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Polychaete Taxocenes Variability Associated with Sediment Pollution Loading in the Peter the Great Bay (the East Sea/Japan Sea)

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Abstract – Variations in species diversity and abundance of polychaete taxocenes that occurred in 1980-1989 under different contamination levels of bottom sediments were studied in three areas of Peter the Great Bay. The most polluted area was shown to be the Golden Horn Inlet where contaminant contents in the bottom sediments exceed the threshold values of negative biota alterations. Amursky Bay is characterized by a moderate level of contamination, while Ussuriysky Bay has the lowest level of contamination. Pollutant contents vary considerably within the same areas and their separate patches are polluted differently. An integral index characterizing the contamination of bottom sediments is proposed. This index is an average grade of the rank value of contaminant contents in sediments. The index was used to compare the contamination level and data on polychaete species diversity and abundance. The highest species diversity of polychaetes is found in the least affected zones. Monotonous decrease of the species number, as well as decrease in the indices of diversity and evenness, is correlated with pollution level increases. Significant growth of the average polychaete biomass and polychaete density is observed in the case of an increase of contamination from low to moderate levels. Conversely, the biomass and abundance of polychaetes decline following an increase in contamination.

Key words – pollution, bottom sediments, polychaete taxocenes, the East Sea/Japan Sea

1. Introduction

Over many thousands of years prior to the 20th century, the economic activity of mankind had not resulted in any significant negative influences on the coastal marine environment. Fisheries and other similar practices led only to local disturbances. However, in the second half of the 20th century, the threat to the coastal ecosystems has reached an extreme level in many inner and adjacent areas. This is connected, first of all, with the input of bulk different toxicants into these sea areas.

Now the main sources of the contamination are municipal and industrial waste waters, urban and river runoff, marine transport, fishery vessels, and dredged material dumping. According to the level of danger for the marine environment, contaminants may be grouped into three categories; 1) plastic litter, suspended solids; 2) nutrients, organic matter; 3) trace metals, petroleum and chlorinated hydrocarbons. The third group is the most harmful due to a wide range of the action mechanisms affecting marine organisms; from the physical and chemical damage to the carcinogenic and mutagenic effects (GESAMP 1982; GESAMP 1990; GESAMP 1993). Chlorinated hydrocarbon pesticides are a source of special concern because of their persistence in the environment, their concentrations in the food chains and their long-lasting storage and accumulation in the fatty tissues of animals (GESAMP 1990). With regard to toxicity, petroleum hydrocarbons are less dangerous than heavy metals and chlorinated hydrocarbons. However, the results of experiments and *in situ* observations testify to the expressed and stable disturbances of the benthos communities under chronic petroleum contamination due to external (mechanical) and direct toxic effects (GESAMP 1990; GESAMP 1993).

The low-range effect (hereinafter ERL) and median-range effect (ERM) concentrations were determined for some chemicals or chemical groups accumulated in bottom sediments (Long *et al.* 1995; Boyd *et al.* 1998). Two of these values delineate three concentration ranges for a particular chemical. The concentrations below the ERL value represent a minimal-effects range; a range intended to estimate conditions in which effects would be rarely observed (on average, from 1.9 to 9.4% for different chemicals studied). Concentrations equal to and above the

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Table 1. Values of the effect range-low and effect range-median (ERL and ERM, correspondingly) summed up after: Review information ..., 1986; Long *et al.* 1995; Patin 1997; Boyd *et al.* 1998.

Chemicals	ERL	ERM
PHCs, ppt	0.01-0.10	1.0-4.0
Cd, ppm	0.676-1.2	4.21-9.6
Cr, ppm	52.3-81.0	160-370
Cu, ppm	18.7-34.0	108-270
Pb, ppm	30.2-46.7	112-218
Hg, ppm	0.13-0.15	0.70-0.71
Ni, ppm	15.9-20.9	42.8-51.6
Zn, ppm	124-150	271-410
ΣDDT, ppb	1.58	46.10

Note. Hereinafter PHCs – total petroleum hydrocarbons, ΣDDT – the sum of DDT and its metabolites (DDT, DDE and DDD).

ERL, but below the ERM, represent a possible-effects range within which effects would occasionally occur (11.1-47.0%). The concentrations equivalent to and above the ERM value represent a probable-effects range within which effects would frequently occur (for most chemicals studied frequency varied within 42.3-95.0%). Table 1 shows the ranges of ERL and ERM values from different sources.

Unfortunately, due to the present level of technological development and current heavy economic crisis, damage to the marine environment is inevitable, as tremendous financial investments would be for radical efforts to prevent pollution. Because of this, the evaluation of the real status of marine coastal ecosystems is indispensable to minimizing possible damage.

Peter the Great Bay presents a unique natural phenomenon owing to the geographical disposition at the joint point of boreal and subtropical zones, and due to great species diversity of organisms dwelling here. At the same time, many areas of the bay have lost their former importance in fishery and recreational resources because coastal waters had become the site of contaminant dumping over the last 40 years. The extinction and sharp reduction in abundance of separate species has occurred in some regions of the bay (Tkalin *et al.* 1993). Therefore, ecological observations and analysis of the current situation in Peter the Great Bay is necessary for sustainable development of the coastal zone of the East Sea/Japan Sea.

Polychaetes are one of the most abundant groups of bottom invertebrates, and have a high level of tolerance to adverse effects of both pollution and natural perturbation (Gray and Pearson 1982; Ranan and Ganapati 1983; Rygg 1985a,b; Shin and Koh 1998). Thus, the state of polychaete taxocenes may clearly indicate the health state of the marine bottom community as a whole. The goal of this work is to evaluate the changes in polychaete taxocenes that appeared under different levels of anthropogenic stress in the coastal zone of the East Sea/Japan Sea over a 10 year period (1980-1989).

