QUANTITATIVE ASSESSMENT OF EUTROPHICATION: A SCORING SYSTEM FOR CHARACTERISING WATER QUALITY IN COASTAL MARINE ECOSYSTEMS

MICHAEL KARYDIS
Department of Environmental Studies, University of the Aegean, 811 00 Mytilini, Greece

(Received: July 1995; revised: October 1995)

Abstract. A scoring system based on nutrient concentrations was developed to assess coastal water quality according to the trophic level. Three nutrient data sets from eutrophic, mesotrophic and oligotrophic waters were used as the reference information for setting up a semi quantitative water quality scale (from 0 to 5) to express different nutrient loadings. The validity and sensitivity of the method was applied to a number of stations spaced out along the coastal area of Rhodes (Greece). A score for each nutrient / sampling site was calculated and the scorecard formed, was the data matrix used for numerical classification of the stations. The results showed (a) good discrimination between eutrophic, mesotrophic and oligotrophic waters (b) nitrate among the nutrients showed the maximum sensitivity in characterising pollution levels. The reference data sets used for assessing eutrophication levels ensured the objectivity of the method. The proposed method is described step-by-step and it is suggested that the method can be further adapted to describe other forms of pollution becoming a useful quantitative technique in coastal management practices.

1. Introduction

Eutrophication is the process of enrichment of water with nitrogen and phosphorus that stimulate primary production leading to enhanced algal growth and sometimes to phytoplankton blooms (Likens, 1972). The impact from nutrient enrichments is also reflected on the increased bacterial biomass and reduced water transparency, both parameters related to water quality (UN, 1984). Although eutrophication has been considered as the oldest problem of water quality created by mankind (Vollenweider, 1992) in lakes (Goldman and Horne, 1983) and coastal areas (Colombo et al., 1992), the quantitative assessment of eutrophication is still a problem under investigation (Vollenweider et al., 1992). In addition to the complex bodies of data including a large number of variables (Field et al., 1982), the seasonal trends in nutrient concentrations (Pagou and Ignatiades, 1988) and the difficulty in distinguishing between natural (autochthonus eutrophication) and human induced stresses in the environment (Warwick, 1993), methodological shortcomings have also to be taken into account.

Relatively large analytical errors at low concentrations, mainly concerning the control sites eliminate the use of powerful statistical tools (Vounatsou and Karydis, 1991) excluding mainly univariate techniques (Zar, 1984; Austen and Warwick, 1989); In addition, different parametric values recorded in various sampling sites do not necessarily mean different levels of eutrophication and they introduce noise into

Environmental Monitoring and Assessment **41:** 233–246, 1996.

the system (Karydis, 1992). Most statistical methods assume normally distributed variables (Morrison, 1988); however, normality in nature rarely occurs (Jongman et al., 1987) and therefore a powerful transformation of the data is needed. The logarithmic transformation has a predominant place in environmental studies: it has the effect of compressing the larger values, reducing this way the significance of large nutrient concentrations in relation to low nutrient values (Digby and Kempton, 1987). This log transformation seems to diminish the natural information contained in the raw data. Since nutrient enrichment is a continuous process there are no 'limits' between oligotrophic, mesotrophic and eutrophic waters. There are therefore big overlaps in the frequency distributions of the variables under investigation (Heyman et al., 1984; Ignatiades et al., 1992; Giovanardi and Trompellini, 1992). Although frequency distributions have the advantage of assessing water quality by using standard data sets, they can only provide a probabilistic estimate of eutrophication in the concentration scale for a specific nutrient. In addition, these distributions have been log trasnformed so that the natural scale has been distorted.

In the present paper a methodological procedure is presented for quantitative assessment of eutrophication based on the following points: (a) the use of standard nutrient data sets as a reference for assessing eutrophic levels (b) the development of a scoring system, that is a discrete quantitative method, to assess trophic levels and (c) the evaluation of the method in a case study.

2. Development of the Method

2.1. Reference Nutrient Data Sets

Three nutrient data sets characteristic of Eastern Mediterranean waters (Ignatiades et al., 1992) formed the basis of the scoring system that is the development of an ordinal scale for assessing eutrophication. The first data set (347 observations – two sampling sites) came from a eutrophic area located in the vicinity of the sewage dispersion field of Saronicos Gulf (Inshore Gulf Water). The data of the second data set (579 observations) characterizing mesotrophic conditions were collected from seven stations located in the remaining area of Saronicos Gulf. The data of the third data set (197 observations) were collected from 5 stations along the S.E. side of the Island of Rhodes, from an area known as oligotrophic (Vounatsou and Karydis, 1991). The distribution characteristics of these data sets were studied and they were charasterized as eutrophic, mesotrophic and oligotrophic in a previous work (Ignatiades et al., 1992). The station locations of the a priori characterised data sets are given in Figures 1 and 2.

