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Trend-Surface and Principal Component Analysis of Invertebrate Data from a Pilot Survey of Morecambe Bay

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Introduction

In two previous papers (Jeffers, 1969 a, and Jeffers, 1969 b) the results of trend-surface and principal component analyses of chemical and physical variables determined on sand and mud samples taken during a pilot survey of Morecambe Bay have been described. At the same time that the sand and mud samples were taken, the numbers of six species of invertebrates in samples of fixed size were determined. This paper describes an analysis of the recorded numbers of the six invertebrate species.

The methods of analysis used in this paper follow closely those employed in the two previous papers, and no further descriptions of the methods are given. The numbers of individuals of each of the six species were subjected to a trend-surface analysis, and trend-surface maps were plotted for those species for which significant trends were obtained. The same data were also subjected to a principal component analysis, the components again being plotted as trend-surfaces, and as clusters. The species and the components were, in addition, compared with the components extracted from the chemical and physical data, in order to assess the relationship between the invertebrates and the chemical and physical properties of the sands and muds of the Bay.

Species Included in the Analysis

The following species were included in both the trend-surface and the principal component analysis:-

1. Macoma balthica
2. Tellina tenuis
3. Hydrobia ulvae
4. Corophium volutator
5. Nereis diversicolor
6. Arenicola marina

Results: Trend-Surface Analysis

The proportions of the variability accounted for by the linear, quadratic, and cubic terms of the regressions of the numbers of the six species on the grid co-ordinates are given in Table 1.

For three of the species, i.e. Tellina tenuis, Hydrobia ulvae, and Arenicola marina, there were no significant regressions of the numbers of specimens in the samples on the grid co-ordinates. For Nereis diversicolor, only the linear term of the regression was significant, but the quadratic trend-surface accounted for just over a quarter of the variability in the numbers of specimens. For Macoma balthica and Corophium volutator, the quadratic terms of the regressions were significant, but the accountable proportions of the variability in the numbers of specimens recorded were very different. Only about one-fifth of the variation in numbers of Macoma was accounted for, while the quadratic regression accounted for nearly a third of the variation in numbers of Corophium. It is notable that the trend-surfaces are generally less useful in predicting the numbers of invertebrates than in predicting the levels of many of the chemical and physical variables, and this suggests that there are other factors influencing the distributions of the invertebrates.

The coefficients defining the predictive equations are given in Table 2.

The trend surfaces determined by these coefficients are plotted in Figures 1, 2, and 3. The three species all show very different patterns of distribution, Malcoma balthica having its greatest numbers in the mid-tidal area, Corophium volutator its greatest numbers along the shores, and especially close to the Silverdale and Morecambe shores, and Nereis diversicolor showing a steady increase in numbers towards the mouth of the Bay.

Results: Principal Component Analysis

The data for the six species included in the analysis are summarised in Table 3, and the coefficients of the correlations between the numbers of each species are given in Table 4.

Table 3. Summary of species numbers

Species	Minimum	Mean	Maximum	Standard deviation
1	0	11.12	34	10.84
2	0	0.49	5	1.16
3	0	5.42	76	14.02
4	0	6.81	51	12.03
5	0	1.28	4	1.32
6	0	1.56	10	2.34

Table 4. Coefficients of correlations between species

1					
-0.226	2				
0.547**	-0.166	3			
0.297	-0.237	0.414**	4		
-0.024	0.220	-0.145	-0.295	5	
0.284	0.090	0.047	-0.048	0.210	6

The numbers of Macoma balthica, Hydrobia ulvae, and Corophium volutator were significantly or appreciably inter-correlated, and there was some evidence of correlation of the numbers of Arenicola marina with those of Macoma balthica. The numbers of Corophium volutator and Nereis diversicolor were appreciably negatively correlated.

The proportions of the variability accounted for by the principal components of the correlation matrix of the numbers for the individual species are summarised in Table 5, and the weightings given to the individual species by the first four components are given in Table 6.

