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Changes in benthic communities along a presumed pollution gradient in Vancouver Harbour

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Abstract

Samples of macrobenthic organisms were obtained at seven stations on a presumed pollution gradient from the head of Vancouver Harbour through to outer Howe Sound. Polychaetes (83 apparent species) and molluscs (43 apparent species) were the most abundant faunal groups numerically (44.8 and 47.9%, respectively). Molluscs accounted for most of the biomass (87.9%). The following univariate and multivariate methods were used to investigate structural changes in the benthic communities: ANOVA, Abundance–Biomass Comparisons and related statistics, cluster analysis, multidimensional scaling, and the BIOENV procedure. Most of the analyses divided the seven stations into three groups: Port Moody Arm (Inner Harbour): two stations; Inner and Outer Harbour: four stations, and Gibsons (Howe Sound): one station. Further cause–effect investigations are needed to determine the sensitivity to organic pollution of indicator species identified in the survey. However our data correlating benthic community changes to sediment chemistry suggest the inner harbour was dominated by pollution-tolerant species. Depth and sediment grain size were confounding factors for the interpretations.

Keywords: Benthic community; Pollution gradient; Multivariate analysis; Vancouver Harbour

1. Introduction

In this paper, we report results of a collaborative benthic sampling and analysis program carried out during the PICES Workshop to examine benthic habitats in

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Vancouver Harbour along a presumed pollution gradient and into the Strait of Georgia. The primary objective of the project was to share expertise and approaches among the various investigators. As with previous Practical Workshops (Bayne, Gray, & Clarke, 1988; Addison & Clarke, 1990; Stebbing, Dethlefsen, & Carr, 1992), results were also used to compare pollution assessment methods based on measurements at various levels in the ecosystem (e.g., cellular vs. individual organism vs. community responses) (see other papers in this issue).

Previous work on benthic communities in Vancouver port has been restricted to locations within the harbour proper. A brief summary of previous work is given below to provide a summary of existing knowledge of the benthic ecology of the area. Burd and Brinkhurst (1990) used cluster analyses to determine that stations in the outer, central, and inner harbour formed significantly different groupings. In general there were fewer species and individuals in Port Moody Arm relative to the outer and central harbour, and the authors attributed these differences to contaminants such as metals and organics in sediments, an interpretation also offered by Boyd, Baumann, Hutton, Bertold, and Burd (1998). The latter authors also conducted sediment bioassays with amphipods (*Rheopoxynius abronius*) and found that sediments in the central harbour and another in Port Moody Arm were more toxic than those from outer Burrard Inlet. Hall, McCallum, Lee, and Macdonald (1998) also used sediment bioassays in an impact study of combined sewer overflows (CSOs) on the south side of the inner harbour. They found a decreasing gradient of toxicity with distance from the outfall in tests with amphipods (*Rheopoxynius abronius*) and blue mussel (*Mytilus edulis*) larvae.

2. Materials and methods

2.1. Benthic sediment collections and identifications

Benthic sediment samples were collected at seven stations along a presumed pollution gradient from the head of Vancouver Harbour through to Howe Sound. (Levings, Stein, Stehr, & Samis, 2003). Two stations [B-41B, depth (d) 8 m; B-38, d 12 m] were in the Inner Harbour (Port Moody Arm), three were in the central harbour (B-48, 27 m; B-11B, 25 m; B-3A, 9 m), one was in the outer harbour (B-49, 39 m), and a reference station was located near Gibsons, in Howe Sound (B-50, 30 m). Five samples of at least 5 l volume were collected with a van Veen grab (0.1 m^2) from each station. Each grab sample was emptied into a clean plastic container and then sieved through a 0.5 mm mesh screen. The remaining fauna on the sieve were fixed with 10% formalin solution neutralized by seawater. Five core samples (2.5 cm diameter; 10 cm depth) were obtained from a sixth grab sample for meiofauna analyses at a later stage in the project. The top one cm of one of these cores was used for grain size analyses at the Korean Ocean Research and Development Institute (KORDI) in Ansan, Korea.

In the laboratory, the fauna were sorted into major taxonomic groups and identified to the presumed species level as far as possible. Identification of polychaetes ophiuroids, nemertineans, crustaceans, sipunculans and others was then completed in Russia (FEHRI, Vladivostok); and molluscs at KORDI. Counts and wet weight data were then obtained. The basic faunal data are based on apparent species. Because of time constraints and logistics, it was not possible to compare specimens with local reference collections and therefore all identifications to the species level must be considered preliminary.