2.2. Graphical Representation of Data

The four nutrient variables of the three data sets were illustrated using a distribution free method, called Box-and-Whisker Plot (Ott, 1988). The skeletal box plot is

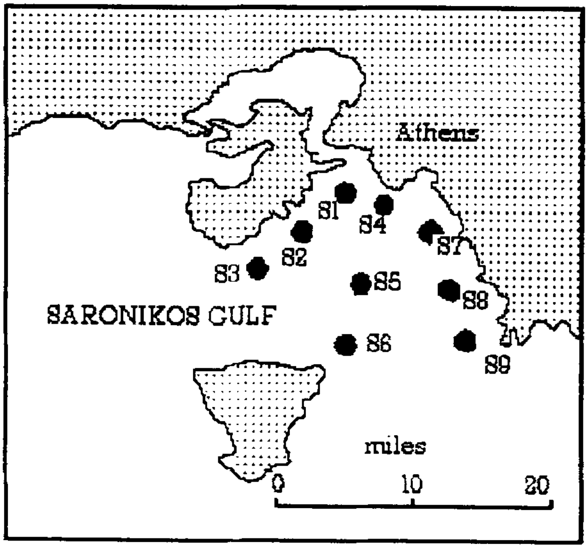

Fig. 1. Station locations in eutrophic (S1, S2) and mesotrophic (S3–S9) waters of Saronicos Gulf (Greece).

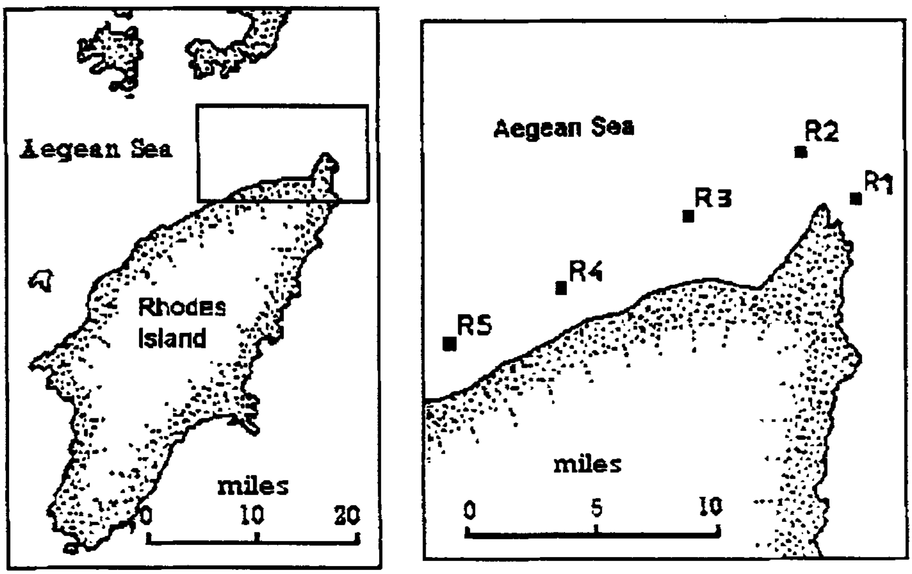

Fig. 2. (a) The area used for sampling in the oligotrophic marine environment of Rhodes (b) station locations

constucted by drawing a box between the lower (Q_1) and upper quartiles (Q_3) with a line drawn across the box to locate the median (Q_2). Straight lines (whiskers) are connecting the box to maximum values and to minimum values respectively

