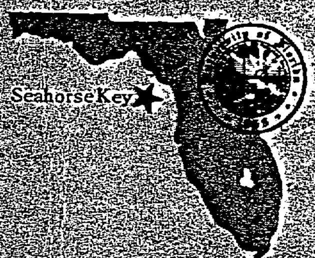
MULTIVARIATE ANALYSIS OF THE MAFLA WATER COLUMN BASELINE DATA



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for the
BUREAU OF LAND MANAGEMENT
United States Department of Interior
under Contract No. 08550-CT5-27

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FOREWORD

This report represents a statistical summarization of the interdisciplinary water column study from the Bureau of Land Management sponsored MAFLA (Missippi, Alabama, Florida) eastern Gulf of Mexico environmental baseline study. Many of the techniques of analysis employed herein are unfamiliar to the general reader interested in the results of our analyses. Appendix 2 provides a moderately technical discussion of the analytical techniques and their underlying assumptions and also give suggested further reading on the topic. Appendices 3-36 provide the computer printouts which served as the data base for the body of this report. These printouts are available from the authors for the cost of generating the output.

The remainder of this foreword is devoted to a very generalized discussion of the analysis procedure and methods.

The patterns of zooplankton community fluctuations are best understood when considered in the context of the environment. The zooplankton and environmental variable states are interdependent and can not be split apart and analyzed separately; hence, the need to use multivariate analysis. What is it that distinguishes multivariate statistical methods from other statistical or data analysis approaches? In multivariate methods we realize that the variables we measure are related to each other, and we design our sampling schemes to collect data on all the variables simultaneously. Then, when we analyze the data we are able to propose models that not only have multiple independent variables but also many dependent variables as well. If one is able to assign a cause and effect meaning to the analysis, then the independent variables are the causative effects and the dependent variables are determined by the independent ones. The presence of multiple dependent variables in an analysis is generally the distinguishing characteristic of multivariate analyses. Those analyses with only one dependent (or effect) variable are called univariate analyses.

The basic approach in our analyses was to define two multivariate sets of data: the zooplankton community variables and the environmental variables. Although the ideal design of the data survey would be to have complete synopticity, this is not realized because of logistic and other problems. Thus our analysis was fragmented more than we would have liked, but at least the conceptually unified areas of trace metals and hydrocarbons could be treated as a unit.

The zooplankton community data set contained the #s/M^3, standing crop, of the different types of plankters encountered. The environmental data set contained physical features of the water column (salinity, temperature, station depth, etc.) and level of the various water column pollutants measured (trace metals, and hydrocarbons). Our first goal was to discover the statistically valid relationships between these two sets of data. We used the regression techniques, two closely allied methods entitled multivariate regression and canonical correlation, to uncover these relationships. Because the analysis methods are mathematical in nature, the results are in the form of equations with many terms and highly complex coefficients. The use of these equations is the task of interpretation of the results. In essence, both regression techniques find strong relationships between the two variable sets. There may be several such relationships; in this case each relation between the two variable sets is formed so that it is independent of all others found. Additionally, this analysis approach provides quantitative statistics to assess the strength of the relationships between the zooplankton community and the environment.

Using this approach, we were able to determine the effect of the environmental variation on the zooplankton community variation and also show the magnitude of effect present levels of pollutants have on the zooplankton community variability.

Our second objective was to establish a relationship between pollutant levels in a zooplankton community and its composition. This was then followed up by an analysis of the relationship between overall pollutant level of the zooplankton and the pollutant level of the water from which the plankton were sampled.

Thus we are asking two questions of the data: (1) What is the relationship of community structure and environmental structure? (2) What is the relationship betweeen environmental pollution and zooplankton levels of pollutants?

The report is organized basically into three areas: (1) setting the stage (introduction, material and methods, etc.), (2) technical results and, (3) discussion and a generalized summary. The technically trained, or interested, reader is urged to study sections I and II and appendices 1 and 2. Those readers interested primarily in the interpretation, our assessment of what the results mean in relatively plain English, may skip directly to section IV and refer back as necessary.

EXECUTIVE SUMMARY

The ultimate goal of any group of ecological analyses is to transform the diverse and often complex results into interpretive statements about the system. Multivariate analysis, a complex statistical correlation tool, was the primary procedure used to approach this objective.

In the MAFLA region, a strong correlation exists between the zooplankton community and its environment. Two general regimes of environmental factors weigh heavily in this strong correlation: 1) inshore-offshore factors, and 2) surface to bottom layering. Important components of inshore-offshore patterns include station depth, net range, and salinity range, all of which are associated with deeper, more offshore stations; whereas, net depth, temperature, and temperature and salinity range are associated with surface to bottom layering. For example, in Lease Tracts IV and V, the calanoid copepods Acartia, Centropages, and Eucalanus, and the chaetognaths are negatively correlated with salinity and station depth and positively related to temperature and salinity range. This species assemblage is related to the shallower, warmer, more heterogeneous inshore waters.

In general, species assemblages found to be correlated with the environment are regulated either by depth factors or changes in salinity and temperature.

The low correlation between the zooplankton community and suspended trace metals indicates the low trace metal levels in the MAFLA area are not an important factor governing zooplankton community structure. However, the variation of trace metals within the zooplankters themselves is highly dependent on the species composition of the zooplankton community. This analysis suggests three types of zooplankters in the community with respect to trace metals: 1) positive or high level concentrators (*Oikopleura* and nickel), 2) those species negatively correlated with trace metals (*Centropages* and nickel), and 3) species not correlated at all with trace metals. The species indicated as high concentrators suggest possibilities for further studies as to their role in transport of these metals. Although correlations are low, there is a predictable relationship between trace metals in the zooplankton and the species composition of the plankton. 'The determination of the zooplankton species composition is therefore important to the monitoring of trace metals in the system.

The relationship between zooplankton trace metals and water column trace metals was analyzed to determine if the trace metals encountered in a zooplankter reflect the environment or the metabolic idiosyncrasies of the organism. In general, most trace metals in the zooplankton were positively correlated with those in the environment. For example, in Lease Tracts I-III, cadmium contained in the organisms increased with its concentration in the water column; in Lease Tracts IV-V lead showed the same relationship. For all lease areas, lead was shown to be an important trace metal to be considered in future studies. Some conflicting behavior of cadmium and chromium occurred, indicating the importance of monitoring water mass movements in order to determine the origin of the water at the time of collection.

As in trace metals, variation in zooplankton hydrocarbons was influenced greatly by the species composition of the zooplankton. This suggests that different organisms are affected differentially by hydrocarbons.

In summary, much of the variation in the zooplankton community can be attributed to depth, salinity, temperature and, because of their low levels, to a lesser extent trace metals and hydrocarbons.

It is important to note that low levels of many substances can have sublethal but important effects. This analysis is valid only for these low levels of trace metals and hydrocarbons; if levels change, the plankton community may show a different response.

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Tables and Figures

Introduction

Variability in zooplankton composition and patchiness are well known phenomena and often present severe problems in analyzing and obtaining a clear understanding of zooplankton community structure. Patchiness and variability of standing crop for various community components are often better understood when compared with the patchiness and variability of the environment. The various chemical and physical factors within the water column inhabited by the planktonic community act either singly or in concert to shape the structure of the community. This shaping can occur by: 1) the organisms exhibiting positive or negative tropisms (e.g. phototropisms), 2) levels of certain organisms being affected as a result of the chemical composition of the environment, and 3) the physical-chemical nature of the environment favoring the presence of one organism over another. Any of the above biotic-abiotic interactions might result in either exclusion of certain organisms or reduction in their numbers. In addition, there are biotic-biotic interactions that also serve to shape the community composition. These interactions are the classic ones of competition, predation, mutalism, etc. Thus, the patterns of zooplankton community fluctuations are probably best understood when considered in the context of the community and its environment.

This follow up study investigates the interrelationships of the zooplankton community components and their environment, utilizing the analytical techniques contained within the generic term of Multivariate General Linear Hypothesis (MGLH). More specifically, the techniques of multivariate regression, canonical correlation and factor analysis were used to examine the relationships of the various water column variables.

The sample collection and laboratory techniques for each of the variables used in this analysis have been discussed in detail in the SUSIO Final Report on the Baseline Environmental Survey of the MAFLA Lease Areas and thus will not be presented here. However, Appendix 1 contains a listing of the samples used and the variables contained within the sample, and the derivation of the actual value employed.

Statistical Methods

Most techniques of multivariate analysis require that the data set be composed of observations on a set of variables which contain no missing values. As a result of this requirement and the distribution of missing values in the total water column data set (analyses not performed, chemical samples lost etc.), several submodels were utilized. Another characteristic of the data set which was reported in the SUSIO Final Report is the difference between the faunas of the planktonic communities of the north central Gulf of Mexico in the region of lease tracts IV and V as compared with the planktonic communities of the eastern Gulf of Mexico in the region of lease tracts I-III. Thus, the data are divided into four general submodels: trace metal analyses for the separate geographic regions and hydrocarbon analyses for the separate geographic regions. Table 1 lists the analysis models performed in this study as well as the appendix containing the computational results of the analyses. In addition to the multivariate analyses performed as a result of this study, several univariate statistical analyses and data description techniques were possible as options of the computer programs that performed the multi variate procedures. These are also included in the listing found in Table 1 along with their appropriate appendices. These univariate analyses were included for two reasons: 1) they are the more familiar type of statistical analysis and could quite easily be of interest to other investigators who would use this report, and 2) they will often offer a further aid in interpreting the results of a multivariate analysis, just as repeated t-tests may aid in the interpretation of a univariate analysis of variance. If the techniques listed in Table 1 are unfamiliar, Appendix 2 contains a nontechnical discussion of the methods and their interpretation.

A final analysis technique was utilized in the data sets which had particularly problematical distribution of missing values, namely, the high molecular weight hydrocarbons from lease tracts I, II, and III. It is possible to estimate the original variable intercorrelations using an option known as pairwise deletion of cases. In this manner the correlations are estimated utilizing all samples that contain valid data values for the pair of variables in question. This method assures that the maximum information available will be used in the estimation of the correlations. However, it does have a drawback in that it is possible that the correlations for different pairs of variables may be calculated from different subgroups of the entire sample. For example, if the distribution of missing values of a variable is not random, but instead is systematic (e.g. all mid water tows or all inshore stations, etc. are missing) then the correlation matrix may in fact be a very poor estimation of the actual parametric correlation matrix for the samples of Eastern Gulf of Mexico water. As stated before, our philosophy is one of data

Table 1   A list of data analyses performed and submodels investigated.

I. Lease Tracts I, II, III

A) Trace Metals

1) Dissolved in water column as predictors of zooplankton

a) Univariate multiple regression (appendix 3)

b) Multivariate multiple regression (appendix 4)

c) Canonical correlation (appendix 5')

2) Zooplankton as predictors of zooplankton trace metal content

a) Univariate multiple regression (appendix 6)

b) Multivariate multiple regression (appendix 7)

c) Canonical correlation (appendix 8)

3) Water column trace metals as predictors of zooplankton trace metals adjusting for the levels of zooplankton categories

a) Univariate multiple regression (appendix 9)

b) Multivariate multiple regression (appendix 10)

c) Canonical correlation (appendix 11)

4) Factor analysis of trace metals

a) Water column trace metals (appendix 12)

b) Zooplankton trace metal residuals (appendix 13)

B) Hydrocarbons

1) Dissolved in water column as predictors of zooplankton - canonical correlation

2) Zooplankton as predictors of zooplankton hydrocarbon content

a) Univariate multiple regression (appendix 14)

b) Multivariate multiple regression (appendix 15)

c) Canonical correlation (appendix 16)

II. Lease Tracts IV, V

A) Trace Metals

1) Dissolved in water column as predictors of zooplankton

a) Univariate multiple regression (appendix 17)

b) Multivariate multiple regression (appendix 18)

c) Canonical correlation (appendix 19)

2) Zooplankton as predictors of zooplankton trace metal content

a) Univariate multiple regression (appendix 20)

b) Multivariate multiple regression (appendix 21)

c) Canonical correlation (appendix 22)

3) Water column trace metals as predictors of zooplankton trace metals adjusting for the levels of zooplankton categories

a) Univariate multiple regression (appendix 23)

b) Multivariate multiple regression (appendix 24)

c) Canonical correlation (appendix 25)

4) Factor analysis of trace metals

a) Water column trace metals (appendix 26)

b) Zooplankton trace metal residuals (appendix 27)

B) Hydrocarbons

1) Dissolved in water column as predictors of zooplankton - canonical correlation

2) Zooplankton as predictors of zooplankton hydrocarbon content

a) Univariate multiple regression (appendix 28)

b) Multivariate multiple regression (appendix 29)

c) Canonical correlation (appendix 30)

III. Special Tables

A) Descriptive statistics

1) Means for all variables

a) Lease tracts I, II, III (appendix 31)

b) Lease tracts IV, V (appendix 32)

2) Correlation matrices of all variables

a) Lease tracts I, II, 111 (appendix 33)

b) Lease tracts IV, V (appendix 34)

B) Canonical correlations of as many variables as possible

1) Lease tracts I, 11, 111

2) Lease tracts IV, V

C) Factor analysis of error matrices for species interactions

1) Lease tracts I, II, III (appendix 35)

2) Lease tracts IV, V (appendix 36)

analysis utilizing several multi variate approaches to discover relationships between the biotic and abiotic factors of the Eastern Gulf of Mexico water column. When the results of these analyses support each other, we conclude that a real phenomenon has been demonstrated. Where the results contradict, we propose further investigation into the subject. In all cases the data analysis procedure in this first pioneering examination of an interrelated water column data set runs the risk of discovering relationships for which we have no explanation and can only suggest further research. However, these techniques of data analysis will greatly reduce the number of possible avenues of investigation and point out those likely to be most fruitful.

For analysis purposes, the 81 zooplankton categories used for identification and density counts of lease tract I, II, and III samples were condensed to 33 categories, and these 33 categories were transformed using the equation:

$$\text{density} = \log_{10} (\text{density} + 1)$$

so that their distribution more closely resembled the multivariate normal distribution. The condensing of categories was carried out according to the following scheme:

Reporting Category	Counting Category
1. Globigerina	Globigerina
2. Other Protozoa	Pyrocystis Tintinnids
3. Siphonophores	Siphonophores
4. Medusae	Hydromedusae Scyphozoan medusae

Reporting Category	Counting Category cont.
5. Polychaetes	Polychaetes
6. Gastropod veligers	Gastropod veligers
7. Pteropods	Cavolina longirostris Clio species Creseis virgula Limacina inflata Limacina lesevri Other Thecosomata Desmopterus papilio Gymnosomata species A Gymnosomata species B Other Gymnosomata
8. Bivalve larvae	Bivalve larvae
9. Cladocera	Cladocera
10. Ostracods	Ostracods
11. Centropages furcatus	Centropages furcatus
12. Eucalanus species	Eucalanus elongatus Eucalanus species, other
13. Undinula vulgaris	Undinula vulgaris, female
14. Other Calanoid copepods	Candacia curta Euchaeta marine Mecynocera clausii Pontella species Rhincalanus cornutus Scoleothrix danae Temora species Other Calanoids
15. Harpacticoid copepods	Harpacticoid copepods
16. Corycaeus species	Corycaeus species
17. Oithona species	Oithona species
18. Oncaea species	Oncaea species
19. Other Cyclopoid copepods	Copilia mirabilis, female Copilia mirabilis, male Copilia quadrata, female Copilia quadrata, male

Reporting Category	Counting Category cent.
	Corissa species Farranula species Sappinrina species Vettoria species Other cyclopoids
20. Copepodi tes	Calanoid copepodites Harpacticoid copepodites Cyclopoid copepodites
21. Copepod Nauplii	Copepod Nauplii
22. Lucifer species	Lucifer faxoni Lucifer, mysis-stage
23. Other shrimp-like forms	Other shrimp-like forms
24. Crab larvae	Crab zoea Crab megalops
25. Other crustacea	Barnacle larvae Stomatopod larvae Mysids Amphipods Euphausiids Phyllosoma larvae Anomurans Other crustaceans
26. Echinoderm larvae	Echinoderm larvae
27. Chaetognaths	Sagitta enflata Sagitta hispida-helenae complex Sagitta tenuis-bipunctata complex Other chaetognaths
28. Oikopleura	Oikopleura
29. Fritillaria	Fritillaria
30. Other Tunicates	Doliolida Salphida Other Thaliaceans Other Larvaceans
31. Fish eggs	Fish eggs
32. Fish larvae	Fish. larvae

Reporting Category	Counting Category cont.
33. Other plankters	Heteropods Cephalopods Trochophore larvae Other plankters

Thirty-two distinct zooplankton density categories, similarly log-adjusted, were used in the analysis of lease tract IV and V data. These were:

1. Pyrocystis
2. Ceratium
3. Foraminifera
4. Siphonophores
5. Hydromedusae
6. Polychaetes
7. Gastropod larvae
8. Bivalve larvae
9. Cladocerans
10. Acartia species
11. Calanus species
12. Centropages species
13. Eucalanus species
14. Euchaeta species
15. Paracalanus species
16. Temora species
17. Undinula species
18. Other Calanoid copepods
19. Euterpina species
20. Other Harpacticoid copepods
21. Corycaeus species
22. Oithona species
23. Oncaea species
24. Other Cyclopoid copepods
25. Copepod nauplii
26. Decapod larvae
27. Other Crustaceans
28. Chaetognaths
29. Larvaceans
30. Salps
31. Fish eggs
32. Fish larvae

The following environmental variables were employed in at least some part, if not all, of the multivariate analyses:

1) Hour of the day - Time in hours, on a 24-hour clock, of the collection of the sample.

2) Sunlight - A qualitative estimate of the light intensity at the time of sampling, 0 = dark, 1 = dawn or dusk, 2 = full sunlight.

3) Poc - Particulate organic carbon, measured in mg/l, average of three determinations.

4) DOC - Dissolved organic carbon, mg/l; average of three determinations.

5) ATP

6) Suspended copper, ppb.

7) Suspended lead, ppb.

8) Suspended chromium, ppb.

9) Suspended cadmium, ppb.

10) Suspended iron, ppb

11) Dissolved C_{17}/pristane ratio

12) Dissolved C_{18}/phytane ratio

12a) Dissolved pristane/phytane

13) Dissolved odd to even paraffin ratio

14) Dissolved n-paraffin/phytane ratio

15) Dissolved n-paraffin/C_{16} ratio

16) Dissolved total aromatics µg/l

17) Dissolved total aliphatics µg/l

17a) Dissolved CH_4 nannoliters/liter

17b) Dissolved C_2H_4 nannoliters/l

17c) Dissolved C_3H_8 nannoliters/l

18) Depth of station where sample was collected

19) Median depth of net collecting sample

20) Depth range for net collecting sample

21) Mean temperature within portion of water column sampled .