2.2. Statistical analysis

ABC (abundance biomass comparison) curves proposed by Warwick (1986) were used to investigate community perturbation at the study sites. Adequate sampling is a prerequisite of the ABC method, since the large biomass dominants are often represented by few individuals, which will be liable to a higher sampling error than the numerical dominants (Clarke & Warwick, 1994). Therefore, total abundance and biomass data of five combined samples from each site were used in the ABC analyses and subsequent comparisons. Species diversity (H') and evenness (J) were also computed from the combined sample data. ABC plots were constructed for each site and also reduced to two summary statistics that describe the configuration and relative distance between the abundance and biomass curves in ABC plots.

The first, the W statistic from Clarke (1990), involves summing the differences between the ranked cumulative percentages of abundance and biomass values. In this statistic, W takes values in the range $(-1, 1)$, with W at $+1$ for even abundance across species but biomass dominated by a single species, which is an undisturbed community, and W at -1 in the converse case. The other summary statistic used, the Shannon–Wiener Evenness proportion (SEP) recommended by McManus and Pauly (1990), is based on the Shannon–Wiener diversity index. SEP values greater than 1.0 indicate disturbed communities while values less than 1.0 are indicative of stable assemblages.

The abundance data were also compared using two multivariate measures of community structure in order to compare the results of these methods with the results of ABC analyses; transformed abundance data were subjected to weighted group-average linked cluster analyses (transformed using $\log_e$) and non-metric multidimensional scaling (MDS) using the Bray–Curtis similarity index (transformed using fourth root) as specified in Clarke and Warwick (1994).

To investigate the main factors affecting distributions of macrobenthic assemblages, the BIOENV procedure from Clarke and Ainsworth (1993) was used.

3. Results and discussion

3.1. Macrobenthic communities

Raw data from the survey are given in Je and Belan (2001). A total of 171 apparent species and 3,348 individuals from eight phyla was identified (Table 1). Polychaetes and molluscs were the most abundant faunal groups. Eighty-three

Table 1
Abundance, biomass and number of apparent species for the major taxonomic groups when data were combined over all the stations

	Abundance	%	spp.	%	Biomass	%
Mollusca	1605	47.9	43	25.1	350.5	87.7
Arthropoda	204	6.1	36	21.1	2.1	0.5
Annelida	1501	44.8	83	48.5	44.9	11.2
Others	38	1.1	9	5.3	2.1	0.5
Total	3348	100	171	100	399.6	100

apparent species (48.5%) were polychaetes and this taxon was the main contributor to species richness. Molluscs were the most important taxa (47.9%) in terms of numerical abundance and biomass.

The number of apparent species at each station varied from 23 (Stn. B-41B) to 72 species (Stn. B-50). There was a distinct tendency towards increasing number of apparent species at stations towards Howe Sound relative to those at the head of the harbour at Port Moody Arm (Fig. 1). The faunal density at each station ranged from 262 individuals m^{-2} (Stn. B-41B) to 1,788 individuals m^{-2} (Stn. B-49) and the average density was 957 individuals m^{-2}. Numerical abundance at both stations B-49 and B-48 was over 1400 individuals m^{-2} and relatively low abundance occurred in station B-41B (Fig. 1). Biomass ranged from 13.1 g m^{-2} (Stn. B-41B) to 620.3 g m^{-2} (Stn. B-49). The latter was due to *Compsomyax subdiaphana* (bivalve) accounting for about 72% of the overall biomass at Station B-49 (Je & Belan, 2001) (Fig. 1).

Species richness and diversity at each station consistently showed a gradual increase from the interior to the exterior of the harbour (Figs. 1 and 2). Total numerical abundance and total biomass, however, peaked in station B-49 for both variables. Numerical abundance was maximum at Stn B-48. A one-way ANOVA on each of the parameters indicated significant differences ($P<0.05$) between the stations (Table 2). Comparisons between stations using Tukey's test are shown in Table 3. Data from stations located in the outer and central part of the harbour (B-11B, B-3A and B-49) were not significantly different ($P>0.05$) for all variables but were different with respect to the Port Moody Arm and Indian Arm stations (B-41B, B-38 and B-48) which were also themselves different to each other with a few exceptions (stations B-41B and B-38 for diversity, B-38 and B-48 for evenness and B-48 and B-11B for both diversity and number of apparent species). Stations B-49 and B-50 were also different ($P<0.05$) except number of apparent species.