Table 5. Proportions of variability accounted for by principal components

Component	Proportion	Cumulative proportion
1	0.330	0.330
2	0.212	0.542
3	0.154	0.696
4	0.135	0.831
5	0.114	0.945
6	0.055	1.000

Table 6. Weighting given to individual species by components

Species	Component			
	1	2	3	4
1	1.00	0.55	0.01	0.06
2	-0.60	0.55	0.01	1.00
3	1.00	0.49	0.01	0.12
4	0.76	-0.46	-0.18	0.43
5	-0.24	1.00	0.64	0.27
6	-0.15	0.79	-1.00	0.23

The first four components accounted for 83 per cent of the variability in the numbers of the six species, and of these components the first two accounted for 54 per cent of the variability. The first component, accounting for 33 per cent of the variability, is an index of the numbers of Macoma balthica and Hydrobia ulvae and Corophium volutator. The second component, accounting for a further 21.2 per cent, is almost entirely a measure of the numbers of Nereis diversicolor, while the third component, accounting for 15.4 per cent, is almost entirely a measure of the absence of Arenicola marina. The fourth component, accounting for 13.5 per cent, is a direct measure of the numbers of Tellina tenuis.

Trend surfaces were fitted to the four components, but only for the first two components were there significant regressions of the component values on the grid co-ordinates, accounting for 15.6 and 29.3 per cent of the variability of the first and second components respectively. The computed trend surfaces are plotted in Figures 4 and 5.

A cluster analysis was also carried out on the component values of the individual sample points, using the same techniques as described in Jeffers, 1969 b. The main result of the analysis was to separate sampling points which had relatively high numbers of Macoma balthica, Hydrobia ulvae, and Corophium volutator from the remaining points. These points are plotted as X's in Figure 6, in contrast to the O's for the remaining points.

Correlations between Invertebrates and Chemical and Physical Components

The coefficients of the correlations between the four invertebrate components and the five components of the chemical and physical variables determined on cores from 0-5 cms. and 0-10 cms. are given in Tables 7 and 8 respectively.

Table 7. Coefficients of correlations between invertebrate components and chemical and physical components: 0-5 cms.

Chemical and physical component	Invertebrate component 1	2	3	4
1	0.411**	-0.156	0.038	-0.099
2	0.508**	-0.195	-0.063	0.015
3	0.155	0.625**	0.130	-0.118
4	0.005	-0.198	0.037	-0.139
5	-0.124	-0.135	0.186	-0.196

Table 8. Coefficients of the correlations between invertebrate components and chemical and physical components: 0-10 cms.

Chemical and physical component	Invertebrate component 1	2	3	4
1	0.455**	-0.388**	-0.129	-0.050
2	-0.001	0.356*	0.244	-0.246
3	-0.133	0.205	-0.346*	0.054
4	0.099	0.153	-0.232	0.144
5	-0.018	-0.061	0.031	0.035

Thus, the first component of the invertebrates, i.e. the index of the numbers of Macoma balthica, Hydrobia ulvae, and Corophium volutator, was significantly, and positively, correlated with the first and second components of the physical and chemical variables determined on cores from 0-5 cms., i.e. with the amounts of P and NH_4-N in the interstitial water, wet sand, and dry sand, moisture content, loss on ignition, and total percentages of K and N and with the contrast of the amounts of Na and NO_3-NO_2-N. The second invertebrate component, the numbers of Nereis diversicolor, was significantly but negatively correlated with the third chemical and physical component, the contrast of the amounts of Na and NO_3-NO_2-N with the total percentages of P. The other two invertebrate components were not significantly correlated with the components of the chemical and physical variables of the cores from 0-5 cms., and the fourth and fifth chemical and physical components were not significantly correlated with any of the invertebrate components.

The joint index of the numbers of Macoma balthica, Hydrobia ulvae, and Corophium volutator was positively correlated with the index of moisture content, Na in interstitial water, and percentages of K and P, but not with any of the other components calculated for the 0-10 cms. cores. The numbers of Nereis diversicolor were negatively correlated with the index of moisture content, Na in interstitial water, and percentages of K and P, but positively correlated with the amounts of P in the interstitial water, dry sand, and wet sand. The absence of Arenicola marina was negatively correlated with the amounts of NH_4-N in the interstitial water, wet sand, and dry sand, and the percentage of calcium. The fourth invertebrate component was not significantly correlated with any of the chemical and physical components, and the fourth and fifth chemical and physical components were not significantly correlated with any of the invertebrate components.

The inter-relationships between the invertebrate and chemical and physical components are shown diagrammatically in Figure 7.

Discussion

Trend-surface analysis of the numbers of the six individual species of invertebrates recorded in the pilot survey of Morecambe Bay accounted for only relatively small proportions of the variability of the numbers of each species. The maximum proportion of the variability accounted for was 0.32 for Corophium volutator, and only two of the remaining species showed any significant regressions of their numbers on the grid references of the sampling points, i.e. Macoma balthica and Nereis diversicolor, for which the proportions of the variability accounted for were 0.21 and 0.24 respectively.