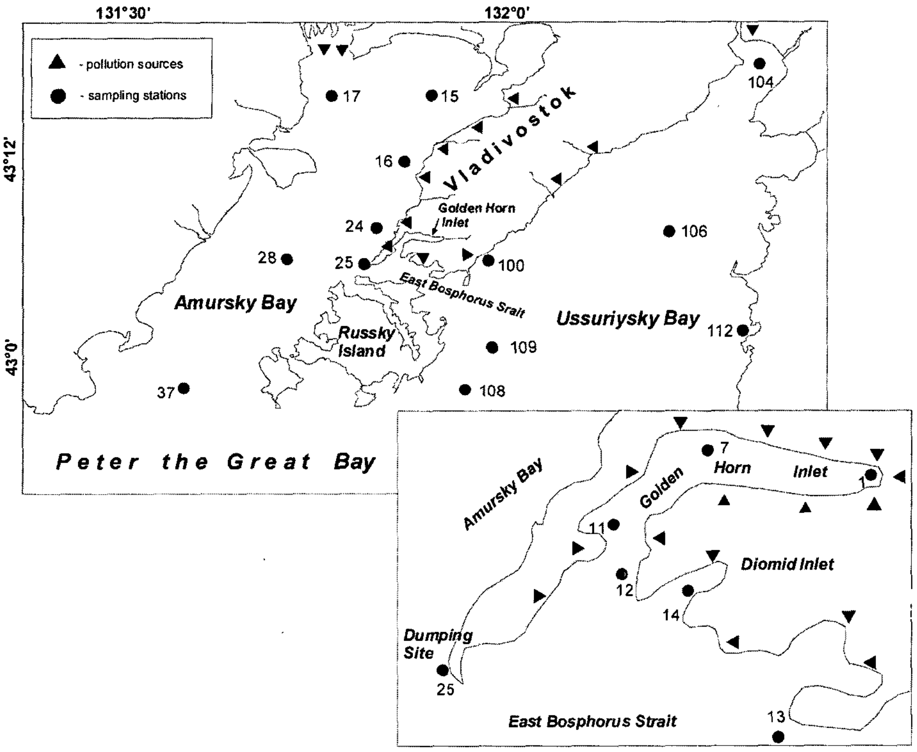

Fig. 1. Map of sampling design in 1980-1989 and 1994 in the Peter the Great Bay.

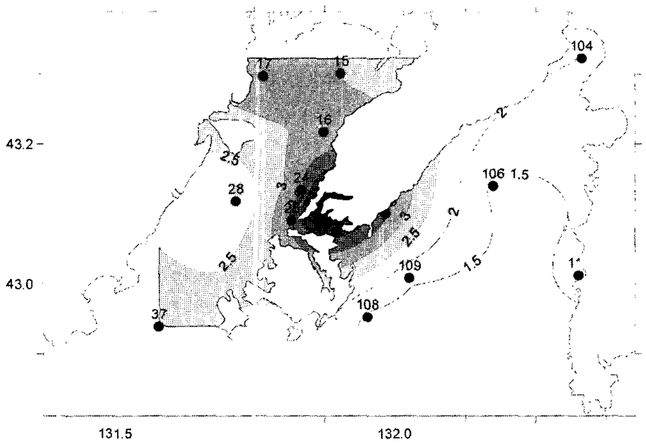

Fig. 2. Sampling stations (stations are designated as dotted circles with numbers) and integral pollution levels (distribution of the TPF values).

2. Materials and Methods

Sampling design

Benthic samples were collected in three areas of Peter the Great Bay from 1980 to 1989 seasonally: at stations 1, 7, and 11 in Golden Horn Inlet: at stations 16, 24, and 37 in Amursky Bay; at stations 104, 106, and 108 in Ussuriysky Bay. Only in 1994 was data on contamination and benthos characteristics simultaneously collected at all stations (Figs. 1 and 2). Two to three replicate sediments samples were taken at each station with a 0.11 m^2 van Veen grab for benthos and a chemical study.

Sample processing

Only surface sediments (1-2 cm) were collected for chemical analysis (trace metals Cd, Cu, and Pb, chlorinated hydrocarbons, total non-polar petroleum hydrocarbons, phenols). For TM analysis, sediments were digested by a mixture of HNO_3 and $HClO_4$, concentrations of trace metals were determined using a flame atomic absorption spectrophotometer. Detection limits (ppm) were as follows: Zn 0.5, Pb 0.1, Cu 0.02, Cd 0.002. PHCs were measured by IR spectrophotometry after extraction with acetone and methylene chloride and column chromatography on Al_2O_3. The detection limit was 0.05 ppt (parts per thousand). Chlorinated hydrocarbon concentrations were determined using a Russian gas chromatograph LCM-80 with a glass packed column (1 m length, 3 mm inner diameter, SE stationary phase) and an electron capture detector. Detection limits for DDT, DDD and DDE were 0.3-0.5 ppb, for α-HCH and γ-HCH - 0.1 ppb. Concentration of total phenols was determined using a spectrophotometry method; the detection limit was 5 ppm.

The sediments for biological analysis were washed with seawater through a 1-mm sieve and residues, including macrobenthos, were preserved in a 4% buffered formaldehyde solution. In the laboratory polychaetes were picked out of the sediment. Most individuals were identified by species level, but some polychaetes could be identified with higher taxa only. To determine wet weight, polychaetes were blotted and air-dried for approximately one minute prior to weighing.

Data analysis

To characterize polychaete taxocenes the following parameters were used: biomass (B, g/m^2), density (N, ind/m^2), number of species (S), Shannon-Wiener diversity index (H), and Pielou evenness index (e). Ecological indices were calculated as:

$$H = -\Sigma p_i \times (\log_2 p_i),$$
$$e = H/\log_2 S,$$

where p_i is the proportion of abundance of *i-th* species in relation to total abundance of polychaetes.

