicates for 0%, 20% and 50%; and, means of 4 replicates for 100%

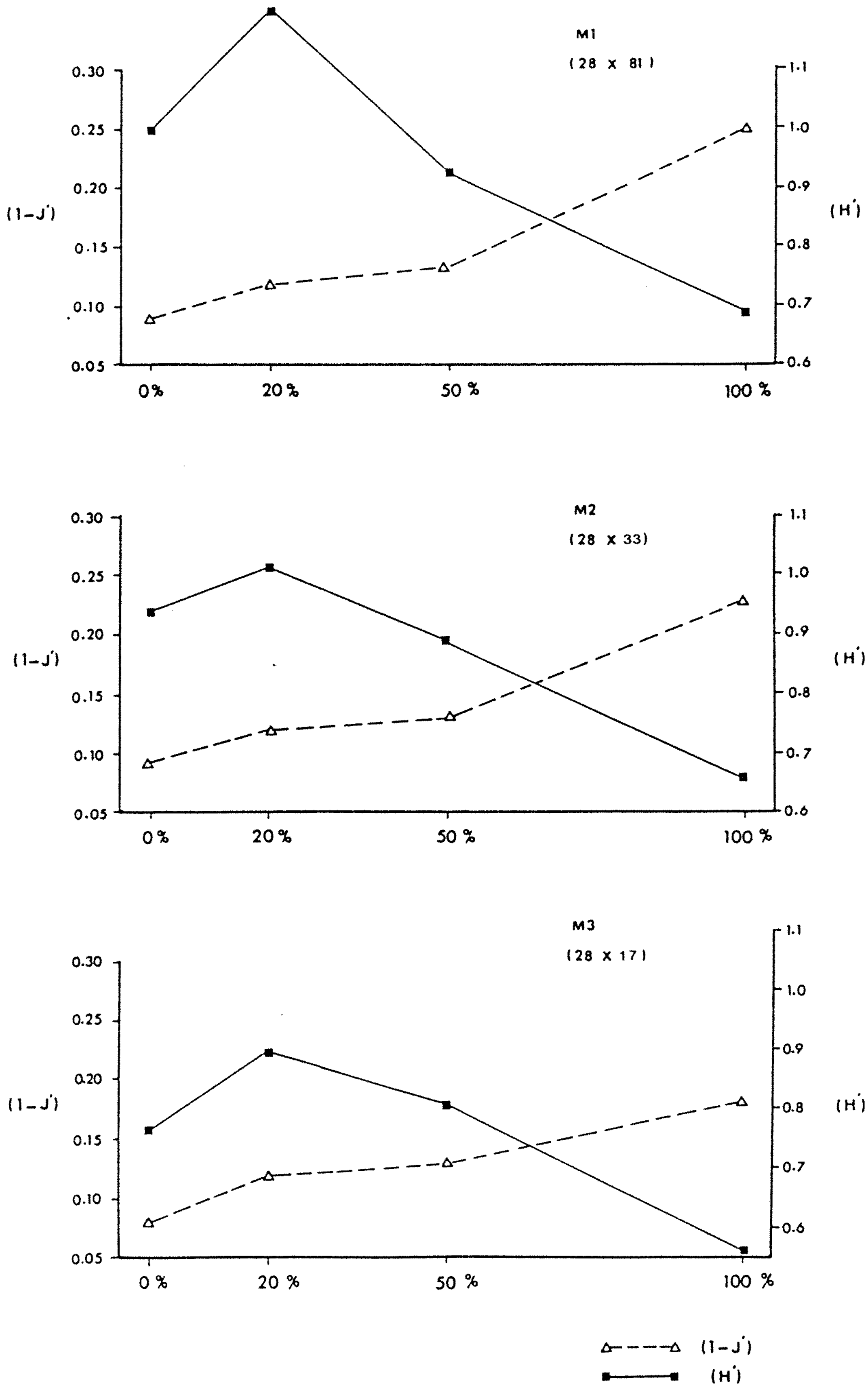

Fig. 3. Trends in mean diversity (H') and mean dominance (l-J') for the three data matrices analyzed.