The principal component analysis of the numbers of the six species suggests that three of the species are associated, i.e. Macoma balthica, Hydrobia ulvae, and Corophium volutator, and that, for all practical purposes, the distribution of these species can be indicated by a single index. Only the first two components had significant regressions on the grid references of the sampling points, the resulting trend-surfaces being very similar to those for the individual species. Cluster analysis of the samples separates the samples into two groups, a small group of sample points for which the numbers Macoma balthica, Hydrobia ulvae, and Corophium volutator were high, and a larger group of samples with lower numbers of these species, and considerable variations in the numbers of the other species.

The first two invertebrate components were significantly correlated with three of the components extracted from the chemical and physical determinations on samples from 0-5 cms., so that estimates of the numbers of Macoma balthica, Hydrobia ulvae, Corophium volutator, and Nereis diversicolor could be derived from the associated components, or from one or more of the chemical and physical variables contributing significantly to these components. Similarly, the first three invertebrate components were significantly correlated with three of the components of the chemical and physical determinations on samples from cores at 0-10 cms., and appropriate estimates could be derived from either the components or the individual variables indicated by these correlations.

The numbers of Macoma balthica, Hydrobia ulvae, and Corophium volutator are positively associated with the moisture content, loss on ignition, and amounts of P, NH_4-N, total K, and total N in samples from 0-5 cms., and also with the contrast between the amounts of Na and NO_3-NO_2-N in the same samples. The same species are also associated with the amounts of Na, total K and total P in samples from 0-10 cms.

The numbers of Nereis diversicolor are associated with the contrast between the amounts of Na and NO_3-NO_2-N with the amount of total P in samples from 0-5 cms., but negatively associated with the amounts of Na, total K, and total P in samples from 0-10 cms., as well as being positively associated with amounts of P in the same samples.

The numbers of Arenicola marina are positively associated with the contrast between the amount of calcium and the amount of NH_4-N in samples from 0-10 cms. The numbers of Tellina tenuis were not significantly related to any of the chemical and physical components. It is also of some interest that none of the purely physical components were significantly related to any of the invertebrate components.

The examination of the results of this analysis in relation to what is already known about the invertebrate species included in the analayis should also be of some interest. Presumably, there are other known factors which influence the distribution of the invertebrate species, such as the position of the inter-tidal zones, and the heights of the tides in the period immediately before sampling. Information of this kind could readily be included in an extension of the analysis, but the first priority is probably to examine the correlations between the invertebrate and chemical and physical components to see if they are likely to be meaningful, or useful in future predictions. It will also be interesting to see if these correlations are confirmed by the analysis of the data from the main survey of Morecambe Bay.

References

Jeffers, J. N. R. 1969 a. Trend-surface analysis of chemical and physical variables from a pilot survey of Morecambe Bay. Merlewood Research and Development Paper No. 14.

Jeffers, J. N. R. 1969 b. Principal component analysis of physical and chemical data from a pilot survey of Morecambe Bay. Merlewood Research and Development Paper No. 15.