22) Temperature range within portion of water column sampled '

23) Mean salinity within portion of water column sampled

24) Salinity range within portion of water column sampled

The following measurements of zooplankton concentrations of trace metals and hydrocarbons were also included in at least some part of the analyses:

1) Iron, μg/g

2) Chromium, μg/g

3) Nickel, μg/g

4) Copper, μg/g

5) Vanadium, μg/g

6) Cadium μg/g

7) Lead, μg/g

8) C_{17}/Pristane

9) C_{18}/Phytane

9a) Pristane/Phytane

10) odd/even n-paraffin

11) n-paraffin/Phytane

12) n-pariffin/C_{16}

13) Total aromatics mg/g

14) Total aliphatics mg/g

The final report on the "Base line" study contains the specific laboratory techniques employed to obtain these values, and the values themselves.

Results

Lease Tracts I, II, III Trace Metal Analyses

Suspended Trace Metals and Associated Station Characteristics.

In areas I, II, and III the following particulate trace metal determinations occurred often enough in the samples to permit inclusion into the analysis models without resorting to a pairwise deletion correlation matrix: lead, cadmium and iron. In addition the following other environmental variables were entered into the model: hour of the day, level of sunlight, POC, DOC, depth of the station, average depth of the collecting net, net depth range, mean temperature, temperature range, mean salinity, and salinity range. The zooplankton categories used are those listed in the statistical methods section for Lease Tracts I, II, III.

Multivariate Regression. (.appendix 4)

Lead: Lead is related to changes in the zooplankton standing crop at the significance level of 0.0001. The relationship indicated by the canonical variable is centered primarily around three categories, which are positively related to the concentration of particulate lead in the water column. These categories consist of gastropod veligers (.370), Oncaea (.336) and Oikopleura (.264). Of the remaining categories, seventeen have correlations with the canonical variable of less than 0.01, and the remainder all have positive correlations ranging from .125 to .216. The only negative correlations which have an absolute magnitude greater than .10 are Centropages (-.189), Oithona (-.148), echinoderm larvae (-.154), and chaetognaths (-.114).

Cadmium: Levels of particulate cadmium show a significant effect

(.0001) or relationship with some components of the zooplankton community As in the previous terms of the model, the majority (20) of the zooplankton categories show very low correlations with the level of particulate cadmium in the sample. Only four categories, two with positivie correlations and two with negative correlations, possess correlations greater in absolute magnitude than .20. They are: Other protozoans, including Pyrocystis (0.374), Eucalanus (0.273), medusae (-0.267), and crab larvae (-0.263). The remaining categories with correlations between 0.1 and 0.2 all show negative relationships, with the exception of Centropages.

Iron: This particulate trace metal follows the same general patterr of relationships with the zooplankton standing crops as the previous trace metals. There are three categories that seem to display some relationship with particulate iron, while the majority (20) seem to show no relationship, and the remainder have only weak correlations. The categories showing the strongest correlation with particulate iron are the copepods, Eucalanus (0.376), Oithona (0.368), and Centropages (0.284)

Hour: Time of day of sample collection had no significant effect on the observed standing crop of zooplankton categories. This is to say that given the rest of the environmental information available the time of day gives us no significant new information.

Sunlight: The reported probability of the test of significance for the qualitative, but ordinal, sunlight variable is 0.066. This is too large for us to consider significant, but the trends displayed suggest that the amount of sunlight had the expected effect on the zooplankters. The majority of the correlations between the original variables and the sunlight canonical variable are negative. Thus, the brighter the incident light, the lower the standing crop in certain categories. The categories displaying the greatest relationship with the sunlight variable were: shrimp larvae, ostracods, crab and fish larvae with negative correlations, and Eucalanus and Oithona with positive correlations.

POC: The probability for the test of significance was 0.0001. Thus, we will reject the Possibility of there being no relationship between zooplankton standing crop and the level of particulate organic carbon. The CV correlations were generally positive with Corycaeus showing the greatest correlation (.359), followed by Fritillaria (.280), and Oikopleura, Lucifer, Globigerina, chaetognaths, crab larvae, gastropod veligers, bivalve veligers, fish eggs and Centropages (.20 to .29). The only negative correlations of any magnitude were other protozoans (-. 160) and polychaetes (-.152); neither correlation is particularly l arge. The general overall relationship with POC is that as the level of POC tends to increase the standing crop of zooplankton categories also increases, or vice versa.

DOC: This also showed a significance level of 0.0001 and we examined the correlations to assess the type of relationship present between dissolved organic carbon and zooplankton category standing crop. In this relationship only a few of the zooplankton categories seemed to correlate with DOC. Oithona has the greatest magnitude (.237), while the other two correlations that seem to be important, gastropod veligers (-.24) and Oikopleura (-.202), display negative correlations.

Depth of station: This environmental variable and the remaining contern the description of the physical environment in the more classical concepts of temperature, salinity and depth, Within the region of lease tracts i, II and III, depth of station is found to have a significant effect on the structure of the zooplankton community. However, this effect is manifested by the positive correlations of four members of the zooplankton community: Eucalanus (0.429), polychaetes (0.300), bivalve larvae (0.277), and Oikopleura (0.230).

Water temperature: The temperature of the water through which the collecting net was towed also had a significant effect on the composition of the zooplankton. The categories with the largest correlations with the canonical variable all showed positive relationships with water temperature: Fritillaria (0.304), Lucifer (0.268) and Oithona (0.261).

Temperature range: The range of temperatures encountered by the net while sampling a specific portion of the water column is related to the zooplankton category standing crop with a significance of 0.0001. This term has its greatest effect on two categories: Corycaeus (0.345) and Oikopleura (0.317). Both categories display positive relationships with temperature range.

Salinity: This environmental variable, as expected, is significant at the 0.0001 level and shows the strongest correlations between the canonical variable and the dependent variables. Seven categories have correlations whose absolute magnitude is greater than 0.20: other protozoans (0.351), cladocerans (0.322), Tunicata (0.302), Corycaeus (0.266), Oithona (0.251), Lucifer (0.215), and Eucalanus (0.209).

Salinity range: The range of salinities encountered during a net tow, while considered significant, seems to be related primarily to two

Zoop ankton categories: Cladocera (0.247) and other crustaceans (-0.198)

Net depth: The level in the water column in which the sample collection takes place is significant (0.0001) and relates to several of the zooplankton categories in a positive manner: Oithona (0.40), Fritillaria (0.261), Lucifer (0.259), siphonophores (0.212), and Eucalanus (0.200).

Net depth range: The range of depths included in an oblique samplin tow is not considered significant because the significance level reported for the test is 0.0056.

Canonical Correlation. (appendix 5)

The test for statistical significance of remaining canonical correlations showed that there are nine linear relationships between the two sets of variables that we will consider significant. These nine relationships "explain" 52.8% of the observed variation in the zooplankton variable set and 68.4% of the environmental variables data set. In addition, these canonical variates explain 45.5% of the variation in the particulate trace metals variable group. The amount of redundancy between the variable sets is as follows: the amount of variation in the zooplankton variable set explained by variation in the environmental vari set is 46.72%; out of that amount the trace metals themselves account for 3.97% of the zooplankton variation.

Canonical variate pair I: The first variate of this pair explains 10.56% of the zooplankton community variation and has a redundancy with the environmental variables of 10.15%. All but eight of the zooplankton categories have a correlation with an absolute magnitude of greater than 0.20. Only two of the categories display negative correlations of any magnitude: Centropages (-0.329) and ostracods (-0.295). There are nine positively weighted zooplankton categories that have correlations with magnitudes of 1.5 to 2 times the correlations of the remaining categories: Oncaea (0.709), other protozoa (0.629), tunicata (0.553), Corycaeus (0.478), siphonophores (0.462), Eucalanus (0.421), Oikopleura (0.416), Oithona (0.409).

The second member of the pair contains 15.23% of the entire environmental variables set's variance, and explains 2.34% of the variance in particulate trace metal. There are four environmental variables with positive correlations: station depth (0.721), range of net depth (0.759), range of salinity (0.521), and net depth (0.304). Only one variable displays a negative correlation, POC (-0.644). The majority of the variables weighted in this canonical variate are related to the depth of the station. The technique of sample collection, which was to divide the water column into thirds, established strong positive correlations among station depth, net depth range, median net depth, and salinity range (as a result of the net depth range).

Canonical variate pair II: The first variate of this pair accounts for 7.60% of the zooplankton variation and has a redundancy of 7.15% with the environmental variables. This variate displays more of a contrast between the various members of the zooplankton community. The categories with strong positive weighings include: Oithona (0.651), ostracods (0.526), other crustaceans (0.484), shrimp larvae (0.402), Centropages (0.334), and chaetognaths (0.332). The negatively weighted zooplankters included gastropod veligers (-0.445), Cladocera (-0.401), bivalve veligers (-0.356), Undinula (-0.323) and Oikopleura (-0.303).

The second member of this variate pair contains 9.24% of the total environmental variation and 3.56% of the trace metal variation. This variate is primarily a contrast between temperature (-0.470), which is weighted negatively, and the positively correlated variables: net depth (0.542), temperature range (0.504) and salinity (0.495).

Canonical variate pair III: The first member of this variate pair accounts for 7.98% of the zooplankton variable set variation and has a redundancy coefficient of 7.44%. The weighings of the zooplankton variables for this canonical variate are primarily negative. The categories with the strongest negative weighings are: *Corycaeus* (-0.600), *Oithona* (-0.471), *Globigerina* (-0.446), bivalve veligers (-0.440), copepodites (-0.428), *Oikopleura* (-0.409), pteropods (-0.400), copepod nauplii (-0.371), *Oncaea* (-0.360), shrimp larvae (-0.357), other crustaceans (-0.345), crab larvae (-0.306).

The other variate contains 10.42% of the total variation in the environmental variable set and 2.66% of the variation of the trace metal variables. Like the previous environmental variable canonical variates, a contrast between certain of the original variables is apparent from the weighings derived from the correlation coefficients. The majority of the important correlations are negative as is seen by the listing which follows: temperature (-0.674), DOC (-0.318), net depth (-0.568), salinity (-0.413), POC (-0.372).

Canonical variate pair IV: The first variate accounts for 5.70% of the total zooplankton variance, with a redundancy of 5.25%. This variate is a contrast between the various members of the zooplankton community. The categories with positive weighings are: other protozoans

(0.453), Centropages (0.436), ostracods (0.338), other crustaceans (0.312), and Oncaea (0.305). Those categories with the greatest negative weightings include: siphonophores (-0.480), Lucifer (-0.373), Fritillaria (-0.362), and echinoderm (-0.357).

The second variate, which expresses 4.22% of the total environmental variation and 3.21% of the trace metal variation, is primarily concerned with temperature relationships. The two variables receiving the greatest weight in this linear combination are temperature range (0.414) and temperature (-0.429).

Canonical variate pair V: The first variate accounts for a relatively small portion of the total zooplankton variation, 2.47%, with a redundancy coefficient of 2.18%. Only three categories result in correlations with the canonical variate that are of significant magnitude to be considered important. Two of these categories have negative correlations, polychaetes (-0.389) and Eucalanus (-0.343); and one has a positive correlation, tunicates (0.395).

The second variate while expressing only 5.26% of the total environmental variation is the most important variate for expressing trace metal variation, 13.24%. The most important variables comprise a contrastof salinity range (0.324) with lead (-0.414), DOC (-0.348), cadmium (-0.324) and salinity (-0.305).

Canonical variate pair VI: The first canonical variate explains 4.70% of the total zooplankton variation, and has a redundancy of 4.06%. All of the important category loadings are positive: Centropages (0.466), cladocerans (0.462), fish eggs (0.421), chaetognaths (0.376) and other protozoans (0.313).

The second of the pair accounts for 6.82% of the total environmental variation and 5.54% of the trace metal variation. The trace metals contains 17.41% of the canonical variate's dispersion. This variate is a contrast of POC (0.406) and DOC (0.306) with iron (-0.360).

Canonical variate pair VII: This variate accounts for 4.43% of the zooplankton variation with a redundancy of 3.43%. Again, only a few categories display correlations of sizeable magnitude and they are all positive: Fritillaria (0.416, Eucalanus (0.413), ostracods (.407) and tunicates (0.3057).

The second is another of the canonical variates that show some important weighting for the particulate trace metals, 9.76%; however, this variate also expresses a reasonably high percent of the total environmental variation explained, 7.98%. This variate contains the fourth highest amount of total variation explained. Once more a contrast is formed, with sunlight (0,349) being contrasted with DOC (-0.532), iron (-0.532), and salinity range (-0.336].

Canonical variate pair VIII: The first canonical variate accounts for 2.90% of the zooplankton category variation, with a redundancy coefficient of 2.25%. The major emphasis of this canonical variate is a contrast of fish larvae (0.391) and pteropods (0.320) versus Fritillaria (-0.320).

The second variate contains 4.14% of the total environmental variation and 2.35% of the trace metal variation. Two variables are weighted hgihly on this variate, salinity range (-0.386) and temperature range (0.370).

Canonical variate pair IX: The first variate accounts for 6.03% of the zooplankton variaton, with a redundancy of 4.55%. All of the most important correlations to this variate are negative: shrimp larvae (-0.443), chaetognaths (-0.44?), gastropod veligers (-0.333), other crustaceans (-0.332), Eucalanus (-0.327), ostracods (-0.3"14), fish eggs (-0.314) and pteropods (-0.313).

The second variate of this pair expresses 5.06% of the total environmental variation and 2.85% of the trace metal variation. This variate is a contrast of sunlight (0.369) with temperature range (-0.378) and salinity (-0.378).

The remaining canonical correlations were not significant and thus dropped from the model. The order of canonical variates with respect to the amount of zooplankton variable set variance explained is as follows: CV-I, CV-III, CV-II, CV-IX, CV-IV, CV-VI, CV-II, CV-III, CV-V. It is readily apparent that the amount of zooplankton variance explained by a particular canonical variate pair does not decrease in the direct order of the extraction of canonical variates from the variation of the total variable set.

The order of importance for the canonical variates with respect to the amount of the environmental variation is as follows: CV-I, CV-III, CV-II, CV-VII, CV-VI, CV-V, CV-IX, CV-IV. On the other hand, the order of importance with respect to particulate trace metal explained as follows: CV-V, CV-VII, CV-VI, CV-II, CV-IV, CV-IX, CV-III, CV-VIII, CV-I. It is possible to determine the percent contribution trace metals make toward the variation of each canonical variate. The canonical variates ' with a sizeable contribution from trace metals are: CV-V (53.94%), CV-VII

(26.21%), CV-VI (17.41%) and CV-IV (16.30%). The portion of the total environmental variance explained by the canonical variates that is the result of trace metal-explained variance is 9.76%.

Thus, it is apparent that trace metals, while significantly related, are not major aspects of the environmental variation which influences the zooplankton community.

Thus far we have seen that the zooplankton categories often form into groups that behave similarly, i.e., display similar correlations, with respect to the canonical variates.

The next step in interpreting the results of a canonical correlation analysis involves the interrelations of the components which comprise the canonical variate pairs. For example, if a zooplankton category has a large positive correlation with CV-I and an environmental variable has a large negative correlation on CV-I, the interpretation would be that the two variables are inversely related. These aspects will be dealt with in the discussion section.

Factor Analysis of Suspended Trace Metals and Related Environmental Variables - Lease Tracts I-III._(appendix

The results of the zooplankton standing crop versus environmental variables analysis posed certain questions about the environmental variation that a factor analysis approach would best answer. One of the primary questions concerns the possibility that the factors of the environment which best correlate with the fluctuations in the zooplankton community may not align themselves very well with the major factors of the environment itself.

The factor analysis extracted two factors that accounted for 62.81% of the total environmental variation. This correlates very well with the 68.4% of the environmental variation accounted for by the canonical correlation analysis. These two factors, which are almost identical in proportion of the variance explained after varimax rotation, load the highest on depth, temperature and salinity variables.

Factor I: This factor explains 34.53% of the total environmental variation. The variables that load the highest on this factor are: net depth (0.887), salinity (0.878), cadmium (0.676) and temperature range (0.632 as contrasted with temperature (-0.809) and salinity range (-0.554). This axis of the environmental variation is primarily contrasting the mid and bottom sample waters with higher salinities, greater depth and lower temperatures which are presumably of central gulf origin, with the surface sample waters that are warmer, and less saline, suggesting inshore continental shelf origin. It is interesting to note that the levels of particulate cadmium are associated with the more saline, deeper waters.

Factor II: This factor explains 28.28% of the total environmental variation. The variables that load the highest on this factor are station depth (0.928), net range (0.908), iron (0.590) and salinity range (0.596). This environmental axis Is expressing the station to station differences that are related to the station location and hence its depth.

Zooplankton Trace Metal Analyses-Lease Tracts 1.111

The field procedure during the BLM-MAFLA baseline study resulted in samples of zooplankton for which trace metal concentrations were determined but no identification of the numbers/category was made. Samples were also generated in which numbers/category were determined but no trace metal determinations were performed. The unifying factor between these two sets of samples is that they were collected at the same time and place, presumably from the same water mass. Naturally, all of this is subject to the limitations that real time and field conditions place on the simultaneity of sample collection. The purpose of the following sets of analyses is two-fold: 1) to investigate the possibility of relating numerical abundance of particular zooplankton categories in the one set of samples to concentration levels of trace metals in the other set of samples, and 2) if significant results may be obtained, to interpret the relationships. Multivariate regression and canonical correlation were used to achieve these goals.

Multivariate Regression. (appendix 7)

The trace metal elements measured in the zooplankton samples were: iron, chromium, nickel, copper, vanadium, cadmium, and lead. The zooplankton categories employed were those listed earlier for areas I, II, III.

Centropages: The significance level of the test for the relationship between Centropages and the vector of zooplankton trace metals is 0.002. By our decision criterion this is not significant. However, it is close to our previously chosen critical value and will be discussed further.

Centropages displays the greatest positive correlations with iron and copper.

Undinula: Not significant (0.2430).

Other calanoids: Not significant (0.7745).

Corycaeus: Not significant (0.0639).

Oithona: This is a situation similar to that experienced for Centropages, in which the decision criterion is quite close to that preselected for rejection of the null hypothesis (0.0019). The following zooplankton trace metals showed large correlations with the canonical variate: iron (-0.478), lead (0.345) and chromium (0.291). Thus, it is a contrast of iron versus chromium and lead,

Oncaea: This term is significantly related to the concentration of trace metals in the samples (0.0002). The level of nickel in the sample is positively related to the number of Oncaea in the sample (0.569), as are cadmium (0.318) and chromium to a lesser extent.