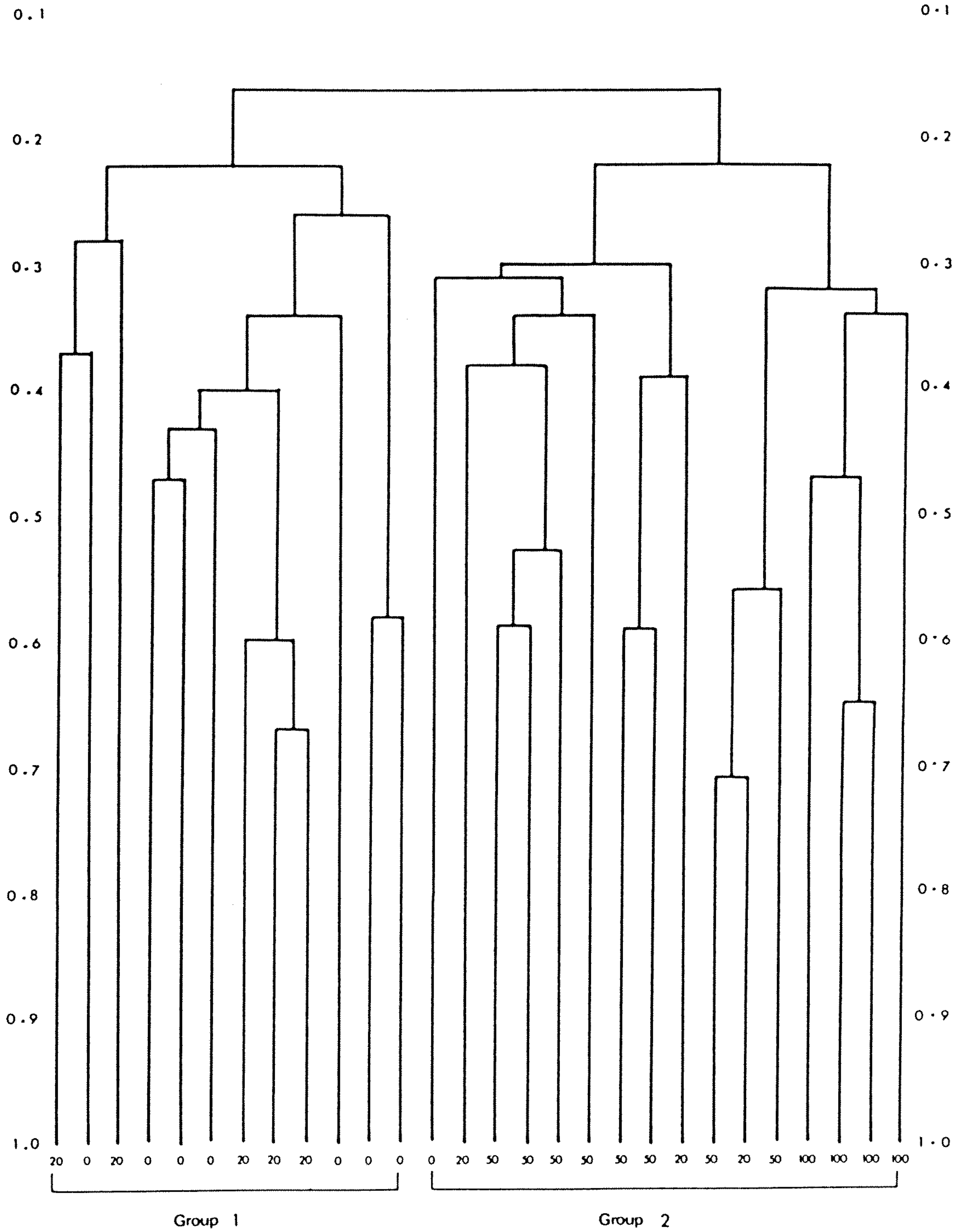

Fig. 4. Cluster analysis treatment groupings derived from MI (original) data matrix.

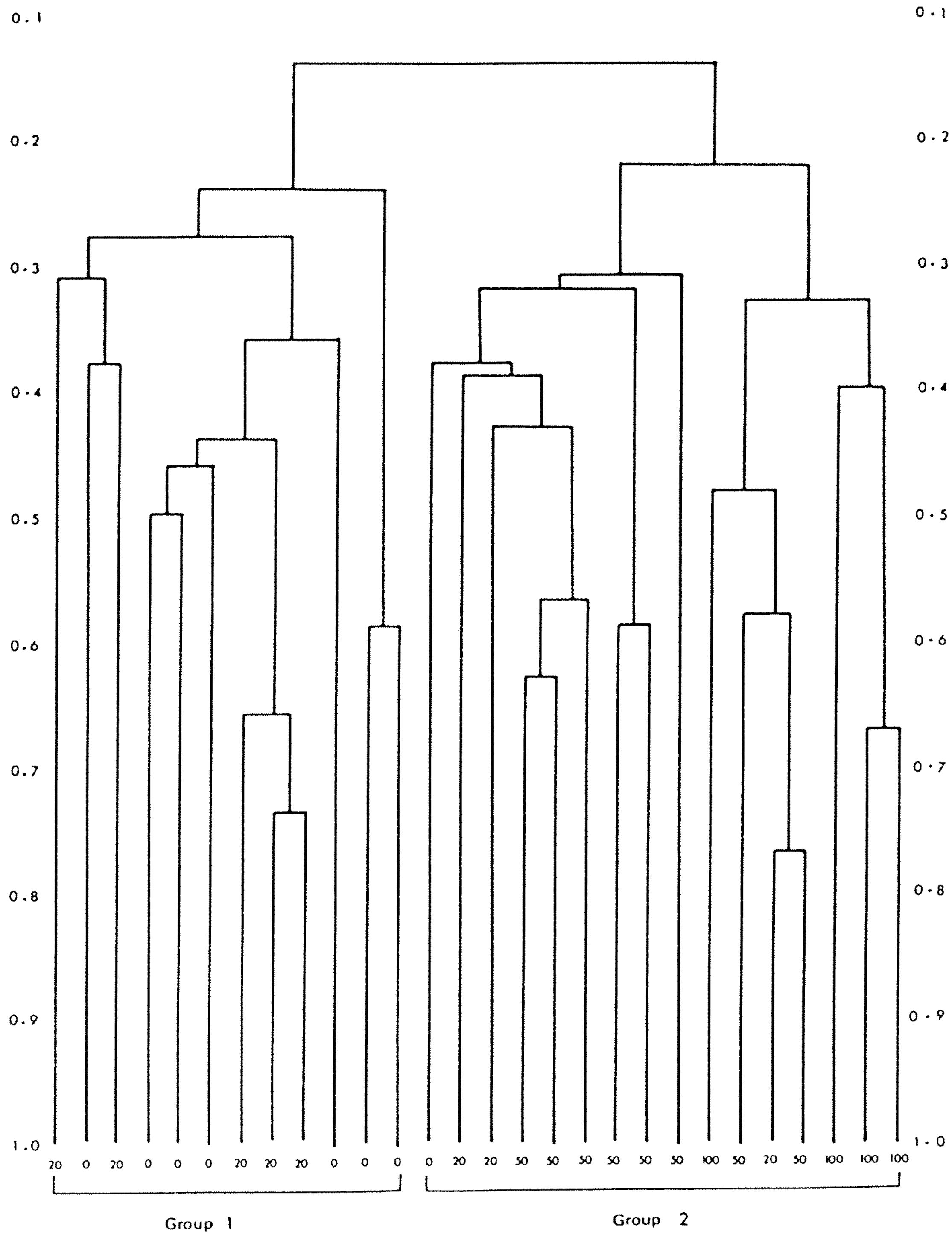

Fig. 5. Cluster analysis treatment groupings derived from M2 (first edit) data matrix.