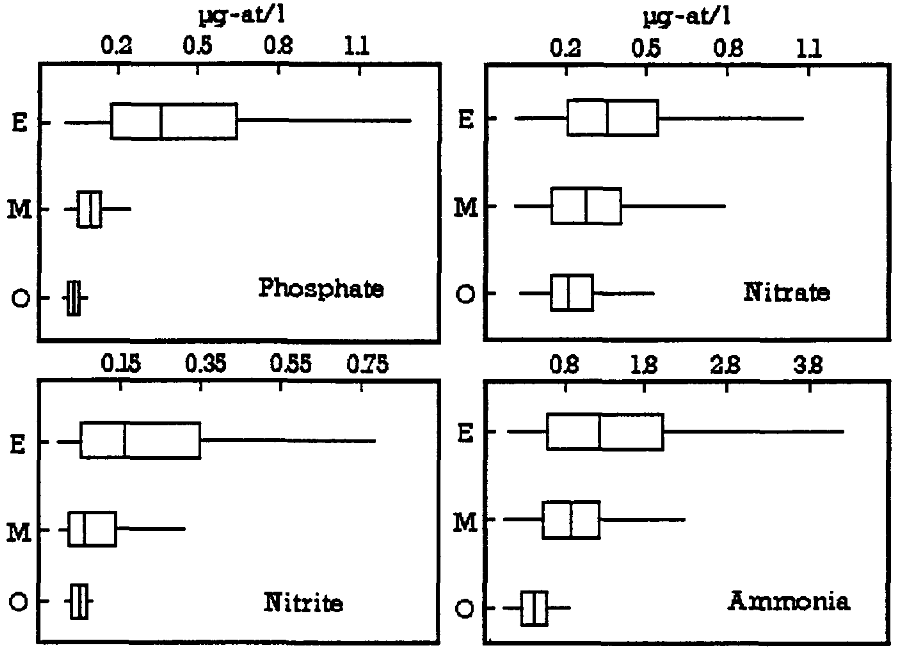

Fig. 3. Box-and-whisker plots of nutrient concentrations from the reference data sets. Three plots are given for each nutrient characterising Eurotrophic (E), Mesotrophic (M) and Oligotrophic (O) conditions.

(Figure 3). Extreme values, defined as the values greater than Q3+1.5*IQR, where IQR is the interquartile range that is the difference $Q_3 - Q_1$ were excluded.

2.3. Eutrophication Scaling

The four quartiles of each nutrient variable divide the nutrient concentrations into six intervals. The first interval ranges from zero to the minimum value, the second interval is defined between the minimum value and the lower quartile (Q1), the third interval between Q1 and the median (M), the fourth between M and the upper quartile (Q3), the fifth between Q3 and the minimum value (max) and the sixth interval refers to concentrations higher than the max values. Ordinal ranking – routinely used in environmental policy analysis (Nijkamp, 1980) – was performed on the above intervals. The ordinal scale 0 to 5 was set and each number was assigned to each interval, 0 expressing the most favorable state of the system (nutrient concentration below the minimum value) and 5 expressing the least favorable environmental condition – highest nutrient loading (nutrient concentrations above maximum values). The scaling system is also given in Table I. For a given nutrient concentration in a sampling site the relevant nutrient load can be expressed in terms of the oligotrophic, mesotrophic and eutrophic system. Given for example a nitrate concentration 0.54 μg-at N/l, an ordinal number can be

TABLE I

Development of the ordinal eutrophication scale based on quartile values of nutrient concentrations from three standard data sets

Water type		Min	LQ	M	UQ	Max
A. PHOSPHATE						
Eutrophic		0.01	0.17	0.36	0.64	1.29
Mesotrophic		0.01	0.05	0.09	0.13	0.24
Oligotrophic		0.01	0.01	0.03	0.04	0.08
Scoring	0	1	2	3	4	5
B. NITRATE						
Eutrophic		0.01	0.20	0.35	0.55	1.07
Mesotrophic		0.01	0.14	0.28	0.41	0.79
Oligotrophic		0.02	0.14	0.21	0.30	0.53
Scoring	0	1	2	3	4	5
C. NITRITE						
Eutrophic		0.01	0.06	0.17	0.36	0.80
Mesotrophic		0.01	0.03	0.07	0.15	0.32
Oligotrophic		0.01	0.01	0.03	0.05	0.11
Scoring	0	1	2	3	4	5
D. AMMONIA						
Eutrophic		0.06	0.55	1.24	2.04	4.25
Mesotrophic		0.02	0.48	0.87	1.22	2.29
Oligotrophic		0.04	0.23	0.38	0.55	0.85
Scoring	0	1	2	3	4	5

MIN: minimum value; LQ: lower quartile; M: median; UQ: upper quartile; MAX: maximum value

assigned for each data set. This concentration can be considered as rather low if it is assumed that comes from a eutrophic system and the score 3 is assigned according to Table I. The same nitrate concentration value characterises rather high nutrient loading for a mesotrophic system (score 4 according to Table I) and extreme value if it is assumed that comes from an oligotrophic system (score 5). The total score characterising nutrient loading from that particular value is the sum of the three scores that is 12. This way a data matrix displaying nutrient concentrations (rows) by stations (columns) can be presented as a scorecard of nutrient loadings for a number of stations. The information is therefore, given in a discrete form and after validation to the three standard nutrient data sets.

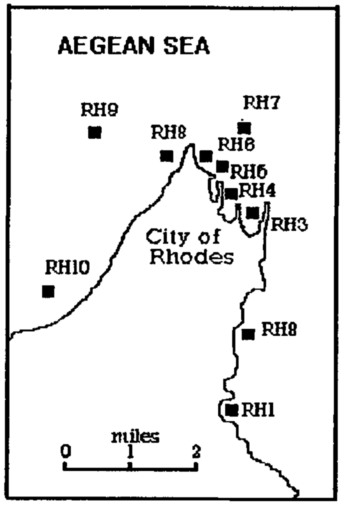

Fig. 4. The coastal area of the city of Rhodes; station locations.