Traditionally, to evaluate the total chemical quality of bottom sediments, the following index is used:

$$CQS = (\Sigma C_i / C_{bi})/n-1,$$

where C_i is a concentration of the *i-th* chemical,
C_{bi} is a background concentration of the *i-th* chemical,
and n represents the number of chemicals included.

Usually, only the first 4 chemicals possessing the highest C_i/C_{bi} are included in calculations. Another way to evaluate the contamination of sediments (only for metals) is to calculate a factor of surface accumulation (FSA) in relation to Clark's amounts of trace elements or in relation to reference, the commonest, metals in the Earth's crust (Driverd 1985):

$$FSA = [Me/Fe \text{ (sample)}]/[Me/Fe \text{ (Clark's)}].$$

The application of CQS poses two main questions: 1) Why should we include only the first 4 variables, which chemicals should be included in this index (how many items should we use in FSA), and 2) what is the background concentration and where can we find them? Besides, CQS and FSA lack any biological logic. The second question is rather simple to address. We can dismiss it using the ERL and ERM values. But the solution of the first question requires more thorough statistical procedures.

For statistical analyses, we used standard procedures and tests offered by "STATISTICA 5.1" software. Stations were joined into groups using the methods of cluster analysis (Kim *et al.* 1989). To study the connections between accumulations of different contaminants, we applied factor analysis (principal components and maximum likelihood methods). To simplify factor structure and to obtain easily interpreted solutions, different methods of axes rotation, the varimax, quartimax, etc., were used (Afifi and Eisen 1982; Kim *et al.* 1989). Selection of number factors was made by Kaiser's criterion and scree plot test. Factor orthogonality was tested using the hierarchical analysis of the oblique factors.

3. Results and Discussion

Pollution, stations grouping and development of an integral index of contamination

The areas studied are affected differently by pollution, even though a single chemical exceeds the ERL value at a

Table 2. Contents of some contaminants in soft bottom sediments of the Golden Horn Inlet, Amursky Bay and Ussuriysky Bay.

Station	PHCs	Phenols	Pb	Cu	Cd	DDT	DDE	DDD	γ-HCH	α-HCH
1	14	14	14	14	14	14	14	14	14	3
	16.43±2.68	3.25±0.90	**303.22±119.04**	**186.72±36.14**	**9.32±1.52**	**90.44±51.14**	3.26±1.99	64.01±40.41	0.31±0.29	trace
7	14	14	14	14	14	14	14	14	13	3
	21.44±7.64	2.04±0.48	**681.32±272.96**	**259.56±55.66**	**4.42±1.26**	**115.85±49.06**	5.13±3.30	69.02±36.12	0.49±0.48	trace
11	9	10	10	10	10	9	9	9	9	2
	12.61±4.20	1.10±0.33	**284.90±60.24**	**208.50±117.64**	***3.90±1.32***	**163.98±143.57**	9.96±8.64	71.09±36.47	11.95±11.00	trace
12	12	13	13	13	13	13	13	13	13	3
	7.22±1.64	1.31±0.68	**136.26±30.84**	***82.76±15.82***	***1.76±0.52***	***22.86±19.12***	1.03±0.46	9.26±3.98	0.67±0.66	trace
13	12	12	12	12	12	12	12	12	12	3
	1.70±0.39	0.38±0.19	***77.26±20.90***	***43.00±9.88***	***2.34±1.12***	***20.57±9.82***	2.58±1.41	5.81±2.69	2.15±1.49	trace
14	14	14	14	14	14	14	14	14	14	2
	10.47±2.70	1.43±0.36	**410.58±130.56**	**277.40±55.24**	**26.50±17.18**	**58.71±31.98**	3.27±3.28	25.32±15.33	4.11±2.87	trace
15	13	14	13	13	13	10	10	10	8	-
	0.46±0.34	0.18±0.10	***39.92±21.74***	32.00±9.56	***2.24±0.90***	**50.54±29.14**	0.38±0.23	9.78±8.60	1.16±0.81	-
16	10	12	11	11	11	8	8	8	6	-
	0.71±0.12	0.83±0.24	***31.11±9.80***	30.46±2.00	***1.54±0.58***	***5.85±4.67***	0.12±0.04	0.78±0.55	1.70±1.80	-
17	14	15	14	14	14	11	11	11	9	-
	0.59±0.33	0.33±0.13	***35.78±13.36***	26.28±5.86	1.14±0.74	***30.19±22.57***	0.43±0.18	5.57±3.88	0.76±0.49	-
25	9	10	9	9	9	6	6	6	5	3
	2.10±0.96	0.55±0.17	**53.16±15.72**	29.00±2.48	***2.76±0.70***	**46.15±21.44**	0.80±0.67	5.28±3.30	0.09±0.00	trace
28	7	8	6	6	6	6	6	6	5	1
	0.19±0.05	0.00±0.00	16.34±7.38	8.84±4.60	***1.50±1.12***	***13.68±8.58***	0.59±0.31	1.83±1.22	0.51±0.47	trace
37	11	13	10	10	10	7	7	7	5	2
	0.23±0.06	0.15±0.11	**59.40±40.82**	37.96±18.92	***1.26±0.98***	***9.35±5.18***	4.54±4.18	4.90±3.68	8.63±6.40	trace
100	13	13	13	13	13	13	13	13	13	2
	0.31±0.07	0.38±0.13	***43.82±17.20***	***53.08±10.56***	***1.76±1.44***	***39.49±18.58***	0.67±0.50	25.22±8.69	1.40±0.97	trace
104	13	13	12	12	12	12	12	12	11	2
	0.15±0.09	0.19±0.11	3.42±2.64	10.08±2.42	1.16±0.60	***7.96±3.55***	0.32±0.15	1.37±0.53	0.68±0.58	trace
106	12	12	12	12	12	12	12	12	12	3
	0.05±0.01	0.00±0.00	3.76±2.66	3.50±1.58	0.00±0.00	***10.91±8.21***	0.56±0.35	2.25±1.75	0.36±0.34	trace
108	11	11	11	11	11	11	11	11	11	3
	0.07±0.01	0.09±0.10	2.04±1.90	3.64±1.06	0.18±0.20	***4.18±3.05***	0.29±0.19	0.55±0.46	0.33±0.30	trace
109	11	11	11	11	11	11	11	11	11	1
	0.10±0.01	0.09±0.10	2.96±2.02	8.36±4.14	0.28±0.28	***7.20±3.18***	0.44±0.25	0.87±0.55	0.29±0.25	trace
112	8	8	8	8	8	8	8	8	7	1
	0.06±0.01	0.06±0.07	0.26±0.18	8.68±5.48	***1.50±0.68***	***3.22±2.28***	1.01±0.92	1.61±1.40	0.46±0.48	trace