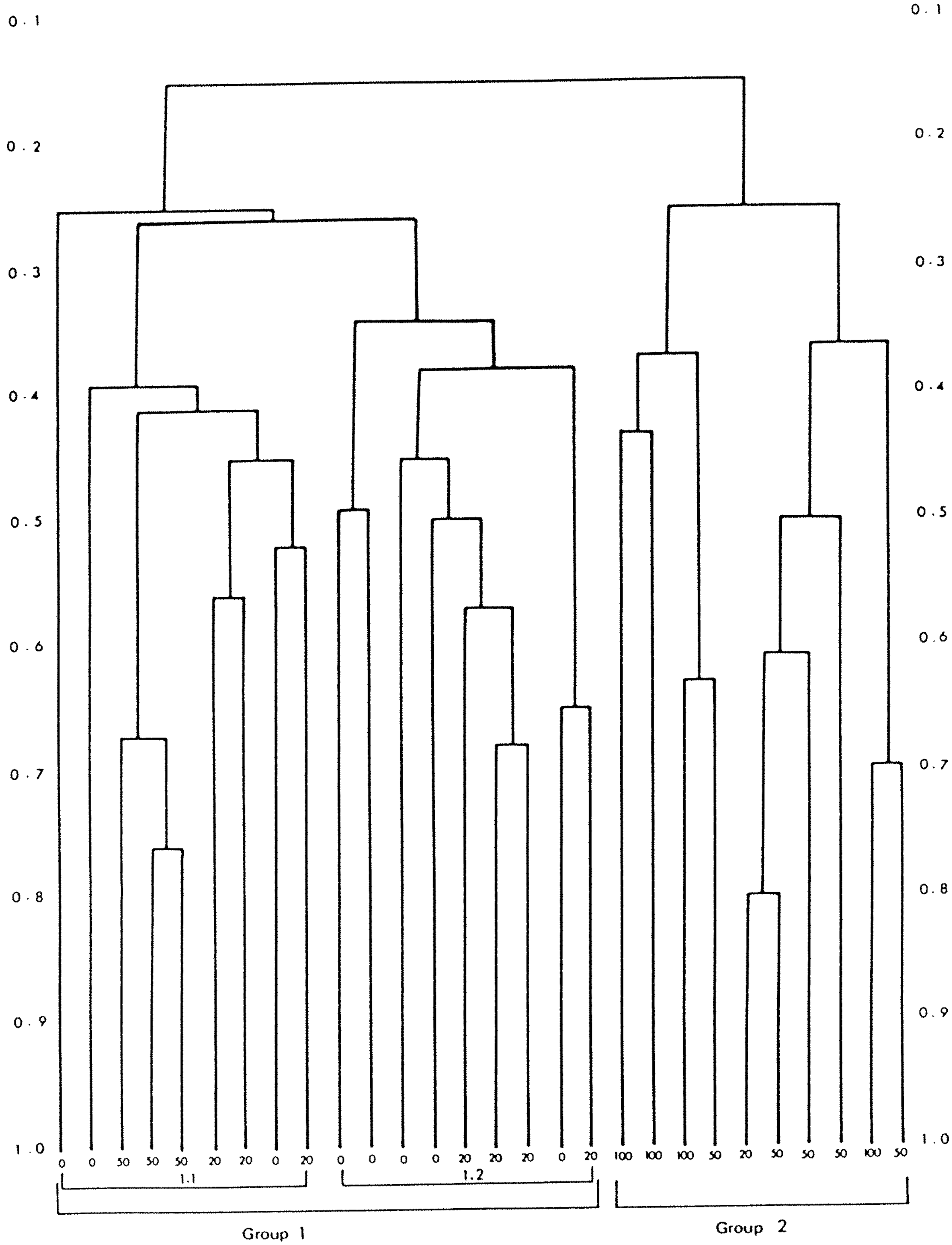

Fig. 6. Cluster analysis treatment groupings derived from M3 (second edit) data matrix.

each concentration within the two major groups were unevenly distributed, indicating generally inconsistent replication among each of the eight samples from a specific concentration.

Species abundance data indicated enhanced recruitment at 20% wood waste, compared to reduced recruitment at 100% (Fig. 6). Cluster analysis by species (or R-type) for the M3 data matrix differentiated three groups of species as shown in Figure 7. A higher abundance of particular species (Fig. 8, Group A) was noted at 20% compared to the other wood waste concentrations. Equally high numbers were noted at 0% and 50%, with very few individuals at 100%. No oligochaetes were found in the 100% treatment. Although little is known about the ecology of the tubificid oligochaetes found in these samples (Limnodriloides spp.), it was obvious from Table 2 and Appendix C that some wood waste enhanced their occurrence. This enhancement may be due to the additional nutrients and bacteria provided by the wood waste (Dr. R.O. Brinkhurst, Institute of Ocean Sciences, pers. comm.).

Similar trends were seen for all of the polychaetes associated with low amounts of wood fibres (Fig. 7, Group A). Ophelina acuminata, Glycera capitata, Tharyx spp. and Lanassa venusta venusta occurred in large numbers at 0% and 20% wood waste, but at much lower numbers in 50% and 100% treatments. The bivalves Lucina tenuisculpta, Psephidia lordi, Mysella spp. and Cyclocardia ventricosa were distinctly limited by 50% and 100% wood waste concentrations, with only Mysella compressa occurring in one sample of 100% treatment.

Group B species (Fig. 7) were clearly sensitive to high concentrations of wood waste (Fig. 8). The one polychaete and four bivalve molluscs comprising this group occurred in high abundance at 0% and 20% concentrations, decreased at 50%, and only the bivalve Mysella compressa was found at 100% wood waste. Abundances of these species in 0% and 20% concentrations were at least double those for other concentrations.

Group C species (Fig. 7) was comprised of nematodes, three polychaete taxa and the wood-burrowing shipworm Bankia setacea. There was a significant increase in all individuals of this group from 0% to 100% concentrations (Fig. 8). The large numbers of nematodes in the 20% concentration contributed to the high number for this concentration in Group C.