3. A Case Study

3.1. Field and Laboratory Work

Ten sampling sites (RH1-RH10) were selected along the coastal area of Rhodes, Greece, in Eastern Mediterranean. The level of eutrophication in these sampling sites has been assessed in previous work (Karydis and Coccossis, 1990; Karydis, 1992; Moriki and Karydis, 1994) and therefore they have been considered as a good case for validating the proposed method. Two sampling sites RH7 and RH9, located offshore (in an area with intense circulation and depth greater than 200m), were chosen as the control sites (Figure 4). Three sampling sites (RH3, RH4, RH5) were selected in areas known as eutrophic (harbour zones) to define the upper limit of the eutrophication scale. The remaining sampling sites, located nearshore and used for swimming and recreation were under examination as far as their eutrophication levels were concerned. Surface samples were collected with VanDorn water bottles on a monthly basis. Phosphate, nitrate and nitrite concentrations were determined according to Strickland and Parsons (1972) and ammonia according to Liddicoat et al. (1976).

3.2. Ordinal Data Matrix

The Mean Annual Concentrations (MAC) of each nutrient was calculated for each station (RH1-RH10). The MAC values are given in Table II. Three ordinal numbers were assigned for each value, one for the eutrophic (E), one for the

TABLE II

Scorecard showing nutrient concentration levels, based on the three standard data sets

	RH1	RH2	RH3	RH4	RH5	RH6	RH7	RH8	RH9	RH10
A. PHOSPHATE										
MAC	0.09	0.06	0.06	0.07	0.07	0.07	0.06	0.07	0.06	0.05
E	1	1	1	1	1	1	1	1	1	1
M	2	2	2	2	2	2	2	2	2	1
O	5	4	4	4	4	4	4	4	4	4
Total score	8	7	7	7	7	7	7	7	7	6
B. NITRATE										
MAC	0.68	0.45	2.51	6.25	3.00	0.60	0.35	0.42	0.28	0.51
E	4	3	5	5	5	4	2	3	2	3
M	4	4	5	5	5	4	3	4	2	4
O	5	4	5	5	5	5	4	4	3	4
Total score	13	11	15	15	15	13	9	11	7	11
C. NITRITE										
MAC	0.05	0.05	0.09	0.13	0.10	0.05	0.05	0.04	0.04	0.04
E	1	1	2	2	2	1	1	1	1	1
M	2	2	3	3	3	2	2	2	2	2
O	3	3	4	5	4	3	3	3	3	3
Total score	6	6	9	10	9	6	6	6	6	6
D. AMMONIA										
MAC	0.82	0.58	0.52	0.59	0.61	1.06	0.44	0.62	0.59	0.50
E	2	2	1	2	2	2	1	2	2	1
M	2	2	2	2	2	3	1	2	2	2
O	4	4	3	4	4	5	3	4	4	3
Total score	8	8	6	8	8	10	4	8	8	6

MAC: Mean Annual Concentrations; E: scoring based on the eutrophic system; M: scoring based on the mesotrophic system; O: scoring based on the oligotrophic system.

mesotrophic (M) and and one for the oligotrophic (O) data set respectively and the sum of these three scores was calculated expressing the eutrophication level of a particular station for a specific nutrient. A 4×10 data matrix (scorecard) was formed (four nutrient variables by ten stations) which was used for multivariate statistical analysis (Table IIIb).

Table III

Data matrices used for the data analysis (A) Log transformed mean annual concentrations; the variables have been standardised (B) Data matrix based on scoring nutrient levels

Variable	RH1	RH2	RH3	RH4	RH5	RH6	RH7	RH8	RH9	RH10
A. Standardized variables of mean annual nutrient concentrations										
Phosphate	2.40	−0.53	−0.53	0.58	0.58	0.58	−0.53	0.58	−0.53	−1.85
Nitrate	−0.22	−0.63	1.07	1.97	1.24	−0.35	−0.88	−0.70	−1.10	−0.51
Nitrite	−0.48	−0.48	1.02	1.96	1.29	−0.48	−0.48	−0.48	−1.05	−1.05
Ammonia	1.24	−0.27	−0.74	−0.19	−0.05	2.35	−1.47	0.02	−0.19	−0.91
B. Scoring eutrophication level										
Phosphate	8	7	7	7	7	7	7	7	7	6
Nitrate	13	11	15	15	15	13	9	11	7	11
Nitrite	6	6	9	10	9	6	6	6	6	6
Ammonia	8	8	6	8	8	10	4	8	8	6

3.3. The Log-Transformed Raw Data Matrix

After the calculation of the mean annual value, the raw data set was organized in the form of a matrix; four nutrients (phosphate, nitrate, nitrite, ammonia) by ten stations (RH1-RH10). Since the raw data were log-normally distributed (Karydis and Ignatiades, 1988), the logarithmic transformation was applied to establish normality:

$$Y_{ij} = \log X_{ij}$$

where: X_{ij} is the raw data value in the ith nutrient variable and the jth station and Y_{ij} the corresponding transformed score.