Note. Hereinafter PHCs are in ppt; phenols and metals are in ppm; chlorinated hydrocarbons (DDT and its metabolites, γ-HCH) are in ppb; for PHCs, metals and DDT the values equal to and above ERM are highlighted in bold; the values equal to and above ERL, but below ERM are italicized and in bold: "-" – data are absent: ±standard error.

Table 3. Rank values (logarithmic scale) of different contaminant concentrations.

Chemicals	Ranks				
	1	2	3	4	5
PHCs, ppt	***0.05-0.16***	***0.17-0.56***	**0.57-1.89**	**1.90-6.35**	**6.36-21.40**
Phenols, ppm	0.00-0.03	0.04-0.10	0.11-0.32	0.33-1.02	1.03-3.25
Pb, ppm	0.26-1.24	1.25-6.06	6.07-29.30	***29.31-141.56***	**141.57-681.40**
Cu, ppm	3.50-8.38	8.39-20.14	***20.15-48.32***	***48.33-115.88***	**115.89-277.40**
Cd, ppm	0.00-0.08	0.09-0.34	***0.35-1.48***	**1.49-6.26**	**6.27-26.50**
DDT, ppb	***3.22-7.06***	***7.07-15.48***	***15.49-33.95***	**33.96-74.48**	**74.49-164.00**
DDE, ppb	0.12-0.28	0.29-0.70	0.71-1.69	1.70-4.08	4.09-9.96
DDD, ppb	0.55-1.45	1.46-3.84	3.85-10.14	10.15-26.81	26.82-71.09
γ-HCH, ppb	0.09-0.23	0.24-0.62	0.63-1.63	1.64-4.30	4.31-11.95

Table 4. Rank evaluation of contamination levels throughout the separate stations and groups.

Station	PHCs	Phenols	Pb	Cu	Cd	DDT	DDE	DDD	γ-HCH	ΣDDT	Metals	TPF
Group I												
1	**5**	5	**5**	**5**	**5**	**5**	4	5	2	5	5	5
7	**5**	5	**5**	**5**	**4**	**5**	5	5	2	5	4.7	5
11	**5**	5	**5**	**5**	**4**	**5**	5	5	5	5	4.7	5
14	**5**	5	**5**	**5**	**5**	**4**	4	4	4	4	5	4.8
ME	**5**	5	**5**	**5**	**4.5**	**4.8**	4.5	4.8	3.3	4.8	4.8	5.0
Group II												
12	**5**	5	***4***	***4***	**4**	***3***	3	3	3	3	4	4.2
13	**3**	4	***4***	***3***	**4**	***3***	4	3	4	3	3.7	3.4
15	***2***	3	***4***	***3***	**4**	**4**	2	3	3	3	3.7	3
16	**3**	4	***4***	***3***	**4**	***1***	1	1	4	1	3.7	3
17	**3**	4	***4***	***3***	**4**	***3***	2	3	3	3	3.7	3.4
24	**3**	4	***4***	***3***	**4**	***2***	4	4	5	3	3.7	3.4
25	**4**	4	***4***	***3***	**4**	4	3	3	1	3	3.7	3.6
37	***2***	3	***4***	***3***	**4**	***2***	5	3	5	2	3.7	2.8
100	***2***	4	***4***	***4***	**4**	**4**	2	4	3	4	4	3.6
ME	**3**	3.9	***4***	***3.2***	**4**	***2.9***	2.9	3	3.4	2.8	3.7	3.4
Group III												
28	***2***	1	***3***	2	**4**	***2***	2	2	2	2	3	2
104	***1***	3	2	2	***3***	***2***	2	1	3	2	2.3	2
106	***1***	1	2	1	1	***2***	2	2	2	2	1.3	1.4
108	***1***	2	2	1	2	***1***	2	1	2	1	1.7	1.4
109	***1***	2	2	1	2	***2***	2	1	2	2	1.7	1.6
112	***1***	2	1	2	**4**	***1***	3	2	2	2	2.3	1.6
ME	***1.2***	1.8	2	1.5	***2.7***	***1.7***	2.2	1.5	2.2	1.8	2.1	1.7

Note. Metals=Cd+Cu+Pb/3, TPF = (PHC+Phenols+Pb+Cu+ΣDDT)/5; ME is the averaged grade for group of stations.

given station (Table 2). The most affected area is the Golden Horn Inlet, where the contaminant contents in the bottom sediments are many times higher than the ERM values. Amursky Bay, as a whole, is characterized by moderate contamination, while Ussuriysky Bay had the least contamination among the areas studied. However, contaminant contents vary heavily within each area, and their different points (stations) may show different levels of pollution.