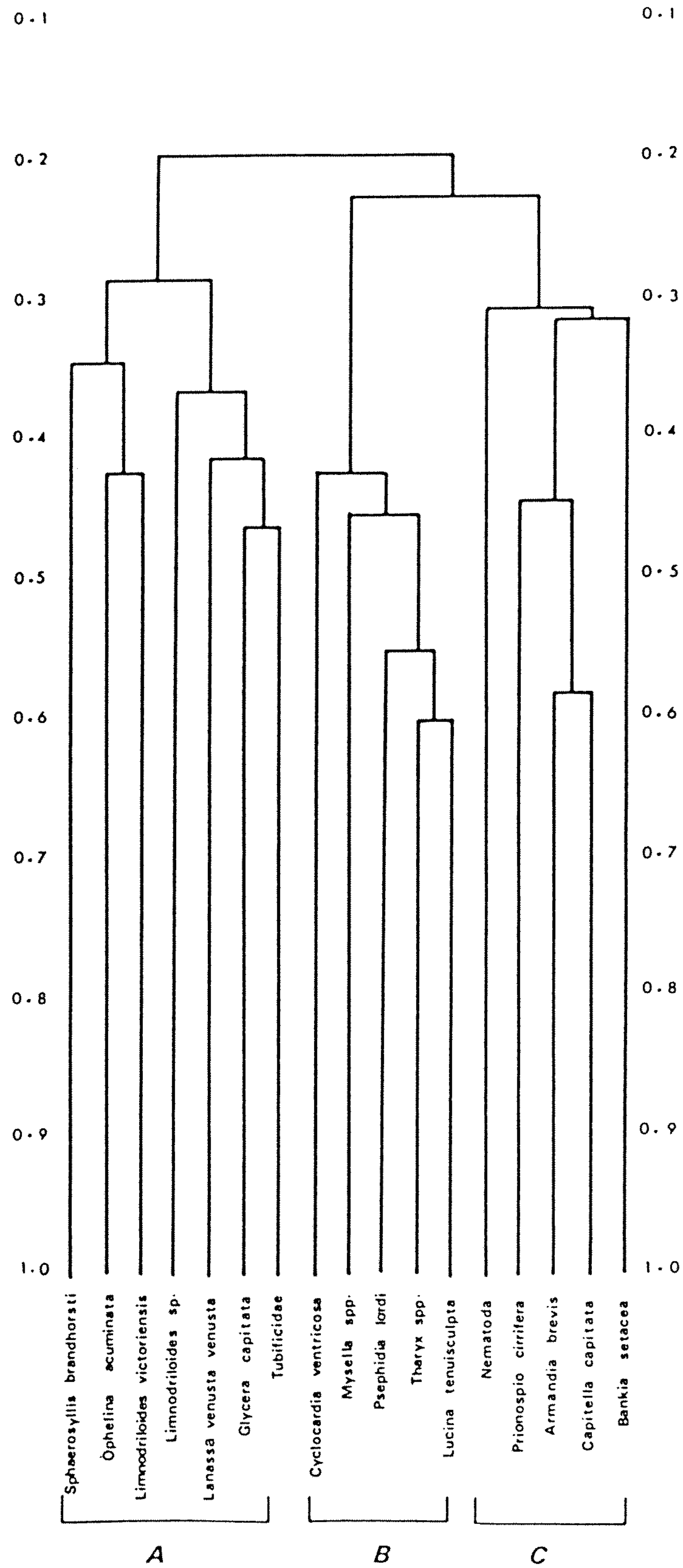

Fig. 7. Cluster analysis species groupings derived from M3 (second edit) data matrix.

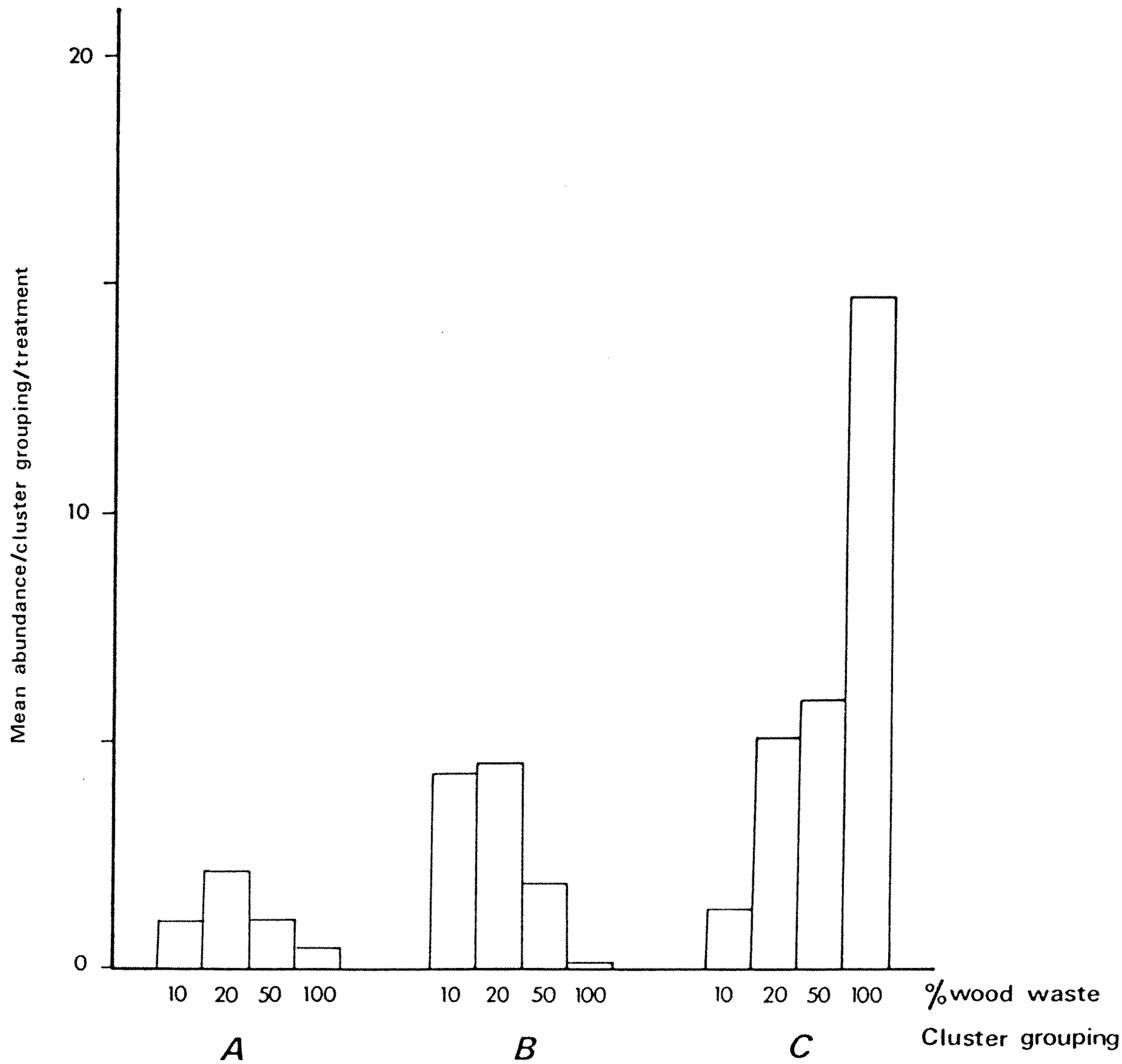

Fig. 8. Mean number of individuals for each cluster analysis species grouping. Data derived from Fig. 6.

Principal components analysis of the M3 data matrix supported the trends derived from the cluster analyses (Fig. 9). Group 1 contained 12 of the total of 16 samples for 0% and 20% treatments. Of the remaining four samples, three were not associated with any grouping while one was similar to the Group 3 50% concentration samples. The 50% samples were divided between Groups 2 and 3. The most distinct set of samples was Group 4, consisting of all of the 100% concentration samples, which indicated major differences among both taxa and individuals when compared to the other three lower wood waste concentrations.

Data on particle size, total nitrogen and total organic carbon in the sediments are shown in Table 2. Substrate particle sizes were highly variable. The amount of sand increased from the 0% to the 50% samples with concomitant decreases in silt and clay. Total nitrogen decreased from the 0% to the 100% samples, while total organic carbon values were variable. Contrary to the faunal data matrices, a correlation matrix incorporating these variables indicated that they did not significantly contribute to the distribution of species among the four wood fibre concentrations. The faunal distribution was due, therefore, to physical or other parameters not measured (e.g. nutrients, bacteria).