MACOMA BALTHICA FIGURE 1

COROPHIUM VOLUTATOR FIGURE 2

MEPEIS DIVERISCOLOR

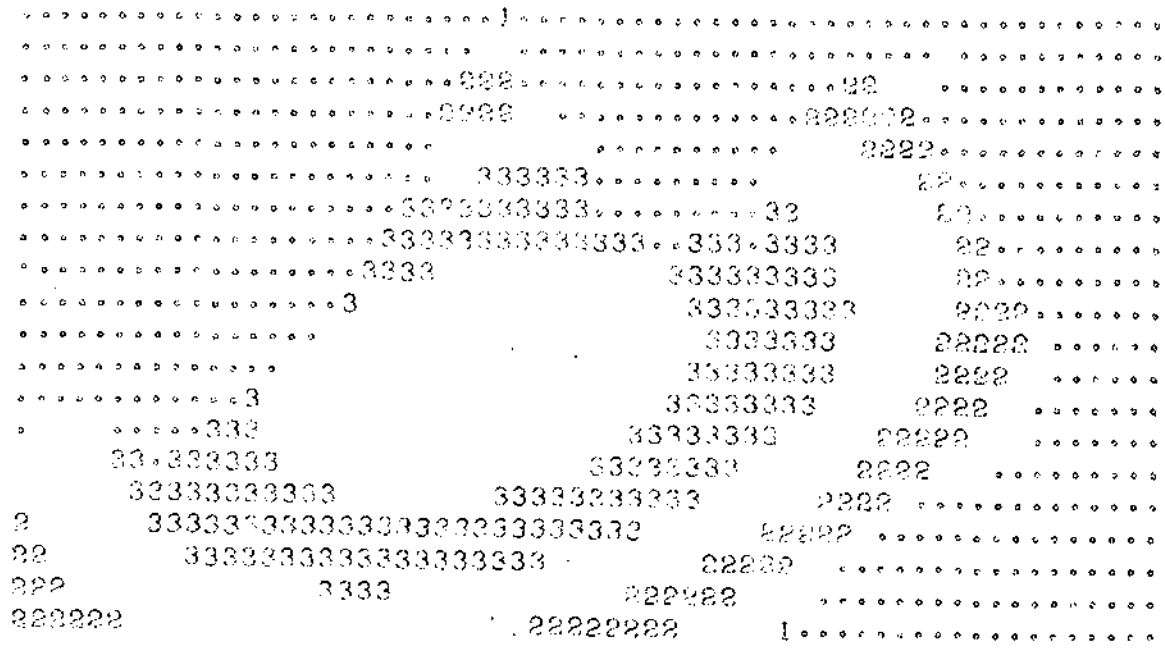
FIGURE 3

FIRST COMPONENT

FIGURE 4

SECOND COMPONENT

FIGURE 5



RESULTS OF CLUSTER ANALYSIS

FIGURE 6

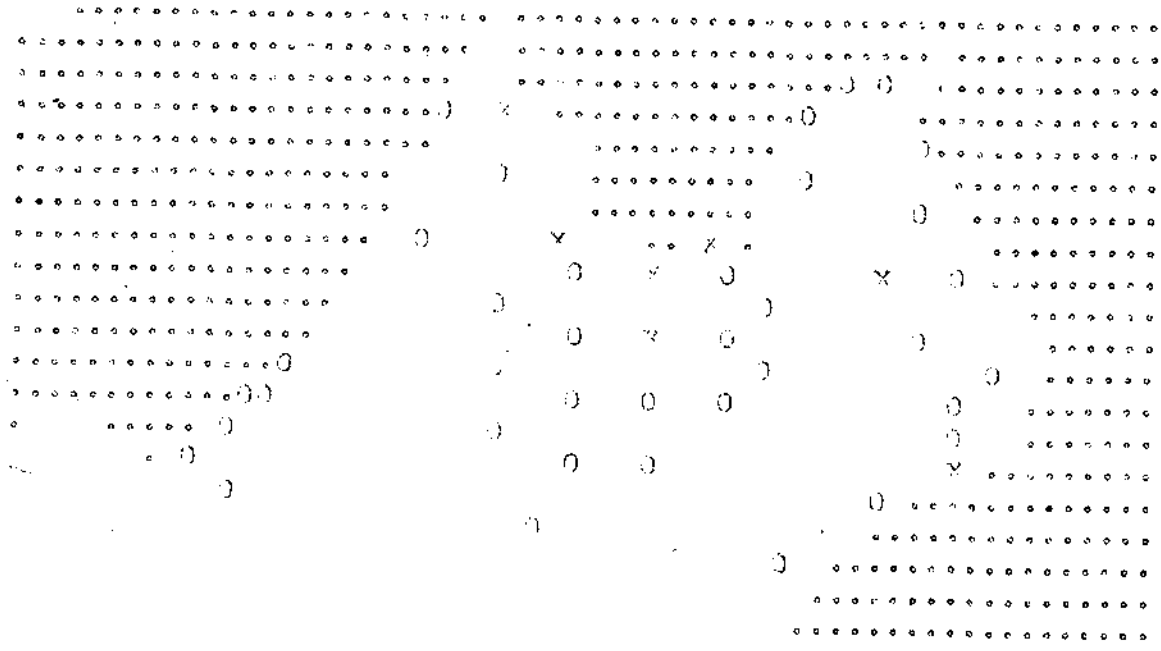


Figure 7. Inter-relationships between Invertebrates and Chemical and Physical Components