Due to different scale of the variables, standardization was applied: the calculated values of each variable after centering were divided by their variance (Pielou, 1984) according to the formula:

$$Z_{ij} = \frac{X_{ij} - y_i}{\sigma_i}$$

Where

Y_{ij} the element of the ith nutrient variable and the jth station

y_i the average value of the ith raw (variable)

σ_i the variance of the elements of the ith raw and

Z_{ij} corresponding standardized value to x_{ij}

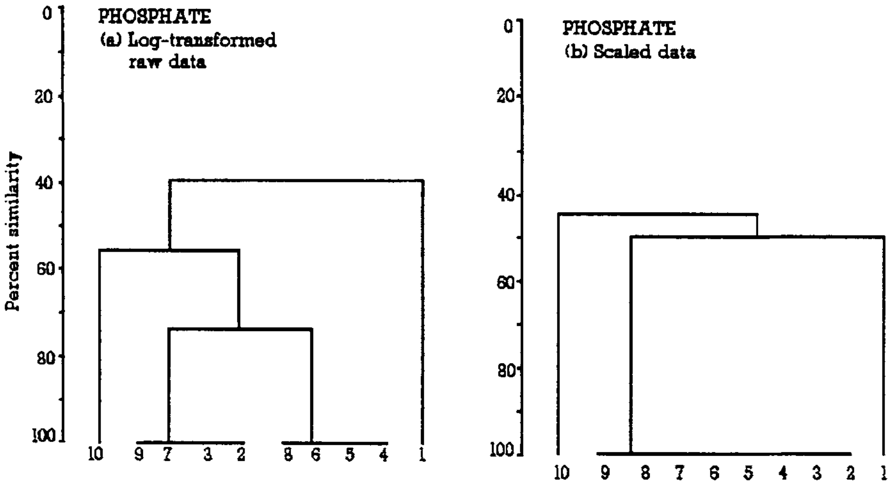

Fig. 5. Station grouping based on phosphate concentrations; (a) log-transformed raw data and (b) data derived through the scoring system proposed

3.4. Dissimilarity Measures

Absolute Euclidean Distance (AD) was chosen as a dissimilarity measure. The absoltute distance is defined as the sum of the absolute concentration differences taken over the four nutrients, according to the formula:

$$d_{(j,k)} = \Sigma|Z_{ij} - Z_{ik}|$$

As the AD index does not place special emphasis on larger differences (Ludwig and Reynolds, 1988) and therefore was expected to be more sensitive in mesotrophic conditions which express the most important state from the management point of view (Karydis, 1992). The absolute euclidean distance was transformed to express relative similarity (scale 0 to 100) by the formula:

$$\psi_{ij} = [(d_{max} - d_i)/d_{max}] \times 100$$

where d_{max} the maximum value observed.

3.5. Numerical Classification

Cluster analysis (CA) was applied in the present work to place similar stations into groups which are arranged in an hierarchical tree-like structure known as dendrogram. The group average distance was chosen as the clustering algorithm since this clustering technique introduces relatively little distortion to the relationships between stations (Boelsch, 1977).

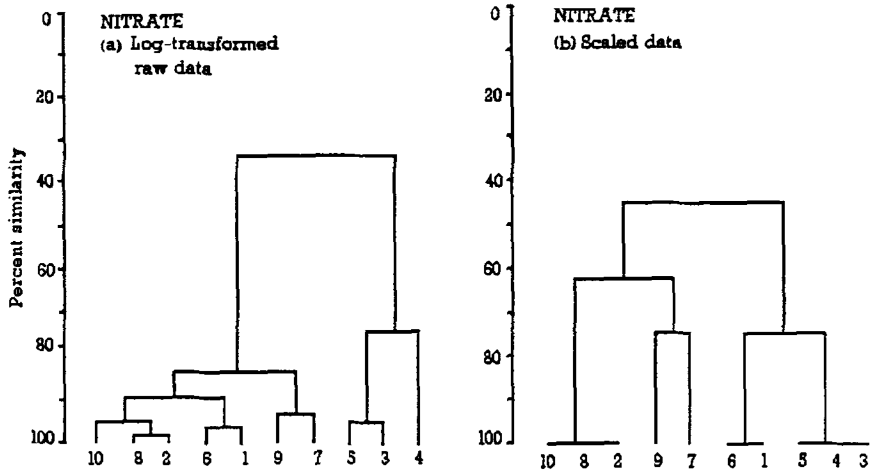

Fig. 6. Station grouping based on nitrate concentrations; (a) log-transformed raw data and (b) data derived through the scoring system proposed.