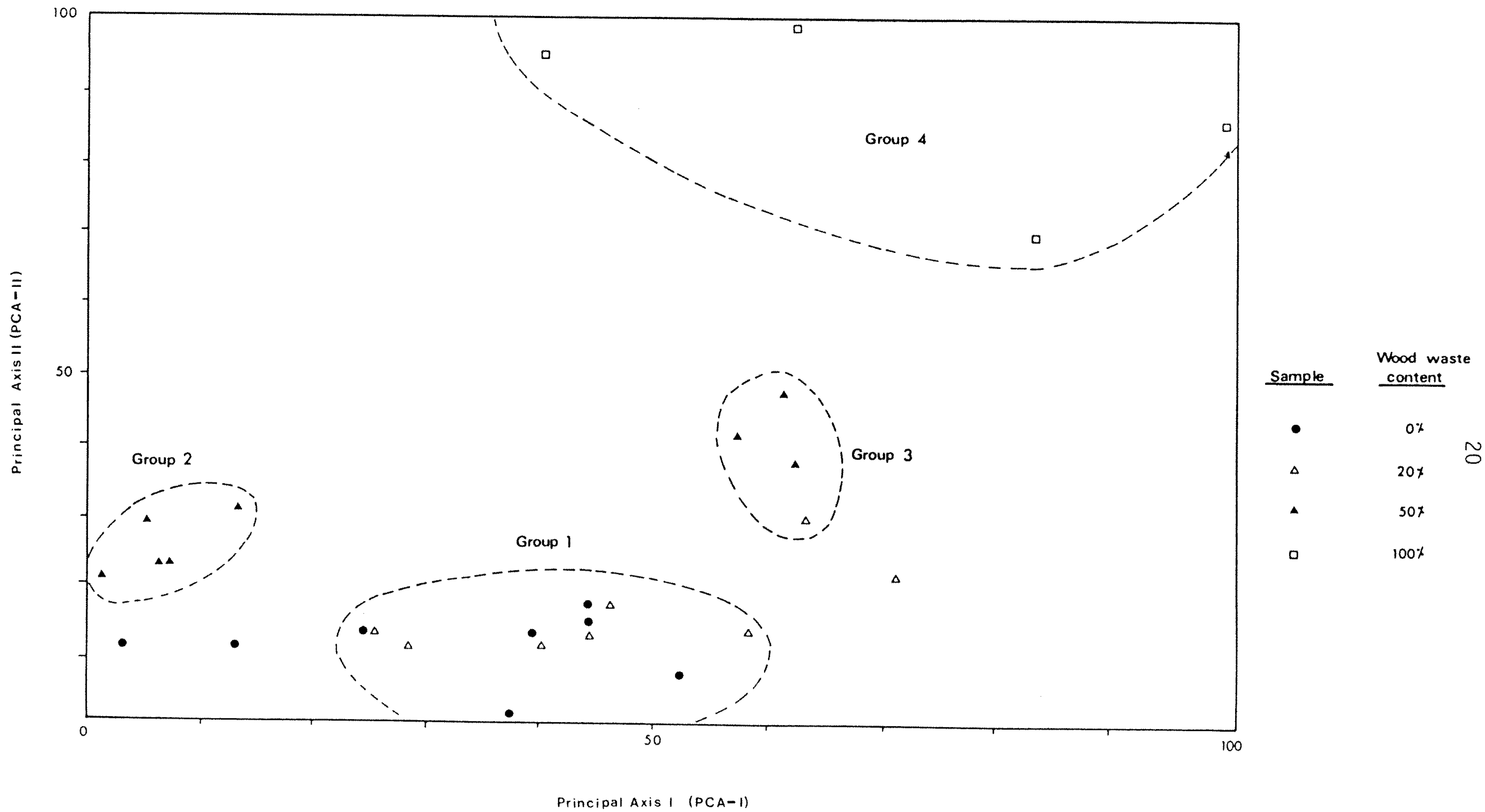

Fig. 9. Groupings of samples with varying wood waste concentrations using principal components analysis (PCA).

TABLE 2

SUBSTRATE PARTICLE SIZE, TOTAL NITROGEN AND TOTAL ORGANIC CARBON IN EACH CONCENTRATION OF WOOD WASTE

Parameter	0%	20%	50%	100%
Particle Size				
Sand (.063-2 mm)	30.8	58.7	68.5	-
Silt (.004-.063 mm)	35.3	18.7	13.4	-
Clay (<.004 mm)	33.9	22.6	16.1	-
Total Nitrogen	0.14	0.06	0.04	0.02
Total Organic Carbon	4.21	7.58	6.70	46.20

All values expressed as percentages.

DISCUSSION

Most investigations of recolonization have described disturbance related events (see, for example, Bonsdorff, 1980; McCall, 1977; Pearson and Rosenberg, 1978), although some studies have dealt specifically with benthic colonization using in situ sampling techniques (Arntz and Rumohr, 1982, Rumohr, 1982). The present study is discussed primarily with respect to the latter investigations.

The two dominant groups of recolonizing organisms collected during this study were polychaete worms and bivalve molluscs. Two other groups, nematodes and oligochaete worms, showed secondary importance in the initial or pioneering stage of benthic recruitment (see Table I and Fig. 6). In a three year study of benthic succession and seasonal variation in the Baltic Sea, Arntz and Rumohr (1982) found that polychaetes were always the most abundant organisms, followed by molluscs, regardless of exposure time. Crustaceans ranked third in abundance. In neither study were other taxonomic groups of major significance to the overall pattern of colonization or variation. In the present study, elimination of 48 (first edit; M2) or 64 (second edit; M3) occasional taxa from a total of 81 (original) taxa did not affect the patterns and trends for species richness, diversity, abundance, and cluster and ordination classification.

Pronounced variability was observed among samples for each concentration of wood waste tested. Four subsamples from a given concentration never clustered together, although they generally occurred within a single major cluster group. Several factors could have caused these differences among replicates. Because natural spatial dispersion of benthic invertebrates is usually contagious (Elliott, 1977), composition and abundance is often different among replicates. This effect can be compounded if small samples within a small area are taken. The short (i.e. 11 week) exposure time may have prohibited establishment of a stable community structure throughout the experimental containers, resulting in further patchiness. Differences in substrate characteristics (e.g. particle size, organic content, pH) among containers could also have encouraged the establishment of different faunal assemblages. As Rumohr (1980) and Arntz and Rumohr (1982) point out, those organisms which settle first have an advantage over those still in the plankton, while certain planktonic larvae will only settle after certain other species have already established themselves.

Based on the results of this study, the potential for benthic invertebrate colonization was enhanced if there was an approximate 1:3 ratio of wood waste to natural sediment. This combination of sediment and wood waste may increase available niches and provide more nutrients than sediments with no wood waste or too much wood waste. The upper percentage limit of beneficial mixtures of wood waste and sediment lies between 20% and 50%. Overall, the 20% samples showed high diversity, species richness and evenness, and low dominance. The 50% samples showed an opposite trend. It was concluded that wood waste additions in the range between 10% and 40% enhance benthic invertebrate colonization, provided that sediments/wood waste were well mixed (as in the experimental containers).