Other cyclopoids: Not significant (0.526).

Harpacticoid copepods: Not significant (0.696).

Copepidites: Not significant (0.0833).

Copepod nauplii: Not significant (0.7205).

Cladocerans: Not significant (0.3113).

Ostracods: Not significant (0.3095).

Lucifer: This category is on the borderline of significance (0.0078). The strongest correlations are negative, suggesting that the level of certain trace metals in the zooplankton sample is inversely related to the number of Lucifer in the plankton sample. Nickel (-0.354) and lead (-0.312) show the greatest negative correlations.

Shrimp larvae: Not significant (0.1363).

Crab larvae: Not significant (0.1043).

Other crustaceans: Not significant (0.0303).

Globigerina: Not significant (0.9076).

Other protozoa: Not significant (0.2658).

Medusae: Not significant (0.2776).

Siphonophores: Not significant (0.0165).

Polychaetes: Not significant (0.0384).

Bivalve veligers: Not significant (0.3314).

Gastropod veligers: Not significant (0.7765).

Pteropods: Nonsignificant (0.5465).

Echinoderm larvae: Not significant (0.4037).

Chaetognaths: The chaetognaths are also on the margin of significance (O. 0024). They show the strongest negative correlations with nickel (-0.399) and chromium (-0.239) and a positive correlation with vanadium (0.250).

Oikopleura: Not significant (0.4300).

Fritillaria: Not significant (0.0367).

Tunicates: Not significant (0.6013).

Fish eggs: Nonsignificant (0.8721).

Fish larvae: Not significant (0.2333).

Miscellaneous plankton categories: Not significant (0.5033).

These results indicate that only a few of the zooplankton categories can be considered to have a significant effect when considered as a single independent variable, given that the other variables are already included in the model. This is similar to the partial sums of squares testing approach in multiple regression. It is often possible to obtain a significance for an entire regression without any of the partial sums of squares being significant. In cases such as these the canonical correlation approach is often more informative.

Canonical Correlation. (appendix 8)

The canonical correaltion analysis extracted four significant canonical correlations.

Zooplankton trace metals: The four significant canonical variates of the zooplankton trace metals accounted for 54.09% of the total variation with a redundancy of 46.24%. Thus, 46.24% of the total variation in zooplankton trace metal concentration is accounted for by the variation of the four linear combinations of the zooplankton categories.

Zooplankton categories: The canonical variates accounted for 25.33% of the total zooplankton category variance. This suggests that the canonical correlations are more important in explaining the fluctuation of trace metals as a function of zooplankton standing crop than vice versa.

Canonical variate pair I: This variate contains 22.82% of the trace metal variation with a redundancy of 20.60%. This variate displays all negative correlations, with nickel (-0.623), cadmium (-0.564), iron (-0.533), chromium (-0.522) and copper (-0.458) getting the most emphasis.

The second variate of this pair contains 7.36% of the total zooplankton variation. It is a contrast of the positively weighted categories of ostracods (0.716), *Centropages* (0.680), siphonophores (0.594) and other crustaceans (0.379) against negatively weighted categories such as *Oikopleura* (-0.382), other cyclopoids (-0.372) and harpacticoid copepods (-0.350).

Canonical variate pair II: This variate contained 11.64% of the total zooplankton trace metal variation with a redundancy of 10.51%. The weightings of the original variables produce a contrast of iron (0.520) with lead (-0.402).

The second variate of the pair contains 5.52% of the original zooplankton variation. It is most influenced by bivalve veligers (-0.616) and to a lesser extent by *Corycaeus* (-0.372), *Eucalanus* (-0.371) and echinoderm larvae (-0.350).

Canonical variate pair III: This variate, which contains 8.31% of the original zooplankton trace metal variation with a redundancy of 7.09%, is a contrast primarily of cadmium (-0.477) with iron (0.346).

The second variate of the pair contains 8.54% of the total zooplankton variation. This is a positive-weighted variate with six zooplankton categories having the largest correlations: *Oithona* (0.768), *Oncaea* (0.561), *Eucalanus* (0.503), *Fritillaria* (0.427), copepod nauplii (0.457), and siphonophores (0.388).

Canonical variate pair IV: The first variate contains 11.34% of the original zooplankton trace metal variation with a redundancy of 8.03%. Another exclusively negative relationship, the trace metals given the greatest weight are: cadmium (-0.510), copper (-0.415) and vanadium (-0.413).

The second variate of the pair contains 3.91% of the total zooplankton variation. Most of the large correlations are negative: polychaetes (-0.389), *Oikopleura* (-0.386), bivalve veligers (-0.328), crab larvae (-0.326). However, *Lucifer* (0.348) shows a positive correlation with this canonical correlation.

The order of importance of the canonical variates with respect to the amount of zooplankton trace metal variance they contain is as follows: CV-I, CV-II, CV-IV, CV-III.

The order of importance of the canonical variates with respect to zooplankton variance explained is: CV-I, CV-III, CV-II, CV-IV. The combination of loadings for the two sets of canonical variates gives us a basis for interpreting the analysis as to the. effect of the presence of a particular zooplankter on the expected trace metal level. This interpretation will be deferred until the discussion.

Zooplankton Trace Metal Residuals Analysis-Lease Tracts I-III

The results of the zooplankton trace metal concentration analysis demonstrated that the concentrations of the various trace metal elements in a sample of zooplankton is definitely affected by the composition of the sample with respect to zooplankton type. This fact makes it difficult to determine the relationship between zooplankton trace metal levels and the levels of trace metals suspended in the water column. To investigate this relationship, we performed a canonical correlation of the zooplankton trace metal residuals with the suspended trace metal environmental variable set, The zooplankton trace metal residuals represent the level of trace metal predicted for a zooplankton sample, once the effect of the zooplankton composition of the sample is removed. Thus, if there is a predictable relation between the levels of trace metal in the zooplankton and the levels of trace metal in the environment, this analysis technique should uncover it.

Canonical Correlation. (appendix 11)

The canonical correlation showed four significant correlations for linear combinations between the two variable sets.

Zooplankton trace metal residuals: The four significant canonical variates for this variable set accounted for 66.33% of the residual trace metal variation with a redundancy of 50.08%. A significant portion of the residual variation, 50.08%, is related to variation in the environment.

Suspended trace metals and associated environmental variables: The canonical variates accounted for 33.96% of the environmental variation. However, the suspended trace metals, containing 68.62% of the total canonical variate information had the greatest influence on the canonical variate scores.

The canonical variates found to be significant contained 70.57% of the suspended trace metal variance.

Canonical variate pair I: The first variate of this pair contains 35.6% of the total residual variation and a redundancy of 29.20%. Three trace metal variables are given the strongest weighting in this variate: copper (0.821), lead (0,718) and cadmium (0.714).

The second variate of this pair contains 17.92% of the total environmental variation. The amount of suspended trace metal variance contained is 28.89%. The variation of suspended trace metal accounts for 48.36% of the canonical variate dispersion. Lead, receiving the strongest weighting (-0.671), shows a negative relationship with the canonical variate. The remaining variables which display strong correlations are all positive: cadmium (0.534), net range (0.522), station depth (0.501) and temperature range (0.446).

Canonical variate pair II: The first variate of this pair contains 17.30% of the trace metal residual variation, with a redundancy of 13.34%. Three zooplankton trace metal residual variables are considered the most important: nickel (0.668), chromium (0.646) and lead (0.532).

The second of this pair contains 6.75% of the total environmental variation. This variate contains 21.04% of the suspended trace metal variation. This variation comprises 93.53% of the canonical variate's dispersion. The canonical variate is influenced almost exclusively by the suspended trace metals iron (0.615) and cadmium (0.502).

Canonical variate pair III: The first of this pair contains 6.98%

of the trace metal residual variation, with a redundancy of 4.21%. Three variables display the greatest influence on this variate: nickel (0.394), chromium (0.385) and cadmium (0,328).

The second of this pair contains 4.41% of the total environmental variation. This variate contains 8.62% of the total suspended trace metal variation, which comprises 58.67% of the third canonical variate's dispersion. It is influenced primarily by three trace metals, lead (0.322), cadmium (0.283) and iron (0.273), and to a lesser extent by temperature range (0.239) .

Canonical variate pair IV: The first of this pair contains 6.47% of the zooplankton trace metal residual variation, with a redundancy of 3.33%. A single element, vanadium (0.671), is weighted strongly.

The second of this pair contains the following percentages: 4.88% of the total environmental variation, 12.02% of the suspended trace metal variation. Trace metals account for 73.90% of the canonical variate dispersion. This variate is a contrast of iron (0.503) and salinity range (0.328) with cadmium (-0.328).

The order of importance for the canonical variates with respect to the amount of residual zooplankton trace metal variance explained is the same as the order of their extraction. The canonical variates for the suspended trace metal variable set is essentially the same as that of the residual variable set with the exception of variates III and IV.

Lease Tracts IV, V Trace Metal Analyses

Suspended Trace Metals and Associated Environmental Variables

As a result of missing values of certain variables the zooplankton samples in lease tracts IV and V, the following variables were included in the environmental variable set: lead, chromium, cadmium, iron, station depth, sample water temperature, sample temperature range, salinity, salinity range, net depth, and net depth range. Since all the samples were collected under approximately the same time of day, the qualitative variable, sunlight, was not included. The results of the multivariate multiple regression will be presented first; these will be followed by the canonical correlation results.

Multivariate Regression. (appendix 18)

Lead: The significance level of the statistical test for the effect of particulate lead on the standing crop of the zooplankton categories was 0.0101. According to our rule of acceptance, the variation of particulate lead has a non-significant effect on the variation of the zooplankton community, within the samples observed.

Chromium: The significance level of the test for chromium is 0.0551. This is accordingly considered to be non-significant.

Cadmium: The significance level for iron is CJ.0107, which is determined to be non-significant.

Iron: The significance level for iron is 0.0055, which is on the borderline for significance. Therefore, the trend is worth examination. The relationship is primarily a positive one, with cladocerans (0.453), Eucalanus (0.314) and Centropages (0.239) showing the highest correlations with the canonical function.

Station depth: This term is considered to contribute no significant effect to the proposed data analytical model (significance = 0.024).

Temperature: The effect of temperature on the standing crop of zooplankton categories as determined from the samples available from lease tracts IV and V is non-significant (0.0183).

Temperature range: This environmental variable is also non-significant (0.0483).

Salinity: This variable is non-significant in the data analytical model proposed with the data available (0.0167).

Salinity range: The range of salinity encountered while making a net tow is non-significant (0.0159).

Net depth: This term is non-significant (0.01082).

Net range: This term is non-significant (0.0219).

Canonical correlation: The canonical correlation analysis showed that there were seven significant linear correlations. The results of the multivariate multiple linear regression indicated that there were no single variables that could be considered to have a significant contribution to the zooplankton community variation when analyzed from the partial sum of squares approach. The canonical correlation tells that there are seven linear combinations of the environmental variable set that possess statistically significant relationships with linear combinations of the zooplankton variable set. This situation is similar to the familiar case in univariate multiple regression of the multiple correlation coefficient being significant but none of the partial sum of squares are significant. (appendix 19)

Zooplankton variable set: The seven canonical axes taken as an aggregate contain 48.76% of the zooplankton category variation, with a redundancy of 45.11%.

Environmental variable set: The significant canonical variates contain 72.22% of the total variation observed in the environmental variables, and 50.00% of the observed trace metal variation. The trace metal component of the environmental variables (lead, chromium, cadmium and iron) comprised 32.70% of the canonical variates, and accounted for 12.81% of the zooplankton variation. Thus it is apparent, and was suggested by the results of the multivariate linear regression, that the trace metal composition of the water column in the vicinity of areas IV and V is strongly related with the composition of the zooplankton community. In addition this relationship is much stronger than that observed in the vicinity of lease tracts I, II, III.

Canonical variate pair I: The first variate contains 13.86% of the zooplankton variation with a redundancy of 13.61%. The weighting of the original variables is primarily positive, only *Oithona* has a large negative correlation (-0.503) with the canonical variate. The most important positive correlations are: *Acartia* (0.880), Centropages (0.699), *Eucalanus* (0.644), chaetognaths (0.600) and *Corycaeus* (0.576).

The second variate contains 25.99% of the total variation observed in the environmental variable set. It also contains 5.16% of the trace metal variate. As was seen in lease tracts I, II, III, the first and most important variate is strongly associated with the depth and geographic location of the sampling location. The negatively correlated effects are given the greatest weight for interpretation of the canonical variate:

salinity (-0.923), net depth (-0.551), station depth (-0.551] and net range (0.551). The only variables given a positive weight are temperature (0.626) and salinity range (0.800).

Canonical variate pair II: The first of the pair contains 7.13% of the original zooplankton variation in this variable set and has a redundancy of 6.94% with the environmental variable set. The second canonical variate is a contrast of gastropod veligers (-0.539), cladocerans (-0.486), pelecypod larvae (-0.428) and hydromedusae (-0.409) with *Oncaea* (0.586), *Oithona* (0.435), *Euterpina* (0.410), and *Euchaeta* (0.378).

The second of the pair contains 12.78% of the total environmental variation, with 10.11% of the trace metal variation, which comprises 28.77% of the canonical variate. This variate is a contrast of net depth (0.499) with temperature (-0.617), lead (-0.571), and salinity range (-0.457).

Canonical variate pair III: The first canonical variate contains 7.18% of the original variation with a redundancy coefficient of 6.79%. Most of the correlations that may be considered as indicators of an original variable that is important to the variation of the canonical variate are positive: cladocerans (0.605), *Corycaeus* (0.571), *Centropages* (0.460), *Oithona* (0.379), copepod nauplii (0.367), *Paracalanus* (0.335), pelecypod larvae (0.329) and chaetognaths (0.287). There are four important negative correlations: *Euchaeta* (-0.403), other crustaceans (-0.355), other cyclopoids (-0.320), *Calanus* (-0.287).

The second of the pair contains 5.16% of the total variation, and 2.30% of the trace metal variation, which comprises 16.19% of the canonical variate. Two variables have a relatively hgih loading for this variate: net range (-0.433) and depth (-0.431).

Canonical variate pair IV: This variate contains 4.72% of the zooplankton category variation, with a redundancy of 4.26%. The categories that are most important to the variation of the canonical variate all have negative correlations with the canonical variate. The seven that display the largest correlations are: Ceratium (-0.543), Pyrocystis (-0.531), foraminifera (-0.362), siphonophores (-0.352), Oncaea (-0.338), Euchaeta (-0.332) and salps (-0.309).

The second variate of the canonical variate pair contains 6.10% of the total environmental variation and 7.87% of the trace metal variation, which comprises 46.87% of the canonical variate. A contrast between chromium (0.488) and temperature range (-0.466) is the dominant relationship expressed within this variate.

Canonical variate pair V: The first variate contains 9.36% of the zooplankton variation with a redundancy of 8.13%. Four of the categories show the highest weighings for this canonical variate, all with positive correlations. These categories include: Eucalanus (0.589), other crustaceans (0.553), fish eggs (0.494) and siphonophores (0.432).

The second variate contains 7.14% of the total environmental variation and 12.27% of the trace metal variation. Trace metals explain 62.49% of the canonical variate's dispersion. This variate is a contrast of depth (0.312) and temperature range (0.335) with lead (-0.492) and iron (-0.339).

Canonical variate pair VI: The first variate contains 2.02% of the zooplankton variation, the least of any of the statistically significant canonical variates, with a redundancy of 1.78%. Only one category shows a correlation of greater than 0.250; hydromedusae (0.347).

The second variate of the pair contains 8.31% of the total variation and 6.67% of the trace metal variation, which explains 29.19% of the canonical variate's variation. This variate is made up primarily of the influences from three variables, all of which have positive correlations: temperature range (0.549), net range (0.454) and lead (0.492).

Canonical variate pair VII: The first variate explains 4.49% of the zooplankton variation, with a redundancy of 3.68%. The most important variables, as judged by the absolute magnitude of the correlations, all display negative correlations: Appendicularia (-0.422), Euchaeta (-0.336) and hydromedusae (-0.322).

The second variate contains 6.74% of the total variation arid 5.69% of the total trace metal variation. Trace metal variation accounts for 30.71% of the canonical variate's dispersion. This variate is a contrast of cadmium (0.336) and iron (0.330) with station depth (-0.476) and net range (-0.439).

The remaining canonical correlations are not significant and are dropped from the analysis model. The order of importance of the canonical variates with respect to the amount of zooplankton variation explained are as follows: CV-I, CV-V, CV-II, CV-III, CV-IV, CV-VII, CV-VI.

The order of canonical variates with respect to the amount of environmental variable variation they explain is: CV-I, CV-II, CV-VI, CV-V, CV-VII, CV-IV and CV-III.

Factor Analysis of Suspended Trace Metals and Related Environmental Variables - Lease Tracts IV - V. (appendix 26)

The factor analysis on the suspended trace metals and environmental variables from lease tracts IV and V gave substantially different results than those from lease tracts I, II, and III. Four factors accounting for 89.53%, which is greater than the 72.22% explained by the canonical correlation, of the environmental variation were extracted from the environmental variable correlation matrix. Following varimax rotation the factors explain 30.75%, 19.40% and 19.60% of the original environmental variance, respectively. The factors may be classified into two general types: factors I and III, which are related to station location and water mass characteristics, and factors II and IV, those that are related primarily to trace metal variation in the environment.

Factor I: This factor explains 30.75% of the total environmental variation. The variables that load highest on this factor present a contrast of temperature (0.978), and salinity range (0.862), versus salinity (-0.887) and net depth (-0.801). This environmental axis is similar to the first factor displayed for the environmental variables from lease tracts I, II, and III. The similarity is present both in proportion of variance contained and in structure as indicated by the original variable loadings.

Factor II: This factor contains 19.40% of the total environmental variation. Two trace metals, cadmium (0.978) and iron (0.956), load highly on this factor.

Factor III: This factor contains 19.78% of the total environmental variation. Station depth (0.925) and net depth range (0.972) received the highest loadings. This factor correlates well with the second factor of the lease tracts I, II, and III environmental variable factor analysis.

Factor IV: This factor contains 19.60% of the environmental variation. It is a contrast of salinity (0.727) with chromium (-0.894) and lead (-0.746). This woul d suggest that the highest 1 evels of chromium and lead particulate in the environment are associated with less saline water.

The water column environment of lease tracts IV and V shows the same structural variation as lease tracts I, II and III with the addition of two trace metal axes.