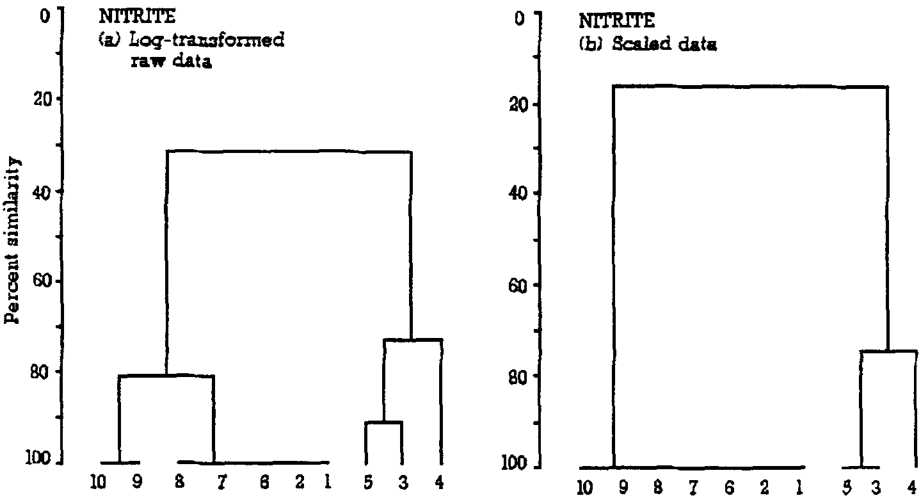

Fig. 7. Station grouping based on nitrite concentrations; (a) log-transformed raw data and (b) data derived through the scoring system proposed.

4. Results

The grouping of stations based on phosphate concentrations is given in Figure 5. In the tree diagram illustrating the log-transformed phosphate values (Figure 5a) there are four groups of stations: [RH1], [RH4, RH5, RH6, RH8], [RH2, RH3, RH7, RH9] and [RH10]. It is observed that the eutrophic station RH3 is grouped together with the oligotrophic stations RH7, RH9. The pattern in the tree diagram

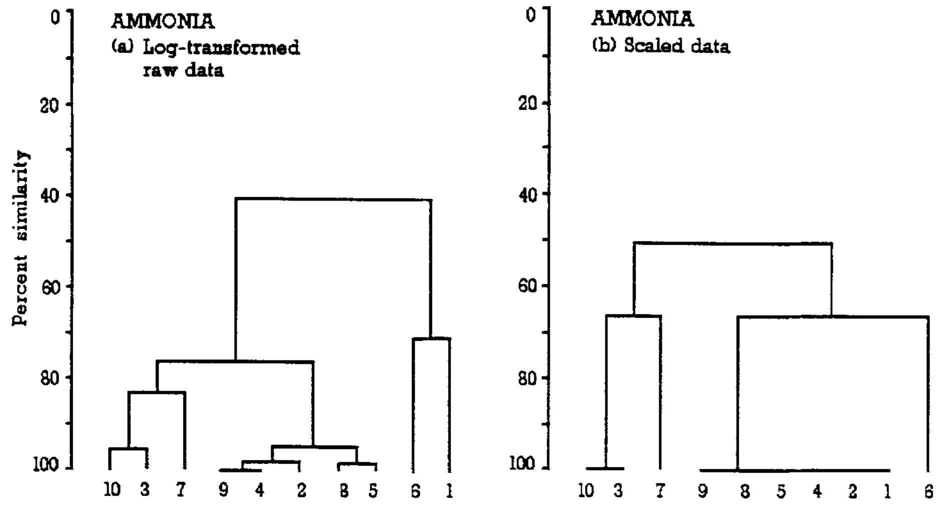

Fig. 8. Station grouping based on ammonia concentrations; (a) log-transformed raw data and (b) data derived through the scoring system proposed.

derived from the scoring system is rather simple grouping 8 out of 10 stations together.

The classification of the stations based on nitrate concentrations is illustrated in Figure 6. Log-transformed data values seem to discriminate between the eutrophic group [RH3, RH4, RH5] and the remaining sampling sites. However, there is no clear classification pattern between the remaining stations oligotrophic and mesotrophic (Figure 6a). The tree diagram based on nitrate values derived from the proposed scoring system showed an excellent discrimination between oligotrophic, mesotrophic and eutrophic conditions. The eutophic stations RH3, RH4 and RH5 were grouped together at 100% similarity level. A distinct group of the oligotrophic stations RH7 and RH9 was also formed; the remaining stations were grouped into two clusters: RH6 and RH1 were grouped near the eutrophic stations and RH2, RH8 and RH10 near the oligotrophic cluster.

In the case of nitrite (Figure 7) similar trends was shown in both cases (Figure 7a and 7b). Although the eutrophic group of stations (RH3, RH4 and RH5) was well discriminated, the remaining stations were grouped together. The station grouping given by ammonia concentrations (Figure 8) has not shown any compatibility either to previous figures or to the already known categorization of the stations.