Only a few species (Capitella capitata, Armandia brevis, Prionospio cirrifera) were found in the 100% wood waste but their occurrence in large numbers indicated successful colonization. Numerous studies have shown C. capitata to be dominant in polluted areas and a good biological indicator species for high levels of organic enrichment (see, for example, Pearson and Rosenberg, 1978; Reish, 1959 and 1980; Reish and Barnard, 1960; Rosenberg, 1973; Wade et al., 1972 and others). No C. capitata were collected in the 0% samples, very few in the 20% and 50% samples (mean value of one per sample), while the 100% samples had a mean value of 26 per sample. Ellis (1970) found C. capitata almost exclusively in a B.C. pulp mill fibre bed. A. brevis increased from a mean of two per sample at 0% to a mean of 21 per sample at 100%. A similar but less significant increase from 0% (mean of one worm) to 100% (mean of six worms) occurred with P. cirrifera. Both A. brevis and P. cirrifera have been associated with fauna occurring in organically polluted areas (Bagge, 1969; Chapman et al., 1982; Comiskey et al., 1984; Leppakowski, 1971). Reish (cited in Pearson and Rosenberg, 1978) found P. cirrifera present where Capitella spp. were dominant.

Increases in numbers of Bankia setacea, the wood-burrowing shipworm (bivalve), would be expected as the wood content increased. A mean number of 0.4 early settling larvae were found in the 0% samples, increasing to 9, 13 and 18 in 20%, 50% and 100%, respectively, with some small adults in the 100% samples.

Data from the present study and from infaunal core samples taken by Conlan (1977) showed similar species and sample cluster groups. Using both quantitative and qualitative clustering techniques, Conlan's (1977) data fell into distinct groupings for samples of control, intermediate and thick wood-fibre mats. Consistent with our findings, she found large numbers of Capitella capitata, Armandia brevis and Bankia setacea present in areas of dense fibre mats, while Mysella tumida and Psephidia lordi were dominant in the controls.

Conlan (1977) found a positive correlation between species presence and trophic relationships in areas of different thicknesses of fibre mats, in a continuous progression from suspension feeders in control areas, to deposit feeders in moderately thick fibre areas, and herbivores in the areas with the most wood content. The species most closely associated with the present 100% samples (Fig. 7) were also deposit feeders or herbivores. However, the wide variety of feeding guilds (carnivore/scavenger, deposit feeder, suspension feeder) represented by those species associated with the 0% and 20% samples may indicate that it was not the type of feeding habit but rather the amount of wood wastes, which determined numerical presence. Habit showed no correlation with a particular cluster group, and habitat was, of course, the same for all samples. The above comparisons further indicated that the 20% wood wastes used in this study enhanced species abundances and diversity regardless of specific ecological and trophic relationships.

RECOMMENDATIONS

Present Study

Wood wastes mixed in approximately a 1:3 ratio with sediments would enhance the potential for benthic invertebrate colonization and provided the concentration of seasoned wood in dredge spoils does not exceed 25%, and is well mixed with the natural sediments, there should be no significant ecological damage.

Future Studies

Several major questions have come to light during this investigation which warrant additional study, including: (1) what are the effects of green vs. aged wood waste, wood species and wood waste size distribution on benthic recolonization; (2) what are the effects of natural sediments overlain by different depths of wood wastes (unmixed) on benthic colonization; (3) what are the available organics, nutrient availability and time for breakdown in wood wastes mixed with sediments; and (4) how does the *in situ* sampler compare with infaunal core samples from areas of wood deposition?

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APPENDIX A

LIST OF TAXONOMIC REFERENCES

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APPENDIX B

LIST OF ALL BENTHIC INVERTEBRATE TAXA COLLECTED DURING STUDY

Coelenterata
  Hydrozoa
    Leptomedusae
      Campanulariidae
        Campanularia denticulata Clark

Nematoda

Annelida
  Oligochaeta
    Tubificida
      Tubificidae
        Limnodriloides sp.
        L. victoriensis Brinkhurst and Baker
        Tectidrilus diversus Erseus
        ?Tubificoides foliatus Baker

  Polychaeta
    Capitellida
      Capitellidae
        Barantolla sp.
        Capitella capitata (Fabricius)
        Heteromastus filiformis Berkeley and Berkeley
        Mediomastus sp.
        M. ambiseta (Hartman)
        M. californiensis Hartman

      Maldanidae
        Praxillela affinis (Sars)
        P. gracilis (Sars)
        Rhodininae

    Cossurida
      Cossuridae
        Cossura soyeri Laubier

    Eunicida
      Dorvilleidae
        Schistomeringos caeca (Webster and Benedict)

      Lumbrineridae
        Lumbrineris cruzensis Hartman
        L. luti Berkeley and Berkeley

      Onuphidae
        Onuphis sp.

Flabelligerida
Flabelligeridae
Pherusa plumosa (Muller)

Opheliida
Opheliidae
Armandia brevis (Moore)
Ophelina acuminata Oersted

Orbiniida
Orbiniidae
Leitoscoloplos pugettensis (Pettibone)

Phyllodocida
Glyceridae
Glycera capitata Oersted

Goniadidae
Glycinde armigera Moore

Hesionidae

Nephtyidae
Nephtys cornuta franciscana Clark and Jones
N. ferruginea Hartman

Phyllodocidae
Anaitides sp.
Eteone californica Hartman

Polynoidae
Harmothoinae

Sigalionidae
Pholoe minuta (Fabricius)

Syllidae
Exogone lourei Berkeley and Berkeley
E. molesta Banse
Sphaerosyllis brandhorsti Hartmann-Schroder
Syllis heterochaeta Moore

Sabellida
Sabellidae
Chone sp.
Euchone incolor Hartman

Spionida
Cirratulidae
Chaetozone setosa Malmgren
Tharyx sp.
T. multifilis Moore

Spionidae
Laonice sp.
Paraprionospio pinnata (Ehlers)
Polydora socialis (Schmarda)
Prionospio cirrifera Wiren
P. steenstrupi Malmgren

Terebellida
Ampharetidae
Ampharete acutifrons (Grube)
A. finmarchica (Sars)

Pectinariidae
Pectinaria sp.
P. californiensis Hartman

Terebellidae
Lanassa venusta venusta (Malm)
Pista cristata (Muller)
Polycirrus sp.

Arthropoda
Crustacea
Ostracoda

Amphipoda
Ampeliscidae
Ampelisca sp.

Anisogammaridae
Ramellogammarus sp.

Atylidae
Atylus sp.

Oedicerotidae
Synchelidium shoemakeri Mills

Phoxocephalidae
Paraphoxus sp.