Zooplankton Trace Metal Analysis-Lease Tracts IV-V

Mutlivariate Regression. (appendix 21)

The trace metal elements determined on the zooplankton samples were: iron, chromium, nickel, copper, vanadium, cadmium, lead. The zooplankton categories employed were those listed earlier for areas IV, V.

Acartia: Nonsignificant (0.0271).

Calanus: Nonsignificant (0.2848).

Centropages: Nonsignificant (0.0696).

Corycaeus: Nonsignificant (0.3344).

Eucalanus: The standing crop of this copepod shows a significant relationship with the levels of trace metals found in a sample of the zooplankton community (significance = 0.0004). The trace metals receiving the highest weightings are copper (0.481), lead (0.327), and nickel (0.293).

Euchaeta: Nonsignificant (0,1603).

Euterpina: This copepod is significant at the 0.0003 level. It is associated with cadmium (0.333), copper (0.279) and iron (0.263).

Oithona: This copepod is on the borderline of being significant (0.0070) and will therefore be presented. It shows a strong negative relationship with vanadium (-0.830), and more moderate negative relationships with iron (-0.464), chromium (-0.433) and nickel (-0.375).

Oncaea: This copepod, like Oithona, is a borderline situation (significance = 0.004) and will be presented. Oncaea shows weak correlations with all the trace metals, except chromium which is essentially zero. The negative correlations include: cadmium (-0.186), iron (-0.177) and nickel (-0.174), whereas the positive correlations include: vanadium (0.198) and copper (0.162).

Paracalanus: Nonsignificant (0.5316).

Temora: Nonsignificant (0.1107).

Undinula: Nonsignificant (0.0949).

Other calanoids: Nonsignificant (0.5011).

Cyclopoid copepods: Nonsignificant (0.1178).

Harpacticoid copepods: Nonsignificant (0.2756).

Copepod nauplii: Nonsignificant (0.1849).

Cladocerans: This term is significant at the 0.0003 level, Cladocerans have a positive effect on cadmium (0.336) and a negative effect on nickel (-0.327), with lesser negative effects on copper (-0.224), chromium (-0.192) and iron (-0.184).

Appendicularians: Nonsignificant (0.5492).

Salps: Nonsignificant (0.0575).

Gastropod veligers: Nonsignificant (0.0258).

Chaetognaths: Nonsignificant (0.3717).

Pelecypod larvae: Nonsignificant (.6025).

Hydromedusae: Nonsignificant (0.0539).

Siphonophores: Nonsignificant (0.0784).

Fish eggs: Nonsignificant (0.5512).

Foraminifera: Nonsignificant (0.5512).

Pyrocystis: Nonsignificant (0.8660).

Ceratium: Nonsignificant (0.4188).

Other crustaceans: Nonsignificant (0.0156).

Decapod larvae: Nonsignificant (0.0103).

Polychaetes: Nonsignificant (0.1040).

Fish larvae: Nonsignificant (0.3981).

Canonical Correlation. (appendix 22)

The canonical correlation extracted five significant linear relations between the two sets of variables.

Zooplankton trace metals: The five significant canonical variates accounted for 62.55% of the trace metal variation with a redundancy of 53.94%. Therefore, almost 54% of the observed variation in zooplankton trace metal concentrations is explainable by-variations in the zooplankton category standing crop.

Zooplankton categories: The canonical variates accounted for 29.32% of the total zooplankton category variance. The canonical variates most important to the variation of the trace metal variables, CV-II and CV-I, are also the most important to the variation of zooplankton category variables. This suggests that the relationship of zooplankton category variation as a predictor of trace metal content is a strong one.

Canonical variate pair I: The first variate contains 17.00% of the total zooplankton trace metal variation with a redundancy of 15.54%. All of the trace metal variables have negative correlations with this variate. However, two trace metals, vanadium (-0.643) and lead (-0.551), have correlations that are much greater in absolute magnitude than any of the others.

The second variate of the pair contains 7.62% of the total zooplankton category variation. It is influenced in a positive manner primarily by Acartia (0.619), Euterpina (0.580), Centropages (0.444) and chaetognaths (0.425). The strongest negative correlations are with Oithona (-0.462), Oncaea (-0.377), Pyrocystis (-0.366) and other calanoids (-0.337).

Canonical variate pair II: The first variate contains 23.25% of the total trace metal variation with a redundancy of 20.60%. It has all positive correlations with the trace metal variables. The variables with the largest correlations are: nickel (0.714), iron (0.689), chromium (0.552) and vanadium (0.516).

The second variate contains 8.93% of the zooplankton category variation. It is primarily a negative correlation-influenced variate with a few of the zooplankton categories displaying sizeable positive correlations: cladocerans (-0.629), gastropod veligers (-0.605), pelecypod larvae (-0. 582), Acartia (-0.434), decapod larvae (-0.414), Corycaeus (-0.383), chaetognaths (-0.359), Oithona (0.461), Oncaea (0.394), and Echuaeta (0.350}.

Canonical variate pair III: The first variate "contains 9.89% of the total trace metal variation with a redundancy of 8.62%. The weighings implied by the correlation coefficients reveal this variate to be a contrastof copper (-0.591) with cadmium (0.425).

The second variate contains 7.72% of the zooplankton category variation. It is influenced primarily by positive correlations with two of the categories possessing strong negative correlations: Corycaeus (0.593), Centropages (0.585), Paracalanus (0.432), cladocerans (0.390), Eucalanus (O. 376), Euterpina (O. 365), other cyclopoid copepods (-O. 382) and other crustaceans (-0.340).

Canonical variate pair IV: The first variate contains 3.60% of the total variation with a redundancy of 3.07%. A single variable, copper (0.418), receives the mephasis of this canonical variate.

The second variate of the pair contains 2.99% of the total zooplankton category variation. The weighings given to the zooplankton categories by their correlations with the canonical variate reveal this variate is a contrast of Eucalanus (-0.307) with foraminifera (0. 356) and other cyclopoid copepods (0. 325).

Canonical variate V: The first variate contains 8.81% of the total zooplankton variation with a redundancy of 6.11%. Two variables, both positively weighted, are emphasized by this linear combinations: copper (0.486) and lead (0.477).

The second variate contains 2.05% of the total zooplankton variation. This canonical variate has three strong negative correlation and one positive correlation: Hydromedusae (-0. 321), gastropod veligers (-0.285), other cyclopoid copepods (-0.271) and siphonophores (0.274).

The order of importance of the canonical variates with respect to the amount of zooplankton variation accounted for is as follows: CV-II, CV-I, CV-III, CV-V, CV-IV. This corresponds well with the order observed in the trace metal variable set: CV-II, CV-III, CV-I, CV-IV, CV-V.

Zooplankton Trace Metal Residuals Analysis-Lease Tracts IV-V

Canonical Correlation. (appendix 25)

The canonical correlation showed three significant correlations for linear combinations between the two variable sets.

Zooplankton trace metal residuals: The three significant canonical variates accounted for 66.73% of the residual trace metal variation with a redundancy of 47.64%.

Suspended trace metals and related environmental variables: The canonical variates associated with this variable set accounted for 25.79% of the environments' variation. The trace metal variables accounted for 65.62% of the canonical variates' dispersion, and the canonical variates contained 45.59% of the suspended trace metal variation.

Canonical variate pair I: The first variate of this pair contains 35.76% of the zooplankton trace metal residual variance, with a redundancy of 28.00%. It is weighted heavily for all the trace metals, with the exception of lead: cadmium (0.679), vanadium (0.674), chromium (0.668), copper (0.662), iron (0.540) and nickel (0.515).

The second variate of this pair contains 2.14% of the environmental variation. Trace metal variation comprises 52.53% of the canonical variate dispersion, but the canonical variate only contains 2.81% of the suspended trace metal variation. The temperature range (-0.275) and cadmium (-0.240) are the major contributors to this variate, with iron (-0.189) and chromium (-O. 137) making contributions of somewhat lesser importance.

Canonical variate pair II: The first variate of this pair contains 13.31% of the zooplankton trace metal residual variance, with a redundancy of 8.92%. This variate is a contrast of lead (0.624) and copper (0.411) with cadmium (-0.455) and vanadium (-0.305).

The second variate of this pair contains 11.64% of the environmental variation. Trace metal variation comprises 57.61% of the canonical variate dispersion. The canonical variate contains 16.77% of the suspended trace metal variation. The environmental variables having the strongest correlations with the canonical variate indicate a contrast of temperature range (0.582) with chromium (-0.553) and lead (-0.494).

Canonical variate 111: The first variate of this pair contains 17.66% of the total zooplankton trace metal residual variation, with a redundancy of 10.72%. All of the variables with significantly large correlations show a negative relationship: vanadium (-0.560), iron (-0.543), chromium (-0.481) and nickel (-0.428).

The second variate of this pair contains 12.00% of the environmental variation and 26.01% of the suspended trace metal variation. The variation of the suspended trace metals accounts for 86.71% of the canonical variate dispersion. Two trace metals are given the greatest weight in this variate: iron (-0.718) and cadmium (-0.716).

The order of importance of the canonical variates with respect to zooplankton trace metal residual variance explained is: CV-I, CV-III, CV-II. The order of importance for environmental variables is: CV-III, CV-II, CV-I. The order of canonical variates with respect to the amount of suspended trace metal variance explained is: CV-III, CV-II, and CV-I.

Lease Tracts I, II, III Hydrocarbon Analyses

Dissolved High Molecular Weight Hydrocarbons.

In the analysis of the relationship of the zooplankton community and the hydrocarbon environment associated with it, insurmountable problems arose concerning the data. The distribution of missing values, representing samples not analyzed, was of such a nature that the inversion of the necessary matrices could not be performed. This was true even if a pairwise deletion approach was employed in constructing the correlation matrices. Thus no multivariate analyses could be performed for this submodel of the data set.

Zooplankton Hydrocarbon Analyses-Lease Tracts I-III

We followed the same rationale for the analysis of zooplankton hydrocarbon variables as that employed in the zooplankton trace metal analyses. The following zooplankton hydrocarbon variables were entered into the multivariate analysis models: C_{17}/pristane, C_{18}/phytane, pristane/phytane, odd/even n-paraffins, n-paraffins/phytane, n-paraffin/C_{16}, total zooplankton aliphatics, and total zooplankton aromatics, The zooplankton categories employed were those listed earlier for lease tracts I-III.

Multivariate Regression (appendix 15)

Centropages: The significance level for Centropages is marginal (O. 0035). The examination of the correlation coefficients between the zooplankton hydrocarbons and the canonical variate show a contrast of C_{17}/pristane (0.493) and C_{18}/phytane (0.407) with odd/even n-paraffin (-0.601).

Eucalanus: Not significant (0.0403).

Undinala: Not significant (0.2307).

Other calanoid copepods: Not significant (0.6417).

Corycaeus: Not significant (0.8183).

Oithona: The correlation of Oithona standing crop to zooplankton hydrocarbon levels is significant (0.0001). The relationship displayed is primarily a negative one: total aromatics (-0.371), n-paraffin/phytane (-0.295), C_{18}/phytane (-0.254) and n-paraffin/C_{16} (-0.231). Only ratio of odd/even n-paraffins shows a positive correlation (0.387).

Oncaea: Not significant (0.0136).

Other cyclopoid copepods: Not significant (0.2958).

Harpacticoid copepods: Not significant (0.5529).

Copepedites: Nonsignificant (0.0237).

Copepod nauplii: Not significant (0.3843).

Cladocerans: Not significant (0.0127).

Ostracods: Not significant (0.0621).

Lucifer: Not significant (0.0991).

Shrimp larvae: Not significant (0.0759).

Crab larvae: Not significant (0.3231).

Other crustaceans: Not significant (0.7745).

Globigerina: Not significant (0.5346).

Other protozoans: This category is on the borderline (0. 0061) of significance. The correlations show a contrast of C_{17}/pristane (0.565) and C_{18}/phytane (0.462) with odd/even n-phytane (-353).

Medusae: Not significant (0.0811).

Siphonophores: This category si close to the cutoff point for significance (0.0045). A single positive relationship with n-paraffin/$6 (0.415) is indicated.

Polychaetes: This category is also on the borderline of significance (0.0012). The polychaetes show a positive relationship with total al iphatics (0.548) and aromatics (0.392).

Bivalve larvae: Not significant (0.8093).

Gastropod veligers: Not significant (0.0864).

Pteropods: This category is marginally significant (0.0068). The correlations indicate a single relationship with the ratio odd/even n-paraffins (0.506).

Echinoderm larvae: Not significant (0.0969).

Chaetognaths: This category shows a strongly significant (0.0001) relationship of chaetognaths with pristane/phytane (0.208), total aromatics (0.193) and C_{18}/phytane (0.165).

Oikopleura: The standing crop of these zooplankters also shows a significant effect on the zooplankton hydrocarbon variables (0.0001). The relationship displayed is primarily positive: C_{17}/pristane (0.337), pristane/phytane (0.245), n-paraffin/C_{16} (0.227) and odd/even n-paraffin (0.204).

Fritillaria: Not significant (0.0436].

Tunicates: Not significant (0.8955).

Fish eggs: Not significant (0,0665).

Fish larvae: Not significant (0.2539).

Miscellaneous categories: Not significant (0.1316).

Canonical Correlation-Lease Tracts I-III (appendix 16)

The canonical correlation of zooplankton hydrocarbon variables on the zooplankton category variables resulted in five significant correlations.

Zooplankton hydrocarbons: The five canonical variates of the zooplankton hydrocarbons accounted for 55.65% of their total variation with a redundancy of 49.61%. Thus, almost half of the observed variation in the zooplankton hydrocarbons is accounted for by variation in linear combinations of the zooplankton category variables.

Zooplankton categories: The canonical variates accounted for 29.07% of the total zooplankton category variation.

Canonical variate pair I: The hydrocarbon related variate contains 9.34% of the total variation with a redundancy of 8.99% with the zooplankton variable set. The most important weighings are negative: C_{17}/pristane (-0.503) and C_{18}/phytane (-0.551).

The second member of this variate pair contains 8.51% of the total zooplankton variation. The weighings are all positive, hence a negative relationship with those hydrocarbon variables emphasized by the first variate of the canonical variate pair: ostracods (0.579), Oithona (0.572), other protozoans (0.566), Eucalanus (0.557), Centropages (0.472), other crustaceans (0.437), Oncaea (0.395), copepod nauplii (0.378) and shrimp larvae (0.371).

Canonical variate pair II: The hydrocarbon variate contains 9.76% of the total variation, with a redundancy of 9.13%. The most important weighings are positive: odd/even n-paraffin (0.626) and total aromatics (0.421).

The zooplankton related variate contains 7.69% of the total variation. This variate is primarily a positive relationship with the zooplankton with one important negative correlation: Oncaea (0.556), Oikopleura (0.495), gastropod veligers (0.422), other protozoa (0.422), Corycaeus (0.391) and Centropages (-0.377).

Canonical variate pair III: The first, or hydrocarbon related, variate contains 20.17% of the hydrocarbon variables set variation, with a redundancy of 17.99%. This variate represents a contrast of C_{17}/pristane (0.585), n-paraffin/phytane (0.471), total aliphatics (0.437) and C_{18}/phytane (0.401) with odd/even n-paraffin (-0.582) and pristane/phytane (-0.468).

The second, or zooplankton related, variate contains 4.18% of the total zooplankton variation. This variate is primarily influenced by negative correlations, but is contrasted with two positive correlations: Oithona (0.322), siphonophores (0.278), Centropages (-0.457], chaetognaths (-0.373), Eucalanus (-0.323), Undinula (-0.317), bivalve larvae (-0.306) and cladocerans (-0.291).

Canonical variate pair IV: The first variate contains 6.85% of the hydrocarbon variable set variation, and a redundancy with the zooplankton variable set of 5.89%. This variate is a contrast of total aliphatics (0.41 9) and total aromatics (0.337) with C_{17}/pristane (-0.315) and C_{18}/phytane (-0.342).

The second variate of the pair contains 2.88%of the total zooplankton variation. Only the polychaetes (0.521) are weighted strongly by this variate. This is the least important of the canonical variates with respect to the amount of zooplankton variation explained.

Canonical variate pair V: The first variate contains 9.53% of the hydrocarbon variation, with a redundancy of 7.61%. Two of the zooplankton hydrocarbon variables are emphasized by this variate: C_{17}/pristane (-0.440) and n-paraffin/C_{16} (-0.436].

The zooplankton category related variate of this canonical variate pair contains 5.81% of the variation. This variate represents a contrast of one positively correlated variable with four negatively correlated variables: cladocera (0.499), shrimp larvae (-0.470), ostracods (-0.440), gastropod veligers (-0.378) and fish larvae (-0.352).

The order of importance of the canonical variates with respect to the amount of zooplankton hydrocarbon variation explained exhibits an interesting distribution. There is one variate that is obviously the most important, CV-III, while the remainder are relatively equal in importance: CV-II, CV-V, CV-I, CV-IV. The order of importance with respect to the zooplankton approximately follows the order of extraction: CV-I, CV-II, CV-V, CV-III, CV-IV.

Lease Tracts IV-V Hydrocarbon Analyses

Dissolved High Molecular Weight Hydrocarbons

The same problem encountered in the dissolved high molecular weight hydrocarbons of lease tracts I-III was also case for lease tracts IV-V.

Zooplankton Hydrocarbon Analyses-Lease Tracts IV-V

The same hydrocarbon variables were used in areas IV-V as were employed in areas 1-III. The zooplankton categories used in the analysis models were those listed earlier for lease tracts IV-V.

Multivariate Regression. (appendix 29)

Acartia: Not significant (0.0990).

Calanus: Although not significant (0.0093), the results of the statistical test are borderline. This copepod category indicates a negative realtionship with the ratio of pristane to phytane (-0.402).

Centropages: This category displays a significant relationship with the vector of zooplankton hydrocarbon variables (0.0001). The relationship indicated by the correlations of the original hydrocarbon variables with the canonical variate is a contrast of total aromatics (0.482) and total aliphatics (0.329) with odd/even n-paraffins (-0.322).

Corycaeus: Not significant (0.6384).

Eucalanus: Not significant (0.2946).

Euchaeta: Not significant (0.1884).

Euterpina: Not significant (0.0454).

Oithona: The relationship of Oithona standing crop to zooplankton hydrocarbon levels is significant (0.0004). The canonical variate emphasizes one variable, n-paraffin/C_{16} (0.589). This was one of the variables emphasized in areas 1-111. However, the sign of the relationship between Oithona and n-paraffin/C_{16} is reversed.

Oncaea: This term in the regression model is also significant (0.0005). The resulting canonical variate is primarily a contrast of total aromatics (0.410) with C_{18}/phytane (-0.586), Paracal anus: Not significant (0.5354).

Temora: Not significant (0.1579).