5. Discussion and Conclusions

The discrimination of polluted sites or the assessment of pollution levels is usually based on statistical comparison between the contaminant-affected sites and one or more sites which are spatial controls that is relatively unaffected sites (Clarke and Green, 1988). It is therefore evident the importance of the reference stations in assessing pollution levels. However, there is a number of shortcomings related to this type of experimental design (a) only a minimal amount of data is usually available from unimpacted sites due to the small number of control sites (b) the upper limits of the scale of measurement in the natural environment are not usually taken into account and (c) different spatial controls are used for each study so there is not compatibility of the results when different areas are compared in pollution effects studies. It was realised that use of reference data sets would be an answer to these problems. Voluminous data sets can be built at a high cost and they cannot be constructed each time an area is studied. In addition, they summarise a lot of information including temporal and depth fluctuations and therefore, these differences can be smoothed out. If the eutrophication level of each nutrient is assessed according to those nutrient distributions then it will be possible to have results compatible to eutrophication assessment from other areas as opposed to comparisons limited to a few control sites only.

An additional group of shortcomings refers to the data analysis. Deviation from the statistical assumptions of the raw data indicates the need of data transformations. Logarithmic transformations are usually used in pollution studies (Boelsch, 1977) and there are certain advantages for that: the variables are normalised and put into the same scale of variation (percentage variation). However, this data handling reduces the sensitivity of the methods in discriminating impacted sites since it is mainly reducing the high values and distorts the natural information of the raw data. It is therefore evident that further data analysis reflects the features of the transformed data set rather than the information of the original matrix introducing, therefore, artifacts. The answer to this problem was data handling without powerful transformations and the use of non-parametric multivariate methods of analysis. The methodology suggested that is the development of the scoring algorithm and the numerical classification are both distribution free techniques.

The scoring system developed resulted into a smoothing of minor differences among similar values and into an accentuation of larger values. That trend was reflected into the tree-diagrams of the four nutrients investigated. Phosphate concentrations being very near the analytical zero of the laboratory technique applied (Strickland and Parsons, 1972) practically resulted into a 'flat cluster' that is a grouping of eight stations at 100% similarity level. This is an indication that phosphate is not a variable with high sensitivity that could be recommended to describe marine eutrophication levels. Similar trends of uniform patterns were also observed in the case of nitrite. Apart from the cluster of the eutrophic stations there was no grading of trophic levels among the remaining stations. Nitrite concentrations occuring at barely detectable levels in the euphotic zone (Riley and Chester, 1971; Ignatiades et al., 1992) may also account for lack of sensitivity in assessing eutrophication. The same pattern was observed for ammonia. Nitrate showed the highest sensitivity and reliability in assessing eutrophic levels. Previous work based on eutrophication assessment (Karydis, 1992; Moriki and Karydis, 1994) has also shown that nitrate values had the largest variation among the four variables tested and also the most clear-cut differences between eutrophic / mesotrophic and mesotrophic / oligotrophic conditions. In addition, the existing information from studies in marine ecology indicating nitrogen as the limiting nutrient in the marine environment (Carpenter and Capone, 1983; Valiela, 1984) and the fact that nitrate forms the final product of nitrification (Riley and Chester, 1971), suggest that nitrogen in the form of nitrate can be recommended as the most effective nutrient variable for eutrophication assessment based on the proposed algorithm.

The following conclusions concerning the proposed methodology can be drawn from the present work (a) The use of reference (standard) data sets contributes towards an objective assessment of pollution levels (b) limited number of data points can be effective in assessing eutrophication levels provided that standard data sets are available as a reference (c) the scoring method proposed does not use data transformations compressing high values and therefore, is sensitive in characterising nutrient enrichment in the marine environment (d) minor differences due to methodological errors or natural fluctuations are smoothed out, reducing the noise of the system and (e) The use of nitrate as the only parameter for assessing trophic levels in the marine environment is suggested due to the high sensitivity and effectiveness.

References

Austen, M. C. and Warwick, R. M.: 1989, 'Comparison of univariate multivariate aspects of estuarine meiobenthic community structure', *Estuarine, Coastal and Shelf Science* **29**, 23–42.

Boesch, D. F.: 1977, Application of Numerical Classification in Ecological investigations of Water Pollution, *U.S Environ. Protection Agency*, EPA-600/3-77-033.

Carpenter, E. J. and Capone, D. G.: 1983, *Nitrogen in the marine environment*, Academic Press, New York, 900 pp.

Clarke, K. R. and Green, R. H.: 1988, 'Statistical design and analysis for biological effects study', *Mar. Ecol. Prog. Ser.* **46**, 213–226.

Clarke, K. R.: 1993, 'Non-parametric multivariate analyses of changes in community structure', *Australian Journal of Ecology* **18**, 117–143.

Colombo, G., Ferrari, I., Ceccherelli, V. U. and Rossi, R., (eds.): 1992, *Marine Eutrophication and Population Dynamics*. Olsen and Olsen, Fredensborg.