Clustering of the stations based on the contaminant contents (data were preliminary ranked according to a logarithmic scale, base=10, Tables 3 and 4) shows the existence of the following three groups of stations (Fig. 3):

- the stations with extremely high contamination of

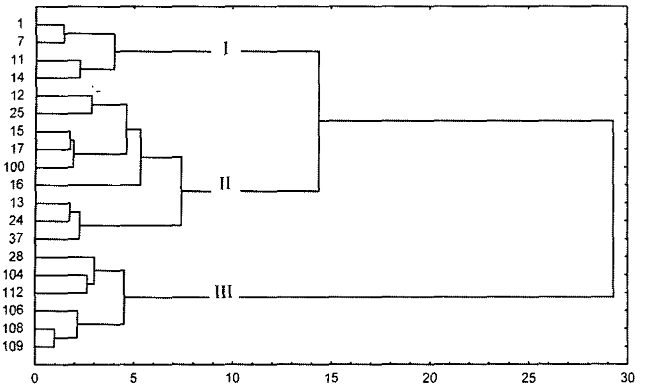

Fig. 3. Dendrogram (Ward' method) showing the similarity of stations studied according to the rank values of contamination contents. Horizontal axis shows the values of within-group square deviations. Groups are designated by Roman numbers.

Table 5. Pollution characteristics shown throughout the group of stations.

Chemicals	Groups		
	I (1, 7, 11, 14)	II (12, 13, 15-17, 24, 25, 37, 100)	III (28, 104, 106, 108, 109, 112)
PHCs, ppt	**15.23 ± 2.78** **17.95 ± 7.52***	**1.67 ± 0.89** **4.24 ± 4.59***	***0.10 ± 0.03*** 0.07 ± 0.03*
Phenols, ppm	1.95 ± 0.55	0.51 ± 0.15	0.07 ± 0.03
Pb, ppm	**420.00 ± 105.56** **287.00 ± 50.81***	***59.58 ± 12.98*** ***96.29 ± 70.33****	4.80 ± 2.60 2.75 ± 3.18*
Cu, ppm	**233.04 ± 24.54** **80.75 ± 65.20***	***41.82 ± 7.08*** ***30.71 ± 6.79****	7.18 ± 1.28 5.03 ± 2.88*
Cd, ppm	**11.04 ± 6.12** **7.48 ± 1.36***	***2.10 ± 0.14*** ***2.43 ± 0.81****	0.78 ± 0.32 ***1.08 ± 0.17****
ΣDDT, ppb	**170.00 ± 25.67**	***37.76 ± 6.22***	***9.54 ± 1.78***
γ-HCH, ppb	4.22 ± 3.15	2.07 ± 1.03	0.44 ± 0.07

Note. The groups shown are significantly ($p<0.05$, Mann-Whitney's test) different from each other in terms of contaminant concentrations in all cases.
*data for 1994.

Table 6. Factor loading obtained using the principal component method and varimax rotation in the analysis of the averaged contamination contents in the soft bottom sediments of the region studied

Contaminants	Factor 1	Factor 2	Factor 3
PHCs	**0.950**	0.054	0.272
Phenols	**0.858**	–0.144	0.320
Pb	**0.854**	0.080	0.406
Cu	**0.790**	0.240	0.554
Cd	0.243	0.093	**0.956**
DDT	**0.847**	0.449	0.059
DDD	**0.938**	0.288	0.079
γ-HCH	0.113	**0.971**	0.103
Variance explained	4.661	1.323	1.582
Percent of total variance	0.583	0.165	0.198

Note. Loading factors equal to and above 0.7 are in bold.

bottom sediments (stations 1, 7, 11, and 14 in Golden Horn and Diomid Inlets);

- the stations with moderate contamination (station 12 in the Golden Horn Inlet; station 13 in East Bosphorus Strait; stations 15-17, 24, 25, 37 in the Amursky Bay; station 100 in Ussuriysky Bay);
- relatively clean stations (stations 104, 106, 108, 109, and 112 in the Ussuriysky Bay; station 28 in the Amursky Bay).

Average concentrations of contaminants in the bottom sediments for these groups of stations are shown in Table 5. The groups obtained are significantly ($p<0.05$, Mann-Whitney's test) different from each other in terms of contaminant concentrations in all cases. Also, in this table, we show some data on the contaminant contents in 1994, the only year in the last decade where the data on contamination and benthos characteristics were simultaneously collected.

It should be noted that the contents of contaminants in the bottom sediments of the region studied changed somewhat in the middle of the 1990s. In the 1st group of stations, metal concentrations, especially Cu, decreased noticeably (Cd increases are statistically insignificant, Table 5). In the bottom sediments of the 2nd group of stations, petroleum hydrocarbons and Pb increased, while Cu concentration decreased. But, according to the data dispersion, these variations are not significant as indicated by the results of Mann-Whitney's test. In the 3rd group of stations, there were no significant changes in pollution concentrations, although the Cd concentration exceeded the ERL value, but this increase is also statistically insignificant.

To decide which chemicals should be included in the index, we have to determine the structure of the relationships between contaminant contents. To do this, their averaged values were processed by factor analysis using the principal component and maximal likelihood methods. Contaminant concentrations may be expressed as three factors explaining more than 94% of the variance of the primary variables (chemical contents, Table 6). The 1st factor may be interpreted as the input of all pollutants, excluding γ-HCH and cadmium, the 2nd and the 3rd factors describe the inputs of two latter chemicals separately. The determination of exactly three factors is based on the results of the scree plot (Fig. 4).