In order to investigate the spatial distribution of benthic fauna to the presumed pollution gradient, a cluster analysis using Bray–Curtis percent similarity and weighted pair group average linkage was performed. The dendrogram resulting from cluster analysis showed that three station groups were grouped together (Fig. 3). Each station group was classified by the distance from the inner harbour. Station group I was composed of two stations in Port Moody Arm (B41-B, B-38), and station group II was composed of four stations (B-48, B-11B, B3A, and B-49) in the

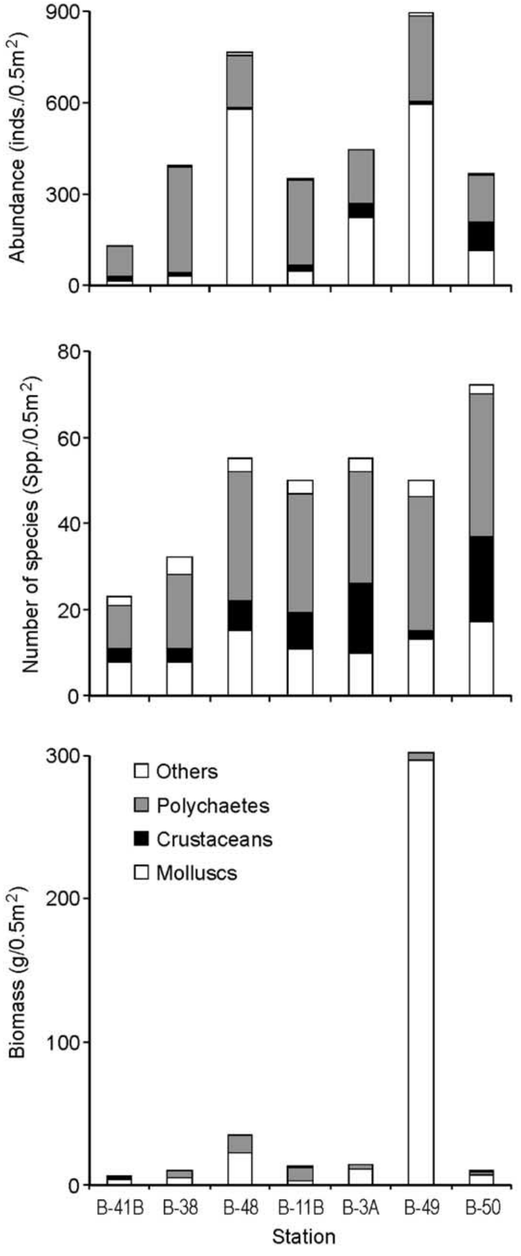

Fig. 1. Graphical representation of the total number of apparent species (middle panel), number of individuals (upper panel), and biomass (lower panel) for each of the stations, calculated by summing the data from five samples.

central and outer harbour. Station group II may be divided into two sub-groups (B-48 and B-49; B3A and B11-B).

To determine the community characteristics of each station group, ecological parameters were calculated and the mean numerical abundance of the 17 most abundant apparent species was calculated. Station group I was mainly dominated by polychaetes, especially *Tharyx multifilis*. Station group II-1 was represented by

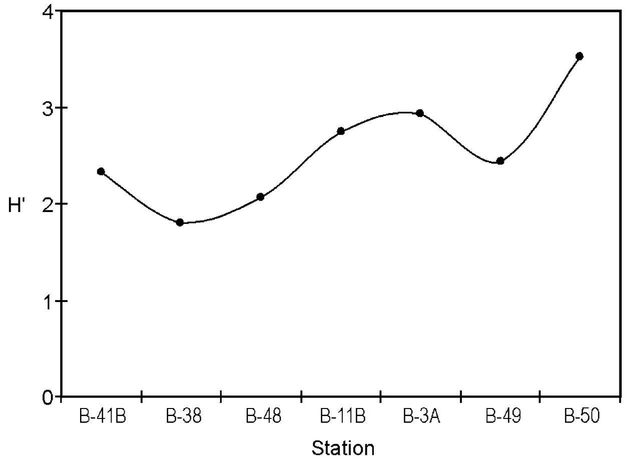

Fig. 2. Species diversity (H') for each of the stations.