Undinula: Not significant (0.5328).

Other calanoid copepods: Not significant (0.6947).

Other cyclopoid copepods: Not significant (0.5580).

Other harpacticoid copepods: Not significant (0.2499).

Copepod nauplii: Not significant (0.3559).

Cladocerans: This zooplankton category is considered to be a borderline case (0.0029). The resulting canonical variate suggests a contrast of pristane/phytane (0.589), n-paraffin/phytane (0.370), odd/even n-paraffin (0.357) and n-paraffin/C_{16} (().333) with \$8/paraffin (-0.374).

Appendicularia: Not significant (0,0557).

Salps: This is another of the borderline cases (0.0068). The original variable correlations with the canonical variate formed by the multivariate regression model indicate that the standing crop of salps is positively related to the level of three of the zooplankton hydrocarbon variables: pristane/phytane (0.475), total aromatics (0.371) and total aliphatics (0.330).'

Gastropod veligers: Not significant (0.0798).

Chaetognaths: Not significant (0.2469).

Pelecypod larvae: Not significant (0.5120).

Hydromedusae: This term is significant at the 0.0001 level. The canonical variate emphasizes n-paraffin/\$6 (0.654).

Siphonophores: Not significant (0.0370).

Fish eggs: Not significant (0.7276).

Foraminifera: Not significant (0.6194).

<u>Pyrocystis:</u> Not significant (0.7631).

<u>Ceratium:</u> Not significant (0.3470).

<u>Other crustaceans:</u> Not significant (0.3185).

<u>Decapod larvae:</u> Not significant (0.0936).

<u>Polychaetes:</u> Not significant (0.0855).

<u>Fish larvae:</u> Not significant (0.9171).

Canonical Correlation-Lease Tracts IV-V (appendix 30)

The canonical correlation analysis extracted four significant canonical variate pairs.

Zooplankton hydrocarbons: The four significant canonical variates accounted for 56.56% of the total zooplankton hydrocarbon variation with a redundancy of 49.38%. Thus almost half of the observed dispersion in zooplankton hydrocarbon variables is related to variation of linear combinations of the zooplankton category variables.

Zooplankton categories: The canonical variates accounted for 26.65% of the total zooplankton category variation.

Canonical variate pair I: The first, or hydrocarbon related, member of the variate pair contains 12.11% of the total zooplankton hydrocarbon variation, and a redundancy with the zooplankton variable set of 11.32%. One variable, n-paraffin/C_{16} (0.675), has a correlation with the canonical variate that is at least twice that of any of the other hydrocarbon correlations,

The second, or zooplankton category related, member of the canonical variate pair contains 9.83% of the total zooplankton variation. This variate is a contrast of Acartia (0.693), Centropages (0.570), Eucalanus (0. 531), chaetognaths (0.511), gastropod vel igers (0.491), Corycaeus (0.442) and Appendicularia (0.365) with Oithona (-0.595) and Oncaea (-0.362).

Canonical variate pair II: The first of this variate pair contains 16.34% of the total zooplankton hydrocarbon variable set dispersion, with a redundancy of 14.91%. Two of the hydrocarbon variables receive the greatest weighting: pristane/phytane (0.806) and odd/even n-paraffin (0.588).

The second variate contains 7.87% of the zooplankton category variation.

The variables receiving the greatest weight are all positive: _Corycaeus_ (0.557), _Centropages_ (0.525), cladocerans (0.512), chaetognaths (0.494), _Paracalanus_ (0.443) and _Eucalanus_ (0.395).

Canonical variate pair III: The first of this variate pair contains 11.40% of the hydrocarbon variation with a redundancy of 9.77%. A single variable, C_{18}/phytane (-0.717), is emphasized by a large negative correlation.

The second variate contains 6.61% of the zooplankton variation. The variables receiving the greatest weight are again all positive: _Oncaea_ (0.528), salps (0.510), siphonophores (0.464) and _Oithona_ (0.429).

Canonical variate pair IV: The first variate contains 16.70% of the hydrocarbon variable set dispersion with a redundancy of 13.38%. This variate is a contrast of odd/even n-paraffin (0.535) and total aromatics (0,513) with n-paraffin/phytane (-0.660).

The second of this variate pair contains 2.34% of the total zooplankton variation. The variate is a contrast of pelecypod larvae (0.377) with hydromedusae (-0.412).

The order of the canonical variates in importance with respect to the amount of hydrocarbon variance explained is: CV-IV, CV-II, CV-I, CV-III. The importance with respect to zooplankton is in the same order as thier extraction, CV-I to CV-IV.

Canonical Correlation of the Entire Data Set.

The problems encountered in the canonical correlation of the dissolved hydrocarbon data were also present in this situation.

Factor Analysis of Zooplankton Category Error Matrices. (appendices 35-36)

The goal of an error matrix factor analysis is to identify inter-species associations of the zooplankton. These associations indicate assemblages of species who show similiar patterns of variation after the effects of the environment have been removed.

Lease Tracts I-III.

The factor analysis extracted eleven factors that accounted for 71.1% of the total zooplankton residual variation. Following a varimax rotation, the first factor contained 28% of the total zooplankton variation. The amount of original variation contained by the remaining factors shows a sharp decrease following the first factor. The second factor contains 6.6% of the variation, and the nine remaining factors display a gradual decrease until the eleventh factor contains 2.8% of the original zooplankton variation. As a result of this distribution of contained variance, only the first factor will be presented.

Factor I: This factor contains only positive loadings, with five of the zooplankton categories being the most heavily influenced: Centropages (0. 703), Chaetognaths (0.624), Eucalanus (0.595), Bivalve Veligers (0.576), and ostracods (0.514).

Lease Tracts I-IV.

The factor analysis extracted nine factors that accounted for 72.5% of the total residual zooplankton variation. Following a varimax rotation, the first factor contained 35% of the variation, with the next largest factor containing 8%. As in lease tracts I-III, there seems to be only one major species assemblage that is separable from the assemblages that are related to patterns of environmental variability.

Factor I: This factor contains only positive loadings of any magnitude, with seven zooplankton categories being the most heavily influenced: Centropages (0.709), Corycaeus (0.707), Eucalanus (0.670), Paracalanus (0.663), Acartia (0.566), Temora (0.552), Gastropod Veligers (0.516).

Original Variable Names and Their Alaises

As a result of the limitations of computer packages in the area of variable labelling, we often had to use either mnemonics or numerical alaises for the actual names of the variables employed. The original variable names and their alaises for lease tracts I-III are listed below:

Variable Name	Alaises	
Globigerina	GLOBIGER	VAR018
Other Protozoa	OTHERPRO	VAR019
Siphonophores	SIPHONO4	VAR021
Medusae	MEDUSAE	VAR020
Polychaetes	POLYKETE	VAR022
Gastropod Veligers	GASTROVE	VAR024
Pteropods	PTEROPOD	VAR025
Bivalve Larvae	BIVALVE	VAR023
Cladocera	CLADOC	VAR012
Ostracods	OSTRACOD	VAR013
Centropages furcatus	CENTROP	VAR001
Eucalanus sp.	EUCALAN	VAR002
Undinula vulgaris	UNDINULA	VAR003
Other Calanoids	OTHERCAL	VAR004
Harpacticoids	HARPAC	VAR009
Corycaeus sp	CORYCEUS	VAR005
Oithona sp	OITHONA	VAR006

Variable Name	Aliases	
Onacaea sp	ONCAEA	VAR007
Other Cyclopoids	OTHERCYC	VAR008
Copepodites	COPEDITE	VAR010
Copepod Nauplii	NAUPLII	VAR011
Lucifer sp.	LUCIFER	VAR014
Shrimp Larvae	SHRIMPLV	VAR015
Crab Larvae	CRAB	VAR016
Other Crustaceans	OTHRCRUST	VAR017
Echinoderm Larvae	ECHINO	VAR026
Chaetognaths	SAGPLUS	VAR027
Oikopleura	OIKOPLEU	VAR028
Fritillaria	FRIT	VAR029
Other Tunicates	TUNICATA	VAR030
Fish Eggs	FISHEGGS	VAR031
Fish Larvae	FISHLARV	VAR032
Other plankters	ASSORTED	VAR033

The original variables and their aliases for lease tracts IV_V are listed below:

Variable Name	Alaises	
Pyrocystis	PYROC	VAR027
Ceratium	CERATM	VAR028
Foraminifera	FORAMS	VAR026
Siphonophores	SIPHON	VAR024
Hydromedusae	HYDROM	VAR023
Polychaetes	POLLY	VAR031

Variable Name	Aliases	
Gastropod Larvae	GASTRO	VAR020
Bivalve Larvae	PELCYP	VAR022
Cladocerans	CLADOC	VAR017
Acartia sp.	ACARTIA	VAR001
Calanus sp.	CALANUS	VAR002
Centropages sp.	CENTROP	VAR003
Eucalanus sp.	EUCAL	VAR005
Euchaeta sp.	EUCHAET	VAR006
Paracalanus sp.	PARACAL	VAR010
Temora sp.	TEMORA	VAR011
Undinula sp.	UNDINULA	VAR012
Other Calanoids	CALNIDS	VAR013
Euterpina sp.	EUTERP	VAR007
Other Harpacticoids	HARPAC	VAR015
Corycaeus sp.	CORYC	VAR004
Oithona sp.	OITHONA	VAR008
Oncaea sp.	ONCAEA	VAR009
Other Cyclopoids	CYCLPD	VAR014
Copepod Nauplii	NAUPLII	VAR016
Decapod Larvae	DECAPD	VAR030
Other Crustaceans	CRUSTY	VAR029
Chaetognaths	CHAETO	VAR021
Larvaceans	APPENDC	VAR018
Salps	SALPS	VAR019
Fish Eggs	FSHEGG	VAR025
Fish Larvae	FSHLRV	VAR032

The original names of the environmental variables and their alaises are listed below:

Variable Name	Alaises
Hour of the day	HOUR
Sunlight	SUNLIGHT
Poc	Poc
DOC	DOC
ATP	ATP
Suspended Copper	COPPER
Suspended Lead	LEAD
Suspended Chromium	CHRM
Suspended Cadmium	CAD
Suspended Iron	IRON
Dissolved C_{17}/pristane	WHC1
Dissolved C_{18}/phytane	WHC2
Dissolved pristane/phytane	WHC3
Dissolved odd/even paraffin	WHC4
Dissolved paraffin/phytane	WHC5
Dissolved paraffin/C_{16}	WHC6
Dissolved total aliphatics	WHC7
Dissolved total aromatics	WHC8
Station Depth	DEPTH1
Median depth of net	NET_DPTH
Depth range of net	NET_RNG
Mean sample temperature	TMP
Sample temperature range	TMP_RNG

Variable Name	Alaises
Sample mean salinity	SALT
Sample salinity range	SAL_RNG

The original names of the trace metal and hydrocarbon variables determined from the zooplankton samples and their alaises are listed below:

Variable Name	Alaises
Iron	ZPTM1
Chromium	ZPTM2
Nickel	ZPTM3
Copper	ZPTM4
Vanadium	ZPTM5
Cadmi urn	ZPTM6
Lead	ZPTM7
C_{17}/pristane	ZHC1
C_{18}/phytane	ZHC2
Pristane/phytans	ZHC3
Odd/even paraffin	ZHC4
Paraffin/phytane	ZHC5
Paraffin/C_{16}	ZHC6
Total aliphatics	ZHC7
Total aromatics	ZHC8

Table 2. Summary of the Multivariate Regression of Suspended Trace Metals[1] on the Zooplankton Community of Lease tracts I-III

Source	Significance	Variables Important to the Structure of the Canonical Variate: Positive Relationship	Variables Important to the Structure of the Canonical Variate: Negative Relationship
Lead	0.0001	Gastropod Veligers, Oncaea, Oikopleura	
Cadmium	0.001	Protozoans, Eucalanus	Medusae, Crab Larvae
Iron	0.0001	Eucalanus, Oithona, Centropages	
Hour	0.7764		
Sun Light	0.066		
Poc	0.0001	Corycaeus, Fritillaria, Oikopleura	
DOC	0.0001	Oithona	Gastropod Veligers, Oikopleura
Depth	0.0001	Eucalanus, Polychaetes, Bivalve larvae Oikopleura	
Temperature	0.0001	Fritillaria, Lucifer, Oithona	
Temp. Range	0.0001	Corycaeus, Oikopleura	
Salinity	0.0001	Protozoans, Cladocerans, Tunicates Corycaeus, Oithona	
Sal. Range	0.0001	Cladocerans	Other Crustaceans
Net Depth	0.0001	Oithona, Fritillaria, Lucifer	
Net Range	0.0056		

[1]See page 13 for a complete list of variables.

Table 3. Summary of the Mu t variate Regression of Suspended Trace Meta s on the lankton Community o Lease Tracts IV-V

Source	Significance	Variables Important to the Structure of the Canonical Variate: Positive Relationship	Negative Relationship
Lead	0.0101		
Chromium	0.0551		
Cadmium	0.0107		
Iron	0.[illegible]55	*Eucalanus*, Cladocerans, ________	
Depth	[illegible].0240		
Temperature	0.0[illegible]83		
Temp. Range	0.0483		
Salinity	0.0167		
Sal. Range	0.0159		
Net Depth	0.0108		
Net Range	0.0219		

[1]See page 35 for a complete ist of variables.

Table 4 . Summary of Canonical Correlation of Suspended Trace Metals with Zooplankton Categories[1] - Lease Tracts I-III

Source	Total Variation	Redundancy	Positive Relationships	Negative Relationships
Canonical Variate Pair I				
Zooplankton Variate	10.56%	10.15%	Oncaea, Other Protozoans, Tunicates, Corycaeus, Siphonophores, Eucalanus, Oikopleura, Oithona	Centropages, Ostracods
Environmental Variate	15.23%		Station Depth, Net Depth Range, Salinity Range, Net Depth	Poc
Canonical Variate Pair II				
Zooplankton Variate	7.60%	7.15%	Oithona, Ostracods, Other Crustaceans, Shrimp Larvae, Centropages, Chaetognaths	Gastropod Veligers, Cladocera, Bivalve Veligers, Undinula, Oikopleura
Environmental Variate	9. 24%		Net Depth, Temperature Range, Salinity Range	Temperature
Canonical Variate Pair III				
Zooplankton Variate	7.98%	7.44%		Corycaeus, Oithona, Globigerina, Bivalve Veligers, Copepodites, Oikopleura, Pteropods, Copepod Nauplii, Oncaea, Shrimp Larvae, Other Crustaceans, Crab Larvae
Environmental Variate	10.42%			Temperature, POC, DOC, Net Depth, Salinity

Source	Total Variation	Redundancy	Positive Relationships	Negative Relationships
Canonical Variate Pair IV				
Zooplankton Variate	5.70%	5.25%	Other Protozoans, Centropages, Ostracods, Other Crustaceans, Oncaea	Siphonophores, Lucifer, Fritillaria, Echinoderm Larvae
Environmental Variate	4. 22%		Temperature Range	Temperature
Canonical Variate Pair V				
Zooplankton Variate	2.47%	2.18%	Tunicates	Polychaetes, Eucalanus
Environmental Variate	5.26%		Salinity Range	Lead, DOC, Cadmium, Salinity
Canonical Variate Pair VI				
Zooplankton Variate	4. 70%	4.06%	Centropages, Cladocerans, Fish Eggs, Chaetognaths, Other Protozoans	
Environmental Variate	6.82		POD, DOC	Iron
Canonical Variate Pair VII				
Zooplankton Variate	4.43%	3.43%	Fritillaria, Eucalanus, Ostracods, Tunicates	
Environmental Variate	7.98%		Sunlight	DOC, Iron, Salinity Range
Canonical Variate Pair VIII				
Zooplankton Variate	2.90%-	2.25%	Fish Larvae, Pteropods	Fritillaria
Environmental Variate	4.14%		Temperature Range	Salinity Range

Source	Total Variation	Redundancy	Positive Relationships	Negative Relationships
Canonical Variate Pair IX				
Zooplankton Variate	6.03%	4.55%		Shrimp Larvae, Chaetognaths, Gastropod Veligers, Other Crustaceans, *Eucalanus*, Ostracods, Fish Eggs, Pteropods
Environmental Variate	5.06%		Sunlight	Temperature Range, Salinity
TOTAL		46.46%		

[1]See page 13 for a complete list of variables used

Table 5 . Summary of Canonical Correlation of Suspended Trace Metals with Zooplankton Categories[1] - Lease Tracts IV and V

Source	Total Variation	Redundancy	Positive Relationships	Negative Relationships
Canonical Variate Pair I				
Zooplankton Variate	13.86%	13.61%	Acartia, Centropages, Eucalanus, Chaetognaths, Corycaeus	Oithona
Environmental Variate	25.99%		Temperature, Salinity Range	Salinity, Net Depth, Station Depth, Net Range
Canonical Variate Pair II				
Zooplankton Variate	7.13%	6.94%	Oncaea, Oithona, Euterpina, Euchaeta,	Gastropod Veligers, Cladocerans, Pelecypod Larvae, Hydromedusae
Environmental Variate	12.78%		Net Depth	Temperature, Lead, Salinity Range
Canonical Variate Pair III				
Zooplankton Variate	7.18%	.6.79%	Cladocerans, Corycaeus, Centropages, Oithona, Copepod Nauplii, Paracalanus, Pelecypod Larvae, Chaetognaths	Euchaeta, Other Crustaceans, Other Cyclopoids, Calanus
Environmental Variate	5.16%		Net Range, Depth	

Source	Total Variation	Redundancy	Positive Relationships	Negative Relationships
Canonical Variate Pair IV				
Zooplankton Variate	4.72%	4.26%		Ceratium, Pyrocystis, Foraminifera, Siphonophores, Oncaea, Euchaeta, Salps
Environmental Variate	6.10%		Chromium	Temperature Range
Canonical Variate Pair V				
Zooplankton Variate	9.36%	8.13%	Eucalanus, Other Crustaceans, Fish Eggs, Siphonophores	
Environmental Variate	7.14%		Depth, Temperature Range	Lead, Iron
Canonical Variate Pair VI				
Zooplankton Variate	2.02%	1.78%	Hydromedusae	
Environmental Variate	8.31%		Temperature Range, Net Range, Lead	
Canonical Variate Pair VII				
Zooplankton Variate	4.49%	3.68%		Appendicularians, Euchaeta, Hydromedusae
Environmental Variate	6.74%		Cadmium, Iron	Station Depth, Net Range
TOTAL		45.19%		

[1]See page 35 for a complete list of variables used.