However, the results of hierarchical factor analysis contradict to some degree the accepted factor solution. Although the 1st and 2nd, and the 2nd and 3rd factors calculated for clusters of variables with unique loadings are almost orthogonal (correlation coefficients between

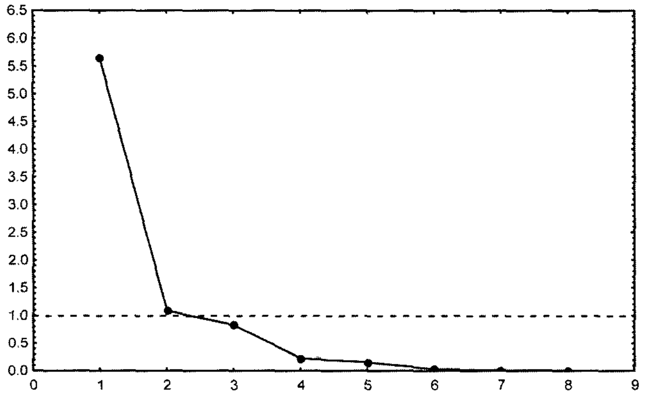

Fig. 4. Scree plot test. Dotted line shows the value of Kaiser's criterion. Abscissa axis presents factor number; eigenvalues are plotted along ordinate axis (standard units).

oblique factors are equal 0.310 and 0.222, correspondingly), the 1st and 3rd factors noticeably correlate to each other (R=0.538). Therefore, there are only two groups of variables showing a high level of uniqueness. This indicates that the solution with two factors is more appropriate, and, principally, does not contradict the results of the scree plot test or, especially, the Kaiser's criterion (Fig. 4). In this case, the factors are all contaminants, excluding γ-HCH, and α-HCH. At the same time, under the two-factor solution, the loadings for cadmium are noticeably lower than 0.7, and a considerable portion of the variance explained by its variations would be lost.

The distribution pattern of the stations in the field of the 1st and 2nd and the 1st and 3rd factors confirms the results of classification revealed using the cluster analysis. Essentially, there are three main groups of stations that differ chiefly in terms of total content of pollutants (a "cloud" of points spreads mainly along a horizontal axis, along which the 1st factor scores of the three-factor solution are plotted, Fig. 5). Stations 11, 14, and 37 are the only ones absent from this row. Station 14 differs in terms of anomalously high Cd content, but shows extremely high concentrations of other contaminants that are common for the first group of stations. Stations 11 and 37 being within the limits of proper groups according to the 1st factor scores show anomalously high γ-HCH content.

Therefore, the results of the factor analysis help us to determine an answer the first question: to compare the contamination with the parameters characterizing polychaete taxocenes, we should use any index which includes all of the chemicals studied without Cd and γ-HCH, as these two would be compared separately. In the first case scenario we can use, for example, the scores of the 1st factor. At the same time, factor scores lack any biological logic. We dismiss this problem, and simplify the calculations using the rank values of the chemical contents only: *TPF* (total pollutant factor) =$\Sigma R_i/n$, where R_i has a rank value of *i*-th chemical content (chemicals were determined according to the results of factor analysis), *n* is the number of chemicals included (Table 4). The distribution pattern of TPF-values is shown in Fig. 2. Using this map one may easily conceive a synoptic view of contamination, and the separate polluted areas. Simultaneously, the map shows the areas, which range in toxity for benthic organisms. Among them the most adverse ones are the regions closed to Vladivostok, and, naturally, the Golden Horn inlet.

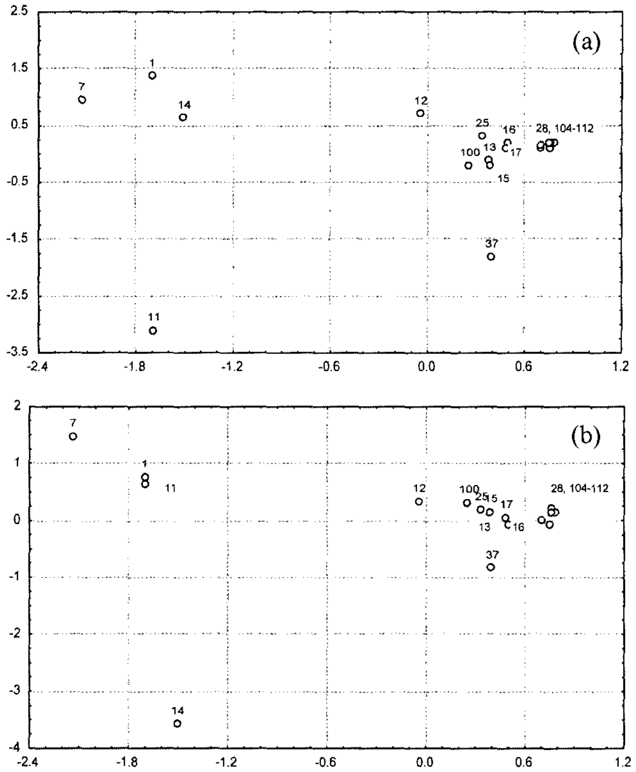

Fig. 5. Ordination of stations in the field of the 1st and 2nd (a), and the 1st and 3rd (b) factor scores. Abscissa axis shows the scores of the 1st factor, ordinate axis presents those of the 2nd (a) and 3rd (b) factors (standard units).

Variations of polychaete taxocenes under different contamination levels

The highest species diversity of polychaetes in the 1980s was recorded in the Ussuriysky Bay, while minimal diversity was detected in the Golden Horn Inlet. During 1980-1989, 28 families and 81 polychaete species were identified in the Ussuriysky Bay, 24 families and 61 species were found in the Amursky Bay, and only 14 families and 25 species were observed in the Golden Horn Inlet.