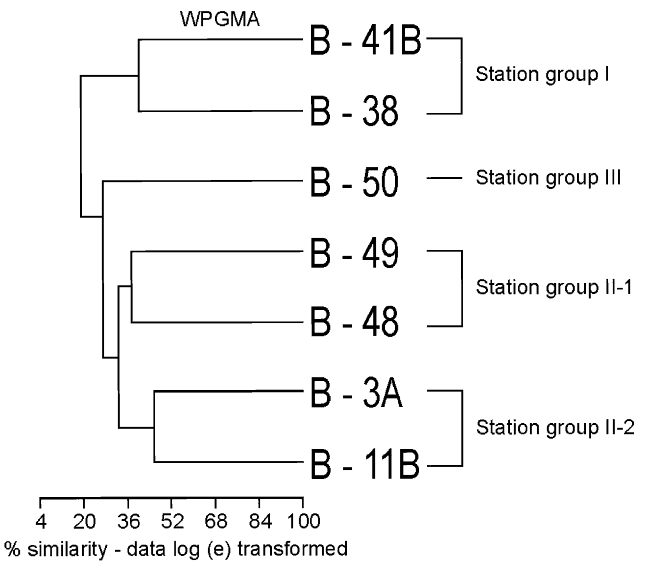

Fig. 3. A dendrogram from the cluster analysis using abundance data for macrobenthos (numerical data combined over five samples) from the seven stations, analyzed using percent similarity (Bray–Curtis) and weighted pair group average linkage.

Table 2
One-way ANOVA (F ratio values) obtained for the inter-station univariate analysis (1, 8 degrees of freedom)

Sites	Species diversity H'	Evenness J	Total number of individuals	Total number of apparent species
B41B–B38	n.s	21.94***	25.11***	7.62*
B38–B48	8.08*	n.s	16.43**	45.87***
B48–B11B	n.s	21.13***	20.42***	n.s
B11B–B3A	n.s	n.s	n.s	n.s
B3A–B49	n.s	n.s	6.2*	n.s
B49–B50	13.29**	11.39*	11.76**	n.s

n.s., not significant.
* $P<0.05$.
** $P<0.01$.
*** $P<0.001$.

Table 3
One-way ANOVA using data from all stations for the various univariate analyses

	d.f.	*M.S.*	*F*
Total species	6	219.1	15.71****
Total individuals	6	13726	9.86****
Species diversity (H')	6	0.9741	16.69****
Evenness (J)	6	0.0538	8.14****

****$P<0.0001$.

polychaetes, *Ophelina acuminata* and *Lumbrineris luti*, and molluscs, *Axinopsida serricata* and *Transenella tantilla* and station group II-2 by molluscs, especially *Axinopsida serricata, Macoma calcarea* and an unidentified bivalve (bivalvia indet.5) Station group III was occupied by three major faunal groups, polychaetes, molluscs and crustaceans in relatively equal abundance (Table 4). Both mean number of species and diversity (H') were higher in Station group III than those in station group I and II, mean number of individuals was the highest in station group II-2 (Table 4).

3.2. Sediment chemistry

Results of the sediment chemistry investigations to determine concentration of low molecular weight aromatic compounds, high molecular weight aromatic compounds, chlordanes, PCBs, DDTs, hexachlorobenzene, lindane, heptachlor epoxide, aldrin, and dieldrin are given in Table 5. The data are mean concentrations for individual stations, using raw data from a variety of investigators in the workshop, and presented in Stehr and Horiguchi (2001). Data on grain size (phi) and depth (m) are also given.