Isopoda
Pleurogonidae
Pleurogonium rubicundum (G.O. Sars)

Leptostraca
Nebaliidae
Nebalia pugettensis (Clark)

Mollusca
Bivalvia
Myoida
Myidae
Mya arenaria Linnaeus

Teredinidae
Bankia setacea (Tryon)

Mytiloidea
Mytilidae
Megacrenella columbiana (Dall)

Nuculoidea
Nuculanidae
Nuculana hindsii (Hanley)
N. minuta (Fabricius)

Nuculidae
Nucula tenuis (Montagu)

Pholadomyoida
Lyonsiidae
Lyonsia arenosa (Møller)

Veneroida
Cardiidae
Clinocardium nuttallii (Conrad)
Nemocardium centifilosum (Carpenter)

Carditidae
Cyclocardia ventricosa (Gould)

Lucinidae
Lucina tenuisculpta Carpenter

Montacutidae
Mysella compressa (Dall)
M. tumida (Carpenter)

Tellinidae
Macoma carlottensis Whiteaves
M. eliminata Dunnill and Coan

Veneridae
Compsomyax subdiaphana (Carpenter)
Humilaria kennerleyi (Reeve)
Psephidia lordi (Baird)

Gastropoda
Mesogastropoda
Littorinidae
Littorina sitkana Philippi

APPENDIX C

DENSITY AND DISTRIBUTION FOR BENTHIC INVERTEBRATES COLLECTED IN VARYING AMOUNTS OF WOOD WASTE AND SEDIMENT

Wood waste	0%								20%								50%								100%				
Replicates	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8	1	2	3	4	(5 - 8)*
Coelenterata																													
Hydrozoa																													
Leptomedusae																													
Campanulariidae																													
Campanularia denticulata								1 colony		1 colony				1 colony		1 colony													
Nematoda	4	4	2	2	4		6		4	4	8		1	8	2	68		4	4	22	1	6	4	10		4	6		
Annelida																													
Oligochaeta																													
Tubificida																													
Tubificidae			2			2	1			6	4			5		4	6	2											
Limnodriloides sp.			2	2	4					4	2	4		1		4		2		4		2							
L. victoriensis											2	3	3		2	4													
Tectidrilus diversus		2			4					2										2									
?Tubificoides foliatus										2																			
Polychaeta																4**													
Capitellida																													
Capitellidae																													
Barantolla sp.	2																												
Capitella capitata									2	1	4	2						1		4		4			12	24	36	32	
Heteromastus filiformis											2																		
Mediomastus sp.			3													2													
M. ambiseta			2											1															
M. californiensis										2																			
Maldanidae			2																										
Praxillela affinis															2														
P. gracilis			2																										
Rhodininae														1															
Cossurida																													
Cossuridae																													
Cossura soyeri															2														
Eunicida																													
Dorvilleidae																													
Schistomeringos caeca	2																			2									

Wood waste	0%								20%								50%								100%				
Replicates	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8	1	2	3	4	(5 - 8)*
Lumbrineridae																													
Lumbrineris cruzensis				2		1						2				2								2					
L. luti	2		2		1				2					1		2											2		
Onuphidae																													
Onuphis sp.																			2										
Flabelligerida																													
Flabelligeridae																													
Pherusa plumosa														1															
Opheliida																													
Opheliidae																													
Armandia brevis	2	2	2		4	4	2		4	2	6	2	3	6	4	2	10	6	8	8	4	6	6	6	4	36	18	24	
Ophelina acuminata		4	4		10	3		4	2		4	6				6		3	4		1						4		
Orbiniida																													
Orbiniidae																													
Leitoscoloplos pugettensis		2	4									2				2		1	2										
Phyllodocida																													
Glyceridae																													
Glycera capitata		4			2		2			2			4	5		8			2		1	2	4				2		
Goniadidae																													
Glycinde armigera																4			2										
Hesionidae					2								2					2								2		2	
Nephtyidae																													
Nephtys cornuta franciscana																2					1					2			
N. ferruginea				2																									
Phyllodocidae																													
Anaitides sp.																2													
Eteone californica		2	2				2						2	2	2														
Polynoidae																													
Harmothoinae															2														
Sigalionidae																													
Pholoe minuta			2												2														
Syllidae																													
Exogone lourei																2													
E. molesta													1																
Sphaerosyllis brandhorsti					8											12					2	2		4	4		2		
Syllis heterochaeta														1															

Wood waste	0%								20%								50%								100%				
Replicates	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8	1	2	3	4	(5 - 8)*
Sabellida																													
Sabellidae																													
Chone sp.															1														
Euchone incolor											2																		
Spionida																													
Cirratulidae																													
Chaetozone setosa														1															
Tharyx sp.						2							4								1								
T. multifilis	4	18	8	8		4	6			2			9	6	10	16	4	3				2		2					
Spionidae																													
Laonice sp.			2			1	2					2																	
Paraprionospio pinnata									2								2	1							2	2			
Polydora socialis		2		2	2									2	2											2			
Prionospio cirrifera	4		2		2						2	8	2		6	2	2	5	4	4	1	2				6	18		
P. steenstrupi																		1											
Terebellida																													
Ampharetidae																													
Ampharete acutifrons									2	2																			
A. finmarchica														1															
Pectinariidae																													
Pectinaria sp.																2													
P. californiensis												2																	
Terebellidae																													
Lanassa venusta venusta							4		2		2	2	4	1	2	6													
Pista cristata												2	1	1															
Polycirrus sp.	2				2				2					1															
Arthropoda																													
Crustacea																													
Ostracoda					4	1	2				2		1	2				1	2		2	2			2				
Amphipoda																													
Ampeliscidae																													
Ampelisca sp.										2		2	1	1															
Anisogammaridae																													
Ramellogammarus sp.																									2				

Wood waste	0%								20%								50%								100%				
Replicates	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8	1	2	3	4	(5 - 8)*
Atylidae																													
Atylus sp.							2																						
Oedicerotidae																													
Synchelidium shoemakeri						1		2		4	2																		
Phoxocephalidae																													
Paraphoxus sp.																2											2		
Isopoda																													
Pleurogonidae																													
Pleurogonium rubicundum																										1			
Leptostraca																													
Nebaliidae																													
Nebalia pugettensis																										1			
Mollusca																													
Bivalvia																													
Myoida																													
Myidae																													
Mya arenaria														1															
Teredinidae																													
Bankia setacea			3							6	28			4	10	2	10		28	50	2		12		8		60	5	
Mytiloidea																													
Mytilidae																													
Megacrenella columbiana														1															
Nuculoidea																													
Nuculanidae																													
Nuculana hindsii																		1											
N. minuta																			1										
Nuculidae																													
Nucula tenuis													1	2	4			1						2					
Pholadomyoida																													
Lyonsiidae																													
Lyonsia arenosa											2																		
Veneroida																													
Cardiidae																													
Clinocardium nuttallii					2								1																
Nemocardium centifilosum						1		2					3																