Among the clusters detected, based on contamination level, the "cleanest" group (3) was characterized by the

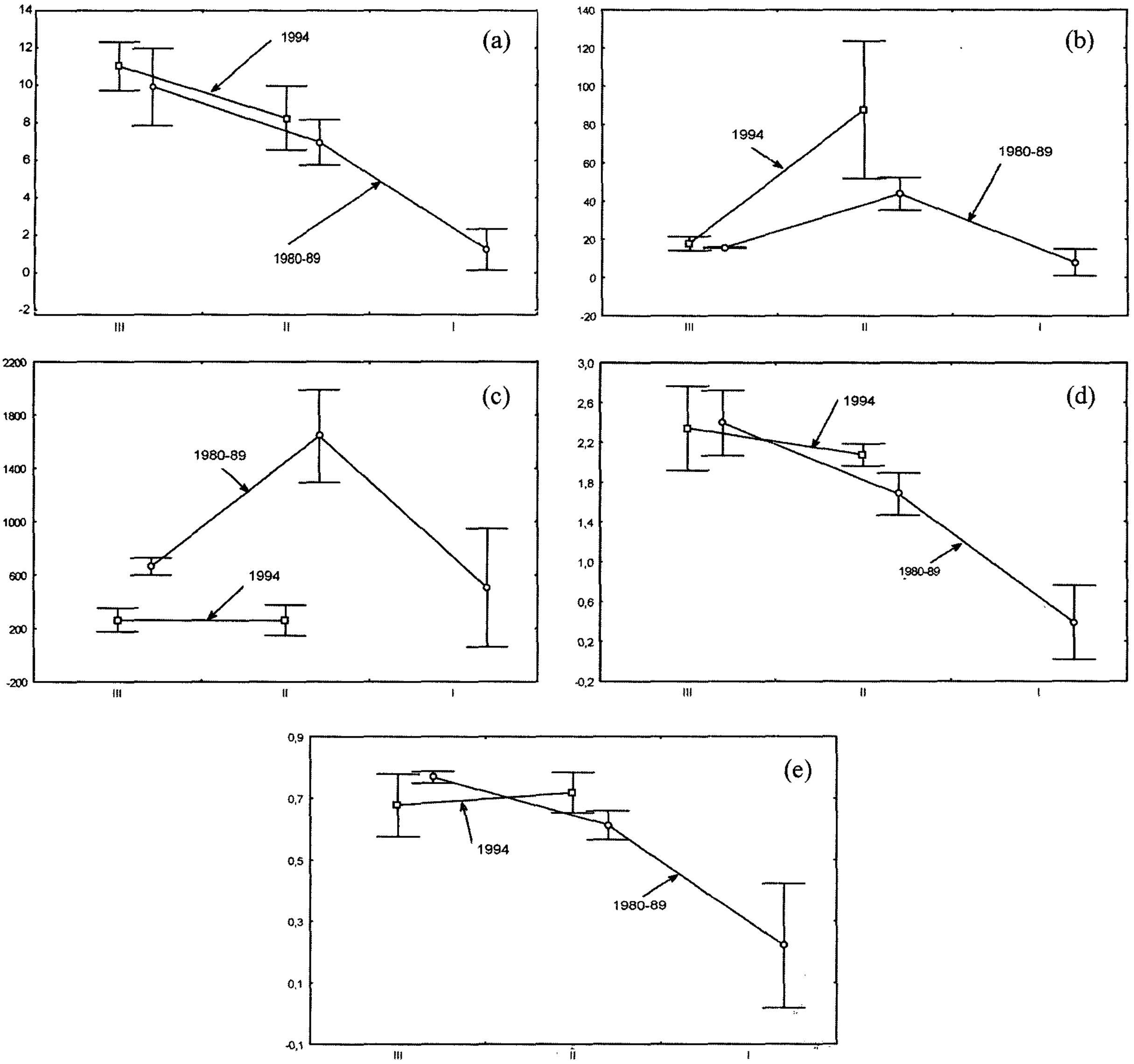

Fig. 6. Variations in species number (ordinate axis, a), biomass (b, g/m^2), density (c, ind/m^2), Shannon-Wiener diversity (d) and Pielou evenness (e) indices according to the contamination level (group of stations, abscissa axis). Whiskers show standard error values.

highest species diversity (Fig. 6). In addition, polychaete taxocenes in this group displayed a maximal evenness index, *i.e.* the domination of one or a small number of species is minimal here. Monotonous decrease in species number, diversity, and evenness were observed in association with an increase in contamination. The variations in pollution levels (the TPF values were used to characterize it) explain more than 67% of the variance in these taxocene characteristics in all cases (Fig. 7). It should be noted that species number, Shannon-Wiener diversity and Pielou evenness indices correlate with TPF, which are noticeably closer than both with separate chemicals, and the averaged grade of rank values of all contaminants. The correlation of taxocene characteristics and the scores of the 2nd and 3rd factors was also low and statistically insignificant.

Changes in biomass and density of polychaetes associated with an increase in contamination is not monotonous. When contamination of bottom sediments increases from a low to moderate level, a considerable growth of biomass and, especially, density of polychaetes occurs (Figs. 6, 7). An increase of contamination from moderate to heavy levels results in a drop in both biomass and abundance for polychaetes.

In the 1990s, the investigations of polychaete taxocenes at the stations of the first group were not carried out. In 1994, a considerable increase in biomass, and a decline in