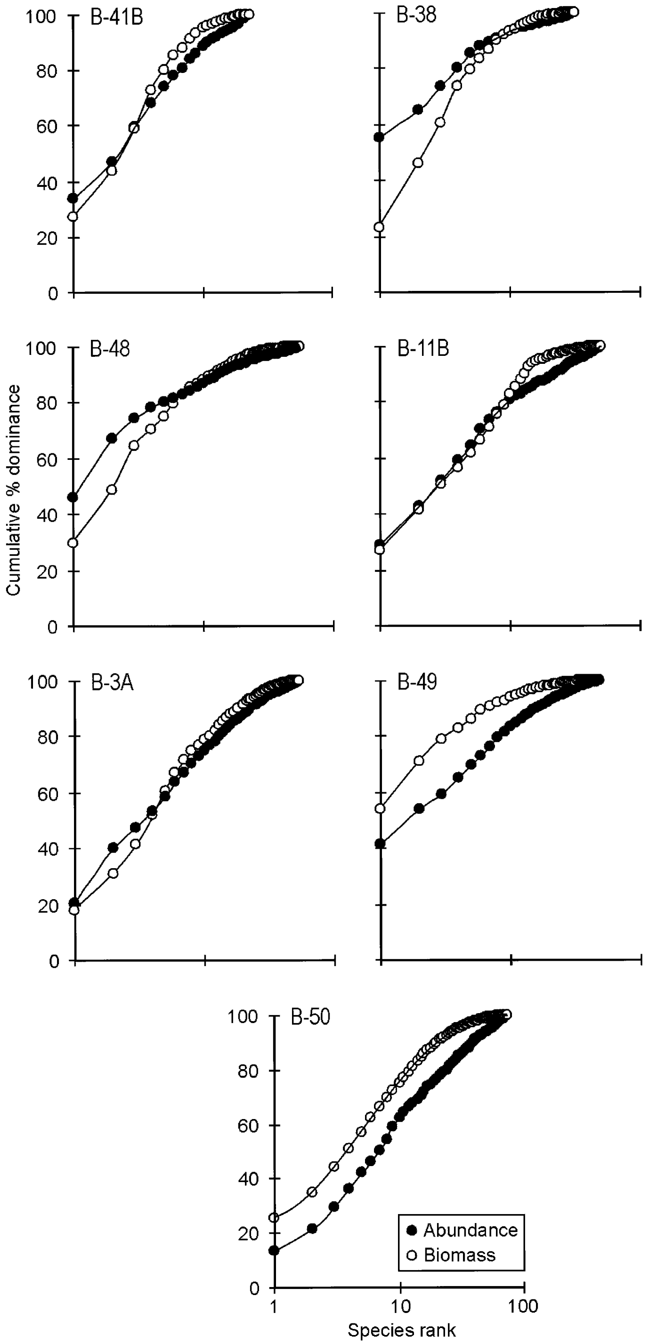

Fig. 4. ABC (Abundance and Biomass Comparison) plots based on combined data from five samples at each of the seven stations.

Table 4
Ecological parameters and numerically dominant apparent species at each station group

Parameters/Station group	I	II-1	II-2	III
Number of station (n)	2	2	2	1
Number of species	45	77	84	72
Mean no. of species (Spp./0.5m2)	27.5	52.5	52.5	72
Mean density (Inds./m2)	526.0	798.0	1658.0	732
Ecological indices				
Species diversity (H')	2.06	2.87	2.28	3.51
Eveness (J)	0.63	0.73	0.58	0.82
Dominant species (Inds./m2)				
Tharyx multifilis (P)	**235**	1	–	–
Nephtys cornuta franciscanum (P)	**81**	16	8	–
Spionidae indet.1 (P)	**45**	–	14	2
Lumbrineris luti (P)	**36**	**81**	57	**56**
Axinopsida serricata (M)	21	**104**	**717**	**96**
Transenella tantilla (M)	–	**89**	–	2
Ophelina acuminata (P)	–	**122**	13	–
Bivalvia indet.5 (M)	1	1	**161**	–
Macoma calcarea (M)	3	–	**143**	–
Nucula tenuis (M)	1	–	23	**52**
Tellina capenteri (M)	–	–	–	**26**
Pinnixa rathbunae (C)	5	–	–	**62**
Tanaidacea indet. (C)	–	–	–	**42**
Chaetozone setosa (P)	–	4	5	**30**
Glycera sp. (P)	1	–	6	**32**
Nephtys firruginea (P)	1	16	61	**30**
Scoloplos armiger (P)	–	3	1	**30**

Bold numbers indicates the mean abundance of dominant species in each station group. "–" indicates the species did not occur. P: polychaetes; M: molluscs; C: crustaceans.

3.3. Disturbance of benthic communities along the presumed pollution gradient

An interpretation of the ABC curves (Fig. 4) suggested a gradient of effects from Port Moody Arm to Thornbrough Channel, with Station B-41B an outlier. Stations B-38 and B-48 showed a "severely disturbed" pattern, stations B-41B, B-11B and B-3A a "moderately disturbed" pattern and stations B-49 and B-50 showed an "undisturbed" pattern. The results of condensing the abundance/biomass data to the two summary statistics are presented in Fig. 5. Values obtained for the W statistic and SEP again showed a similar pattern. At stations B-38 and B-48, values were below 0 for W statistic and over 1 for SEP, which may indicate that communities at these stations were disturbed. Stations B-49 and B-50 were the only two stations that appeared to be undisturbed.