Table 6. Summary of the Multivariate Regression of Zooplankton Trace Metals[1] on the Zooplankton Community of Lease Tracts I-III

Source	Significance	Positive Relationships	Negative Relationships
Centropages	0.0020	Iron, Copper	
Undinula	0.2430		
Other Calanoids	0.7745		
Corycaeus	0.0639		
Oithona	0.0019	Lead, Chromium	Iron
Oncaea	0.0002	Nickel, Cadmium, Chromium	
Other Cyclopoids	0.5260		
Harpacticoid Copepods	0.6960		
Copepodites	0.0833		
Copepod Nauplii	0.7205		
Cladocerans	0.3133		
Ostracods	0.3095		
Lucifer	0.0078		
Shrimp Larvae	0.1363		Nickel, Lead
Crab Larvae	0.1043		
Other Crustaceans	0.0303		
Globigerina	0.9076		

Source	Significance	Positive Relationships	Negative Relationships
Other Protozoa	0.2658		
Medusae	0.2776		
Siphonophores	0.0165		
Polychaetes	0.0381		
Bivalve Veligers	0.3314		
Gastropod Veligers	0.7765		
Pteropods	0.5465		
Echinoderm Larvae	0.4037		
Chaetognaths	0.0024	Vanadium	Nickel, Chromium
Oikopleura	0.4300		
Fritillaria	0.0367		
Tunicates	0.6013		
Fish Eggs	0.8721		
Fish Larvae	0.2333		
Misc. Plankton	0.5033		

[1] See page 26 for a complete list of variables.

Table 7. Summary of the Multivariate Regression of Zooplankton Trace Metals on the Zooplankton Community of Lease Tracts IV & V

Source	Significance	Positive Relationship	Negative Relationship
Acartia	0.0271		
Calanus	0.2848		
Centropages	0.0696		
Corycaeus	0.3344		
Eucalanus	0.0004	Copper, Lead, Nickel	
Euchaeta	0.1603		
Euterpina	0.0003	Cadmium, Copper, Iron	
Oithona	0.0070		Chromium, Vanadium, Iron, Nickel
Oncaea	0.0040	Vanadium, Copper	
Paracalanus	0.5316		
Temora	0.1107		
Undinula	0.0949		
Other Calanoids	0.5011		
Cyclopoid Copepods	0.1178		
Harpaticoid Copepods	0.2756		
Copepod Nauplii	0.1849		
Clodocerans	0.0003	Cadmium	Nickel, Copper, Chromium, Iron

Source	Significance	Positive Relationships	Negative Relationships
Appendicularians	0.5492		
Salps	0.0575		
Gastropod Veligers	0.0258		
Chaetognaths	0.3717		
Pelecypod Larvae	0.6025		
Hydromedusae	0.0539		
Siphonophores	0.0784		
Fish Eggs	0.5512		
Foraminifera	0.55[illegible]2		
Pyrocystis	0.8660		
Ceratium	0.4188		
Other Crustaceans	0.015[illegible]		
Decapod Larvae	0.0103		
Polychaetes	0.1040		
Fish Larvae	0.3981		

[1]See page 43 for a complete list of variables.

Table 8. Summary of Canonical Correlation of Zooplankton Trace Metals[1] with Zooplankton Categories - Lease Tracts I-III

Source	Total Variation	Redundancy	Positive Relationship	Negative Relationship
Canonical Variate Pair I				
Trace Metal Variate	22.82%	20.60%		Nickel, Cadmium, Iron, Chromium, Copper
Zooplankton Variate	7.36%		Ostracods, Centropages, Siphonophores, Other Crustaceans	Oikopleura, Other Cyclopoids, Harpacticoid Copepods
Canonical Variate Pair II				
Trace Metal Variate	11.64%	10.51%	Iron	Lead
Zooplankton Variate	5.52%			Bivalve Veligers, Corycaeus, Eucalanus, Echinoderm Larvae
Canonical Variate Pair III				
Trace Metal Variate	8.31%	7.09%	Iron	Cadmium
Zooplankton Variate	8.54%		Oithona, Oncaea, Eucalanus, Fritillaria, Copepod Nauplii, Siphonophores	
Canonical Variate Pair IV				
Trace Metal Variate	11.34%	8.03%		Cadmium, Copper, Vanadium
Zooplankton Variate	3.91%		Lucifer	Polychaetes, Oikopleura, Bivalve Veligers, Crab Larvae
		TOTAL 46.23%		

[1] See page 26 for a complete list of variables.

Table 9. Summary of Canonical Correlation of Zooplankton Trace Metals[1] with Zooplankton Categories-Lease Tracts IV and V

Source	Total Variation	Redundancy	Positive Relationships	Negative Relationships
Canonical Variate Pair I				
Trace Metal Variate	17.00%	15.54%		Vanadium, Lead
Zooplankton Variate	7.62%		Acartia, Euterpina, Centropages, chaetognaths	Oithona, Oncaea, Pyrocystis, other calanoids
Canonical Variate Pair II				
Trace Metal Variate	23.25%	20.60%	Nickel, Iron, Chromium, Vanadium	
Zooplankton Variate	8.93%		Oithona, Oncaea, Euchaeta	cladocerans, gastropod veligers, bivalve larvae, Acartia, decapod larvae, Corycaeus, chaetognaths
Canonical Variate Pair III				
Trace Metal Variate	9.89%	8.62%	Cadmium	Copper
Zooplankton Variate	7.72%		Corycaeus, Centropages, Paracalanus, cladocerans, Eucalanus, Euterpina	Other cyclopoids, other crustaceans
Canonical Variate Pair IV				
Trace Metal Variate	3.60%	3.07%	Copper	
Zooplankton Variate	2.99%		Foraminifera, other cyclopoids	Eucalanus
Canonical Variate Pair V				
Trace Metal Variate	8.81%	6.11%	Copper, Lead	
Zooplankton Variate	2.05%		Siphonophores	Hydromedusae, gastropod veligers, other cyclopoids
	TOTAL	53.94%		

[1]See page 43 for a complete list

Table 10. Summary of Zooplankton Trace Metal Residuals' Canonical Correlation Analysis Lease Tracts I-III

Source	Total Variation	Redundancy	Positive Relationship	Negative Relationship
Canonical Variate Pair I				
Residual Variate	35. 6%	29.20%	Copper, Lead, Cadmium	
Water Column Variate	17.92%		Cadmium, Net Range, Station Depth, Temperature Range	Lead
Canonical Variate Pair II				
Residual Variate	17.30%	13.34%	Nickel, Chromium, Lead	
Water Column Variate	6.75%		Iron, Cadmium	
Canonical Variate Pair III				
Residual Variate	6.98%	4.21%	Nickel, Chromium, Cadmium	
Water Column Variate	4.41%		Lead, Cadmium, Iron, Temperature Range	
Canonical Variate Pair IV				
Residual Variate	6.47%	3.33%	Vanadium	
Water Column Variate	4. 88%		Iron, Salinity Range	Cadmi urn
	TOTAL	50.08%		

[1]See page 32 for a complete list of variables.

Table 11. Summary of Zooplankton Trace Metal Residual s' Canonical Correlation Analysis for Lease Tracts IV & V.

Source	Total Variation	Redundancy	Positive Relationship	Negative Relationship
Canonical Variate Pair I				
Residual Variate	35.76%	28.0%	Cadmium, Vanadium, Chromium, Copper, Iron, Nickel	
Water Column Variate	2.14%			Temperature range, Cadmium, Iron, Chromium
Canonical Variate Pair II				
Residual Variate	13.31%	8.92%	Lead, Copper	Cadmium, Vanadium
Water Column Variate	11.64%		Temperature Range	Chromium, Lead
Canonical Variate Pair III				
Residual Variate	17.66%	10.72%		Vanadium, Iron, Chromium, Nickel
Water Column Variate	12.00%			Iron, Cadmium
	TOTAL	47.64%		

[1]See page 48 for a complete list of variables.

Table 12. Summary of the Multivariate Regression of Zooplankton Hydrocarbon: on the Zooplankton Community of Lease Tracts I-III.

Source	Significance	Positive Relationship	Negative Relationship
Centropages	0.0035	C_{17}/pristane, C_{18}/phytane	odd/even n-parrafin
Eucalanus	0.0403		
Undinula	0.2307		
Other Calanoids	0.6417		
Corycaeus	0.8183		
Oithona	0.0001	Odd/even n-parrafin	Total aromatics, n-parrafin/phytane, C_{18}/ phytane, n-parrafin/C_{16}
Oncaea	0.0136		
Other Cyclopoids	0.2958		
Harpacticoid copepods	0.5529		
Copepodites	0.0237		
Copepod Nauplii	0.3843		
Cladocerans	0.0127		
Ostracods	0.0621		
Lucifer'	0.0991		

Source	Significance	Positive Relationship	Negative Relationship
Shrimp Larvae	0.0759		
Crab Larvae	0.3231		
Other Crustacea	0.7745		
Globigerina	0.5346		
Other Protozoans	0.0061	C_{17}/pristane, C_{18}/phytane	odd/even n-phytane
Medusae	0.0811		
Siphonophores	0.0045	n-parrafin/C_{16}	
Polychaetes	0.0012	Total aliphatics, Total aromatics	
Bivalve Larvae	0.8093		
Gastropod Veligers	0.0864		
Pteropods	0.0068	odd/even n-paraffins	
Echinoderm Larvae	0.0969		
Chaetognaths	0.0001	pristane/phytane, Total aromati s C_{18}/phytane	
Oikopleura	0.0001	C_{17}/pristane, pristane/phytane, n-parrafin/C_{16}, odd/even n-parrafin	
Fritillaria	0.0436		

Source	Significance	Positive Relationship	Negative Relationship
Tunicates	0.8955		
Fish Eggs	0.0665		
Fish Larvae	0.2539		
Miscellaneous	0.1316		

[1]See page 51 for a complete list of variables.

Table 13. Summary of Canonical Correlation of Zooplankton Hydrocarbon[1] with Zooplankton Categories - Lease Tracts I-III

Source	Total Variation	Redundancy	Positive Relationship	Negative Relationshi
Canonical Variate Pair I				
Hydrocarbon Variate	9. 34%	8.99%		C_{17}/Pristane, C_{18}/Ph
Zooplankton Variate	8.51%		Oithona, Other Protozoans, Eucalanus, Centropages, Other Crustaceans, Oncaea, Copepod Nauplii, Shrimp Larvae	
Canonical Variate Pair 11				
Hydrocarbon Variate	9. 76%	9.13%	Odd/Even n-paraffin, Total Aromatics	
Zooplankton Variate	7.69%		Oncaea, Oikopleura, Gastropod Veligers, Other Protozoans, Corycaeus	Centropages
Canonical Variate Pair III				
Hydrocarbon Variate	20.17%	17.99%	C_{17}/Pristane, n-paraffin/Phytane, Total Aliphatics, C_{18}/Phytane	Odd/Even n-paraffin, Pristane/Phytane
Zooplankton Variate	4.18%		Oithona, Siphonophores	Centropages, Chaetog Eucalanus, Undinula, valve Larvae, Cladoc

Source	Total Variation	Redundancy	Positive Relationships	Negative Relationships
Canonical Variate Pair IV				
Hydrocarbon Variate	6.85%	5.89%	Total Aliphatics, Total Aromatics	C_{17}/Pristane, C_{18}/Phytane
Zooplankton Variate	2. 88%		Polychaetes	
Canonical Variate Pair V				
Hydrocarbon Variate	9. 53%	7.61%		C_{17}/Pristane, n-paraffin/C_{16}
Zooplankton Variate	5.81%		Cladocerans	Shrimp Larvae, Ostracods, Gastropod Veligers, Fish Larvae
	TOTAL	46.61%		

[1]See page 54 for a complete list of variables.

Table 4. Summary of the Multivariate Regression of Zooplankton Hydrocarbons on the Zooplankton Community of Lease Tracts IV and V

Source	Significance	Positive Relationships	Negative Relationships
Acartia	0.0990		
Calanus	0.0093		Pristane/Phytane
Centropages	0.0001	Total Aromatics, Total Aliphatics	Odd/Even n-paraffins
Corycaeus	0.6384		
Eucalanus	0.29 *6		
Euchaeta	0. 884		
Euterpina	0.0454		
Oithona	0.0004	n-paraffin/C_{16}	
Oncaea	0.0005	Total Aromatics	C_{18}/Phytane
Paracalanus	0.5354		
Temora	0.1579		
Undinula	0.5328		
Other Calanoids	0.6947		
Other Cyclopoids	0.5580		
Other Harpacticoids	0.2499		
Copepod Nauplii	0.3559		
Cladocerans	0.0029	Pristane/Phytane, n-paraffin, Phytane, Odd/Even n-paraffin, n-paraffin/C_{16}	C_{18}/Paraffin

Source	Significance	Positive Relationships	Negative Relationships
Appendicularians	0.0557		
Salps	0.0068	Pristane/Phytane, Total Aromatics, Total Aliphatics	
Gastropod Veligers	0.0798		
Chaetognaths	0.2469		
Pelecypod Larvae	0.5120		
Hydromedusae	0.0001	n-paraffin/C_{16}	
Siphonophores	0.0370		
Fish Eggs	0.7276		
Foraminifera	0.6194		
Pyrocystis	0.7631		
Ceratium	0.3470		
Other Crustaceans	0.3185		
Decapod Larvae	0.0936		
Polychaetes	0.0855		
Fish Larvae	0.9171		

[1]See page 58 for a complete list of variables.

Table 15. Summary of Canonical Correlation of Zooplankton Hydrocarbon[1] with Zooplankton Category - Lease Tracts IV and V

Source	Total Variation	Redundancy	Positive Relationships	Negative Relationships
Canonical Variate Pair I				
Hydrocarbon Variate	12.11%	11.32%	n-paraffin/C_{16}	
Zooplankton Variate	9.83%		Acartia, Centropages, Eucalanus, Chaetognaths, Gastropod Veligers, Corycaeus, Appendicularians	Oithona, Oncaea
Canonical Variate Pair II				
Hydrocarbon Variate	16.34%	14.91%	Pristane/Phytane, Odd/Even n-paraffin	
Zooplankton Variate	7.87%		Corycaeus, Centropages, Cladocerans, Chaetognaths, Paracalanus, Eucalanus	
Canonical Variate Pair III				
Hydrocarbon Variate	11.40%	9.77%		C_{18}/Phytane
Zooplankton Variate	6.61%		Oncaea, Salps, Siphonophores, Oithona	
Canonical Variate Pair IV				
Hydrocarbon Variate	16.70%	13.38%	Odd/Even n-paraffin, Total Aromatics	n-paraffin/Phytane
Zooplankton Variate	2.34%		Pelecypod Larvae	Hydromedusae
	TOTAL	49.38%		

[1]See page 61 for a complete list of variables.

Discussion

The ultimate goal of any group of ecological analyses is to transform the many and diverse numbers generated and reported as results into interpretative statements about the system investigated. To facilitate this process we have created a set of tables that summarizes the results (see tables 2-15). The ensuing discussion will strive to achieve the conversion from numbers to consistent interpretation.

In both general geographic regions, the relationship between the zooplankton community structure and the environment is strong, with 45-46% of the zooplankton community variation being correlated with various aspects of the environmental variation. By this we mean that approximately 45-46% of the variation of the zooplankton population can be explained by changes in the values of the various environmental parameters. The redundancy (see definition p. 17) of the canonical variate pairs was used to arrive at these figures. By adding the redundancies of the canonical variate pairs we are essentially adding the total amount of variation in zooplankton levels accounted for by the variation in environmental parameters as revealed by our analysis. For instance, in table 4 there are nine canonical variate pairs. Each of these pairs contributes to the total statement we wish to make about the relationship of environmental variation and zooplankton community variation.

Let us examine canonical variate pair one in table 4. The first member of the variate pair is concerned with zooplankton levels and explains 10.56% of the total variation of zooplankton levels. The second member, an environmental variate, explains 15.23% of the total variation among the measurements of the various environmental variables. The redundancy essentially puts these two bits of information together. The figure of 10.15% for this pair of variates indicates that the first canonical variate pair consists of a group of environmental variables which explain 10.15% of the total variation among the zooplankton levels. Looking further into table 4 we see that particular environmental variables (station depth, net depth, etc.) are more important in this particular environmental variate than the other aspects of the environment measured and that particular zooplankton categories (Oncaea, other protozoans, etc.) are more important in this particular zooplankton variate than the other categories recorded. Recall that individual variables in each of the canonical variates can have either a positive or negative contribution to the make up of the variate. Since we are comparing the inter-relationships of two groups of variables it should become clear after a little thought that groups of variables which have the same sign inside a variate pair are directly related and groups with opposite signs are inversely related to the same degree. Thus, in canonical variate pair I in table 4 POC is inversely related to levels of Oncaea, other protozoans, etc. and directly related to levels of Centropages and ostracods.

It should now be clear that to obtain the total variation of zooplankton levels accounted for by the environmental variables dealt with in table 4 we need only add the redundancies of the nine significant canonical variate pairs. For lease tracts I-III (table 4) this number is 46.46%. The remaining variation is the accumulated result of the effects of unmeasured parameters in both the environment and the zooplankton, sampling errors, and the inherent "noise" of the system.

Tables 4, 5, 8, 9, 13 and 15 can be interpreted in the same manner. The only difference is in the environmental and zooplankton categories used for analysis.

In each area the most important environmental factors related to the structure of the zooplankton community are the inshore-offshore considerations and the surface to bottom layering of the water column. The group of environmental variables associated with inshore-offshore consideration is composed of station depth, net range, and salinity range which are all more or less associated with deeper stations (more offshore). Surface to bottom layering of the water column is expressed more fully by the group of environmental variables including: net depth, temperature, temperature range, and salinity range. Both of these groups are important in the canonical variate pairs I and II of tables 4 and 5. For example, in lease tracts IV-V. (table 5), a negative relationship is established of Acartia, Centropages, Eucalanus, and chaetognaths versus salinity and station depth; while at the same time these zooplankton categories are positively related to temperature and salinity range. This species assemblage makes up a greater proportion of the zooplankton community in the shallower, warmer, more heterogeneous inshore waters. In lease tracts I-III the assemblage of Oncaea, Corycaeus, and Eucalanus among others seem to be positively related to the deeper stations and water of the various stations sampled. This relationship can be seen in canonical variate pair I of table 4 where this assemblage is associated with the station depth, net range group mentioned above.