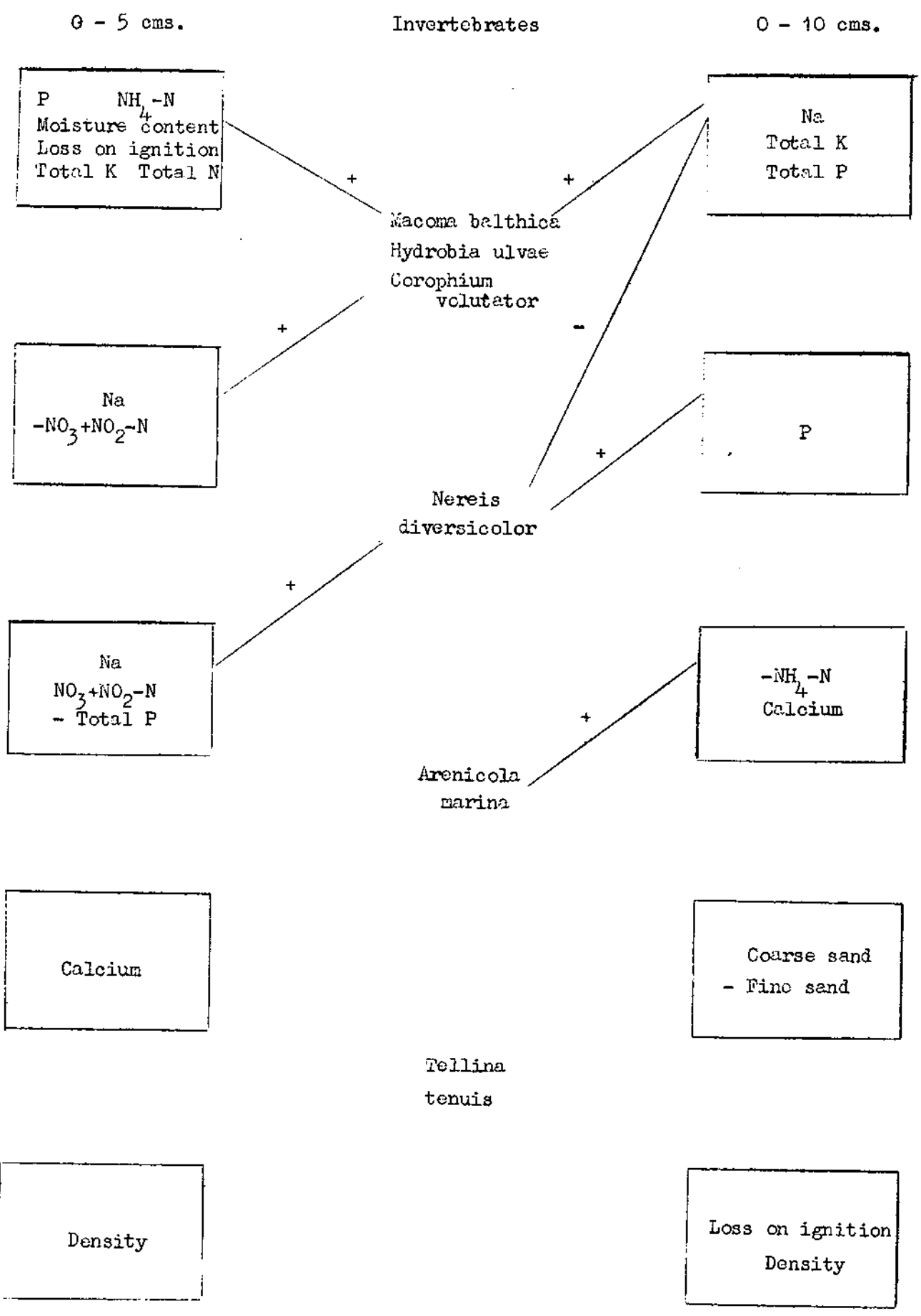


Table 1. Proportions of variability accounted for by the linear, quadratic and cubic terms of the regressions on grid co-ordinates

Variable	Proportion of Variability			Cumulative Proportions	
	Linear	Quadratic	Cubic	Quadratic	Cubic
1	0.0791	0.1357*	-	0.2148	-
2	0.0462	0.0417	-	0.0879	-
3	0.0703	0.0526	-	0.1229	-
4	0.1378*	0.1828**	0.0749	0.3206	0.3955
5	0.2421**	0.0201	-	0.2622	-
6	0.0357	0.0793	0.0111	0.1150	0.1261

Table 2. Coefficients defining predictive equations

Coefficient	Macoma balthica	Corophium volutator	Nereis diversicolor
Constant	-1927.81	-817.317	2.81870
X	87.7627	73.6699	-6.50989
Y	496.902	186.175	4.09338
X^2	-6.84827	16.4671	-0.165222
Y^2	-33.4393	-5.97913	-0.575535
XY	-4.65234	-26.5029	0.953827