The results of cluster analysis separated seven stations into three groups (Fig. 3). This separation was more marked when the data were subjected to MDS ordination, which separated the stations into the same three groups (Fig. 6a). By superimposing

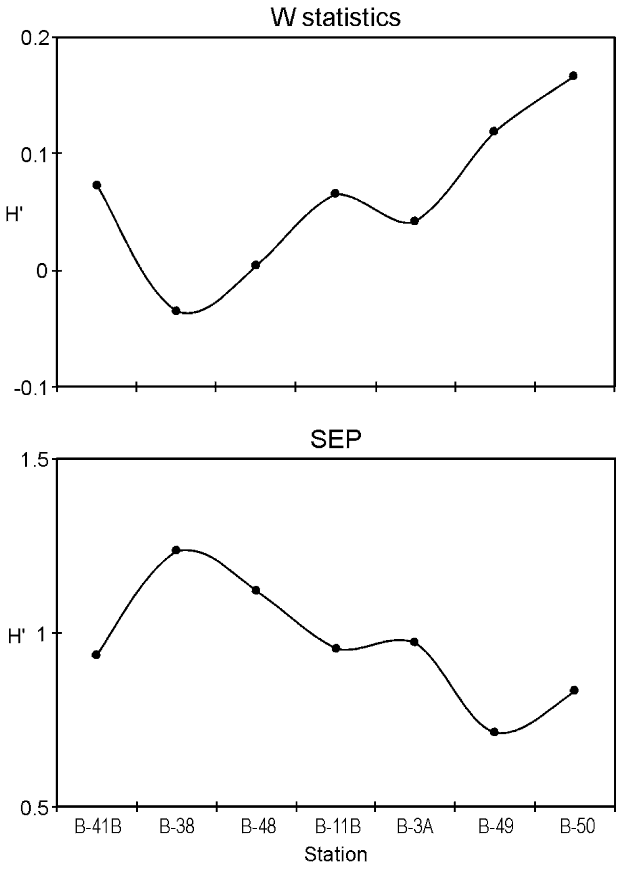

Fig. 5. Results of two summary statistics for the ABC data. Upper panel: W statistic (Clarke, 1990); lower panel SEP (Shannon–Wiener Proportion Index) (McManus & Pauly, 1990).

some of the measured environmental variables on the two-dimensional configuration of the site positions from the faunistic multivariate analyses, an indication can be obtained of the variables that correlate with group differences (Clarke & Warwick, 1994; Field, Clarke, & Warwick, 1982). Fig. 6 shows the MDS ordination from fourth root transformed species abundances (Fig. 6a), with superimposition of one natural variable, median grain size of sediments (Fig. 6b), and three pollution variables, total DDTs (Fig. 6c), total PCBs (Fig. 6d) and total PAHs (Fig. 6e). DDTs correlate closely with the site positions as do PCBs and PAHs with the exceptions of Station B-48 for PCBs and Station B-38 for PAHs. Low values of all pollution variables correlated with the position of station B-50, which indicated an "undisturbed" condition. The pattern was similar to that shown for SEP, the *W* statistic (Fig. 5) and apparent species diversity (Fig. 2). The results from the ABC plots (Fig. 4) also suggested that both stations B-38 and B-48 were "severely disturbed", B-41B, B-11B and B-3A "moderately disturbed", and B-50 was undisturbed".

Table 5
Summary of sediment chemistry results. Units are ng g-1 dry weight of sediment

Sites	LACs	HACs	Chlor	PCBs	DDTs	DDE	DDD	HCB	Hept	HPE	Lin	Ald	Die	Mz
B-41B	1600	4400	0	35	2.5	0.52	2	0.44	<0.44	<0.22	0.57	<0.43	0.49	9.05
B-38	1900	4500	0	34	2	<0.45	2	0.51	<0.53	<0.3	<0.46	<0.53	0.77	8.48
B-48	1400	4800	0.56	48	1.7	0.37	1.3	2.5	<0.32	<0.18	<0.28	<0.32	0.32	5.95
B-11B	950	3400	0	7.8	0.76	<0.32	0.76	<0.3	<0.38	<0.22	<0.33	<0.38	<0.35	5.07
B-3A	2200	8800	0.3	23	1.1	0.29	0.76	0.21	<0.21	<0.11	0.18	<0.21	<0.19	7.11
B-49	690	2000	0	9.5	0.81	0.26	0.55	0.17	<0.2	<0.1	<0.17	<0.19	<0.18	8.06
B-50	70	29	0	0	0	<0.14	<0.23	<0.13	<0.17	<0.094	<0.14	<0.16	<0.15	1.98