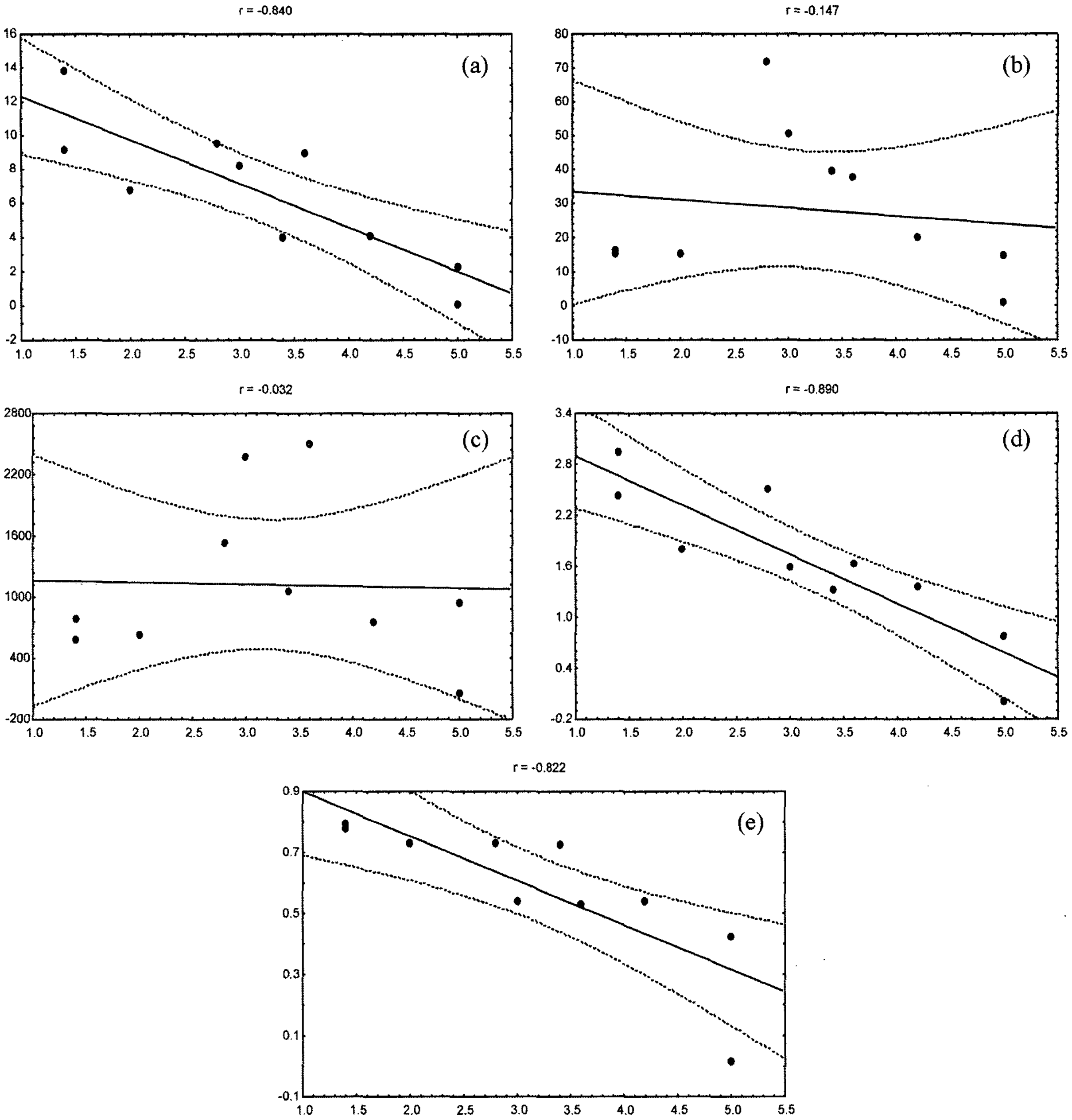

Fig. 7. Variations of species number (ordinate axis, a), biomass (b, g/m^2), density (c, ind/m^2), Shannon-Wiener diversity (d) and Pielou evenness (e) indices according to the contamination (TPF values, abscissa axis, standard units). The solid line shows a regression; dotted lines show 95-% confidence limits.

the density of polychaetes (more than 4 times) were found in the moderately contaminated areas (the second group of stations). However, the number of species, indices of diversity, and evenness did not change here. In relatively "clear" zones (the third group of stations) only polychaete biomass changed (its changes showed more than a twofold decrease).

Species diversity is a function of the species richness and the evenness of the distribution of individuals through the species. Numerous investigations showed that the disturbance of the environment, mainly as a result of pollution, resulted in changes in these two components (Gray and Pearson 1982; Rygg 1985a,b). It is well known that pollution often leads to structural changes in benthic communities. A few tolerant or opportunistic species will become relatively more numerous and will dominate the community, while many less tolerant species become increasingly rare or disappear. Benthic communities under conditions of pollution are characterized by low diversity and evenness.

High densities of pollution-insensitive species in the Peter the Great Bay were previously observed between 1975-1980. There were *Tharyx pacifica, Schistomeringos japonica, Capitella capitata* and *Nereis* spp., which appeared at the sites where moderate and low contaminant levels were found (Bagaveeva 1992). At the beginning of the 1980s, no new positive indicator species were found, and the sets of dominant and subdominant species remained unchanged. Thus, the communities investigated had changed prior to this study.

Evidently, with an increase in contamination all benthic communities, and polychaete taxocenes in particular, pass through some of the following phases: 1) at background locations, there is a decrease in species diversity due to the disappearance of sensitive long span species; 2) some opportunistic species (positive indicators of pollution) appear, become gradually dominant, and may increase both in terms of biomass and density according to their proper biological traits, (for example, sizes, productivity, etc) - intermediate stage; 3) then as more abundant and more tolerant species become extinct, biomass and density decrease, and, 4) finally, positive indicator species disappear also. It is possible at the most initial stage for the number of species, and, correspondingly, the index of species diversity to become somewhat greater due to the appearance of the opportunistic species.

If an opportunistic species presents large-sized individuals, total biomass of a taxocene may significantly increase after its settlement, and density may decrease due to the extinction of other species. Conversely, opportunistic polychaetes are small-sized, yet form highly dense settlements, causing biomass to decline (if the settlement density is very high one may observe a biomass increase), and density may increase. Naturally, both density and biomass may stay invariable, when, for example, the sizes and density of the opportunistic worms match those of the dominant and subdominant species of inviolable taxocene. All of these combinations describe a variety of responses by polychaete taxocenes to contamination. For the explanation of their variations at individual stations, it is necessary to analyze the changes in the opportunistic, dominant and subdominant species in greater detail.

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