Wood waste	0%								20%								50%								100%				
Replicates	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8	1	2	3	4	(5 - 8)*
Carditidae																													
<u>Cyclocardia ventricosa</u>	2	2	4	24		6		8	6	2					8		2	3	2	4	2	2							
Lucinidae																													
<u>Lucina tenuisculpta</u>		12	4	6	4	5	4		2	2	2	4	16	18	18	6		2		4	4								
Montacutidae																													
<u>Mysella compressa</u>						6		6		4		2	7	6	6		4	10	2		6	8	2					4	
<u>M. tumida</u>		2						2	2			2		1	1														
Tellinidae																													
<u>Macoma carlottensis</u>					4								1												2			2	
<u>M. eliminata</u>														1				1											
Veneridae																													
<u>Compsomyax subdiaphana</u>							2											1											
<u>Humilaria kennerleyi</u>	2																												
<u>Psephidia lordi</u>	4			10	8	3	2	2		2		2	10	7	6	2	4	2			2								
Gastropoda																													
Mesogastropoda																													
Littorinidae																													
<u>Littorina sitkana</u>																		1						1					

*<u>in situ</u> container lost
**vial broke; polychaetes lost

APPENDIX D-1

STATISTICAL PARAMETERS FOR ORIGINAL DATA SET
(M1: 28 concentrations x 81 taxa)

	Site	Species Richness (S)	Shannon-Weaver Diversity Index (H')	Evenness (J')	Dominance (1-J')	Simpson Diversity Index (D)
0%	1	10	0.97	0.97	0.03	0.08
	2	14	0.98	0.85	0.15	0.14
	3	16	1.15	0.96	0.04	0.06
	4	11	0.84	0.80	0.20	0.20
	5	17	1.16	0.95	0.05	0.07
	6	14	1.04	0.91	0.09	0.08
	7	13	1.06	0.96	0.04	0.07
	8	8	0.81	0.90	0.10	0.15
20%	9	11	0.99	0.95	0.05	0.09
	10	18	1.21	0.97	0.03	0.05
	11	15	0.93	0.79	0.21	0.19
	12	17	1.17	0.95	0.05	0.06
	13	23	1.19	0.87	0.13	0.08
	14	30	1.24	0.84	0.16	0.07
	15	20	1.18	0.90	0.10	0.08
	16	26	1.06	0.75	0.25	0.18
50%	17	11	0.95	0.91	0.09	0.12
	18	22	1.21	0.90	0.10	0.06
	19	12	0.84	0.78	0.22	0.23
	20	10	0.72	0.72	0.28	0.28
	21	16	1.12	0.93	0.07	0.06
	22	13	1.05	0.94	0.06	0.08
	23	7	0.77	0.91	0.09	0.17
	24	8	0.79	0.88	0.12	0.17
100%	25	10	0.90	0.90	0.10	0.14
	26	9	0.65	0.68	0.32	0.30
	27	10	0.70	0.70	0.30	0.26
	28	5	0.52	0.74	0.26	0.36

APPENDIX D-2

STATISTICAL PARAMETERS FOR FIRST EDIT DATA SET
(M2: 28 concentrations x 33 taxa)

	Site	Species Richness (S)	Shannon-Weaver Diversity Index (H')	Evenness (J')	Dominance (I-J')	Simpson Diversity Index (D)
0%	1	7	0.82	0.97	0.03	0.12
	2	14	0.98	0.85	0.15	0.14
	3	13	1.06	0.95	0.05	0.08
	4	10	0.80	0.80	0.20	0.21
	5	15	1.11	0.95	0.05	0.07
	6	13	1.01	0.91	0.09	0.09
	7	11	0.99	0.95	0.05	0.09
	8	6	0.71	0.91	0.09	0.19
20%	9	10	0.95	0.95	0.05	0.10
	10	14	1.11	0.97	0.03	0.06
	11	12	0.83	0.77	0.23	0.23
	12	13	1.05	0.95	0.05	0.08
	13	17	1.09	0.88	0.12	0.09
	14	19	1.09	0.85	0.15	0.10
	15	16	1.09	0.90	0.10	0.09
	16	19	0.94	0.74	0.26	0.21
50%	17	11	0.95	0.91	0.09	0.12
	18	16	1.09	0.91	0.09	0.08
	19	10	0.76	0.76	0.24	0.26
	20	9	0.69	0.72	0.28	0.29
	21	14	1.07	0.93	0.07	0.07
	22	13	1.05	0.94	0.06	0.08
	23	7	0.77	0.91	0.09	0.17
	24	7	0.75	0.89	0.11	0.19
100%	25	9	0.86	0.90	0.10	0.15
	26	6	0.57	0.73	0.27	0.33
	27	9	0.68	0.71	0.29	0.26
	28	5	0.52	0.74	0.26	0.36

APPENDIX D-3

STATISTICAL PARAMETERS FOR SECOND EDIT DATA SET
(M3: 28 concentrations x 17 taxa)

	Site	Species Richness (S)	Shannon-Weaver Diversity Index (H')	Evenness (J')	Dominance (1-J')	Simpson Diversity Index (D)
0%	1	6	0.76	0.98	0.02	0.14
	2	8	0.75	0.83	0.17	0.21
	3	9	0.90	0.94	0.06	0.11
	4	6	0.63	0.82	0.18	0.28
	5	10	0.93	0.93	0.07	0.11
	6	8	0.86	0.96	0.04	0.12
	7	7	0.80	0.95	0.05	0.14
	8	4	0.56	0.92	0.08	0.26
20%	9	7	0.80	0.95	0.05	0.14
	10	11	1.00	0.96	0.04	0.08
	11	9	0.72	0.75	0.25	0.28
	12	9	0.90	0.94	0.06	0.12
	13	13	1.01	0.91	0.09	0.11
	14	11	0.92	0.89	0.11	0.13
	15	13	1.01	0.91	0.09	0.11
	16	14	0.84	0.73	0.27	0.25
50%	17	9	0.87	0.92	0.08	0.13
	18	12	1.00	0.93	0.07	0.10
	19	8	0.68	0.75	0.25	0.30
	20	8	0.66	0.73	0.27	0.31
	21	12	1.00	0.93	0.07	0.08
	22	11	0.97	0.94	0.06	0.10
	23	6	0.72	0.92	0.08	0.19
	24	5	0.62	0.88	0.12	0.25
100%	25	5	0.65	0.93	0.07	0.23
	26	4	0.49	0.81	0.19	0.37
	27	7	0.64	0.75	0.25	0.28
	28	4	0.47	0.78	0.22	0.38