LAC (Total Low molecular weight aromatic compounds) = sum of naphthalene; 2-methylnphthalene; 1-methylnaphthalene; biphenyl; 2,6-dimethylnaphthalene; acenaphthylene; acenaphthene; 2,3,5-trimethylnaphthalene; fluorene, dibenzothlophene; phenathrene, anthracene, 1-methylphenanthrene. HAC (Total high molecular weight aromatic compounds) = sum of fluoranthene; pyrene; benz[*a*]anthracene; chrysene + triphenylene; benzo[*b*]fluoranthene; benzo[*j*]-fluoranthene + benzo[*k*]fluoranthene; benzo[*e*]pyrene; benzo[*a*]pyrene; perylene, lndeno[1,2,3-*cd*]pyrene; dibenz[*a,h*]anthracene + dibenz[*a,c*]anthracene; benzo[*ghi*]perylene. Chl (Total Chlordanes) = estimated sum of γ-chlordane, α-chlordane, *trans*-nonachlor and *cis*-nonachlor. PCB = Total PCB concentrations determined by multiplying the sum of congeners 18, 28, 44, 52, 66, 101, 105, 118, 128, 138, 153, 170, 187, 195, 206, 209 by 2. DDT = The sum of *o,p′*-DDE; *p,p′*-DDE; *o,p′*-DDD; *p,p′*-DDD; *o,p′*-DDT; *p,p′*-DDT. HCB = Hexachlorobenzene: Lin = Lindane: Hept = Heptachlor: HPE = Heptachlorepoxide: Ald = Aldrin : Die = Dieldrin: Mz = Mean phi: Dep = Depth. **p,p′*-DDE and *p,p′*-DDD are also reported individually here because they were the significant contributors to the total DDTs. All other DDT derivatives were present at less than one ppm.

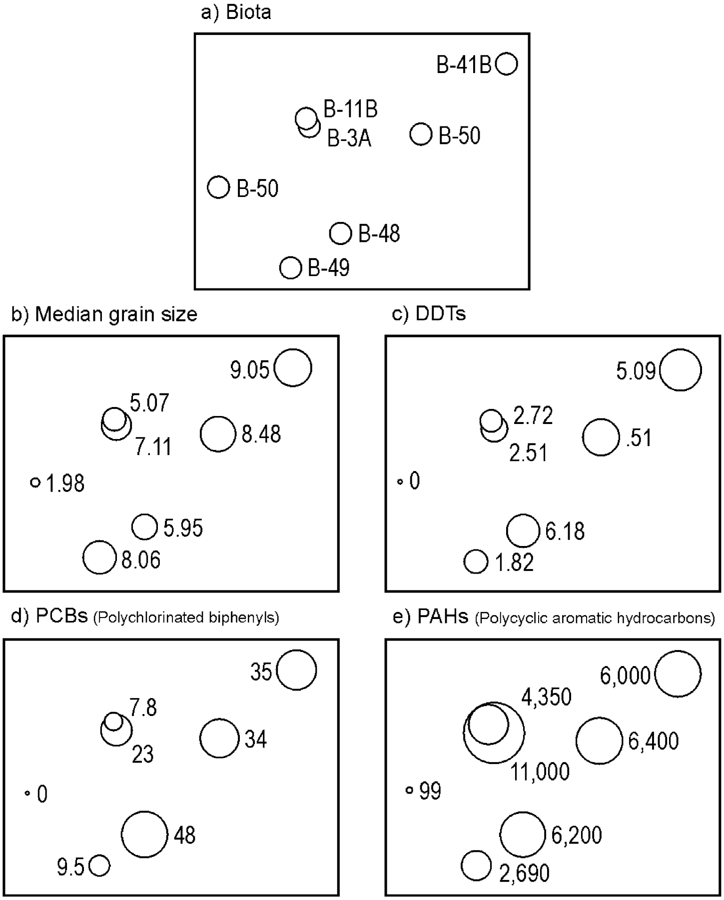

Fig. 6. (a) MDS ordination of Bray–Curtis similarities from fourth-root transformed species abundance data at the seven stations; (b)–(e) same ordination but with superimposed circles whose area is proportional to: (b) median grain size (phi) and (c)–(e) concentrations of DDTs, PCBs, and PAHs, respectively (ng g^{-1} dry weight sediment).

In order to investigate relationships between biotic and abiotic variables, the BIO–ENV procedure was used which contrasts the station similarity matrix obtained for species abundance data via cluster analysis to the resulting matrix of Euclidean distances obtained following PCA ordination of all the possible combinations of selected environmental variables. This allowed us to extract those variables that show greatest correlations (weighted Spearman rank correlation, ρ_w). An analysis was undertaken which incorporated the pollutant concentrations, sediment variables and water depth. Results are given in Table 6. The single abiotic factor which best grouped the stations, in a manner consistent with the faunal patterns, was the DDT concentration ($\rho_w = 0.504$). The variables that gave the highest correlation were low aromatic hydrocarbons (LAC), DDT, lindane (Lin), Mz ($\rho_w = 0.676$).