Most of the species assemblages found to be related to factors of the environment are regulated either by the above mentioned depth factors, or by increases and decreases in salinity and temperature values. Other species seem to be related in numbers to the range of temperature and salinity encountered in collection. For example, in lease tracts I-III both _Eucalanus_ and _Oithona_ are positively related to salinity range as can be seen in table 4, canonical variate pairs I and 11. _Oithona,_ in lease tracts IV-V, is inversely related to salinity range in pair I and II of table 5. The magnitude of the salinity and temperature range in some samples seems to indicate that the net traversed a layer of water in which salinity or temperature changed rather rapidly with depth, eg., a, thermo- or halocline. Perhaps the assemblages of organisms may be associated with such layers of water due to factors such as buoyancy or other unknown factors.

Of the considerable amount of zooplankton variation related to the environment, little may be attributed to variation of suspended trace metals. Although specific trace metals were often significantly correlated to the levels of zooplankton population (see tables 2 and 3), in general the amounts of variation in the population levels of zooplankton accounted for by these was not as great as that of other environmental variables. Note that in table 4 only lead, cadmium, and iron appear as components of any of the nine significant canonical variate pairs. Lead and cadmium appear important only in the fifth pair which is the axis accounting for the smallest variation in zooplankton (2.18%) while iron appears as an important component of the sixth and seventh pair (a combined score of 7.49%). In areas IV and V as can be seen in table 5,lead appears in two variate pairs and iron in one. Thus, the variations observed in suspended trace metals do not seem to be very important in shaping the structure of the zooplankton community, at least at the low levels observed in the MAFLA study.

Now let us turn from levels of suspended trace metals to trace metals contained within the bodies of the zooplankters. Recall that trace metal determinations were done on entire zooplankton samples. As would be expected the variation in trace metals measured was found to be highly dependent on the category composition of the zooplankton. Tables 8 and 9 represent a summary of the information generated concerning the levels of trace metals in the zooplankton and the relationship of those levels to the community structure. In this case the redundancy figures indicate the percent of variation in zooplankton trace metals accounted for by variation in zooplankton category numbers. If the procedure used above is followed and the redundancy of the four significant canonical variate pairs in table 8 is added, a total 46.23% is produced. Table 9 for areas IV and V produces a 53.94% figure. As expected, this information supports the conclusion that different categories of zooplankton treat trace metals in different ways, and consequently the composition of the community contributes to the levels of trace metals measured. In other words, a large portion of the variability in zooplankton trace metal concentrations is explainable by fluctuations in the zooplankton composition. Examination of the relationships expressed by the canonical correlations in tables 8-9 suggests three types of zooplankters with respect to trace metals: 1) positive concentrators (Oikipleura and nickel), 2) negative concentrators, unusually low amounts of the trace metal (Centropages and nickel), and 3) those with no particular relationships. The negative correlation shown here of Centropages and nickel is in direct contrast to the work of Nicholls et al. (1959) who suggested that nickel accumulation may be typical of copepods. Further, they point out that Centropages contained high levels of lead, suggesting this species may be a lead concentrator. This association was not found to be significant in our analyses. Further investigation is needed in order to determine if Centropages is perhaps the exception to the rule. Those individuals indicated as concentrators suggest possibilities for experimental studies as to their roles in transport. For example, the consistently positive relationship between the molluscan larvae and lead and the negative one with iron bears further investigation.

The end result of this analysis is that, considering all the "noise" introduced into the data by the collection scheme, there is a predictable relationship of the zooplankton trace metals and the composition of the zooplankton. The source of variation in the trace metal levels in a zooplankter depends on the type of zooplankter it happens to be. Thus, the determination of the species composition of the sample is of prime importance to the monitoring of the zooplankton trace metals.

A final question about the trace metal situation is the relationship of the zooplankton trace metal levels and the water column trace metal levels. It is important to know whether the trace metals encountered in a zooplankter reflect the environment or the metabolic idiosyncrasies of the organism. Our analysis of trace metal residuals was designed to answer that question (see tables 10-11). In this analysis the variation due to the composition of the zooplankton has been removed leaving information which has to do only with the relationship of suspended trace metals to the trace metals incorporated in a putative "average" zooplankter. Tables 10 and 11 present the relationships of the residual trace metals with the suspended trace metal group of environmental parameters. The results from lease tracts I-III (table 10), an area where suspended trace metals are in low concentration, showed generally positive relationships. This positive relationship is known to occur in micro-organisms (Knauer and Martin, 1972; Lamanna and Mallette, 1965) who, up to a certain point, are enhanced by low levels of metals in their environment. It is possible this same mechanism can be applied to the zooplankton in this area. For these lease areas, after the variation due to category composition of the zooplankton is removed, cadmium contained in the organisms increased with its concentration in the water column while lead decreased and iron showed no relationship to the respective concentrations in the water.

In lease areas IV and V as shown in table 11, lead showed the same relationship between residuals and water column concentration as was found in lease areas I-III. Cadmium and chromium showed negative relationships. The analyses indicate that for all the lease areas, lead is an important trace metal to be considered in future studies. The conflicting behavior of chromium and cadmium may perhaps be due to the very different histories of the water masses and therefore of the zooplankters of the two groups of lease areas. In other words, the presence of fresher water species of zooplankters in "lease tracts IV and V (Acartia) indicate that there is an important contribution of fresher (perhaps Mississippi) waters with very different concentrations of trace metals. Areas IV and V may therefore be viewed as regions of mixing where zooplankters found in water with certain concentrations of trace metals may not necessarily have always been exposed to these same levels.

As in trace metals, the hydrocarbon measurements which were suitable for analysis were done in bulk samples of zooplankton. As shown in tables 13 and 15, the variation of hydrocarbons in the zooplankton was influenced greatly by the category composition of the population. Total redundancy for lease tracts I-III (table 13) was 49.61% and for lease tracts IV and V (table 15), 49.38%. This means that about one-half of the hydrocarbon variation in zooplankton is accounted for by the categories of zooplankton present. This would indicate the presence of groups of organisms in the zooplankton which have different methods of dealing with and therefore different levels of the various hydrocarbons measured (See hydrocarbon bibliography, final report: Contract 08550-CT4-11). The absence of compatible water column hydrocarbon information prevented the use of the residual technique used above with trace metals. Also, analysis of the relationship of zooplankton population levels and additional water column hydrocarbons which had not already been considered were precluded.

The major result of this analysis is a confirmation of the complexity of the interacting systems of variables which govern zooplankton populations in the Gulf of Mexico. The analysis also showed that with an intensive level of sampling much of the variation of the system can be assigned to the forces of salinity, depth, and temperature and to a lesser extent to trace metals and hydrocarbons. Indeed, it was the purpose of this study to identify these relationships which can now be further studied and hopefully better understood in the future.

The majority of scientific work to date involves concentrations of hydrocarbons and other substances which were much higher (lethal doses) than those encountered in this project (Becker and Thatcher, 1973; Eisler, 1973; Vinogradov, 1953; Corner and Sparrow, 1956). It is important to keep in mind that low levels of many substances can have sublethal but important effects such as reduced growth and fecundity (Soyer, 1963; Bougis, 1965). As the development of drilling and production takes place in the MAFLA area, changes in the concentrations of trace metals and hydrocarbons may take place. It is important to remember that this analysis is valid only for the low levels of hydrocarbons and trace metals which were measured in this collection. If and when these levels change, the complex plankton community may exhibit quite a different response.

SUMMARY AND CONCLUSIONS

The purpose of this study was two-fold. The first objective was to discover if any meaningful relationships existed between the observed zooplankton standing crop at a sampling point and the measured conditions of the environmental variables. At first consideration, the system of biotic and abiotic interactions might seem to be so complex and variable that relationships would be extremely difficult, if not impossible, to establish and explain. Additionally, we were investigating a collection of systems that are highly time dependent, utilizing one sample representative of a few weeks out of one season, the spring of 1974. In some respects, this may be likened to selecting one set of frame sequences out of a motion picture and attempting to discover the plot. Depending on the representativeness of the sequence, our reconstruction of the story may or may not be accurate. Even though, as our results demonstrate, the data about the system available to us may be organized into principles that we can understand, there is no assurance that the relationships are not time dependent, and therefore must be established for other points in time as well.

The second objective was to look for relationships between the zooplankton categories and the possible pollutants from drilling activites: trace metals and hydrocarbons. This objective is perhaps of a more practical nature, as it might point out pollutant indicators. These indicators might be discovered either by their standing crop displaying a" marked relationship to the level of one of the pollutants, or by the individual zooplankter acting as a concentrator for one or more of the pollutants. The discovery of concentrator organisms was not a part of the "baseline" survey. However, if one can accept the assumptions brought out in the zooplankton trace metals results section, our analyses indicate representatives to be investigated as concentrator organisms.

The most interesting and conclusive results emerged from the various trace metal analyses. In the region containing lease traces I-III the variation of trace metals is not a particularly important part of the total environmental variation. This is borne out by the results of the canonical correlation and the factor analysis. Consequently, there were no strong associations between the standing crop of zooplankton and the levels of suspended trace metal elements. The canonical correlation did, however, establish the strong relationship of the zooplankton community with the water column environment. The major determinants of the zooplankton community structure were those that related to the station depth or vertical heterogeneity of the water mass sampled. Additionally, it displayed that the relationships of the zooplankton community with the environment parallel the major axes of the environmental variability, as described by the factor analysis. Thus, the structure of the zooplankton community is being strongly shaped by the same factors that influence the physical parameters of the water masses and are not fluctuating randomly or in an unpredictable manner. Nor is the zooplankton community structure being shaped by some minor aspect of the environment.

The geographic area including lease tracts IV-V showed the trace metals to be a more important factor of the environment, as witnessed by the factor analysis. This is to be expected, when one considers the proximity of the Mississippi River and other sources of water likely to be polluted by industrial wastes. Even though the trace metals are a more important aspect of the environmental variation, their importance in predicting the structure of the zooplankton community is still relatively minor; the strongest relationship is with lead. It is our interpretation that the levels of trace metals encountered in the MAFLA area do not influence the structure of the zooplankton community to a large extent; the trace metal-zooplankton relationships observed are most likely serving as a further indicator of the source of the water mass. The most important driving functions of the zooplankton community at this time in the eastern Gulf of Mexico are those related to temperature, salinity, and water mass origin. This is not to say that levels of trace metals in the water column could not at some future time become important determinants of the zooplankton community; at their present low levels, they are of minor importance.

The analyses of zooplankton trace metals with the zooplankton categories showed three kinds of zooplankton with respect to trace metal concentrations: positive, neutral, and negative concentrators. The zooplankters that fall into these categories could be studied experimentally to determine the effect of sublethal levels of trace metals, and also to establish their relationship to the transport mechanisms of trace metals in the food chain. The results of these analyses also show that the concentration of trace metals in the zooplankton categories is quite sensitive to small changes in the zooplankton category composition.

The best technique for monitoring the environmental changes and their effects on the zooplankton community would be to sample both as simultaneously as possible. We feel that the sampling effort expended on the water column during the baseline sampling was the minimum necessary for a seasonal analysis of the data to be worthwhile. This is quite possibly considered too expensive. On the other hand, the level of effort currently being invested in the water column will only prove fruitful, in our opinion, over the long term (a minimum of 3-5 years). Further, it is pointless to measure levels of hydrocarbons and trace metals dissolved or suspended in the water without also determining the structure of the biotic community present, since it is the fate of the biotic community that determines the importance of the pollutant level. It is also pointless to determine the concentration of trace metals in the zooplankton without knowing the species composition of the zooplankton sample. Our studies suggest that it may not be entirely necessary to separate the samples and perform trace metal assays on each species type; one could either employ regression to predict the trace metal concentration of each plankton type or select representative species from each of our lists of trace metal concentrators and do separate assays on them.

It is also important, as evidenced by the hydrocarbon situation, to collect enough sample for the various physical determinations so that there is a backup sample in case it is needed.

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Appendix 1

Data included in this report were obtained from the following sources as shown in Vol. II: Final Report on the Baseline Environmental Survey of the MAFLA Lease Areas, BLM Contract No. 08550-CT4-11:

Variable	Lease Tract(s)	Principle Investigator
Zooplankton identification	I, II, III	Maturo
Zooplankton identification	Iv, v	Woodmansee
ATP	All	LaRock
Poc	All	Knauer
DOC	All	Knauer
Zooplankton trace metals	All	Betzer - Knauer
Suspended trace metals	All	Betzer
Dissolved low molecular weight hydrocarbons	All	Sackett - Schink
Dissolved low molecular weight hydrocarbons	All	Calder
Zooplankton hydrocarbons	All	Calder

Not included in Final Report - Obtained from PI

Salinity	All	Rinkle
Temperature	All	Rinkle

Appendix2

Statistical Considerations

While the techniques for sample determinations were reported in sufficient detail in earlier works, the methods for data analysis are sufficiently different and complicated to warrant discussion beyond that presented in the SUSIO final report. The purpose of this discussion of data analytical methods is to present in as clear a fashion as possible the underlying assumptions of the techniques, the purpose of selecting the methods employed, the biological and/or environmental significance of the output of the methods, and finally, but definitely not least, a basic understanding of the procedure for interpreting the types of results obtainable from the methods used in this study. Those who are sufficiently aware of the techniques encompassed by the Multivariate General Linear Hypothesis may choose to skip this section.

The problems of analysis and interpretation of zooplankton data seem to require more than the "ordinary" statistical approaches. The results of earlier investigations (e.g. Cassie, 1963) suggest that zooplankters are not randomly distributed throughout the water column. Rather, they seem to show distributions that are highly correlated with the conditions of their immediate environment. Physical oceanography studies in the MAFLA region (Rinkel, pers. comm.) indicates that the geographic distribution of water mass types is quite complex, making regional generalization of types (or sources) of water in the water column a difficult problem. Relating a particular sampling site at a specific time of year to its water type may not be initially possible. Thus, an analysis and interpretative approach that would attempt to explain the observed variation in standing crops of various types of zooplankters should incorporate as much information about the environment as is possible. This information must be relevant to the zooplankton sample obtained and therefore one should strive for as near to simultaneity of water column sample collection as is possible.

Another aspect of zooplankton analysis that rules out the more standard statistical approaches concerns the diversity of the samples. In many cases, of which this is one, the researcher is interested in most, if not all, components of the zooplankton community. Analysis by univariate statistical methods (i.e., considering each component species or group separately) assumes that each of the zooplankton categories behaves independently of all the other categories. This type of approach tends to ignore the importance of interaction, or covariance, among the members of the zooplankton community. Another related problem of the univariate approach results from the confusing multitude of patterns possible from many univariate analyses of the same statistical model. With thirty or more zooplankton categories each to be used as a univariate dependent variable for a regression or analysis of variance model, there is a distinct possibility that no two categories will show the same results. In addition, the time consumed in carefully interpreting the results of each univariate analysis often makes adequate analysis difficult within reasonable time constraints. All of this adds up to the result that a multivariate analysis approach supplies the best techniques for interpreting the zooplankton data. This is true from a theoretical statistics aspect, since we have multiple intercorrelated variables (the standing crop of zooplankton categories) from each observation, and from a biological standpoint because the multivariate approach is best suited to supply information for inference into the biological questions. The ability to discern patterns of zooplankton abundances, identify species assemblages, and detect statistically significant differences in zooplankton communities, both in structure and abundances are afforded via multivariate analysis.

In a univariate analysis, one considers a statistical model with single dependent variate (e.g., density of calanoid copepods/cubic meter) and an independent set of variables that vary in their number and complexity. Since there is only one variable, each sample could be represented by its location on a line or single axis. In fact, most of the statistical hypothesis testing performed revolves about hypotheses concerning the location parameter (e.g., mean, mode, or median) of groups of samples. If one were to add another dependent variable to consider simultaneously with the first (e.g. density of cyclopoid copepods) then each bivariate sample could be defined by its location in a two dimensional coordinate system. One axis would be the density of calanoid copepods and the other axis would be the density of cyclopoid copepods. If one adds variables, then one also adds axes to the coordinate system, until one has a multivariate system with a dependent vector of p-variates described by a p-dimensional hyper-space. Thus, at least part of multi-variate analysis involves the testing of hypotheses concerning the location parameters, mean vectors, of various groups of samples, where each sample involves the measurement of more than one variable on each unit of observation (e.g., a parcel of Eastern Gulf water with the standing crop of various zooplankton categories being the dependent variables).

All samples have variability which can be apportioned to various sources: noise in measurement, environmentally-induced variations, and covariance with other dependent variables. This necessitates the consideration of the dispersal parameter of a sample (e.g. variance, range) when testing hypotheses about the location parameter. The variability of the data and our ability to reduce this variability through experimental design and explaining it via covariance with other variables determine the precision with which we can place the location " parameter of a group of samples. Thus, in much of our hypothesis testing we are asking "within the precision afforded by the data, is it possible to establish some predictive ability concerning location parameters of these groups of samples"? Other types of testing are concerned with specific hypotheses about the dispersion parameters themselves.

It is this dispersion or variability of the data that requires confidence intervals to be associated with the location parameter. Thus , in the univariate case, the location and dispersion parameters help to define a line segment on the coordinate axis. In a bivariate system one obtains an ellipse with the intersection of its major and minor axes being the location parameter. In the p-dimensional, multivariate case the result is a hyper-ellipse. Therefore, we can mentally visualize the basis for multivariate hypothesis testing, much of which is, at least conceptually, a generalization from the univariate, single dimension case to the multivariate case.

Considering the dependent variables as axes for a multidimensional coordinate system, we then utilize multivariate General Linear Hypothesis

(GLH) as the tool for ascertaining the information contained in the raw data. The techniques encompassed by GLH include multivariate extensions analysis of variance and multiple regression. In our particular situation, we have employed multivariate multiple regression, canonical correlation, and factor analysis. These methods and their underlying statistical models will now be described in a general sense.

In our preliminary analysis (which was performed before most of the environmental data became available) contained within the SUSIO Final Report, we employed a multivariate analysis of covariance (MANCOVA). In the absence of data for measured environmental variables, the model proposed contained factors, non-continuous variables, to represent such terms as: between station differences, differences resulting from the depth of the sample, between lease tract differences, and others. With the inclusion of the environmental data that are now available, the various factors may be replaced with continuous variables that measure a specific aspect of the environment. Thus, now we are employing a multivariate multiple linear regression model rather than a MANCOVA. Although not every environmental factor was measured, indeed this would be virtually impossible, the inclusion of general ANOVA factors to account for trends of variation not "explained" by the various measured environmental variables was not possible due to confounding in the mode?. This confounding of effects will have to be taken into consideration during the interpretation of results. For example, if the calanoid copepod, Centropages sp., shows a definite relationship with a low molecular weight hydrocarbon, this does not necessarily indicate that the hydrocarbon is displaying a direct cause and effect relationship with *Centropages*. It may be that the hydrocarbon is an indicator of a particular environmental condition, e.g., a particular water mass, or that it is confounded with some environmental factor not measured. However, there were over twenty-five environmental variables measured at the site of zooplankton sampling. The selection of these variables was a process of interaction of the BLM-MAFLA Baseline water-column principle investigators and colleagues. Thus, we feel that the environmental variable set is the best set of environmental descriptor variables that might be chosen *a priori*.