Digby, P. G. N. and Kempton, R. A.: 1987, *Multivariate analysis of ecological communities*. Chapman and Hall, London.

Field, J. G., Clarke, K. R. and Warwick, R. M.: 1982, 'A practical Strategy for Analysing Multispecies Distribution Patterns', *Mar. Ecol. Prog. Ser.* **8**, 37–52.

Giovanardi, F. and Tromellini, E.: 1992, 'Statistical assessment of trophic onditions. Application of the OECD methodology to the marine environment, in: *Marine Coastal Eutrophication*, ed. Vollenweider, R.A., Marchetti, R. and Viviani, R., Elsevier, London, pp. 211–233.

Goldman, C. R. and Horne, A. J.: 1983, *Limnology*. McGraw-Hill, London.

Heyman, U., Ryding, S. V. and Forsberg, C.: 1984, 'Frequency distributions of water quality variables. Relationships between mean and maximum values', *Water Res.* **18**, 787–794.

Jongman, R. H. G., ter Braak, C. J. F. and van Tongeren, O. F. R.: 1987, *Data analysis in community and landscape ecology*, Pudoc Wageningen, Den Haag.

Ignatiades, L., Karydis, M. and Vounatsou, P.: 1992, 'A possible method for evaluating oligotrophy and eutrophication based on nutrient concentration scales', *Mar. Poll. Bull.* **24**, 238–243.

Karydis, M. and Coccossis, H.: 1990, 'Use of multiple criteria for eutrophication assessment of coastal waters', *Environmental Monitoring and Assessment* **14**, 89–100.

Karydis, M.: 1992, 'Scaling Methods in Assessing Environmental Quality: A Methodological Approach to Eutrophication', *Environmental Monitoring and Assessment* **22**, 123–136.

Liddicoat, M. I., Tibbitis, S. and Butler, E. I.: 1976, 'The determination of ammonia in natural waters', *Water Research* **10**, 567–568.

Likens, G.: 1972, *Eutrophication and Aquatic Ecosystem. Nutrient and Eutrophication.* The American Society of Limnology and Oceanography. Special Symposia, Volume I, pp. 3–13.

Ludwig, A. J. and Reynolds, J. F.: 1988, *Statistical Ecology: A Primer on Method and Computing,* J. Wiley & Sons, New York.

Moriki, A. and Karydis, M.: 1994, 'Application of multicriteria choice-methods in assessing eutrophication', *Environmental Monitoring and Assessment* **33**, 1–18.

Morrison, D. F.: 1988, *Multivariate Statistical Methods*, Second Edition, McGraw-Hill Book Company, Auckland.

Nijkamp, P.: 1980, *Environmental Policy Analysis: Operational Methods and Models*, J. Wiley & Sons, Chichester.

Ott, L.: 1988, *An Introduction to Statistical Methods and Data Analysis*, 3rd Edition, PWS Publ. Co.

Pagou, P. and Ignatiades, L.: 1988, 'Phytoplankton Seasonality Patterns in eutrophic Marine Coastal Waters', *Biological Oceanography* **5**, 229–241.

Pielou, E. C.: 1984, *The Interpretation of Ecological Data: A Primer on Classification and Ordination.* J. Wiley & Sons, New York.

Riley, J. P. and Chester, R.: 1971, *Introduction to Marine Chemistry*, Academic Press. London and New York, 465pp.

Strickland, J. D. H. and Parsons, T. R.: 1972, *A Practical Handbook of Seawater Analysis, Fisheries Research Board of Canada*, Bulletin 167 (2nd edition).

UN: 1984, *Coastal Area Management and Development (United Nations Department of International Economic and Social Affairs)*, Pergamon Press, Oxford, 188pp.

Valiela, I.: 1984: *Marine Ecological Processes*, Springer-Verlag, New York, 546 pp.

Vollenweider, R. A.: 1992, 'Coastal marine eutrophication: principles and control', in: *Marine Coastal Eutrophication,* ed. Vollenweider, R.A., Marchetti, R. and Viviani, R., Elsevier, London, pp. 1–20.

Vollenweider, R. A., Marchetti, R. and Viviani, R. eds.: 1992, *Marine Coastal Eutrophication,* Elsevier, London

Vounatsou, P. and Karydis, M.: 1991, 'Environmental characteristics in oligotrophic waters: data evaluation and statistical limitations in water quality studies', *Environmental Monitoring and Assessment* **18**, 211–220.

Warwick, R. M.: 1993, 'Environmental Impact Studies on Marine Communities: Pragmatical considerations', *Aust. J. Ecol.* **18**, 63–80.

Zar, J. H.: 1984, *Biostatistical Analysis,* 2nd edn. Prentice-Hall Inc., Englewood Cliffs, N.J.