Table 6
Combinations of the 13 environmental variables, taken k at a time, yielding the best matches of biotic and abiotic similarity matrices for each k, as measured by weighted Spearman rank correlation ρ_w

k	Best variable combinations (ρ_w)												
1	DDT 0.504	Lin 0.331	Mz 0.254	LAC 0.177	Die 0.127	Hept 0.081	HAC 0.060	Ald 0.056	Chl −0.341	HCB −0.232	Dep −0.195	HPE −0.052	PCB −0.025
2	Lin, Mz 0.641	DDT, Mz 0.622	DDT, Lin 0.548	LAC, Lin 0.485	LAC, DDT 0.455	...							
3	DDT, Lin, Mz 0.662	LAC, Lin, Mz 0.658	Hept, Lin, Mz 0.581	...									
4	LAC, DDT, Lin, Mz 0.676	HAC, DDT, Lin, Mz 0.642	DDT, Lin, Ald, Mz 0.612	...									
5	LAC, DDT, Hept, Lin, Mz 0.650	HAC, DDT, Hept, Lin, Mz 0.641	...										
6	LAC, HAC, DDT,Hept, Lin, Mz 0.590	...											
⋮													

LAC (Total Low molecular weight aromatic compounds) = sum of naphthalene; 2-methylnphthalene; 1-methylnaphthalene; biphenyl; 2,6-dimethylnaphthalene; acenaphthylene; acenaphthene; 2,3,5-trimethylnaphthalene; fluorene, dibenzothlophene; phenathrene, anthracene, 1-methylphenanthrene. HAC (Total high molecular weight aromatic compounds) = sum of fluoranthene; pyrene; benz[*a*]anthracene; chrysene + triphenylene; benzo[*b*]fluoranthene; benzo[*j*]fluoranthene + benzo[*k*]-fluoranthene; benzo[*e*]pyrene; benzo[*a*]pyrene; perylene, lndeno[1,2,3-*cd*]pyrene; dibenz[*a,h*]anthracene + dibenz[*a,c*]anthracene; benzo[*ghi*]perylene. Chl (Total Chlordanes) = estimated sum of γ-chlordane, α-chlordane, *trans*-nonachlor and *cis*-nonachlor. PCB = Total PCB concentrations determined by multiplying the sum of congeners 18, 28, 44, 52, 66, 101, 105, 118, 128, 138, 153, 170, 187, 195, 206, 209 by 2. DDT = The sum of *o,p′*-DDE; *p,p′*-DDE; *o,p′*-DDD; *p,p′*-DDD; *o,p...*-DDT; *p,p...*-DDT. HCB = Hexachlorobenzene: Lin = Lindane: Hept = Heptachlor: HPE = Heptachlorepoxide: Ald = Aldrin: Die = Dieldrin Mz = Mean phi: Dep = Depth. **p,p′*-DDE and *p,p′*-DDD are also reported individually here because they were the significant contributors to the total DDTs. All other DDT derivatives were present at less than one ppm.

4. Conclusions

Results of a variety of univariate and multivariate statistical methodologies showed that benthic communities changed along the axis of the harbour, with more pollution tolerant organisms found in Port Moody Arm, a shallow embayment at the landward end of the harbour complex. We augmented previous results by showing all our harbour station groups were different from a far field reference site, Thornbrough Channel in Howe Sound. There were complications with comparisons between the harbour and Thornbrough Channel because of differences in depth and sediment type. Thus it is likely that the suite of stations sampled did not necessarily represent a continuum along a pollution gradient, and ecosystems in Thornbrough Channel supported different benthic communities because of natural factors not present at the other stations (e.g., coarser sediments). In addition contaminants originating from point as well as non-point sources (see Levings et al., in press) in the harbour are likely dispersed into the Strait of Georgia via a variety of oceanographic processes and Thornbrough Channel is not necessarily at the "low concentration" end of the gradient. Low level pollution from local sources is a possibility for this area, but our benthic community analyses did not identify any ecological effects. Results from our benthic investigations confirmed findings from previous studies of benthic communities within Vancouver harbour (Boyd et al., 1998; Burd & Brinkhurst, 1990).

The strongest correlations with the affected station groups were found with DDT, low aromatic hydrocarbons, lindane and grain size, and experimental work is needed to further explore toxicity of these compounds to the dominant species in the groups—the cause–effect relationships need to be confirmed experimentally. In addition, while we did not consider metals in the BIO–ENV analyses, significant concentrations of copper, lead, and cadmium are known from certain areas of the harbour and correlations of the station groups with these contaminants need exploring.

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