The multivariate multiple linear regression model relates a vector of dependent variables, in this case usually the zooplankton category standing crops, to a vector of independent variables, the environmental variables. The analysis method then attempts to determine if the variation of a particular term in the independent set of variables will account for a significant portion of the variance-covariance, or dispersion structure, of the dependent set of variables. The portion of the dispersion matrix accounted for by variation in the independent variable is that portion that is not already accounted for by the other variables in the independent variable set. Thus, the model is testing whether or not a particular independent variable has a significant effect on the dependent variable set when the independent variable in question is allowed to vary and all other independent variables are held constant. This method treats the dependent set of variables simultaneously but treats the independent set of variables one at a time. Therefore, it is often difficult to obtain an understanding of the way in which the environmental variables act as a related set, which they most definitely are, upon the zooplankton variables.

The test for significance of the terms in the model involved a transformation of the multivariate test statistic Wilks' λ to an appropriate F statistic. The transformation was developed by Rao (1952) and explained fully in Cooley and Lohnes (1971). The transformation is as follows:

$$(MS - 2B) / (PQ) (1 - \lambda^{1/s}, \lambda^{1/S} \quad F_{P,MS-2B,\alpha}$$

where,

M = (error degrees of freedom) $-.5(P-Q+)\ln(\lambda)$

$S = (P^2Q^2 - 4) / P^2 + Q^2 - 5)$

$B = (PQ - 2) / 4$

P = Number of dependent variables

Q = Rank of hypothesis matrix

The significance of a term in the model has the same basic interpretation as the significance of a partial regression sum of squares in univariate multiple linear regression.

Once significance is detected, the next problem encountered involves explaining the results in a biologically meaningful manner. For this we use the approach known as Canonical Analysis (Cooley and Lohnes, 1971). Since the dependent variables show covariance (if this weren't so, we would use univariate statistics), there is some redundancy contained in the original coordinate axes. (In the fol lowing discussion, the coordinate axes are equivalent to the original dependent variables). Thus, it is possible to make a rotation in axes with the following constraint: the resulting axis will contain the linear relationship between the dependent variable set and the independent variable under consideration. Thus, by concentrating the information content of the original coordinate system, we reduce the dimensionality of the problem with a minimal loss of information. The procedure is further constrained so that the axis maximizes the following determinental equation:

$$(\underline{H}^{-1}\ \underline{A} - \underline{\lambda} I)\ \underline{V} = 0$$

where,

$\underline{H}$ represents the hypothesis sum of squares matrix,

$\underline{A}$ represents the error sum of squares matrix, and

$\underline{\lambda}$ and $\underline{V}$ are the characteristic roots and vectors.

The axis provides the key for interpreting and discovering what the significance represents. Since the axis is a linear combination, a score for a canonical function is defined as follows:

$$CF = \sum_{i=1}^{p} \text{(weighting for ith original variable as determined by the canonical function analysis)} * \text{(score for ith original variable)}.$$

The weighings are obtained from the normalized characteristic vector of the hypothesis matrix. One may then calculate correlations between the original variables and the newly formed CF variable (remember the variable is equivalent to an axis). The sign of the correlation and its magnitude signify the effect the original variable has on the CF score for a sample. For example, a large positive correlation indicates that. the variable will have the effect of increasing the CF score, a large negative correlation will indicate a reduced CF score, and a correlation close to zero will show no effect on the CF. In interpreting the results, one should make use of the original variable correlations with the CF axis to identify what the axis represents.

We realize that the variables measured in the environment are most probably intercorrelated; for example, temperature, salinity and depth show strong correlations. For this reason we wished to employ an analysis technique that would relate two sets of variables to each other as a further analysis of the relationships between the zooplankton community and their environment. As a result of this desire, we were led to another member of the MGLH family, canonical correlation.

Canonical correlation takes as its basic input two sets of variables, each of which can be given theoretical meaning as a set. The basic strategy of canonical correlation analysis is to derive a linear combination from each set of variables in such a way that the correlation between the two linear combinations is maximized. In this manner the analysis technique accounts for the maximum linear relationship between the two sets of variables. Once the first canonical correlation is extracted from the data sets, further linear combinations may be discovered that maximize the relationship between the two variable sets. This further extraction of canonical correlations is subject to the constraints of orthogonality, i.e. independence, with all previous correlations extracted, and the combinations of the original variables must be linear. The linear combinations of the original variables formed in the process of obtaining the canonical correlations are termed canonical variates. Geometrically, the canonical correlation analysis method may be considered an exploration of the extent to which individuals occupy the same relative positions in one variable-set measurement space as in the other. In other words, how well does the variation observed in one set of variables correspond to the variation observed in the set of variables. The actual computation of the canonical correlation analysis involves the solution of the complicated determinental equation which can be formulated in terms of the partitions of the correlation matrices of the two sets of variables: $(R_{22}^{-1} R_{21} R_{11}^{-1} R_{12} - \underline{\lambda} I)\underline{V} = 0$ with the restriction that $\underline{V}R_{22}\underline{V}=\underline{0}$, where

$'_{22}$ = The correlation matrix for variable set 2,

$'_{11}$ = The correlation matrix for variable set 1,

R_{12} = The matrix of intercorrelations of variable set 1 with variable set 2,

$\underline{\lambda}$ = A vector of eigenvalues, and

$\underline{V}$ = A vector of eigenvectors to correspond to the eigenvalues.

The most important pieces of information obtained from a canonical analysis are the canonical variates, the correlations between the variates (i.e. the canonical correlation), and the correlations between the original variables and the canonical variates. The canonical variates come in two sets, one for each of the sets of variables. These variates are related in pairs, that is to say, canonical variate one for variable set one corresponds with canonical variate one for variable set two. In fact, the analysis method is derived so that the correlation between non-corresponding pairs of canonical variates is zero.

The square of the canonical correlation tells us what proportion of the variance in a pair of canonical variates is in common, e.g. the proportion of the variance in the canonical variate for variable set one that is explained by variation in the canonical variate for variable set two, and since correlations do not imply causality, vice versa. The canonical correlation squared is the eigenvalue of the determinental equation listed above. It is possible to test for the significance of the canonical correlations, and thus decide on how many linear, orthogonal relationships between the sets of variables you would wish to recognize. The test used is Bartlett's χ^2, $\chi^2 = -[n-.5(p_1+p_2+1)]\log_e\Lambda$, where,

n = sample size,

p_1 = number of variables in set 1,

p_2 = number of variables in set 2, and

Λ = the product of (1-eigenvalue) for each remaining eigenvalue.

Thus, after a canonical correlation is extracted, the test informs you as to the probability of there being at least one more pair of canonical variates whose correlation is different from zero.

The canonical correlation conveys the information concerning the degree of relationship between the two canonical variates. We also may calculate the correlation between the original variable and its canonical variate. The magnitude and sign of these correlations inform us as to the relative importance of the original variables in the formation of the canonical variate and how the fluctuations of the original variables will affect the value of the canonical variate. Additionally, one may calculate the proportion of the total variance in one data set that is related to the common variance extracted by a canonical correlation. This expresses the amount of actual overlap between the two variable sets as viewed from the vantage point of one of the variable sets. This proportion of explained variance is the sum of the square of the correlation between the original variables and the canonical variate times the canonical correlation: $R_d = (R_{ii}\underline{v}_j/R_{c_j}^2$, where

R_{ii} = the matrix of' intercorrelations for a variable set

i = the index denoting the variable set, 1 or 2

$\underline{v}_j$ = the eigenvector for the jth canonical correlation

pi = the number of variables in the ith variable set

$R_{c_j}^2$ = the jth canonical correlation squared.

It is important to note that the amount of variation explained will necessarily be different for the different variable sets. The shared variance of variable set one and two is $R_{c_j}^2$; the variance extracted from variable set one is not the same as that extracted from variable set two. It is possible that the variance extracted from the first set is a major factor but is correlated with only a minor factor of the variance pattern of the second set. Whereas, the canonical correlation is a measure of overlap of the canonical variates, R_d is a measure of the overlap of set of variables with the other.

Additionally, the canonical variate score may be calculated for each sample for each set of variables and used in graphically displaying the results of the analysis.

Finally, it is possible to combine the analysis procedures of multivariate multiple linear regression and canonical correlation and thus in effect examine the relationships of two sets of variables after adjusting for the effects of a third. For example, we might wish to examine the relationship between dissolved trace metals, or hydrocarbons and levels of the same substances found in the zooplankton. However, we realize that the levels of the substance in the zooplankton sample depend on the constituents of the zooplankton community in the sample. Since a determination of the zooplankton composition of the sample used for elemental or chemical analysis was not made, but such a determination was made on a sample collected from the same time and place, one might wish to perform a canonical correlation between a variable set for dissolved trace metals and zooplankton trace metals following the adjustment of the zooplankton trace metals for fluctuations in the composition of the related zooplankton samples.

A third technique of analysis used in this study is that of factor analysis. Although factor analysis is actually a generic term and a wide variety of methods are subsumed under such a general term, the methods have basically the same orientation. The type of factor analysis we employed is probably one of the more basic techniques. The method used included extraction of common factors from a bivariate correlation matrix using the multiple R^2 as an initial estimate of the communalities, followed by a varimax orthogonal rotation. All factors with eigenvalues of greater than one were retained.

Factor analysis is based on the assumption that the observed intercorrelations between the variables in a data set are the results of some underlying regularity in the data. It is assumed that the observed variable is influenced by various determinants, or factors, some of w} ich are shared with other variables and others are not shared by any other variable. The portion of a variable's response influenced by the shared factors is called common, while that influenced by the idiosyncratic factors is called unique. Common factors determine the observed correlations in the data. The implicit assumption on the part of the researcher is that these underlying common factors are fewer in number than the original variables, and that each common factor accounts for a sizeably greater portion of the total variability of the variable set than does any single variable. We also assume that the factors both common and unique are all orthogonal, that is, uncorrelated to each other. This means that the correlation between two variables is a result of the correlations of the variables with the common factors. Thus, factor analysis can be thought of as a method in which a minimum number of hypothetical variables are specified such that after controlling for these hypothetical factors, e.g. holding them constant, all remaining correlations between the variables are zero.

The factor analysis methods employed here assumes the presence of residual variance which is not accounted for by the common factors. However, the exact amount of the unique variance is not known, but has to be estimated from the data. The determination of the unique portion, or more correctly of its complement, the communality, is one of the most difficult and ambiguous aspects of factor analysis. The technique of communality determination is one of the distinguishing features of the various factor analysis methods.

To factor analyze at the most general level is to express the original variables as linear combinations of a set of independent variables. The resultant output from a factor analysis consists of several different matrices and two- or three-dimensional plots:

1) The correlation matrix of original variables is used by the factor analysis technique as its initial input. This, coupled with the initial estimates of the communalities, provides the data necessary to produce the results of the first step in the factor analysis procedure. In our analysis of the BLM "baseline" data, we employed the square of the multiple correlation coefficient, R*, for each variable as the first estimate for the communality of a variable. The usual interpretation given to the R* is the proportion of the variable's variance that is "explained" by the variance of the remaining variables. This value intuitively makes a reasonable first estimate for the communalities.

2) The initial factor loading matrix is the result of the communality estimation process, an iterative eigenvalue procedure. If there are p original variables, the initial factor loading matrix will be a p x p matrix of coefficients that make up eigenvectors and form the initial solution to the factor analysis problem. These coefficients represent the correlation between the original variables and the initial factors. The proportion of the variance observed in the original variable set that is accounted for by the initial factor structure may be determined by examining the eigenvalues that correspond to the different eigenvectors. The initial factor solution determines linear combinations

of the original variables that contain all the variation of the original variables. It is a property of the eigenvalues that the relation $\lambda_i / \sum_{j=1}^{p} \lambda_j$ tells us what portion of the total variance is contained within the ith initial factor. An integral part of the factor analysis procedure is the process of deciding how many initial factors to retain for the rotation of the factors. This is in effect part and parcel of the communality problem, since the number of factors retained determines the portion of the total variance that is *to* be explained by common factors. Another property of the initial factors is that the first factor extracted contains more of the original variance than do any of the remaining factors. In other words, the eigenvalue of the first factor is the greatest, and each subsequent eigenvalue is greater than any to follow it. Thus, the question is how many should be retained? The rule that we followed is simply to not retain any factors that contain less of the total variance than might be expected to be explained by any one of the original variables, $1/p$. This is usually equivalent to rejecting any factors whose eigenvalue is less than one. The portion of the variance contained by the factors retained is that portion of the variance to be explained by the common factors, while the remainder is that portion that is a result of the factors unique to the original variables. The factor analysis process is now ready for the rotation step.

3) The rotated orthogonal factor matrix is a rectangular matrix with the same number of rows as original variables and columns as the number of initial factors retained. The elements of the matrix represent

the correlations between the rotated factors and the original variables. Thus the magnitude and sign of the correlation may be used in the interpretation of the theoretical, i.e., biological or environmental, meaning of the rotated common factor. As before, there are eigenvalues associated with each rotated factor; they tell us the proportion of the common variance that is contained within each rotated factor. If we multiply the proportion of the common variance by the proportion the common variance is of the total variance, the proportion of the original variance that is contained within the rotated factor is determined.

Also, there are the communalities, or the proportion of the variance of an individual original variable that is "explained" by the common factors. The communality is the sum of the square of the variable factor coefficients.

4) The factor estimate matrix is used to estimate factor scores for the original cases. The procedure used multiplies the rotated factor matrix by the inverse of the original correlation matrix. The result is multiplied by the normalized original variable scores to obtain factor scores for the original cases.

5) Graphical representation of the relationship of the original variables to the factor axes is useful in assessing the success of the factor analysis procedure. As in most of the GLH procedures, one of the results, and often the goal, of factor analysis is a reduction in the dimensionality of the data. This is accomplished in factor analysis by discovering the underlying orthogonal factors and rotating them to simple structure. This is in many ways equivalent to discovering an underlying coordinate system that has the properties of the axes being

orthogonal and fewer in number than the original variable set. The examination of the plots obtained are helpful in determining the applicability of the factor analysis assumptions to the data at hand. In examining the plots the following points should be considered: a) the relative distance of a variable from the two axes, b) the direction of the variable in relation to the axes {indicate a positive, negative or zero loading), and 3) the clustering of the variables and their relationship to one another. In this way one can obtain a feel for the actual relationships of the variables to each other. If, for example, all the variables seem to lie on one factor axis or another the assumption of orthogonality of common factors is supported.

The exact configuration of the factor structure is not unique and there are many statistically and mathematically equivalent ways to define the underlying dimensions of the same set of data. As a result there is no generally accepted best solution to the factor analysis problem and the concept of rotation is entered into the analytical technique. The purpose of rotation is to simplify the factor structure by rotating the factor axes so that: 1) many points will lie near the rotated factor axes, 2) many points will be located near the origin for many of the factor axes, and 3) only a few points will be removed from all the axes. There are many types of rotation available, the selection of a rotation technique is dependent on the research problem at hand. We selected the varimax rotation scheme because its approach is to attempt to make the structure of the factors as simple as possible by maximizing the squared loadings in each column of the factor structure matrix.

Factor analysis may be applied to a wide variety of problems where the original variables are intercorrelated and one wishes to produce uncorrelated variates and reduce the dimensionality of the problem as well. For example, the problem posed by canonical correlation might be also approached using factor analysis. However, the theoretical basis for the statistical models is different and thus the slant of the analysis will also be different. Canonical correlation extracts the linear combinations of both sets of variables that contain the most common variance. A factor analysis approach would extract from each set of variables a set of factors for each variable set that contained the most variation of that variable set. We would then take these two sets of factor scores and perform a multiple regression of one set on the other. This would then find the amount of correlation between the two sets of factor variates, which may or may not express the same results as a canonical correlation study.

It should now be apparent that the techniques classed under the MGLH are quite similar in their methods, with the variations in approach resulting in statistical models with different theoretical implications. The selection of which of the MGLH methods to employ in this study is a result of the underlying statistical model and its applicability to the requirements of the data.

The basic assumptions of the entire family of MGLH techniques are as follows: 1) the models proposed are linear in nature, and 2) the underlying distribution is the multivariate normal. Both of these assumptions have flaws in them to some degree. Linear hypotheses may or may not reflect the true nature of the relationships and the assumption of multivariate normality is not testable. The standard responses to objections along these lines are: 1) linear models are a "good" first approximation to be followed by more sophisticated investigations, and 2) the MGLH procedures are robust enough to afford some deviation from the multivariate normal distribution. Like the objections to the assumptions, these responses are also inherently unprovable and both objections and responses make sense intuitively. Our response to the problem of whether the use of the methods are justified follow those of Tukey (1962) and Cooley and Lohnes (1971):

Tukey argued that there have to be people in the various sciences who are more interested in the sciences than in mathematics, who are temperamentally able to seek for scope and usefulness rather than security, and are willing to err moderately often in order that inadequate evidence shall more often suggest the right answer. They have to use scientific judgement more than they use mathematical judgement, but not the former to the exclusion of the latter. Especially as they break into new fields of science, they must be more interested in indication procedures than conclusion procedures. In fact, most of the methods used are for data analysis and the discovery of relationships than for statistical inference and hypothesis testing. As Cattell (1966) stated the application of multivariate analysis to survey data is potentially more potent than experimental manipulation because it "took life's own manipulations . . . and by more intricate, non-interfering, statistical finesse teased out the causal connections among the data that could not be manipulated." Indeed, the results of more conventional approaches to date analysis as embodied in the trace metal and hydrocarbon sections of the water column final report for SUSIO suggest that the patterns of variation are too complicated to be sorted out by univariate methods (see Knauer's report and Calder's report). As Kendall (1957) stated, "The variates are dependent among themselves to that we cannot split off one or more from the others and consider it by itself. The variates must be considered together".

As a result ouranalysis philosophy, we take a very conservative approach to the results of statistical tests made during the course of the data analysis. The multivariate tests are very sensitive and our assurance of an alpha level being the reported level is low as a result of multiple testing of the same data set. Therefore, we choose to recognize the existence of an effect when the reported alpha level of the test is very small, say less than .001. We make no claim to the absolute statist"ical validity of any of our tests but rather use them as the best, objective procedures available to investigate the inter-relationships of the water column variables.

The bulk of the development of our multivariate data analysis philosophy and techniques is an integration of the ideas set down by the following authors: Cooley and Lohnes (1971), Barret al (?972), Morrison (1967) and Nie et al (1975).

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